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(54) IMPROVEMENTS IN AND RELATING TO THE CONSTRUCTION OF CONCRETE WALLS

(71) We, ICOS CORPORATION OF AMERICA, a Corporation organised and existing under the laws of the State of Delaware, United States of America, of 1 World Trade Center, Suite 1131, New York, State of New York 10048, United States of America, (assignee of GEORGE JOHN TAMARO),

do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to the construction of concrete walls in the ground.

The technique of constructing a reinforced concrete wall in the ground utilizing a stabilising fluid substance or slurry such as bentonite, driller's mud, etc., for retaining the sides of an excavation open during the excavation has been widely used in the past and is disclosed in detail in British Patents Nos. 913,527 and 913,528 and in U.S. Patent Nos. 3,310,952 and 3,139,729. In U.S. Patent No. 3,139,729 pairs of spaced reinforced concrete elements are cast in situ along the line of the wall and the ground between two adjacent reinforced concrete elements is excavated subsequently using special tools for excavating close to and scraping the concrete elements so as to form trench sections between the concrete elements. The concrete elements are used as guide elements for the tools. In accordance with UK Patents Nos. 913,527 and 913,528 and US Patent No. 3,310,952, a concrete curb or guide is cast along the line of a wall to be constructed and a first trench is dug whilst being maintained open by circulation therein of a bentonite solution. Reinforcements may be then lowered into the trench and an interlocking pipe is installed in the trench at least at one end thereof. The trench is then filled with concrete from the bottom (using the tremie concreting method) forming a section of an underground reinforced concrete wall. The interlocking pipe is removed when the concrete in the first trench has hardened or set to an extent as to be self-sustaining in its shape. This forms the key or locking element with respect to the next section of the wall. Subsequent to depositing the concrete in the first trench, a second trench is excavated in an adjacent relation to the first trench. A variation on the above-described technique has been developed in the United States, where cylindrical holes are dug into which H-section beams are placed with their web portions transverse to the line of the wall. These cylindrical holes are then filled with a cementitious material which is just sufficient to maintain the beams in a vertical position. Then, between two adjacent beams the ground is excavated to form trench sections, and the not-so-hard cementitious material is removed from the surfaces of the beams facing each other. These trench sections then may have steel reinforcement cages lowered thereinto and filled with concrete. The main deficiency of the method is the difficulty of maintaining each H-section beam vertical.

In accordance with this invention, there is provided a method of constructing in the ground a waterproof wall formed by interlocked vertical concrete wall panels, comprising the steps of excavating two primary trench sections which are spaced apart by a distance greater than the length horizontally of each primary trench section, the excavation of each primary trench section being carried out in the presence of a thixotropic liquid; inserting a pair of interconnected flanged steel beams into each primary trench section; filling each primary trench section with concrete from the bottom up to form a respective primary wall panel; and then in two stages excavating, in the presence of a thixotropic liquid, the intermediate ground between the pair of primary wall panels, using one beam of one of the pairs of interconnected beams as an excavator guide in one of the stages and one beam of the other of the pairs of interconnected beams as an excavator guide in the other of the stages, to form two secondary trench sections; and displacing the thixotropic liquid from the secondary trench sections by filling them from the bottom up with concrete to form secondary wall panels between the two primary wall panels.

Preferably each beam is of I or H-section and the pairs are welded together at the site utilizing a light weight steel lattice work, a reinforcement cage being tied to the lattice work. For a pair of H-section beams the two outward facing channels may advantageously be filled above ground with non-cementitious excavatable materials such as rigid block polystyrene foam to eliminate the need of end pipe joints or other time consuming and expensive procedures, such as the low strength cementitious material used heretofore to position the H-beam. Such an arrangement is mentioned in an article appearing in October, 1973 issue of *Roads and Streets* magazine entitled "Slurry Wall, Special Equipment Solve "No Room" Excavation Problem".

An H-section beam pair may be lowered into each primary trench section and used therein as a reaming tool. For this purpose, the lower edges of the beams may be sharpened by a grinder, files or a cutting torch. This so formed reaming tool conveniently squares off and evens out each primary trench section prior to installation of a permanent steel framework constituted by another pair of H-section beams joined together by a reinforcement cage and of a somewhat lighter weight metal than the reaming tool. The reaming tool may be used as the concrete reinforcement and H-section beam pair in the final primary trench section to be excavated.

Also included within the scope of the invention is a wall when constructed by the method according to the invention.

In some cases, underground structures such as utilities, telephones etc. may not be met when excavating the trench sections. In this case, typically in the past these utilities have either been rerouted or the trench sections have simply been excavated around the utility and filled with concrete and not reinforced. By means of the present invention, the existing utilities are preferably excavated around as before, and then the excavation is filled with a conventional concrete or a steel fibre reinforced concrete.

The invention is described further, by way of example, with reference to the accompanying drawings, wherein:—

Fig. 1 is a top plan view illustrating a sequence of construction along the line of a wall being built;

Fig. 2 is a side elevation of the sequence of Fig. 1;

Fig. 3 illustrates a modified sequence carried out about an underground obstruction such as a twenty-four inch telephone conduit;

Fig. 4 is an isometric view of a pair of H-section beams and a reinforcement cage used in the sequence of Fig. 1;

Fig. 5 is a top plan view of the beams shown in Fig. 4;

Fig. 6 is a partial top sectional view of a spacer and shuttering device;

Fig. 7 is a top plan view of a wall produced with the aid of the shuttering device; and

Fig. 8 is a plan view of the shuttering device in position between a pair of H-section beams with another spacer.

Referring to Figs. 1 and 2, the line of a wall to be built by the method according to the invention is initially defined by casting in situ a pair of concrete curbs GC as described in UK Patent Specification Nos. 913527 and 913528. These curbs serve as guides for at least one excavation device, which is preferably a clamshell excavator CE, and also as aids in aligning pairs of H-section beams described below.

Next, first and second primary trench sections 10, 11 are excavated using the clamshell excavator CE which has an expanse or bite of, for example, ten feet. These primary trench sections 10, 11 are excavated down to the proposed depth of the wall below ground (which can vary according to bed rock deformation, etc.) and, as excavation work progresses, a thixotropic colloidal liquid or slurry apt to gel, such as a thickish liquid known in the art as a bentonite slurry or driller's mud, is introduced into the trench sections 10, 11 to prevent disintegration and collapse of the walls of the sections 10, 11 during excavation. A bentonite pond, reservoir or tank (not shown) may be provided for cleaning the bentonite slurry for re-use and may supply the same via bentonite feed line shown diagrammatically in Fig. 2, to the individual trench sections as they are excavated.

In Figs. 1 and 2, the first primary trench section 10 and the second primary trench section 11 are shown as being completed and having pairs of interconnected H-section beams and steel reinforcement cages 13 and 14 inserted therein. The primary trench sections 10 and 11 are spaced apart by a distance greater than the expanse or bite of the excavator CE i.e. greater than the length horizontally of each section 10, 11. This permits excavation of the intervening ground to form secondary trench sections 12A, 12B by using one side of one of the H-section beams in each trench section 10, 11 as a guide for one side of the clamshell excavator CS. Again a thixotropic colloidal liquid or slurry apt to gel is used to prevent disintegration of the walls of the sections 12A, 12B during excavation. As shown, the secondary trench sections 12A and 13B are divided by a single intermediate H-section beam 15. These secondary trench sections are now ready also to receive steel reinforcement cages. Alternatively, the secondary trench sections 12A, 12B may be filled with a steel fibre reinforced concrete instead of inserting the steel reinforcement cages.

Before excavation of the secondary trench sections, however, the primary trench sections 10, 11 are concreted, in a manner illustrated with reference to a further primary trench section 20 in Fig. 2, to form primary wall panels. The primary trench section 20 contains the bentonite slurry supplied during excavation and also has inserted therein a pair of interconnected H-section beams and a steel reinforcement cage. In addition, a concrete tremie pipe 22 is shown lowered into the primary trench section 20, this pipe 22 being in the process of depositing concrete 23 to displace the bentonite slurry which is represented by the numeral 24. The bentonite slurry is removed from the trench section 20 at the same rate that concrete is introduced thereto through the tremie pipe 22. Secondary wall panels are formed in a like manner from the secondary trench sections by installing two tremie pipes, one in each secondary trench section, concrete being cast simultaneously through the two tremie pipes so that there is no differential pressure on the beam 15, to kick it either this way or that.

Two further primary trench sections 26, 30 are also illustrated in Fig. 2, the section 26 having been excavated and being prepared for receiving a pair of H-section beams and a steel reinforcement cage, and the second 30 being shown during the course of excavation. The primary trench section 26 has been excavated by the clamshell excavator CE and is in the process of having the side walls and ends thereof reamed by a reaming, smoothing and squaring "tool" in the form of a pair of H-section beams which are strengthened by rigid connecting bars and which have sharpened lower edges. This reaming tool squares off and evens out the trench section 26 prior to the permanent installation of a pair of interconnected H-section beams, the tool being lowered by a crane under the action of gravity. It should be operated by a power implement instead of simply being raised and lowered by the crane. After reaming, any debris remaining in the bottom of the trench section 26 is easily removed by the clamshell excavator CE prior to introducing the pair of interconnected H-section beams which form a petrmanent part of the primary wall panel. The reaming tool is used in each primary trench section and is finally installed in the last primary trench section to be excavated, as a permanent part of the last primary wall panel formed. The primary trench section 30 is at an earlier stage of preparation than the section 26, the clamshell excavator CE being shown in this instance in the initial stages of excavation of the trench section 30 which is filled with the slurry 24 and is maintained full throughout excavation.

A further secondary trench section 16, in the course of excavation is also illustrated in Fig. 2, the section 16 being disposed between a pair of primary trench sections i.e. 11, 20. The clamshell excavator CE is being guided at one side by the channel at one side of the H-section beams in the trench section 11 as mentioned above. Foam blocks retained in this channel by temporary angle irons initially prevent concrete poured into the primary section 11 and leaking between the flanges of the H-section beam and the earth wall from penetrating into the channel. The clamshell excavator CE breaks the angles as it excavates the secondary trench section 16 and any foam which is not retained in the excavator CE floats to the surface of the bentonite slurry and is thereafter removed and discarded. Any foam blocks which remain intact may be reused.

Ths concept of using a pair of interconnected H-section beams having foam-filled outer channels is disclosed in an article entitled "Slurry Wall, Special Equipment Solve "No Room" Excavation Problem", October, 1973 issue of *Roads and Streets* Magazine.

INTERCONNECTED H-SECTION BEAMS

In Fig. 4 there is shown in greater detail a typical pair of interconnected H-section beams, having foam-filled outer channels, and a steel reinforcement cage, for use in a primary trench section. The pair of beams 50 and 51 are standard rolled beams having wide flanges 52, 53 and 54, 55 and are arranged in the completed wall to have their connecting web portions 56, 57, respectively, transverse to the longitudinal direction of the wall. The outer channels of the beams 50 and 51 are respectively filled with blocks 60 and 61 of polystyrene foam which are retained in place by means of steel angles 66 and plates 67, 68. The foam blocks 60, 61 are inserted between the flanges at both ends of each beam and eliminate the need for pipe joints and other time consuming and expensive construction procedures and most importantly, permit the easy cleaning out of the channels in the beams and enable a structurally sound, clean, water-tight joint between a primary wall panel and the adjacent secondary wall panel to be achieved.

The steel reinforcement cage shown in Fig. 4 includes relatively lightweight vertical bars 70 and horizontal bars 71 intermediate weight horizontal bars 72 and spacer elements 74 and 75 (see also Fig. 5). The vertical bars 70 and horizontal bars 71 and 72 are arranged to form two generally rectangular grids which are joined as shown in Fig. 5 to form the cage by the spacer elements 74 and 75 which are U-shaped and which are tied to the bars 70, 71 and 72. In addition a plurality of bars L and angles A serve rigidly to connect together the two beams 50, 51, being welded at the ends to the beams. The bars 70, 71 and 72 are tied to the bars L and angles A. A structure is thus provided which is open at the top to permit lowering of the tremie pipe 22 to the bottom of the associated trench section.

The reinforcement cage may, however, comprise merely the lightweight vertical bars 70, for example No. 5's ($\frac{5}{8}$ in diameter) and the intermediate weight horizontal bars 72, for example No. 7's ($\frac{7}{8}$ inch diameter). The bars 72 then provide the necessary reinforcement, carrying the load of the soil to the two beams 50, 51, whilst the bars 70 are used for positioning the bars 72.

In the case of the reaming tool shown in Fig. 1 as being lowered into the primary trench section 26, the bars L and angles A are replaced by similar but heavier elements, and the lower edges of the beams are provided with earth cutting edges, as mentioned earlier.

STEEL FIBRE REINFORCED CONCRETE WALLS

Instead of using the reinforcement cages in the secondary trench sections 12A, 12B, for example, the two inner beams of the primary wall panels in the sections 10, 11 may be used in combination with the intermediate H-beam 15 to form a steel fibre reinforced concrete secondary wall panel as mentioned previously. In this instance, steel fibre reinforced concrete is introduced into the sections 12A, 12B by way of tremie pipe 22. This steel fibre reinforced concrete is available from Ribbon Technology Corporation and is described in that company's Bulletin No. SSB—101, January, 1974 and Bulletin No. SB—102, (undated).

In particular, there are instances, for example, where there are underground obstructions such as utilities, telephone lines, etc. when the use of steel fibre reinforced concrete is preferable to utilising reinforcement cages to permit the formation of an uninterrupted reinforced concrete wall. Such an instance is illustrated in Fig. 3 wherein a telephone conduit TC which may be four feet square provides an obstruction. In this case, the primary wall panels 10^1, 11^1 in the primary trench sections are formed one on each side the telephone conduit TC. The beam 80 of the primary wall panel 10^1 closer to the conduit TC is positioned at approximately a distance of the bite of the clamshell excavator CE from the conduit TC. In this case, with a clamshell excavator CE having a bite of seven feet, the beam 80 is positioned at slightly greater than seven feet from the left hand vertical wall of the telephone conduit TC as illustrated. The secondary trench section 12A to the left of the telephone conduit TC is excavated using the foam-filled channel of the beam 80 as a guide for the excavator CE. In a like manner, the secondary trench section 12B to the right of the conduit TC is excavated by the excavator CE using as a guide the foam-filled channel of the beam 81 of the panel 11^1 closer to the conduit TC. Then the clamshell excavator is lowered down into the secondary trench section 12A below the level of the telephone conduit TC and the cable and support system of the clamshell excavator CE is translated towards the telephone conduit TC. The excavator is thus enabled to excavate the ground beneath the conduit TC. A bite of earth is first removed just beneath the conduit TC, this permitting the clamshell excavator then to be positioned for a vertical excavation under the left hand half of the telephone conduit TC. A similar excavation under the right hand half of the telephone conduit TC is also performed until the earth beneath the telephone conduit TC is removed the conduit being cleaned free of earth. After this, the bentonite which is maintaining the excavation walls is displaced by the introduction of the steel fibre reinforced concrete. The steel fibre reinforced concrete then, in combination with the beams 80 and 81 forms secondary reinforced concrete wall panels which have a strength approaching that of secondary wall panels including steel reinforcement cages.

1973 TEST INSTALLATION IN WASHINGTON, D.C.

In this installation, the H-section beams were 80 feet long having $10\frac{1}{2} \times 1$ inch flanges and $28\frac{1}{4} \times \frac{5}{8}$ inch web. Respective channels of the beams were filled with blocks of polystyrene foam held in place by steel angles and bars. At a location where there were no longer adjacent loads, such as buildings, etc., a test construction of two secondary wall panels formed in secondary trench sections such as the sections 12A and 12B in Fig. 2 was conducted. The results demonstrated that while the combined span of the secondary wall panels was double the span between the two beams of a primary wall panel, the work was safely able to proceed at a relatively highly accelerated rate. The foam-filled channels of the beams of the two spaced primary wall panels permitted easy two-step excavation of the secondary trench sections to be carried out without any significant drifting of the beam 15 from the vertical. There was no noticeable subsidence of neighboring streets (the test was not permitted to be carried out adjacent any buildings).

SPECIAL PANEL SECTIONS

One face of the wall built by the method according to the invention may be exposed by later excavations to form e.g. subways, basement walls, etc. Decorative and other architectural effects can then be applied to this face.

Figs. 7 and 8 show how a finished surface may be achieved on, for example, a primary wall panel of such a wall. Initially a unit comprising two H-section beams 201, 202, a steel reinforcement cage 203, and a shuttering device 204, which may be constructed from plywood, or some other easily removed material, is inserted into a primary trench section. In this embodiment, the shuttering device 204 comprises two sheets 206, 207 of three-quarter inch plywood and a plurality of 2 × 4 spacers 208 to 212. The primary trench section is then concreted, the shuttering device 204 preventing the concrete from filling a portion of the primary trench section. Subsequently the shuttering device is removed to expose a smooth recessed concrete surface 220 as shown in Fig. 7 for use, for example, as a subway wall. If desired, the surface 220 can be provided with indicia, lettering or decorative patterns or can be otherwise textured. This may be achieved by using one face of the shuttering device as a mould.

In order to ensure that the surface 220 is not disfigured by elements of the reinforcement cage, i.e. in order to ensure that the cage has a certain amount of concrete covering it, a spacer is provided to keep the reinforcement cage clear of the shuttering device whilst the primary trench section is being concreted. In Fig. 8 a bent wire spacer is illustrated for spacing the shuttering device from the cage. Turning to Fig. 6, a pipe spacer 215 is used instead.

The shuttering device 204 permits the construction of for example, an 18 inch wide wall in a 24 inch wide trench section, in that once the trench section is concreted and the shuttering device is removed, a longitudinal portion 225 (see Fig. 7) of each beam may be cut away.

If a wall is to be constructed with a finished surface it is important to take into consideration the bentonite slurry and concrete loading effects on the shuttering device. The shuttering device must not affect the positioning of the reinforcement cage and must itself remain in position during concreting. Thus any buoyancy of the shuttering device is lowered by aperturing its ends so that the device may fill with thixotropic liquid as the associated trench section is filled. This is particularly important when the reinforcement cage and shuttering device are inserted in a secondary trench section. If the shuttering device were hollow, light weight and sealed, the buoyancy thereof could cause the cage to be poorly positioned or aligned in the trench section. Another advantage of an open ended shuttering device is that it tends to avoid buckling and distortion thereof and hence shifting of the reinforcement cage and itself during the pouring of the concrete. For example, a sixty foot depth of concrete which, exemplarily, has a density of 150 pounds per cubic foot, is a large load on plywood sheets forming the shuttering device and this may be offset somewhat by permitting the shuttering device to fill with bentonite slurry so that the differential loading is significantly less. While a small amount of concrete may enter the space between the 2 × 4 spacers of the shuttering device the space remains predominantly filled with bentonite slurry.

While solid shuttering devices may be used, it should be appreciated that they can be more expensive and, in the end more difficult to separate from the concrete.

Advantages of the preferred embodiment of the present invention may be as follows:—

1. The panels are installed without the need of pre-drilling and pre-setting of H-section beams prior to removing soil between the beams,
2. Watertight connections between the wall panels are assured by the use of steel beams as a water stop. Styrofoam blocks inserted between the flanges of the beams eliminate the need of "end-joint" pipes or other time consuming and expensive construction procedures, permit the easy cleaning of the joint and assure a structurally sound, clean, watertight joint,
3. Vertical and horizontal alignment of the rigid H-section beam framework is assured by the steel lattice work. This rigorous control of the structural elements of the wall assures a simple quick connection of bracing to the beam flanges at the time of general excavation. These braces can be placed at any elevation along the length of the beam. Furthermore, the method allows for changes in brace location during construction,
4. Insertion of the primary structural framework is facilitated by an innovative combination of double H-section beams used as a reaming tool. This tool squares off and evens out each primary trench section prior to the installation of the permanent steel framework.

WHAT WE CLAIM IS:—

1. A method of constructing in the

ground a waterproof wall formed by interlocked vertical concrete wall panels, comprising the steps of excavating two primary trench sections which are spaced apart by a distance greater than the length horizontally of each primary trench section, the excavation of each primary trench section being carried out in the presence of a thixotropic liquid; inserting a pair of interconnected flanged steel beams into each primary trench section; filling each primary trench section with concrete from the bottom up to form a respective primary wall panel; and then in two stages excavating, in the presence of a thixotropic liquid, the intermediate ground between the pair of primary wall panels, using one beam of one of the pairs of interconnected beams as an excavator guide in one of the stages and one beam of the other of the pairs of interconnected beams as an excavator guide in the other of the stages, to form two secondary trench sections; and displacing the thixotropic liquid from the secondary trench sections by filling them from the bottom up with concrete to form secondary wall panels between the two primary wall panels.

2. A method as claimed in claim 1 further comprising inserting steel reinforcement cage in the secondary trench sections.

3. A method as claimed in claim 2 further comprising inserting a steel H-section beam between the secondary trench sections, the steel reinforcement cage means comprising two cages which are placed one at each side of the H-section beam.

4. A method as claimed in claim 1, 2 or 3 further comprising positioning a shuttering device adjacent to one surface of at least one of the trench sections prior to filling same with concrete; removing the surrounding ground to expose said shuttering device; and removing said shuttering device.

5. A method as claimed in claim 4 wherein said shuttering device is apertured to permit said thixotropic liquid to enter therein.

6. A method as claimed in claim 4 or 5 wherein a face of said shuttering device has a decorated surface for decorating the surface of the concrete on removal of said shuttering device.

7. A method as claimed in claim 6 wherein the decorated surface is provided with indicia.

8. A method as claimed in claim 1 wherein the secondary trench sections are filled with steel fibre reinforced concrete.

9. A method as claimed in any preceding claim further comprising using a reaming tool in the form of a pair of interconnected H-section beams for squaring off and evening out the primary trench sections.

10. A method as claimed in claim 9 wherein the pair of flanged beams in one primary trench section comprises the reaming tool.

11. A method as claimed in claim 1 wherein each flanged beam has a channel containing polystyrene foam.

12. A method substantially as herein particularly described with reference to the accompanying drawings.

13. A concrete wall when constructed by the method claimed in any preceding claim.

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1561053 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

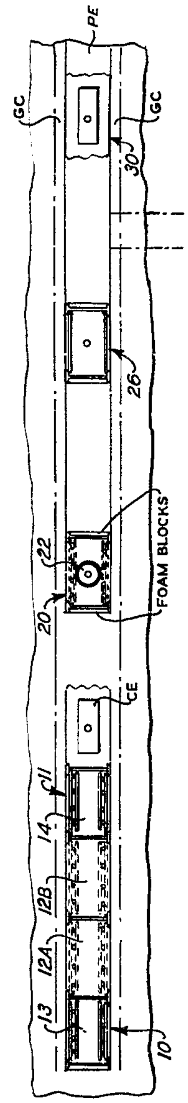

Fig-1

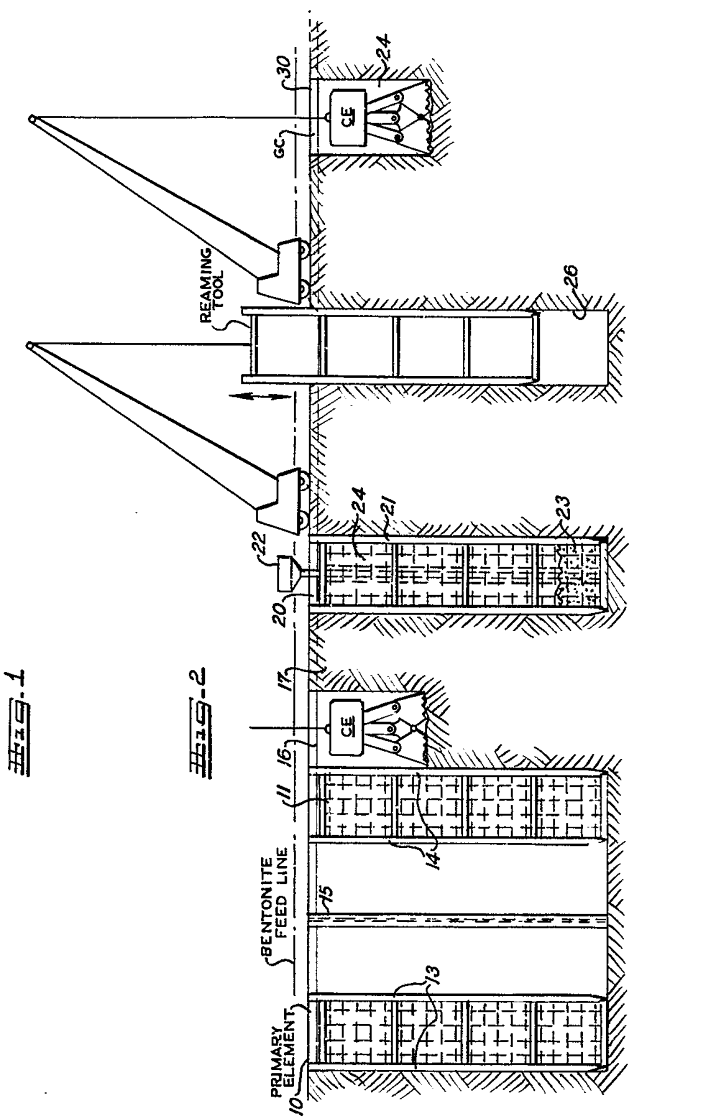

Fig-2

1561053 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

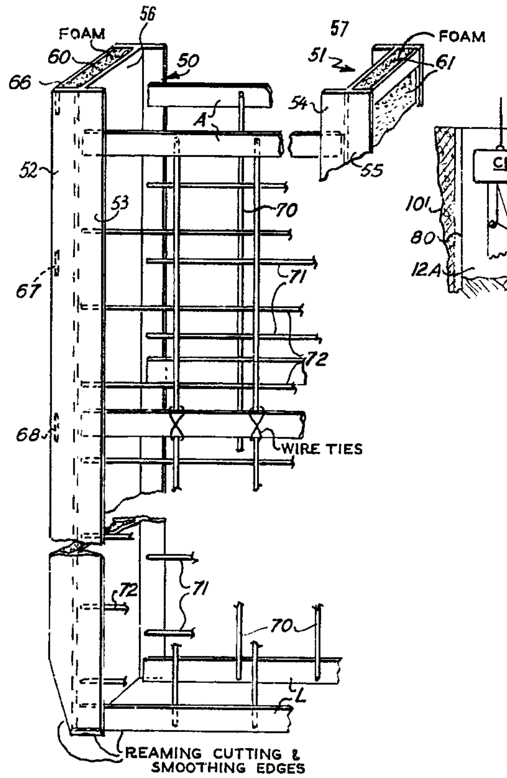

FIG.4

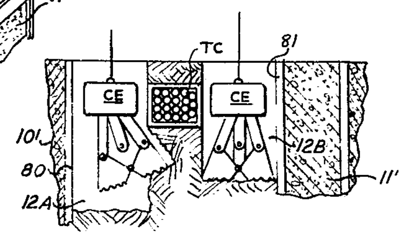

FIG.3

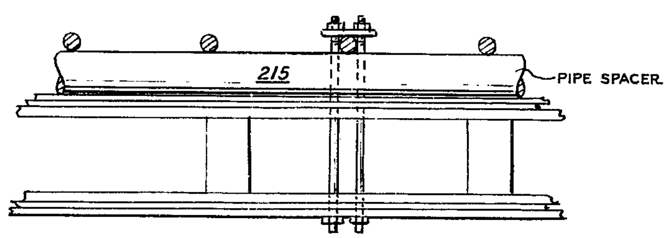

FIG.6

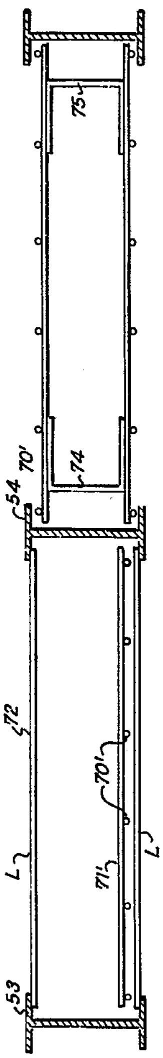

FIG. 5

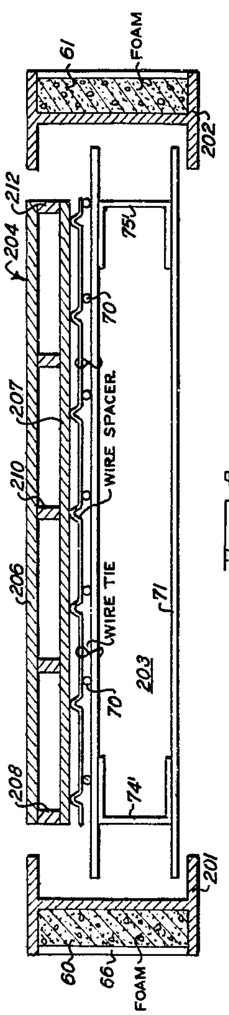

FIG. 6

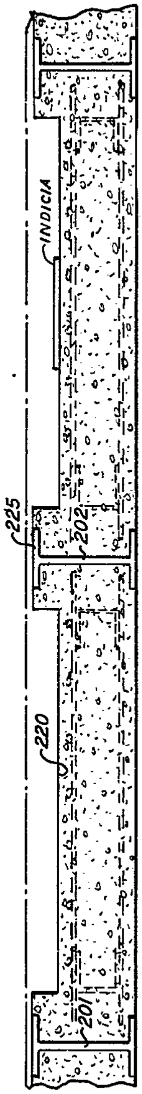

FIG. 7