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(54) IMPROVEMENTS IN OR RELATING TO MARINE STRUCTURES

(71) I, EINAR KNUTSEN, a Norwegian Citizen, of Astrupsvei 36, 5000 Bergen, Norway, do hereby declare the invention, for which I pray that a Patent may be granted to me, and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention relates to a method of building a submersible marine structure afloat in a body of water, and, a submersible marine structure such as a quay or jetty, storage tank, platform, or similar marine installation. The invention is concerned with building such a structure without the use of dry dock facilities.

Current oil and gas exploration, and oil and gas production activities, require large marine structures to be located in a body of water, such as the sea. For example, in the North Sea, marine structures such as drilling platforms and other offshore platforms as well as storage tanks are required and are examples of these structures. Further, requirements exist to produce marine structures such as piers, quays, small boat harbours, tunnels, and other installations on or immediately adjacent the coast.

At the present time, large marine structures, such as described above, are built frequently in large dry docks and thereafter are towed, in a buoyant condition, to an operational site.

When building such a marine structure in a dry dock, one is dependant to a large degree upon the configuration of the bottom of the structure corresponding substantially with the bottom of the dry dock in order to avoid problems arising when towing the structure out of the dry dock.

It is an object of the present invention to provide a method of building such a marine structure, such method being independent of the building location. Thus, the building of such a structure could be carried out at a convenient location with respect to a

supply of labour and raw materials; for example it would be advantageous to have a sandpit or a fitting-out workshop near the building site.

In the type of oil storage tank such as that used in the Ekofisk field in the North Sea, the bottom of the tank was made especially strong so as to withstand its loadings when resting on the sea bed. In order that a tank can be located positively, in a stable condition, on the sea bed, it is preferred to cast or mould the lower surfaces of the structure so that they correspond to the contours of the sea bed at the site where the tank is to be installed. It will be understood that such casting or moulding, in addition to forming a strong tank bottom, is an expensive form of construction.

According to the present invention, there is provided a method of building a marine structure afloat in a body of water, which method comprises the steps of providing a plurality of buoyant construction elements in the body of water, each element having opposed side surfaces and at least two intersecting slots therein, said slots extending across said element and intersecting said side surfaces, said slots emerging in the surface of said element uppermost in the operative position of the structure and extending vertically in a major part of the height extension of said element; assembling said elements in abutting coupled relationship with slots in adjacent elements in lateral communication to form a continuous network of intersecting slots; positioning reinforcing means in said slots to form a reinforced semi-rigid foundation raft; filling said network with water-proof mouldable and settable material while said raft construction is afloat and thereby embedding said reinforcing means in said material so as to form a substantially rigid submersible foundation raft having a network of reinforced beams so formed in said slots; forming the remainder of the marine structure on the reinforced rigid

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submersible foundation raft in united relationship thereto.

5 The method may include the step of positioning said reinforcing means in only the upper portions of said slots. Preferably, the reinforcing means include tensioning means. The element may have upwardly
10 extending vertical portions partially defining said slots, the method including the step of positioning a stiffening member to surround vertical portions of adjacent said elements to connect the said adjacent elements in aligned relationship to each other. The stiffening member may be
15 positioned in a vertically central region of the portions of the slots defined by the vertical portions.

20 Preferably, the method includes the step of positioning the elements relative to each other to define a configuration for the bottom of the structure which correspond with the contour of the bed of the body of water at an intended position of use of the structure, said method further including the
25 step of adjusting the weight loading on said structure to submerge it to rest on the bed at the position of use.

30 According to another aspect of the present invention, there is provided a marine structure comprising a submersible foundation raft and the remainder of said structure permanently united with said raft, said foundation raft comprising a plurality
35 of buoyant construction elements having laterally extending and upwardly opening slots therein; and means for coupling said elements together in mutually abutting relation with slots in adjacent elements in lateral communication with each other, said slots co-operating to define, in the
40 operative position of said structure, at least two laterally extending and upwardly opening location slots intersecting in crossing relationship; a marine structure comprising a submersible foundation raft
45 and the remainder of said structure permanently united with said raft, said foundation raft comprising a plurality of buoyant construction elements having laterally extending and upwardly opening
50 slots therein; means coupling said elements together in mutually abutting relation with slots in adjacent elements in lateral communication with each other, said slots co-operating to define, in the operative
55 position of said structure, at least two laterally extending and upwardly opening location slots intersecting in crossing relationship; and a plurality of intersecting reinforced beams formed from a mouldable and settable material, each of said beams being disposed in an associated one of said
60 slots.

65 The beams may be made from concrete and at least one of said beams has a

prestressed portion uppermost in its operative position. Each of the construction elements may comprise a block of buoyant material having laterally
70 extending top and bottom surfaces and vertically extending side faces in abutting engagement with side faces of adjacent elements, said block having a base portion and a plurality of integral upwardly
75 projecting vertical portions, said vertical portions and said base portion defining said slots in said block. The coupling means may comprise an endless stiffener member surrounding the vertical portions of adjacent elements.

80 The invention will now be described by way of example with reference to the accompanying drawings in which:

85 Figs. 1 to 4 show schematically, in side elevation, the step-by-step building of a marine structure afloat and its subsequent submersion onto the sea bed;

90 Figs. 5 to 10 show schematically, in side elevation, certain details in the building of a structure afloat;

Fig. 11 is a plan view of a raft;

95 Fig. 12 is a perspective view of a type of construction element for use in carrying out the method in accordance with the invention;

Fig. 13 is a plan view of a raft formed from a plurality of construction elements shown in Figure 12;

100 Fig. 14 is a partly sectioned view of the raft shown in Figure 13;

Fig. 15 is a section of the raft shown in Figure 13 after filling the slots with concrete;

105 Fig. 16 is a partly sectioned view of an alternative form of construction element; and,

Fig. 17 is a partly sectioned view of a further embodiment of a construction element.

110 Referring firstly to Figures 1 to 4 of the drawings, there is shown, in diagrammatic form, stages in the construction of a marine structure built by the method of the invention. The structure comprises a plurality of elongate and upstanding
115 buoyant construction elements 22 whose preferred form and interconnection will be described hereinafter; Briefly, however, the elements are firstly attached to each other whilst floating in a body of water 21 having a contoured bed 25. Upon the upper
120 surfaces of the construction elements 22 is built a base 23 formed by a layer of mouldable reinforced material, such as concrete. The attached construction elements 22 and the base 23 together form a submersible foundation raft 20. The buoyant construction elements 22 are
125 displaced vertically with respect to each other so that the bottom configuration of 130

the raft 20 corresponds to the profile of the sea bed 25 at the site at which the marine structure is to be installed. The remainder of the marine structure is then built upon the raft 20 so that the combination of the raft and a structural part 24 are permanently united and form the complete marine structure which is subsequently submerged onto the sea bed 25. It will be noted that Figures 1 and 2 show the marine structure built above a region 25a onto which the structure is to be finally sunk. However, in practice, part of the structure, for example, the raft 20 may be built at one coastal site whilst the remainder of the structure 24 can be built at another coastal site. In this instance, the two parts are then finally assembled to form the marine structure and thereafter towed to the operational site and sunk onto the sea bed. Thus, the raft 20 and the remainder of the structure 24 may each be built at separate locations where labour and/or materials are readily available.

It will be understood that a predetermined number of construction elements 22 will be provided to build the required raft, the elements 22 being ballasted as appropriate to give the necessary bottom configuration to the raft corresponding with the profile of the sea bed 25. In the above example, the marine structure is a storage tank defined axially by the structural part 24.

The following description relates to an alternative construction method which forms no part of the invention, and is provided merely for comparative purposes.

In Figs. 5 to 11, the buoyant construction elements 22 are hexagonal in horizontal cross-section and have six vertical side walls 26, an open bottom 27, and a closed top 28 as shown in Figure 5. In this case, when the foundation raft 20 is sunk onto the sea bed by suitable ballasting, projecting portions of the sea bed penetrate up into the construction elements 22 and crush or deform their side walls 26 which are pressed laterally outwards into adjacent spaces occurring between the raft and the sea bed. It will be understood that further ballasting of the raft 20 will effect movement of the raft 20 with respect to the sea bed to ensure a close fitting relationship therebetween.

Figures 5 to 10 show details of a method of building the foundation raft 20. As shown, the construction elements 22 comprise cast concrete shells having side walls 26 and a top wall 28, the shells being filled with foam or similar buoyant material 29. The elements 22 are fitted together side face 26 to side face 26 by means of bottom locking means 30 and top locking means 31. Referring to Figure 6, reinforcements 32

are secured through reinforcement supports 33 carried by each top wall 28 of respective construction elements 22. The reinforcement supports 33 may be cast into respective top walls 28.

The base 23 may be formed by casting a hollow concrete member 35 whose internal surface is sealed with a layer 36 constituted by a coating of tar epoxy or other similar material (Figures 7 and 8).

The base 23 may be constituted by a cast multi-layer, hollow concrete member including internal strengthening ribs 37 (Figures 9 and 10). This base 23 is formed on the upper surfaces of the construction elements 22, the side and top surfaces of the support being surrounded by a layer of prestressed concrete 38 including associated prestressing wires 39. The inclusion of the layer of prestressed concrete may be carried out during the construction of the hollow concrete member. The base 23 is cast around the reinforcement supports 33; the base 23 may also include the reinforcements 32 for the raft 20.

The construction elements 22 are attached to each other in groups of three in triangular formation, the groups of construction elements 22 being interconnected such that the reinforcements 32, defined by rods, extend along the lines B, C and D as shown in Figure 11. In this arrangement, the buoyant construction elements 22 are hexagonal in horizontal cross-section, but it will be understood that they may have other suitable horizontal cross-sections, for example, triangular, rectangular or other polygonal form. Further, the construction elements 22 may be of different sizes and different strengths according to the design parameters. For example, Figure 5 shows buoyant construction elements 22 of equal height, but if required, these construction elements will be of a different height so that their lower ends are at different depths with their upper ends at the same level so as to form a raft with a flat or substantially flat upper surface. As an example, the construction elements 22 have a height of 1 meter with a diameter of 1 meter, and contain a core member of foamed material reinforced by wire netting or expanded metal; the core member is surrounded by cast concrete or other mouldable material.

Having described one way of constructing a marine structure from floating buoyant elements, reference is now made to Figs. 12-17 which show particular embodiments of construction elements for use with the method in accordance with the invention. Figure 12 illustrates the construction of a construction element 50 comprising a unitary elongate block of

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buoyant material upstanding in its operative position and of hexagonal horizontal cross-section. The element 50 includes a bottom portion 50a carrying upwardly and mutually separate vertical portions 50b defining at least two vertical and intersecting slots 50c emerging at the upper surface 50f and respective ones of side walls 50d; the slots intersect in the central region of the element. As shown in Fig. 13 a plurality of the elements 50 are assembled in abutting coupled relationship by means of three triangular stiffening members 51 which are received in the slots 50c which each extend vertically in a major part of the height extension of the element. In order to obtain a desired stressing between the elements 50, the walls of the slots 50c converge downwardly, slightly, towards the bottom portion 50a which has a bottom surface 50e. The triangular members 51 are used mainly for initially connecting and holding the construction elements 50 together in such a manner that the slots 50c in adjacent elements 50 are in lateral communication to form a continuous network of slots. After such connection, those elements 50 interconnected by a single triangular member 51 can be pulled together by means of pre-tensioning and reinforcing means 52 located in the upper portions of the aligned slots 50c (Figure 14). Figure 14 shows that the triangular members 51 are arranged centrally of the slots whilst the tension means 52 are located in the upper portion of the respective slots. Thereafter, as shown in Figure 15, the slots 50c are filled with waterproof mouldable material such as concrete which, when set, forms beams located in the aligned slots 50c. Moreover, the triangular members 51 in the concrete effectively define a boundary between a reinforced upper connecting portion 53 of the beams, and, a non-reinforced lower portion 54. The same mouldable material i.e. concrete, is used in the connecting portions 53 and the lower portions 54 which are formed simultaneously so as to avoid sharp divisions therebetween. In an alternative arrangement, the lower portions 54 are produced separately and inserted into the slots. Thereafter, the pre-tensioning and reinforcing means 52 is inserted as described above, and the slots filled with concrete to form, with the lower portions 54, beams. Thus, the production of the lower portions can be controlled according to the use to which they are to be put later.

Figure 16 illustrates an alternative form of buoyant construction element 60 having a disc shaped bottom portion 60a carrying a central and upwardly tapering stem 60b which abuts with the lower part of vertical

sections 60c. The element 60 includes a top surface 60d which is spaced from the upper end of the stem 60b thereby separating the upper and opposed surfaces of the vertical portions. Thus, opposed upper surfaces of the vertical portions 60c are separated from each other. In a similar manner to that shown in Figure 12, intersecting slots 61 are arranged in the element 60, the slots being formed in the shape of a cross or star centrally aligned over the stem 60b, the lower portions 62 of the slots lying between adjacent portions 60c and extending outwardly from the stem 60b. A foundation raft is built from the construction elements 60 in a similar manner to that illustrated in Figures 13—15, the triangular members 51 and pre-tensioning and reinforcing means 52, are located in the upper portions of the slots 61 which are filled with concrete which forms the beams. In this case, the stem portion 60b ensures that the lower part of the raft is weaker than the upper portion so that it may deform as already explained above.

Figure 17 illustrates a further alternative design for a buoyant construction element 65 where, in view of the expected profile of the sea bed, one of the construction elements 65 is required to project downwardly to a level lower than that of adjacent elements. The element 65 is provided with slots 66 arranged to be aligned with slots 50c in neighbouring elements 50. The lower portion of the slots 66 include a laterally extending portion 67 whose outer ends are limited by upwardly projecting lower wall portions 68 extending from the base of the element 65. The slots 66 are arranged, as in the embodiment shown in Fig. 12, to intersect at a common point to define a lower portion providing local reinforcement at that point of intersection. The slots are filled with reinforcing means and concrete in similar manner to that described with reference to Figs. 13—15, and it will be understood that resistance against deformation of the beams may be reduced by providing means for destroying the point of intersection, or if necessary, adjacent portions of concrete inserted in the slots. Thus, the breaking strength of the concrete in the slots may be controlled.

Attention is drawn to the Complete Specification filed in connection with our co-pending Patent Application No. 18580/77, (Serial No. 1510543).

WHAT I CLAIM IS:—

1. A method of building a marine structure afloat in a body of water, which method comprises the steps of providing a plurality of buoyant construction elements in the body of water, each element having



buoyant material upstanding in its operative position and of hexagonal horizontal cross-section. The element 50 includes a bottom portion 50a carrying upwardly and mutually separate vertical portions 50b defining at least two vertical and intersecting slots 50c emerging at the upper surface 50f and respective ones of side walls 50d; the slots intersect in the central region of the element. As shown in Fig. 13 a plurality of the elements 50 are assembled in abutting coupled relationship by means of three triangular stiffening members 51 which are received in the slots 50c which each extend vertically in a major part of the height extension of the element. In order to obtain a desired stressing between the elements 50, the walls of the slots 50c converge downwardly, slightly, towards the bottom portion 50a which has a bottom surface 50e. The triangular members 51 are used mainly for initially connecting and holding the construction elements 50 together in such a manner that the slots 50c in adjacent elements 50 are in lateral communication to form a continuous network of slots. After such connection, those elements 50 interconnected by a single triangular member 51 can be pulled together by means of pre-tensioning and reinforcing means 52 located in the upper portions of the aligned slots 50c (Figure 14). Figure 14 shows that the triangular members 51 are arranged centrally of the slots whilst the tension means 52 are located in the upper portion of the respective slots. Thereafter, as shown in Figure 15, the slots 50c are filled with waterproof mouldable material such as concrete which, when set, forms beams located in the aligned slots 50c. Moreover, the triangular members 51 in the concrete effectively define a boundary between a reinforced upper connecting portion 53 of the beams, and, a non-reinforced lower portion 54. The same mouldable material i.e. concrete, is used in the connecting portions 53 and the lower portions 54 which are formed simultaneously so as to avoid sharp divisions therebetween. In an alternative arrangement, the lower portions 54 are produced separately and inserted into the slots. Thereafter, the pre-tensioning and reinforcing means 52 is inserted as described above, and the slots filled with concrete to form, with the lower portions 54, beams. Thus, the production of the lower portions can be controlled according to the use to which they are to be put later.

Figure 16 illustrates an alternative form of buoyant construction element 60 having a disc shaped bottom portion 60a carrying a central and upwardly tapering stem 60b which abuts with the lower part of vertical

sections 60c. The element 60 includes a top surface 60d which is spaced from the upper end of the stem 60b thereby separating the upper and opposed surfaces of the vertical portions. Thus, opposed upper surfaces of the vertical portions 60c are separated from each other. In a similar manner to that shown in Figure 12, intersecting slots 61 are arranged in the element 60, the slots being formed in the shape of a cross or star centrally aligned over the stem 60b, the lower portions 62 of the slots lying between adjacent portions 60c and extending outwardly from the stem 60b. A foundation raft is built from the construction elements 60 in a similar manner to that illustrated in Figures 13—15, the triangular members 51 and pre-tensioning and reinforcing means 52, are located in the upper portions of the slots 61 which are filled with concrete which forms the beams. In this case, the stem portion 60b ensures that the lower part of the raft is weaker than the upper portion so that it may deform as already explained above.

Figure 17 illustrates a further alternative design for a buoyant construction element 65 where, in view of the expected profile of the sea bed, one of the construction elements 65 is required to project downwardly to a level lower than that of adjacent elements. The element 65 is provided with slots 66 arranged to be aligned with slots 50c in neighbouring elements 50. The lower portion of the slots 66 include a laterally extending portion 67 whose outer ends are limited by upwardly projecting lower wall portions 68 extending from the base of the element 65. The slots 66 are arranged, as in the embodiment shown in Fig. 12, to intersect at a common point to define a lower portion providing local reinforcement at that point of intersection. The slots are filled with reinforcing means and concrete in similar manner to that described with reference to Figs. 13—15, and it will be understood that resistance against deformation of the beams may be reduced by providing means for destroying the point of intersection, or if necessary, adjacent portions of concrete inserted in the slots. Thus, the breaking strength of the concrete in the slots may be controlled.

Attention is drawn to the Complete Specification filed in connection with our co-pending Patent Application No. 18580/77, (Serial No. 1510543).

WHAT I CLAIM IS:—

1. A method of building a marine structure afloat in a body of water, which method comprises the steps of providing a plurality of buoyant construction elements in the body of water, each element having



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opposed side surfaces and at least two intersecting slots therein, said slots extending across said element and intersecting said side surfaces, said slots emerging in the surface of said element uppermost in the operative position of the structure and extending vertically in a major part of the height extension of said element; assembling said elements in abutting coupled relationship with slots in adjacent elements in lateral communication to form a continuous network of intersecting slots; positioning reinforcing means in said slots to form a reinforced semi-rigid foundation raft; filling said network with water-proof mouldable and settable material while said raft construction is afloat and thereby embedding said reinforcing means in said material so as to form a substantially rigid submersible foundation raft having a network of reinforced beams so formed in said slots; and forming the remainder of the marine structure, on the reinforced rigid submersible foundation raft in united relationship thereto.

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2. A method as claimed in Claim 1 including the step of positioning said reinforcing means in only the upper portions of said slots.

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3. A method as claimed in Claim 1 or Claim 2 wherein said reinforcing means include tensioning means.

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4. A method as claimed in anyone of the preceding claims wherein said elements have upwardly extending vertical portions partially defining said slots, the method including the step of positioning a stiffening member to surround vertical portions of adjacent said elements to connect the said adjacent elements in aligned relationship to each other.

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5. A method as claimed in Claim 4 wherein said stiffening member is positioned in a vertically central region of the portions of the slots defined by the vertical portions.

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6. A method as claimed in any one of the preceding claims including the step of positioning said elements relative to each other to define a configuration for the bottom of the structure which corresponds with the contour of the bed of the body of water at an intended position of use of the structure, said method further including the step of adjusting the weight loading on said structure to submerge it to rest on the bed at the position of use.

7. A method of building a marine

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structure afloat as claimed in claim 1, the method being substantially as herein described with reference to Figures 1 to 4 as modified by Figures 12 to 15, 16 or 17.

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8. A structure built by a method as claimed in any one of the preceding claims.

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9. A marine structure comprising a submersible foundation raft and the remainder of said structure permanently united with said raft, said foundation raft comprising a plurality of buoyant construction elements having laterally extending and upwardly opening slots therein; means coupling said elements together in mutually abutting relation with slots in adjacent elements in lateral communication with each other, said slots co-operating to define, in the operative position of said structure, at least two laterally extending and upwardly opening location slots intersecting in crossing relationship; and a plurality of intersecting reinforced beams formed from a mouldable and settable material, each of said beams being disposed in an associated one of said slots.

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10. A structure as claimed in Claim 9 wherein said beams are made from concrete, and at least one of said beams has a prestressed portion uppermost in its operative position.

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11. A structure as claimed in Claim 9 or Claim 10 wherein each of said construction elements comprises a block of buoyant material having laterally extending top and bottom surfaces and vertically extending side faces in abutting engagement with side faces of adjacent elements, said block having a base portion and a plurality of integral upwardly projecting vertical portions, said vertical portions and said base portion defining said slots in said block.

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12. A structure as claimed in Claim 11 wherein said coupling means comprise an endless stiffener member surrounding the vertical portions of adjacent elements.

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13. A marine structure as claimed in claim 9 and substantially as herein described with reference to, and as shown in, Figures 1 to 4 and Figures 12 to 15, as modified by Figures 16 or 17.

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