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(72) Inventeurs/Inventors:
BRINKMANN, CARL R., US;
BRUEN, FINBARR J., US;
KOKKINIS, THEODORE, US;
YOUNAN, ADEL H., US

(73) Propriétaire/Owner:
EXXONMOBIL UPSTREAM RESEARCH COMPANY, US

(74) Agent: BORDEN LADNER GERVAIS LLP

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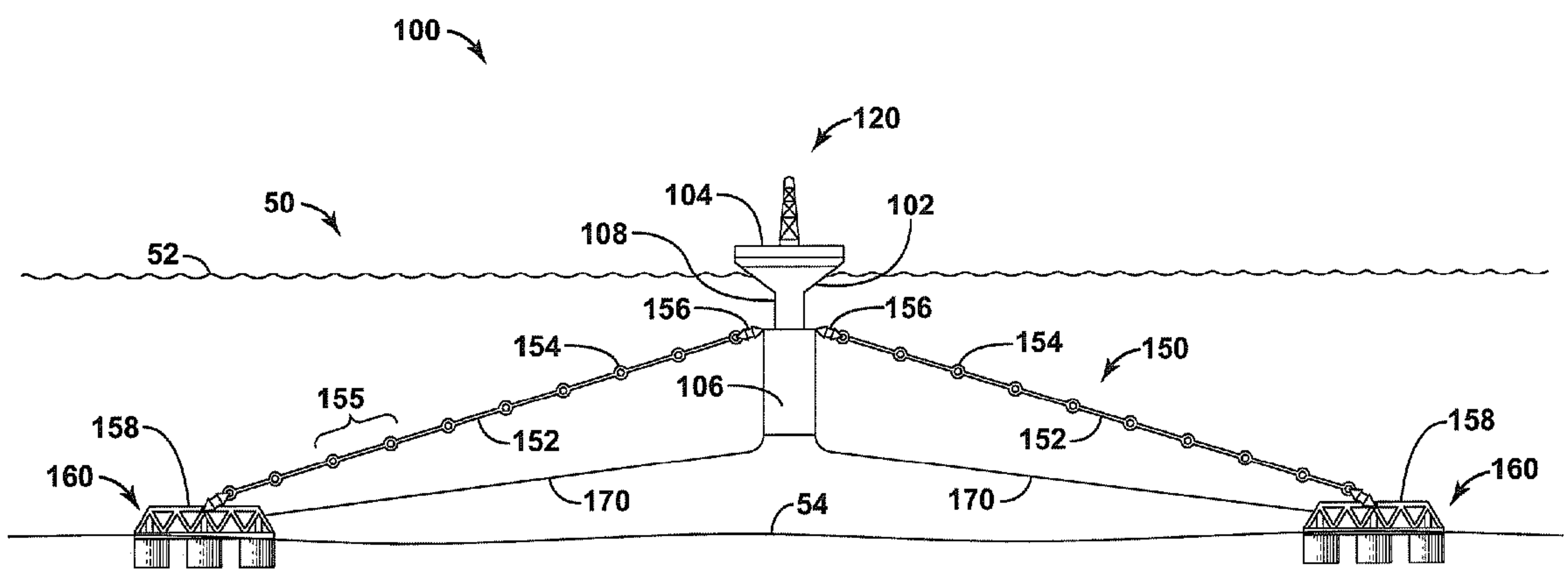

(57) Abrégé/Abstract:
A mooring system for a floating vessel such as a drilling unit is provided. The floating vessel has a platform for providing drilling, production or other operations in a marine environment, and a tower for providing ballast and stability below a water line in the marine environment. The mooring system generally includes a plurality of anchors disposed radially around the tower along a seabed, and a plurality of mooring lines. Each mooring line has a first end operatively connected to the tower, and a second end operatively connected to a respective anchor. Each mooring line further comprises at least two substantially rigid links joined together using linkages. Each joint is at least five meters in length. The mooring system is capable of maintaining station-keeping for the vessel greater than about 100 Mega-Newtons such that operations may be conducted when the marine environment is substantially iced over.

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(71) Applicant *(for all designated States except US)*: **EXXONMOBIL UPSTREAM RESEARCH COMPANY** [US/US]; CORP-URC-SW-359, P.O. Box 2189, Houston, TX 77252-2189 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **BRINKMANN, Carl, R.** [US/US]; 4401 Jim West Street, Bellaire, TX 77401 (US). **BRUEN, Finbarr, J.** [US/US]; 35 Crescent View Court, The Woodlands, TX 77381 (US). **KOKKINIS, Theodore** [US/US]; 4010 Tennyson, Houston, TX 77005 (US). **YOUNAN, Adel, H.** [US/US]; 4603 Meadow Green Drive, Sugar Land, TX 77479 (US).

(74) Agents: **MARSH, Timothy, J.** et al.; Exxonmobil Upstream Research Company, CORP-URC-SW-359, P.O. Box 2189, Houston, TX 77252-2189 (US).

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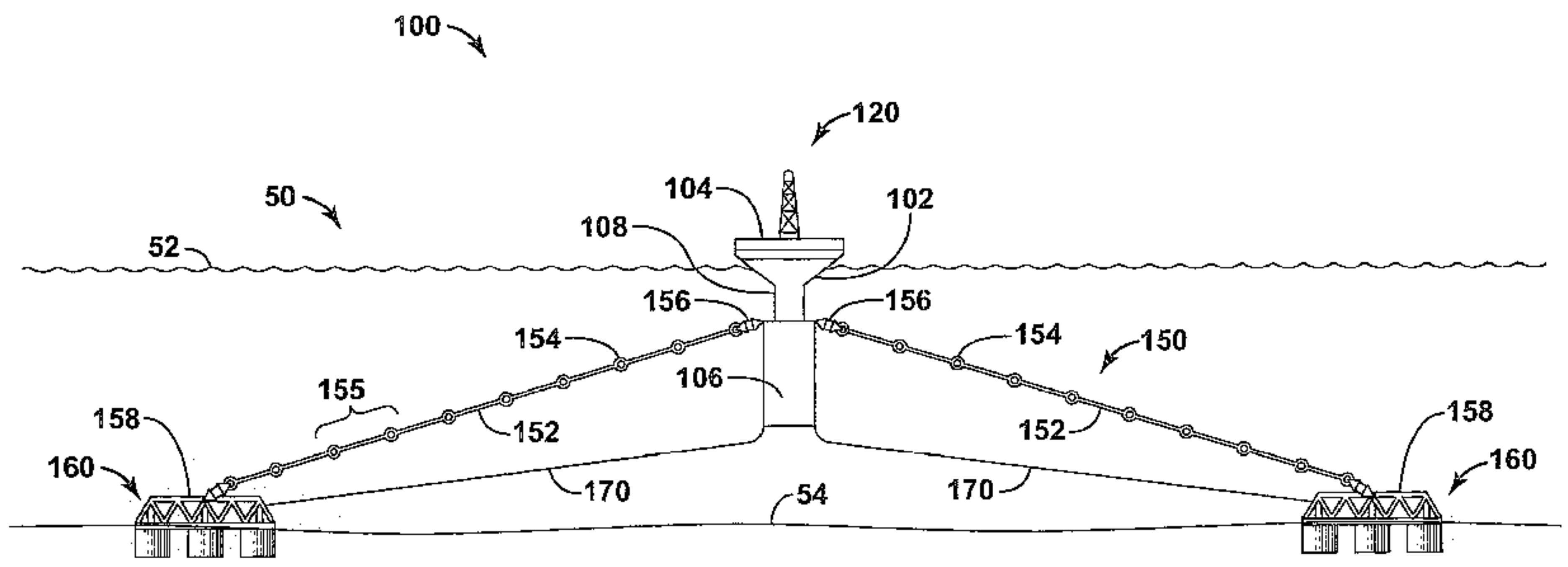


FIG. 1

(57) Abstract: A mooring system for a floating vessel such as a drilling unit is provided. The floating vessel has a platform for providing drilling, production or other operations in a marine environment, and a tower for providing ballast and stability below a water line in the marine environment. The mooring system generally includes a plurality of anchors disposed radially around the tower along a seabed, and a plurality of mooring lines. Each mooring line has a first end operatively connected to the tower, and a second end operatively connected to a respective anchor. Each mooring line further comprises at least two substantially rigid links joined together using linkages. Each joint is at least five meters in length. The mooring system is capable of maintaining station-keeping for the vessel greater than about 100 Mega-Newtons such that operations may be conducted when the marine environment is substantially iced over.

WO 2010/126629 A1

MOORING SYSTEM FOR FLOATING ARCTIC VESSEL

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U. S. Provisional Application No. 61/174,284 filed April 30, 2009.

BACKGROUND OF THE INVENTION

[0002] This section is intended to introduce various aspects of the art, which may be associated with exemplary embodiments of the present disclosure. This discussion is believed to assist in providing a framework to facilitate a better understanding of particular aspects of the present disclosure. Accordingly, it should be understood that this section should be read in this light, and not necessarily as admissions of prior art.

Field Of The Invention

[0003] The present invention relates to the field of offshore drilling technology. More specifically, the present invention relates to a floating marine drilling unit that employs a riser and mooring system suitable for use in icy arctic waters.

Discussion Of Technology

[0004] As the world's demand for fossil fuels increases, energy companies find themselves pursuing hydrocarbon resources located in more remote and hostile areas of the world, both onshore and offshore. Such areas include Arctic regions where ambient air temperatures reach well below the freezing point of water. Specific onshore examples include Canada, Greenland and northern Alaska.

[0005] One of the major problems encountered in offshore arctic regions is the continuous formation of sheets of ice on the water surface. Ice masses formed off of coastlines over water depths greater than 20 or 25 meters are dynamic in that they are almost constantly moving. The ice masses, or ice sheets, move in response to such environmental factors as wind, waves, and currents. Ice sheets may move laterally through the water at rates as high as about a meter/second. Such dynamic masses of ice can exert enormous forces on structural objects in their path. Therefore, offshore structures operating in arctic seas must be able to withstand or overcome the forces created by moving ice.

[0006] Another danger encountered in arctic waters is pressure ridges of ice. These are large mounds of ice which usually form within ice sheets and which may consist of overlapping layers of sheet ice and re-frozen rubble caused by the collision of ice sheets. Pressure ridges can be up to 30 meters thick or more and can, therefore, exert proportionately greater forces than ordinary sheet ice.

[0007] Bottom supported stationary structures are particularly vulnerable in offshore arctic regions, especially in areas of deep water. The major force of an ice sheet or pressure ridge is directed near the surface of the water. If an offshore structure comprises a drilling platform or deck supported by a long, comparatively slender column which extends well below the surface, the bending moments caused by the laterally moving ice may well be sufficient to topple the platform.

[0008] U.S. Pat. No. 4,048,943, issued in 1977 to Gerwick, proposed a drilling unit having an inverted, conically-shaped structure floating generally above the water line. The inverted structure includes a top surface or deck for supporting drilling equipment and activities. The drilling unit also includes a large, cylindrical caisson floating below the inverted conically-shaped structure. The caisson then includes a radially tapered upper portion, preferably conically shaped, connected to the inverted, conically-shaped structure below the water line. Mooring lines are attached to the caisson and then anchored to the sea floor to secure the drilling unit's position in the water.

[0009] The drilling unit of Gerwick includes means for vertically reciprocating the caisson. In this way, the upper portion of the caisson can obliquely contact ice sheets and other ice masses with sufficient dynamic force to pierce and break the ice. The moving ice strikes the slanted wall of the cone-shaped structure, and is uplifted. The uplift of the ice not only tends to break the ice, but also substantially alleviates the horizontal crushing force of the ice on the structure.

[0010] Other drilling structures having inverted, conical-shaped hulls are disclosed in U.S. Pat. No. 3,766,874 issued to Helm, *et al.* and U.S. Pat. No. 4,434,741 issued to Wright, *et al.* Such structures employ hulls that are generally frusto-conical in shape to fracture ice impinging on the hull. The hulls are moored to the sea bottom using traditional chains or wire ropes.

[0011] In traditional offshore operations, the use of chains, wire ropes or synthetic ropes for mooring lines is desirable. These mooring lines offer flexibility to the floating structure, allowing the structure to move in response to waves, wind, and currents. At the same time, such traditional mooring lines may not provide sufficient strength to withstand the high shear forces presented by moving ice sheets. Current mooring systems on floating vessels have limited capability to resist ice loads and are generally limited to open water and warm-weather seasonal drilling or production operations.

[0012] Full development of offshore oil and gas fields requires operations from a given location; for example, the drilling of multiple wells from a given location. This is true even in arctic locations where ice sheets cover the water much of the year. It is desirable to maintain year-round operations to avoid the expense of seasonal relocation and the complexities of multi-year re-entry in partially drilled wells.

[0013] Therefore, a need exists for an improved mooring system that is capable of maintaining an offshore floating unit on a given location in an arctic environment.

SUMMARY OF THE INVENTION

[0014] A mooring system for a floating arctic vessel is provided. The vessel may be, for example, a floating drilling unit. The vessel may alternatively be an axi-symmetric research vessel or other vessel used for offshore drilling, production, exploration, remediation, or research operations.

[0015] The vessel has a platform for providing operations in a marine environment. The vessel further has a tower for providing ballast and stability below a water line in the marine environment. The platform may be supported by a hull having a frusto-conical shape. In this instance, the vessel further comprises a neck connecting the platform structure to the tower.

[0016] The mooring system generally includes a plurality of anchors disposed radially around the tower along a seabed. The anchors may be weighted blocks held on the seabed by gravity. Alternatively, the anchors may each comprise, for example, a frame structure with a plurality of pile-driven pillars or suction pillars secured to the earth proximate the seabed.

[0017] The mooring system also has a plurality of mooring lines. Each mooring line has a first end operatively connected to the tower, and a second end operatively connected to a respective anchor. Each mooring line further comprises at least two substantially rigid links joined together using linkages or pivoting connections. Selected links within each of the plurality of mooring lines may comprise material that increases buoyancy.

[0018] In one aspect, each link is at least five meters in length. Each link may comprise, for example, a plurality of elongated metallic members disposed parallel to one another. In one arrangement, the first end of each of the plurality of mooring lines is connected to the tower proximate an upper end of the tower. Preferably, each of the first ends is selectively connectible to the tower at two or more different depths along the upper end of the tower so as to adjust the draft of the floating drilling unit within the marine environment. In addition, each of the plurality of anchors may comprise a plurality of connection points for selectively connecting each respective mooring line along a corresponding anchor. In this way, the distance of the tower from the connection point may be adjusted.

[0019] The mooring system has the capacity to support offshore operations year-round, even in winter months when the marine environment is substantially iced over. Preferably, the mooring system has the capacity to maintain station-keeping for the vessel in the presence of ice forces greater than about 100 Mega-Newtons.

[0020] The ice forces typically represent moving ice sheets. The forces created by the ice sheets have a horizontal component. In one aspect, each mooring line is capable of withstanding at least about 500 Mega-Newtons of horizontal force.

[0021] In one embodiment, the mooring system further comprises a plurality of secondary mooring lines. Each line has a first end connected to the tower proximate a bottom end of the tower, and a second end connected to a respective anchor. Each of the secondary mooring lines may be fabricated from chains, wire ropes, synthetic ropes or pipes.

[0022] A method for deploying a mooring system for a floating structure is also provided herein. In one aspect, the method includes:

(A) placing a positioning template on a seabed at an offshore work site;

(B) providing a setting line, the setting line having a first end, a second end, and a plurality of substantially rigid links joined together using linkages, each link comprising at least one elongated, metallic member;

(C) connecting the first end of the setting line to the positioning template;

(D) connecting the second end of the setting line to an anchor;

(E) securing the anchor along the seabed according to the first length;

(F) disconnecting the first end of the setting line from the positioning template and the second end of the setting line from the anchor;

(G) repeating steps (A) through (F) for successive anchors such that a plurality of anchors is placed around the positioning template;

(H) providing a permanent mooring line, the mooring line having a first end, a second end, and a plurality of substantially rigid links joined together using linkages;

(I) operatively connecting the second end of the mooring line to an anchor;

(J) operatively connecting, a first end of the mooring line to the floating structure; and

(K) repeating steps (H) through (J) for each of the successive anchors.

[0023] The floating structure is preferably a floating drilling unit. In this instance, the drilling unit may include a platform for providing drilling production operations in a marine environment, and a tower adapted to provide ballast and stability below a water line in the marine environment. The positioning template is placed below the intended location of the tower at the drill-site. Preferably, the first end of each of the respective permanent mooring lines is operatively connected to a top portion of the tower.

[0024] As with the mooring lines in the mooring system described above, each link in the permanent mooring lines comprises a plurality of elongated members disposed parallel to one another. The members may be metallic, ceramic, or other material having high tensile strength. The lings are joined together using a pivoting connector. In one aspect, each of the plurality of elongated members comprises either two or more eyebars or two or more substantially hollow tubular members. Each permanent mooring line is preferably capable of withstanding at least about 100 Mega-Newtons of force from a moving ice sheet.

[0025] A method for relocating a floating structure is also provided herein. The floating structure comprises a platform for providing operations in a marine environment, and a tower for providing ballast and stability below a water line in the marine environment. In one aspect, the method includes disconnecting the tower from the platform. The tower is then lowered within the marine environment to a depth below the depth of an oncoming ice sheet.

[0026] In accordance with the method, the floating structure is moved to a new location in the marine environment. In this way the floating structure is able to avoid impact from the ice sheet.

[0027] In this method, the floating structure is originally stationed in the arctic marine environment by means of a mooring system. The mooring system has a plurality of mooring lines, each mooring line having a first end and a second end. Each mooring line further has at least two substantially rigid links joined together using pivoting connections. The pivoting connections permit the mooring lines to kinematically collapse as the tower is lowered into the marine environment. The mooring system also includes a plurality of anchors placed along the seabed. Each anchor secures a respective mooring line at the second end of the mooring line.

[0028] In one aspect, selected links within each of the plurality of mooring lines receives a material that increases buoyancy. In this way the mooring lines more easily kinematically collapse to accommodate the reduced distance from the respective anchors to the tower as the tower is lowered to the seabed.

[0029] As with the mooring lines in the mooring system described above, each link in the permanent mooring lines comprises a plurality of elongated members disposed parallel to one another. The members may be metallic, ceramic, or other material having high tensile strength. The links are joined together using a pivoting connector. In one aspect, each of the plurality of elongated members comprises either two or more eyebars or two or more substantially hollow tubular members. Each permanent mooring line is preferably capable of withstanding at least about 100 Mega-Newtons of force from a moving ice sheet.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] So that the present inventions can be better understood, certain illustrations, charts and/or flow charts are appended hereto. It is to be noted, however, that the drawings illustrate only selected embodiments of the inventions and are therefore not to be considered limiting of scope, for the inventions may admit to other equally effective embodiments and applications.

[0031] Figure 1 is a side view of a mooring system of the present invention, in one embodiment, for a floating offshore drilling unit. A floating offshore drilling unit is seen in a marine environment.

[0032] Figure 2A shows a side view of an eyebar as may be used as part of a linking joint for a mooring system herein.

[0033] Figure 2B is a plan view of the eyebar of Figure 2A.

[0034] Figure 3A provides a side view of a portion of a mooring line as may be used in the mooring system of Figure 1. Three illustrative links are shown connected together.

[0035] Figure 3B is a perspective view of the portion of the mooring line of Figure 3B. In this view, pins used for joining links of the mooring line are shown exploded from the eyebars.

[0036] Figure 4A presents a side view of an anchor as may be used in the mooring system of Figure 1. Here, the anchor is fabricated from individual suction piles connected via a framing structure.

[0037] Figure 4B is a plan view of the anchor of Figure 4A.

[0038] Figure 5A is a side view of an anchor as may be used in the mooring system of Figure 1, in an alternate embodiment. Here, the anchor is a block gravitationally held on a seabed.

[0039] Figure 5B is a perspective view of the anchor of Figure 5A.

[0040] Figure 5C provides a side view of a connection member as may be used to connect a mooring line to the anchors of Figure 4B or Figure 5B.

[0041] Figure 6A presents a plan view of a link fabricated from one or more eyebars as may be used as part of a link for a mooring system herein, in an alternate embodiment. Here, the link is fabricated in part from a material that imbues buoyancy.

[0042] Figure 6B is a side view of the link of eyebars of Figure 6A.

[0043] Figure 7A is a side view of a mooring system for a floating offshore drilling unit, in an alternate embodiment. In this view, the caisson is attached to the bottom of the drilling structure. The links in the mooring system are in accordance with the illustrative example of Figures 6A and 6B.

[0044] Figure 7B is a side view of the mooring system of Figure 7A. However, the caisson has been detached from the drilling structure and has been lowered within a marine environment. This allows the drilling structure to be towed out of a line of impact with an iceberg.

[0045] Figure 7C is provides a flow chart showing steps for a method for relocating a floating arctic structure.

[0046] Figure 8A is a side view of the mooring system for a floating offshore drilling unit of Figure 1. In this view, the mooring system is arranged to position the drilling structure at the water line for substantially icy conditions.

[0047] Figure 8B is another side view of the mooring system of Figure 1. Here, the mooring system has been arranged to position the drilling structure substantially above the water line for marine wave conditions.

[0048] Figure 9 is an enlarged side view of an upper portion of the tower of a drilling unit. A pivoting eyebar is shown in alternate positions for raising and lowering the drilling structure to accommodate either the substantially icy conditions of Figure 8A, or the substantially marine wave conditions of Figure 8B.

[0049] Figure 10 is another side view of the mooring system for a floating offshore drilling unit of Figure 1. Here, force vectors are shown indicating forces acting on the drilling unit when ice impacts the drilling unit. Thrusters provide active propulsion to help keep the floating structure balanced.

[0050] Figure 11A is a side view of a line used to space an anchor apart from a template. The spacing line may be a segment of a permanent mooring line, or may be a separate, temporary line.

[0051] Figure 11B is an enlarged side view of the spacing line of Figure 11A. The connection between the temporary mooring line and the template is shown.

[0052] Figures 11C and 11D together provide a unified flow chart for a method for deploying a mooring system for a floating structure.

[0053] Figure 12A is a side view of a mooring system of the present invention, in an alternate embodiment, for a floating offshore drilling unit. A floating offshore drilling unit is seen in a marine environment. In this arrangement, the mooring system is secured to a floating tower in such a manner as to position the drilling structure in the marine environment for substantially icy conditions.

[0054] Figure 12B is another side view of the mooring system of the present invention, in an alternate embodiment, for a floating offshore drilling unit. A floating offshore drilling unit is seen in a marine environment. In this arrangement, the mooring system is secured to a floating tower in such a manner as to position the drilling structure in the marine environment for substantially marine wave conditions.

[0055] Figure 13A is a side view of a mooring line as may be used in the mooring system of Figures 12A and 12B.

[0056] Figure 13B provides a cross-sectional view of the mooring line of Figure 13A, seen at line B-B of Figure 13A. A plurality of tubular members is seen.

[0057] Figure 13C presents another cross-sectional view of the mooring line of Figure 13A, seen at line C-C of Figure 13A. A plurality of tubular members is seen with an enclosing wrap to maintain relative position of the tubular members.

[0058] Figure 14A is a side view of a mooring line as may be used in the mooring system of Figures 12A and 12B, in an alternate embodiment.

[0059] Figure 14B provides a cross-sectional view of the mooring line of Figure 14A, seen at line B-B of Figure 14A. A plurality of tubular members is seen.

[0060] Figure 14C presents another cross-sectional view of the mooring line of Figure 14A, seen at line C-C of Figure 14A. A plurality of tubular members is seen.

[0061] Figure 15A shows a side view of a portion of the mooring system of Figures 12A and 12B. Here, the drilling structure has been disconnected from the floating tower. The tower is positioned in the marine environment to avoid contact with a large ice sheet.

[0062] Figure 15B shows a side view of a portion of the mooring system of Figures 12A and 12B. Here, the drilling structure is disconnected from the floating tower. The tower is positioned in the marine environment further to avoid contact with an extreme ice feature such as an iceberg.

[0063] Figure 16A is a side view of an anchor as might be used as part of a mooring system of the present inventions, in one embodiment. An end of a mooring line from Figures 12A and 12B is shown exploded away from a slot attached to the anchor.

[0064] Figure 16B is a plan view of the anchor of Figure 16A. The end of the mooring line from Figures 15A and 15B is again shown exploded away from the slot attached to the anchor.

[0065] Figure 17 is a side view of an upper portion of the floating tower of Figures 12A and 12B. The upper portion has been expanded to demonstrate the selective placement of an end of the mooring lines along the tower. In the illustrative arrangement, a semi-radial connector is provided at the very end of the connecting joint.

DETAILED DESCRIPTION OF CERTAIN EMBODIMENTS

Definitions

[0066] As used herein, the term "hydrocarbon" refers to an organic compound that includes primarily, if not exclusively, the elements hydrogen and carbon. Hydrocarbons generally fall into two classes: aliphatic, or straight chain hydrocarbons, and cyclic, or closed ring hydrocarbons, including cyclic terpenes. Examples of hydrocarbon-containing materials include any form of natural gas, oil, coal, and bitumen that can be used as a fuel or upgraded into a fuel.

[0067] As used herein, the term "fluid" refers to gases, liquids, and combinations of gases and liquids, as well as to combinations of gases and solids, and combinations of liquids and solids.

[0068] As used herein, the term "subsurface" refers to geologic strata occurring below the earth's surface.

[0069] The term “eyebar” refers to any elongated object that has a connection means at opposing ends. A non-limiting example is a “dog bone” that has through-openings at each end for receiving a u-joint or a pin or other pivoting connector.

[0070] The term “seabed” refers to the floor of a marine body. The marine body may be an ocean or sea or any other body of water that experiences waves, winds, and/or currents.

[0071] The term “arctic” refers to any oceanographic region wherein ice features may form or traverse through. The term “arctic,” as used herein, is broad enough to include geographic regions in proximity to both the North Pole and the South Pole.

[0072] The term “marine environment” refers to any offshore location. The offshore location may be in shallow waters or in deep waters. The marine environment may be an ocean body, a bay, a large lake, an estuary, a sea, or a channel.

[0073] The term “ice sheet” means a floating and moving mass of ice, floe ice, or ice field. The term also encompasses pressure ridges of ice within ice sheets.

[0074] The term “platform” means a deck on which offshore operations such as drilling operations take place. The term may also encompass any connected supporting floating structure such as a conical hull.

Description of Specific Embodiments

[0075] **Figure 1** presents a side view of an offshore drilling unit **100**. The offshore drilling unit **100** includes an inverted, generally conical drilling hull **102**. A top side of the hull **102** comprises a platform **104** on which drilling operations take place. A drilling rig **120** is seen extending above the platform **104**. The platform **104** supports additional drilling and production equipment not illustrated. The drilling hull **102**, the platform **104**, and the associated drilling and production equipment together comprise a drilling structure.

[0076] The offshore drilling unit **100** also includes a floating tower **106**. In this illustrative arrangement, the tower **106** defines a substantially cylindrical body that floats in a body of water in an upright position. Such a structure is sometimes referred to in the marine industry as a “caisson.” However, the illustrative tower **106** is not limited to caissons or other specific tower arrangements. The tower **106** is connected to a bottom side of the drilling hull **102** by means of a neck **108**. Thus, as the tower **106** floats in accordance with Archimedes principle, it supports the drilling hull **102** and accompanying drilling operations.

[0077] The floating tower **106** contains controllable ballast compartments to keep the structure upright and stable. The tower **106** may additionally be used as a storage facility for equipment and supplies.

[0078] The offshore drilling unit **100** is shown in a marine environment **50**. More specifically, the offshore drilling unit **100** is shown floating in an arctic body of water. A water line is seen at **52** while a seabed or subsea floor is seen at **54**. In the view of **Figure 1**, the marine environment **50** is substantially free of ice. Thus, it is in a condition where marine waves act upon the drilling unit **100** in response to wind and water currents. However, it is understood that the drilling unit **100** is designed to operate year-round in an arctic environment, including the cold winter months when substantially icy conditions prevail in the marine environment.

[0079] In order to maintain the position of the drilling unit **100** in the marine environment **50**, a mooring system **150** is provided. The use of a mooring system **150** provides what is known as "station-keeping." Station-keeping is important during drilling operations to maintain the drilling unit **100** in proper position over the seabed **54** while a wellbore (not shown) is being formed.

[0080] The mooring system **150** first includes a plurality of anchors **160**. In the view of **Figure 1**, only two anchors **160** are shown. However, it is understood that the mooring system **150** preferably includes at least four and, more preferably six to ten anchors **160**. Each anchor **160** rests on the seabed **54** at a designated distance from the tower **106**. The anchors **160** are disposed radially around the tower **106** along the seabed **54**.

[0081] The mooring system **150** also includes a plurality of mooring lines **152**. Each mooring line **152** has a first end connected to the tower **106**, and a second end connected to a respective anchor **160**. In the arrangement of **Figure 1**, a first pivoting bracket **156** connects the first end of each mooring line **152** to the tower **106**, while a second pivoting bracket **158** connects the second end of each mooring line **152** to a respective anchor **160**.

[0082] It is preferred that mooring line **152** be connected to the tower **106** at an upper end of the tower **106**. The mooring lines **152** may be hung from tower **106** in a catenary fashion. However, unlike conventional wire rope used as a mooring line, the mooring lines **152** of the present invention are preferably maintained in a state of tension. In this respect, it is not necessary in an arctic marine environment to give the mooring line **152** slack, as the shallow nature of the water and the almost annual presence of ice minimizes marine wave forces.

[0083] Each mooring line **152** comprises a plurality of links **155**. The links **155** are joined together using pivoting connectors **154**. The connectors **154** may be, for example, pins placed through aligned through-openings. Alternatively, the connectors are u-joints or other pivoting connection means.

[0084] In the present inventions, the mooring lines **152** are not conventional wires, chains or cables; rather, the mooring lines **152** define multiple links **155** of substantially rigid members. Each link **155** may represent, for example, a set of two or three individual eyebars in parallel. The links **155**, in turn, are connected at respective ends by the connectors **154**.

[0085] **Figure 2A** shows a side view of a single eyebar **210**. **Figure 2B** presents a top view of the eyebar **210** of **Figure 2A**. As seen from the two views together, the eyebar **210** includes an elongated body **212**. At opposing ends **214** of the body **212** are through-openings **216**. The through-openings receive respective connecting pins (not shown).

[0086] The eyebar **210** may be used as part of a link **155** for the mooring system **150** herein. The eyebar **210** defines an elongated steel or other metal body. However, other materials such as fiberglass, ceramic or composites may be considered. The eyebar **210** may be, for example 5 to 50 meters in length. In addition, the eyebar **210** may be about 1,000 mm in height and 250 mm in width. This creates a cross-section of 25,000 mm. This, in turn, provides a tensile capacity of 100 Mega-Newtons or more for the eyebars **210**. This amount is to be contrasted with a typical wire rope used in a conventional mooring system that has a cross-section of about 6 inches with a corresponding tensile capacity of about 15 Mega-Newtons. Hence, an increase in capacity is accomplished by the increased steel area available to resist tension loads.

[0087] As indicated in **Figure 1**, a plurality of links **155** is joined to form a single mooring line **152**. **Figure 3A** shows a side view of three links **155** of eyebars **210**. The links **155** represent a portion of a mooring line as may be used in the mooring system **150** of **Figure 1**. The through-openings **216** of eyebars **210** of adjacent links **155** are aligned and pinned. This provides relative pivotal motion as between the links **155**.

[0088] **Figure 3B** presents a perspective view of the eyebar links **155** of **Figure 3A**. Here, the adjacent links **155** are seen in exploded-apart relation. It can be seen that each link **155** may include two or even three eyebars **210**. The use of multiple eyebars **210** in a link **155** provides additional tensile capacity to a mooring line **152**. In one aspect, each link **155** includes three to eight eyebars **210**. The number of eyebars used will depend on such factors as the cross-sectional area of the individual eyebars **210** and the desired station-keeping capacity. Adding eyebars **210** may increase line capacity up to 600 MN, for example.

[0089] In order to form a mooring line **152**, the individual eyebars **210** of a link **155** are placed in parallel position. The through-openings **216** of the eyebars **210** are again aligned. Pins **220** are then placed through the through-openings **216** of parallel eyebars **210**. Pins **220** as may be used for joining links **155** of the mooring line **152** are shown exploded from the eyebars **210**.

[0090] As noted, the mooring lines **152** are connected at a second end to respective anchors **160**. **Figure 4A** is a side view of an illustrative anchor **160** as may be used in the mooring system **150** of **Figure 1**. **Figure 4B** is a plan view of the anchor **160** of **Figure 4A**. As shown together in **Figures 4A** and **4B**, the anchor **160** comprises a collection of individual piles members **164**. The piles **164** are preferably designed to be attached to the seabed **54** by pile driving, suction driving, or other means known in the art.

[0091] The piles **164** are connected through a framing structure **162**. The framing structure **162** is preferably a lattice of steel elements connected to the piles **164** and welded together. The framing structure allows the connection to take place between a mooring line **152** and the anchor **160** at different places along the anchor **160**. This, in turn, allows the mooring system **150** to better accommodate the length of an individual mooring line **152**.

[0092] The suction pile anchor **160** is able to resist the tension of the mooring line **152** by frictional and hydrostatic forces imposed on the anchor **160**. Because the size requirements of a single suction pile anchor **160** may preclude its fabrication and installation, a group of smaller piles arranged in a structure frame as shown in **Figures 4A** and **4B** can provide the required resistance. The specific number, diameter, penetration and spacing of the piles is specific to a particular application.

[0093] The anchor embodiment **160** of **Figures 4A** and **4B** is not the only possible embodiment for an anchor. **Figure 5A** is a side view of an anchor **560** as may be used in the mooring system of **Figure 1**, in an alternate embodiment. **Figure 5B** is a perspective view of the anchor of **Figure 5A**. Here, the anchor **560** is a block **562** gravitationally held on the seabed **54**.

[0094] The block **562** is preferably fabricated from concrete that is reinforced with steel rebar. The block forming the anchor **560** may be, for example, 100 meters long, 100 meters wide and 44 meters thick. Other dimensions, of course, may be employed. The gravity-based anchor **560** resists the tension of the mooring line **152** by its weight. The weight provides resistance to the vertical component of tension generated within the mooring line **152**. At the same time, the weight provides frictional resistance to the horizontal component of the tension.

[0095] It can be seen in both **Figures 5A** and **5B** that a pivoting connection member **158** is provided on a top surface **564** of the anchor **560**. The connection member **158** is secured by a steel o-ring **159** or other means. The o-ring **159**, in turn, is secured to a steel c-ring **566** cemented in place in the top surface **564** of the block **562**.

[0096] **Figure 5C** is a side view of the connection member **158** as may be used to connect a mooring line **152** to the anchors of **Figure 4B** or **Figure 5B**. The illustrative connection member **158** defines two steel plates **532** connected by a pair of hinges **534**. At opposing ends **538** of the plates **532** are through-openings **536**. The through-openings **536** may be aligned with through-openings **216** in ends **214** of a set of parallel eyebars **210**, and then pinned for a secure, pivoting connection.

[0097] It is understood that the connection member **158** of **Figure 5C** is merely illustrative. Any connection member that allows for a pivoting connection between a mooring line **152** and an anchor (such as anchor **160**) may be used. It is also noted that the connection member **158** of **Figure 5C** may be used as a connection member for connecting the mooring line **152** to the tower **106**.

[0098] In some instances it is desirable to disconnect the tower **106** from the drilling unit **120**. One such example is when the drilling unit is to be towed to another offshore location for new drilling operations. Another example is when the drilling unit **120** is in the oncoming path of a large iceberg or other extreme ice feature. In either instance, a problem arises when disconnecting the tower **106** and lowering it to the seabed **54**. In this respect, the jointed mooring lines **152** of the present invention are designed to accommodate the lowering of the tower **106** by kinematically collapsing.

[0099] To control this situation, selected links **155** of the mooring lines may be endowed with a buoyant characteristic. **Figure 6A** is a plan view of a link **655** of eyebars **610** as may be used as part of a linking joint for the mooring system **150** herein, in an alternate embodiment. **Figure 6B** is a side view of the link **655** of eyebars **610** of **Figure 6A**.

[0100] The illustrative link **655** includes two parallel eyebars **610**. However, a different number of eyebars **610** may be employed. In **Figure 6B**, an eyebar **610** is seen primarily in phantom.

[0101] Each eyebar **610** defines an elongated body **611** having opposing ends **614**. Each end **614** has a through-opening **616**. The through-openings are configured and dimensioned to receive a pivoting connector such as a pin (not shown). The pivoting connector connects adjacent ends **614** of eyebars **610**, thereby providing a connection.

[0102] In the arrangement of **Figures 6A** and **6B**, the link **655** is fabricated in part from a material that imbues buoyancy to the link. Buoyancy is defined as the difference in weight between the buoyancy material and the weight of sea water of the same volume. The buoyant material is seen at **652**. Buoyant materials are known in the offshore oil and gas industry and are generally fabricated from low-density, water-impermeable materials. An example of a buoyancy material is syntactic foam having a density as low as 29 pounds per cubic foot. Each cubic foot of material weighing 29 pounds in sea water provides 35 pounds of buoyancy. Densities of 36 pounds per cubic foot may be required for depths to 6,500 feet.

[0103] U.S. Pat. No. 3,622,437, entitled "Composite Buoyancy Material," discloses a buoyancy material having hollow spheres made of a thermoplastic resin, encased in a matrix of syntactic foam. The buoyancy material is said to offer a density as low as 18 to 22 pounds per cubic foot. Other buoyancy materials may be used such as solid syntactic foam containing no minispheres as offered by Flotation Technologies of Biddeford, Maine. The present inventions are not limited to the type or source of buoyancy material, if any.

[0104] The buoyancy material **652** may be secured in pieces to opposing sides of selected eyebars **610**. Alternatively, the buoyancy material **652** may be wrapped completely around individual eyebars **610** or around a substantial length of a link **655**. Only selected links **655** will receive buoyancy material **652**. Alternatively, all links will have some buoyancy material **652**, but the degree of buoyancy will be selectively alternated as between links or groups of links.

[0105] The links **655** are designed not only to reduce downward load that might otherwise be applied by the mooring system **150** to the drilling unit **100**, but also to improve collapsibility of the mooring lines **152**. This is of benefit when it is desirable to disconnect the tower **106** from the drilling structure **120** so that the drilling structure **120** may be towed to another offshore location. This is of particular benefit should the operator desire to quickly avoid a collision by an oncoming iceberg.

[0106] **Figure 7A** is a side view of a mooring system **150'**, in an alternate embodiment, for a floating offshore drilling unit **100**. The offshore drilling unit **100** is again shown in a marine environment **50**. A water line is seen at **52** while a seabed or subsea floor is seen at **54**. Unlike the marine environment **50** of **Figure 1**, the marine environment **50** of **Figure 7A** includes a large ice mass **710**, or ice sheet. The ice sheet **710** is moving along a path indicated by arrow **712**. The drilling unit **100** is shown in that path.

[0107] The drilling structure **120** and attached tower **106**, making up the drilling unit **100**, are in position for offshore oil and gas operations. Such operations may include drilling, remediation or production. In the view of **Figure 7A**, the tower **106** remains attached to the neck **108** of the drilling structure **120**.

[0108] The drilling unit **100** is maintained in place by a mooring system **150**. The mooring system **150'** is comprised of a plurality of anchors disposed radially around the tower along the seabed **54**. In addition, the mooring system **150'** comprises a plurality of mooring lines **152**. Each mooring line **152** once again has a first end operatively connected to the tower **106** and a second end operatively connected to a respective anchor, such as anchor **560** of **Figure 5A**.

[0109] Each mooring line **152** includes a plurality of links **155**, **655**. The links **155**, **655** are linked together using linkages such as a pin received within the through-openings **216** of **Figure 2A**. In the mooring system **150'** of **Figure 7A**, selected links **655** include a buoyancy material such as buoyancy material **652**. Those links **655** are biased to float upward, that is, they have slightly positive buoyancy, while the links **154** want to sink, that is, they have slightly negative buoyancy. Links **655** are indicated with upward-pointing arrows, while links **155** are indicated with downward-pointing arrows.

[0110] **Figure 7B** is a side view of the mooring system of **Figure 7A**. Here, the tower **106** has been detached from the drilling structure **120**. The tower **106** has also been lowered within the marine environment near the seabed **54**. This allows the drilling structure **120** to be towed out of the line of impact (shown by arrow **712**) with the ice sheet **710**. It also allows the iceberg **710** to clear the tower **106**.

[0111] It can be seen in **Figure 7B** that a vessel **720** has been connected to the drilling structure **120**. The vessel **720** is pulling the drilling structure **120** away from the ice sheet **710**. In this way the drilling structure **120** is spared impact by the ice sheet **710**.

[0112] To enable the tower **106** to be lowered to the seabed **54**, the mooring lines **152** need to be able to collapse. It can be seen in **Figure 7B** that the mooring lines **152** have collapsed. The links **155** within the lines **152** having no or slightly negative buoyancy tend to sink, while the links **655** having a buoyancy material tend to float. In this way, the mooring system **150'** can accommodate "compression" as the tower **106** is lowered to a water depth out of harm's way of the approaching ice sheet **710**.

[0113] Another feature that may optionally be provided as part of the mooring systems herein is the ability to adjust the level of flotation by the drilling unit **100**. Stated another way, it is desirable to change the draft of the drilling unit **100**. Those of ordinary skill in the art will understand that the draft is the distance from the water line **52** to the deepest part of the tower **106**.

[0114] During the winter season and other cold-weather months, the marine environment will be extremely icy, and the drilling unit will be subject to primarily ice loading (as opposed to wave loading). During this time, it is preferable that the conical-shaped drilling hull **102** be positioned in the water so that the conical portion of hull **102** sits in the water to provide the main contact point for the ice. This provides greater ability to withstand forces produced by ice sheets. It also ensures that ice loading is always horizontal and vertically upward, thus, not tending to sing the floating drilling unit **100**.

[0115] **Figure 7C** provides a flow chart showing steps for a method **750** for relocating a floating arctic structure. The method **750** first comprises providing a floating structure. This is shown at Box **755**. The floating structure may be, for example, the drilling unit **100** of **Figure 1**.

[0116] The floating structure generally includes a platform on which operations are performed in a marine environment. The floating structure also includes a tower for providing ballast and stability below a water line in the marine environment. Further, the floating structure is originally stationed in the arctic marine environment by means of a mooring system. The mooring system comprises a plurality of mooring lines having a first end and a second end, wherein each mooring line has at least two substantially rigid links joined together using pivoting connections. The mooring system also includes a plurality of anchors placed along the seabed. Each anchor secures a respective mooring line at the second end of the mooring line. The mooring system may be, for example, the mooring system **150** or the mooring system **150'**.

[0117] The method **750** also includes disconnecting the tower from the platform. This is shown at Box **760**. Those of ordinary skill in the art will understand that the tower can be mechanically disconnected from an offshore operations platform while the structure is still in the water.

[0118] The method **750** next includes lowering the tower within the marine environment. This step is shown at Box **765**. The tower is lowered to a depth below the depth of an oncoming ice sheet. The pivoting connections in the mooring lines permit the mooring lines to kinematically collapse as the tower is lowered into the marine environment.

[0119] The method **750** also includes moving the floating structure to a new location in the marine environment. This is indicated at Box **770** of **Figure 7C**. The new location will, of course, be out of the line of approach by the ice sheet. In this way the floating structure is spared impact with the ice sheet.

[0120] **Figure 8A** is a side view of the mooring system **150** for the floating offshore drilling unit **100** of **Figure 1**. In this view, the mooring system **150** is arranged to position the drilling structure **120** and the attached floating tower **106** so that the conical portion of the hull **102** sits in the water to provide the main contact point for the ice. The draft of the drilling structure **120** is indicated at $\mathbf{D_I}$.

[0121] During the summer season when the marine environment experiences waves, it is preferable to elevate the conical-shaped drilling hull **102** out of the path of incoming waves. In this manner, the waves contact a minimum structural exposure of the drilling structure **120**, that is, the "neck" portion of the drilling unit **100**. This is done by reducing the draft.

[0122] **Figure 8B** is another side view of the mooring system **150** of **Figure 1**. Here, the mooring system **150** has been arranged to position the drilling structure **120** to sit higher above the water line **52**. This allows the drilling structure **120** to be more stable in the face of marine wave conditions. The reduced draft is indicated at $\mathbf{D_W}$.

[0123] In a known and conventional wire rope mooring system, the length of the various mooring lines can be readily adjusted to accommodate changes in draft. For example, the individual lines may be winched at the connection with the floating vessel. However, with the mooring lines **155** or **655** that employ mechanical linkages, it may be difficult to manufacture lines that will allow adjustment in length. Therefore, a unique adjustment system is provided for the mooring lines as one option herein.

[0124] The adjustment system, in one embodiment, employs a selectively pivoting "dog bone" link. This “dog bone” link may be included as part of the respective mooring lines **150**, or excluded as needed. Preferably, the “dog bone” link is maintained in the mooring lines **150** even when not in use. This is demonstrated in **Figure 9**.

[0125] **Figure 9** is an enlarged side view of an upper portion of the floating tower **106** of a drilling unit **100**. Shown in this side view is a pivoting "dog bone" link **900**. The “dog bone” link **900** pivots about pin **902** at a proximal end of the dog bone link **900**. A distal end **904** of the dog bone link **900** opposite the pin **902** is provided. This distal end **904** is attached to a connecting member **156**, which in turn is connected to a mooring line (not shown).

[0126] In one arrangement, the pivoting dog bone link **900** pivots freely from the tower **106**. In this position, the distal end of the link **900** is indicated at **904w**. The corresponding coordinate of force acting against the tower **106** by the mooring line is shown at $\mathbf{F_w}$. In this position, the length of the mooring line is effectively extended. This, in turn, allows the tower **106** and connected drilling structure **120** to be positioned in the marine environment to avoid waves in accordance with **Figure 8B**.

[0127] In an alternate position, the pivoting dog bone link **900** is prevented from pivoting away from the tower **106**. In this position, the distal end of the link **900** is indicated at $\mathbf{904_I}$. The corresponding coordinate of force acting against the tower **106** by the mooring line is shown at $\mathbf{F_I}$. In this position, the length of the mooring line is effectively reduced. This, in turn, causes the tower **106** and connected drilling structure **120** to be lowered in the marine environment to better withstand ice forces. This also reduces the draft so that the draft is in position $\mathbf{D_I}$ in accordance with **Figure 8A**.

[0128] It can be see from **Figure 9** that a relationship exists between the secured location of the dog bone link **900** and the change in draft. The relationship is primarily a function of the mooring line angle. For an 8 meter long dog bone link and a line angle of about 15 degrees, the dog bone will provide a 20 meter change in draft. The 20 meter difference is demonstrated in **Figure 9**. Other dog bone link lengths can be used to effectuate larger or smaller drafts.

[0129] It is understood that the pivoting dog bone link **900** shown in **Figure 9** is merely illustrative. Other adjustable connection arrangements may be employed for changing the draft of the drilling unit **100** between $\mathbf{D_I}$ and $\mathbf{D_W}$. For example, the operator may simply add or remove the dog bone link **900** depending on the water condition. Either arrangement allows the operator to raise and lower the drilling unit **120** to accommodate either the substantially icy conditions of **Figure 8A**, or the substantially marine wave conditions of **Figure 8B**.

[0130] **Figure 17**, discussed in further detail below, provides an alternate connection arrangement for repositioning the drilling unit **120**. In the alternate connection mechanism, an end of the mooring lines may be selectively placed along the upper portion of a floating tower (seen at **106'**).

[0131] Referring now to **Figures 1** and **10** together, another optional feature that may be provided as part of the mooring systems herein is the use of an active propulsion system. In one aspect, thrusters **1020** are employed for active propulsion at the bottom of the tower **106**, **106'**. When activated, the thrusters **1020** provide a force "**R**" within the water below the water line **52** that may be used to maintain the drilling unit **100** in an upright position.

[0132] **Figure 1** presents a pair of illustrative thrusters **109** at the bottom of the tower **106**. The thrusters **109** represent an active or dynamic positioning system using sensors and computer-controlled propellers. The presence of thrusters **1020** provides thruster-assisted mooring. For example, the thrusters **1020** may be any type of propeller (e.g., a controllable pitch, fixed pitch, and/or counter-thrusting propeller), thruster, propulsor, or water jet, and may include features such as pitch control, tunnels for quieter operation, under water replacement, and retractability. Two exemplary propulsion devices are the AZIPOD® podded propulsor made by ABB and the Mermaid™ podded propulsor made by Kamewa™. This system comprises powerful (5-25 megawatts per propulsor) propulsors.

[0133] **Figure 10** provides a side view of a mooring system **150''** for a floating offshore drilling unit of **Figure 1**. Here, force vectors are shown indicating forces acting on the drilling unit **100** in response to impact from an ice sheet **1010**. Because of the conical nature of the drilling hull **102**, the ice sheet **1010** applies both a horizontal force $\mathbf{F_H}$ and a vertical force $\mathbf{F_V}$. The combined horizontal $\mathbf{F_H}$ and vertical $\mathbf{F_V}$ forces create an overturning or tilting force $\mathbf{F_R}$ against the drilling unit **100**.

[0134] A series of counter-forces act against the horizontal force $\mathbf{F_H}$ and the vertical force $\mathbf{F_V}$ of the ice sheet **1010**. For basic hydrodynamic stability, a deep draft caisson or other tower provides a natural restoring moment. To increase this moment, a solid ballast may be added to the lower portion of the tower. Additional buoyancy may be added to the upper portion. This may be done, for example, by increasing the sizes of tankages in the upper **103** and lower **107** portions of the tower **106**. When the tower **106** is tilted due to the application of ice sheet forces, the moment generated by the eccentricity of the gravity and buoyancy forces seeks to restore the tower **106** to a vertical position. Stated another way, the weight and dimension of the submerged tower **106** provides a tilting force $\mathbf{C_R}$ that is opposite in direction to the tilting force $\mathbf{F_R}$ created by the ice sheet **1010**.

[0135] The mooring system **150** and component parts described above present only illustrative embodiments. Other mooring systems that employ a plurality of substantially rigid links connected together connections may be used. For example, in lieu of using one or more eyebars **210** to form a link **155**, a plurality of long, hollow tubular members may be bundled together. In this instance, the link is much longer than the individual eyebars **210**, and the number of connections may be substantially reduced.

[0136] **Figure 12A** presents a side view of the offshore drilling unit **100**. The offshore drilling unit **100** once again includes an inverted, generally conical drilling hull **102**. The top side of the hull **102** comprises a platform **104** on which drilling operations take place. A drilling riser **122** is seen extending down from the platform **104**, through pressure control equipment **124** on the seabed **54**, and into the earth surface. The drilling hull **102**, the platform **104**, and the associated drilling equipment together comprise a drilling structure **120**.

[0137] The offshore drilling unit **100** also includes a tower **106'**. In this arrangement, the tower **106'** defines an elongated framed structure that floats in the marine environment **50** in an upright position. The tower **106'** is connected to a bottom side of the drilling hull **102** by means of a neck **108**. An upper portion **103** and a bottom portion **107** of the tower **106'** contain controllable ballast compartments (not shown) to keep the tower **106'** upright and stable. An upper portion of the tower **106'** may optionally be used for storage for drilling fluids and equipment.

[0138] The offshore drilling unit **100** is shown in a marine environment **50**. More specifically, the offshore drilling unit **100** is shown floating in an arctic body of water. A water line is seen at **52** while a seabed or subsea floor is seen at **54**. In the view of **Figure 12A**, the marine environment **50** is substantially free of ice. Thus, it is in a condition where marine waves act upon the drilling unit **100** in response to wind and water currents. However, it is understood that the drilling unit **100** is designed to operate year-round in an arctic environment, including the cold winter months when substantially icy conditions prevail in the marine environment.

[0139] In order to maintain the position of the drilling unit **100** in the marine environment **50**, a mooring system **1250** is provided. The mooring system **1250** is designed in a manner that is different from the mooring system **150** shown and discussed in connection with **Figure 1**. However, as will be shown below in connection with **Figures 13A-13C** and **14A-14C**, the mooring system **1250** also employs a plurality (at least two and preferably three or more) of substantially rigid links **1255** joined together by connectors **1254**.

[0140] As with mooring system **150**, mooring system **1250** also includes a plurality of anchors **1560**. In the view of **Figure 12A**, only two anchors **1560** are shown. However, it is understood that the mooring system **1250** preferably includes at least four and, more preferably six to ten anchors **1560**. Each anchor **1560** rests on the seabed **54** at a designated distance from the tower **106'**. The anchors **1560** are disposed radially around the tower **106'** along the seabed **54**. It is understood that "radially" does not imply a true circle, but means that the anchors **1560** are selectively placed away from the tower **106'** and along the seabed **54** in such a manner as to fulfill the station-keeping function.

[0141] The mooring system **1250** also includes a plurality of mooring lines **1252**. Each mooring line **1252** has a first end **1255A** connected to the tower **106'**, and a second end **1258** connected to a respective anchor **1560**. The first end is connected to the tower **106'** at the upper end **103** of the tower **106'**. In this position, the first end is designated as **1255A**. This causes the tower **106'** and attached drilling structure **120** to be positioned lower in the marine environment **50**. As noted above in connection with **Figure 8A**, this is advantageous when the marine environment **50** has substantially icy conditions.

[0142] **Figure 12B** presents another side view of the offshore drilling unit **100**. It can be seen that the offshore drilling unit **100** is now sitting higher in the water. As discussed in connection with **Figure 8B**, this condition is advantageous when the marine environment is substantially free of ice. In this condition, marine waves act upon the drilling unit **100**. Because the drilling hull **102** is well above the wave amplitude, wave forces are less than if the drilling unit **100** is positioned lower in the water.

[0143] To permit the drilling unit **100** to be positioned higher in the water, the first end is connected to the tower **106'** at the upper end **103** of the tower **106'**, but at a lower relative point. In this position, the first end is designated as **1255B**.

[0144] In the arrangements of both **Figures 12A** and **12B**, the mooring lines **1252** may be hung from tower **106'** in a catenary fashion. However, unlike conventional wire rope used as a mooring line, the mooring lines **1252** of **Figure 12A** and **Figure 12B** are preferably maintained in a state of tension.

[0145] Each mooring line **1252** comprises two or more rigid links **1255**. In the illustrative arrangement of **Figure 12A**, a pair of rigid links **1252** is provided in each mooring line **1250**, while in **Figure 12B** three rigid links **1252** are used. It is a matter of design judgment as to how many links **1252** are actually used for the respective mooring lines **1250**, although it is preferred that the same number of links **1252** be used in each line **1250**.

[0146] The links **1255** are connected together using connectors **1254**. The connectors **1254** may be, for example, pins placed through aligned through-openings. Alternatively, the connectors **1254** may be u-joints or other pivoting connection means. In the present inventions, the mooring lines **1252** are not conventional wires, chains or cables; rather, the mooring lines **1252** define "tendons" **1255**. Each tendon **1255** , in turn, comprises a bundled set of three or more individual tubular members in parallel.

[0147] **Figure 13A** provides a side view of a portion of a tendon **1255**, in one embodiment. Various tubular members are seen at **1310**. The tubular members **1310** have opposing ends denoted at **1312**. The tubular members **1310** are bundled with clamps **1320** or other bundling means. The tubular members **1310**, **1314** are preferably fabricated from steel due to high tensile strength. However, other materials such as fiberglass, ceramic or composites may be considered.

[0148] **Figures 13B** and **13C** provide cross-sectional views of the tendon **1255** of **Figure 13A**. **Figure 13B** is taken across line **B-B**, while **Figure 13C** is taken across line **C-C**. In this illustrative arrangement, eight outer tubular members **1310** are provided. The outer tubular members **1310** surround a single larger tubular member **1314**. Each tubular member is hollow so as to provide buoyancy to the tendon **1255**. In **Figure 13C**, the clamp **1320** is seen bundling the tubular members **1310**, **1314**.

[0149] **Figure 14A** provides a side view of a portion of a tendon **1455**, in an alternate embodiment. Various tubular members are again seen at **1410**. The tubular members **1410** have opposing ends denoted at **1412**. The tubular members **1410** are once again bundled with clamps **1420** or other bundling means.

[0150] **Figures 14B** and **14C** provide cross-sectional views of the tendon **1455** of **Figure 14A**. **Figure 14B** is taken across line **B-B**, while **Figure 14C** is taken across line **C-C**. In this illustrative arrangement, seven tubular members **1410** are set out in a substantially linear fashion. Each tubular member **1410** is again hollow so as to provide buoyancy to the tendon **1455**. In **Figure 14C**, the clamp **1420** is seen bundling the tubular members **1410**.

[0151] As discussed in connection with **Figures 7A** and **7B** above, it is sometimes desirable to disconnect the drilling structure **120** from the tower **106'**. This may occur, for example, when the drilling structure **120** is to be towed to shore for repairs or temporary storage. Another example is when the drilling unit **100** is in the oncoming path of a large iceberg. In either instance, a problem arises when disconnecting the tower **106'** and lowering it towards the seabed **54**. In this respect, the substantially rigid tendons **1255** or **1455** are not designed to bend in the presence of compressive forces.

[0152] To accommodate this situation, pivoting connectors **1254** provide the mooring lines **1252** with a degree of collapsibility. This is demonstrated in **Figures 15A** and **15B**. First, **Figure 15A** shows a side view of the mooring system **1250**. The mooring system **1250** is connected to the tower **106'**. It can also be seen in **Figure 15A** that a large iceberg **1270B** has moved in a direction "**I**" onto a location of the drill-site. However, the drilling structure **120** has been disconnected from the tower **106'** and moved away from the drill-site and out of harm's way. Further, the tower **106'** has been ballasted and lowered partway into the marine environment **52**.

[0153] It can be seen in **Figure 15A** that the tower **106'** has been lowered a sufficient depth below the water line **52** to avoid contact with the iceberg **1270B**. To effectuate this, the mooring lines **1252** have flexed at connections **1254**. The arrangement of **Figure 15A** shows only one connection **1254** along each line **1252**; however, it is understood that the mooring lines **1252** may each have two and, perhaps, three or four, connections **1254**. In one aspect, the largest link is approximately **700** meters or more.

[0154] **Figure 15B** provides another side view of the mooring system **1250**. The mooring system **1250** is connected to the tower **106'**. It can also be seen in **Figure 15A** that an even larger iceberg **1270B** has moved in a direction "**I**" over the location of the drill-site. The drilling structure **120** has once again been disconnected from the drilling unit **120** and moved away from the drill-site and out of harm's way. Further, the tower **106'** has been ballasted and lowered partway into the marine environment **52**.

[0155] It can be seen in **Figure 15B** that the tower **106'** has been lowered a sufficient depth below the water line **52** to avoid contact with the iceberg **1270B**. To effectuate this, the mooring lines **1252** have flexed at a connections **1254** even further than shown in **Figure 15A**.

[0156] **Figures 16A** and **16B** demonstrate one exemplary means for connecting the second end **1258** of a mooring line **1252** to an anchor **1660**. **Figure 16A** provides a side view of the mooring line **1252** and anchor **1660**, while **Figure 16B** provides a plan view. In the illustrative arrangement, a radial connector **1655** is provided at the very end of the mooring link **1255**. The radial connector **1655** fits into a slot **1658** attached to the anchor **1660**. The slot **1658** allows the radial connector **1655** and the attached substantially rigid link **1255** to pivot.

[0157] **Figure 17** demonstrates one method for connecting the first end **1256A** or **1256B** of a mooring line **1252** to the tower **106'**. **Figure 17** provides a side view of an enlarged portion of the tower **106'** at the upper end **103**. In the illustrative arrangement, a radial connector **1755** is provided at the very end of the mooring link **1255**. The radial connector **1755** fits into one of two slots **1758A** or **1758B** attached to the tower **106'**. The slots **1758A** or **1758B** allow the radial connector **1755** and the attached substantially rigid link **1255** to pivot.

[0158] It is noted that slot **1758A** is higher along the upper end **103** of the tower **106'** than slot **1758B**. Placement of the radial connector **1755** into slot **1758A** will pull the drilling unit **100** lower into the marine environment **50** in accordance with **Figure 12A**. Placement of the radial connector **1755** into slot **1758B** will allow the drilling unit **100** to rise a bit higher in the marine environment **50** in accordance with **Figure 12B**.

[0159] The use of substantially rigid links comprising eyebars or tendons or other metallic members connected together to form a mooring line, combined with the use of anchors along the seabed, offers a considerably increased mooring capacity, that is, an improved ability to maintain station-keeping and to resist high ice loads. The capacity is increased an order of magnitude over conventional mooring systems by replacing the known wire-rope based mooring lines with ones based on substantially rigid structural elements. Multiple eyebars or tubular members can be aligned within a single link to increase capacity as needed. Stated another way, increasing the number and/or size of eyebars or tubular members or other elongated metallic members within each link, the station-keeping capacity of each mooring line may be selectively increased. Moreover, a limited number of the mooring lines may be employed to create tremendous station-keeping capacity, e.g., at least about 100 Mega-Newtons. Such capacity could not be achieved with known wire-based mooring lines or chains, as such a large number of lines or chains would be required that the mooring system would be impractically heavy and difficult to install. Beneficially, the rigid metallic members will be easier to install and can be installed in a shorter time. This is advantageous in the arctic regions where the open water construction season is limited by icy conditions.

[0160] One requirement of a mooring system beyond capacity is to keep the floating drilling unit stable during operation, that is, to maintain the drilling unit upright with respect to tilting. The tilt (sometimes referred to as "roll" or "pitch" or "trim") of a vessel should be maintained within a given tolerance to allow drilling operations to occur. The tolerance is typically about 2 degrees of tilt. The tower (such as tower **106** or **106'**) does provide a long "lever" to resist the overturning tendency caused by ice loading. This overturning stems from the fact that the ice loading is applied near the waterline. However, the primary mooring lines (such as lines **1250**) are located some depth below the waterline **52** to keep them out of harm's way of the ice. Those of ordinary skill in the art will understand that there are several ways to keep the tower within vertical tolerance. One approach is to use a "secondary" mooring system such as lines **170** of **Figure 1**.

[0161] **Figure 10** presents a pair of illustrative thrusters **1020** at the bottom of the tower **106'**. The thrusters **1020** represent an active or dynamic positioning system using sensors and computer-controlled propellers. The presence of thrusters **1020** provides thruster-assisted mooring.

[0162] The thrusters **1020** represent azimuth thrusters. An azimuth thruster is one or more ship propellers placed in pods that can be rotated in any horizontal direction. The operation of thrusters makes a rudder unnecessary. Azimuth thrusters give ships and other vessels better maneuverability than a fixed propeller and rudder system. Further, vessels with azimuth thrusters generally do not need tugs to dock, though they may still require tugs to maneuver in difficult places.

[0163] Second, mooring lines **1052** can act to stabilize the drilling unit **100** if positioned properly. Two illustrative mooring lines **1052** are shown in **Figure 10**. The mooring lines **1052** have a plurality of links (not shown) in accordance with the embodiments of links **155** or **655**, discussed above. A force vector **T** is shown indicating the station-keeping force being exerted by one of the mooring lines **1052**.

[0164] It is understood that in an actual mooring system **150**, more than two mooring lines **1052** would in all likelihood be employed. Two or more of the mooring lines **1052** would share the counter-acting load "**T**." In that instance, counter-acting loads would be divided as "**T1**," "**T2**," and so on. However, for illustrative purposes only a single mooring line **1052** is showing bearing the counter-acting load "**T**." The counter-acting load "**T**" is broken down into a horizontal force $\mathbf{T_H}$ and a vertical force $\mathbf{T_V}$. If the distance between the connection of the mooring lines is sufficiently wide (i.e., the distance D_C), then the vertical component T_V can act as a counter-acting load to resist overturning.

[0165] Another way to counter-act the tilting load "**T**" is to use a secondary set of mooring lines. Such secondary mooring lines are presented at **170** in **Figure 1**. The secondary mooring lines require less capacity than the primary rigid lines and, thus, may possibly be fabricated in accordance with traditional wire rope, polyester line systems.

[0166] Finally, the thrusters **1020** provide a dynamic force "**R**" to help keep the floating structure representing the drilling unit **100** upright. The force "**R**" provided by the thrusters **1020** is a horizontal force that is applied in the same direction as the horizontal force $\mathbf{F_H}$ of the ice sheet **1010**. This horizontal force "**R**" at the bottom of the tower **106** provides a direct means to maintain verticality of the tower **106**. The thrusters **1020** thus become part of the mooring system **150''** of **Figure 10**.

[0167] As can be seen, the arctic floating drilling unit **100**, in conjunction with the mooring systems in their various embodiments described herein, has the capacity to maintain station continuously, or with minimal interruption, even in high arctic ice conditions on a year-round basis. The mooring systems are able to do so without threat of interference from ice sheets. In this respect, the mooring lines are preferably connected to the tower below a depth where ice sheets will float. However, the mooring system is collapsible in the event the operator wishes to disconnect the drilling structure from the tower and lower the tower into the water to avoid an iceberg or for other purposes.

[0168] The mooring systems herein are also compatible with known systems for protecting the drilling riser (not shown) from ice. Protection of the drilling riser may be provided by enclosing the hull of the drilling structure in the vicinity of the ice loads. An example is shown in U.S. Pat. No. 4,434,741 issued in 1984 and entitled "Arctic Barge Drilling Unit." Of course, the present mooring systems are not limited to the configuration of a floating vessel.

[0169] The station-keeping function of the mooring systems herein may be optimized by adjusting the angles of selected individual mooring lines relative to the sea surface and by adjusting the dimensions of the tower **106'**. The angles of the mooring lines and the dimensions of the tower **106'** may be optimized to resist the range of effective angles of the ice loads anticipated to be applied by ice sheets while minimizing the loads within the mooring lines. In one aspect, an angle θ_T of about 30 degrees in combination with tower dimensions of 200 meters in length and 70 meters in width is sufficient to accomplish this objective. Those of ordinary skill in the art will understand that the actual design parameters will vary with each application.

[0170] Interestingly, tuning the angle of a mooring line may allow the "leeward" line, that is, the line opposite the mooring line under highest load, to maintain roughly a zero change in tension. This prevents the leeward line from going into compression and, possibly, inducing some undesirable motions into the drilling unit.

[0171] An issue arises in connection with the use of rigid links in a mooring line. That issue is that the rigidity of the links tends to make the entire line relatively rigid as well. This, in turn, means that a degree of precision is needed when radially spacing the anchors (such as anchors **160**) around the tower **106'**.

[0172] In known wire rope mooring systems, the ability to add or reduce line length is easily accomplished by spooling or winching the line. This reduces the need for precision in the placement of anchors. However, for the mooring systems described herein, the length of the mooring line is not easily adjusted with on-board equipment due to the high capacity requirements of the equipment and the requirement to separate the drilling structure **120** under threat of ice sheets. In addition, it is difficult to place anchors within a high degree of tolerance, e.g., a few centimeters. Therefore, adjustment for installation tolerances in the mooring system is desirable.

[0173] In one aspect, different connection points **158** may be provided along the anchors **160**. However, even this may not be fine enough for subsea installation tolerances. As an alternative, a central positioning template may be employed during installation as a guide for the placement of the various anchors.

[0174] **Figure 11A** demonstrates a schematic for deploying a mooring system **1150** for a floating structure. The floating structure may be, for example, the drilling unit **100** of **Figure 1**. The method meets the need to install substantially rigid mooring lines and corresponding anchors within acceptable tolerances quickly and with minimal support equipment.

[0175] It can be seen in **Figure 11A** that a mooring line **1152** and corresponding anchor **1160** are placed within a marine environment **56**, that is, offshore and under water. The mooring line **1152** comprises a plurality of substantially rigid links **1155** connected together using pivoting connections, such as pins. The links **1155** in the mooring line **1152** may comprise at least two eyebars, or may comprise a plurality of substantially hollow tubular members. The mooring line **1152** is preferably capable of withstanding at least about ten Mega-Newtons of force, and more preferably up to about 100 Mega-Newtons of force. More preferably, the mooring line **1152** is capable of withstanding up to about 500 Mega-Newtons of force.

[0176] The mooring line **1152** has a first end **156** configured to be operatively connected to a caisson (not shown), and a second end **158** operatively connected to the anchor **160**. Each of the first **156** and second **158** ends includes a pivoting connector, such as connector **158** of **Figure 5C**. The mooring line **1152**, the anchor **160** and the connectors make up a mooring system **1150**, indicated by a bracket. Selected links within the mooring line **1152** may receive material that increases buoyancy.

[0177] A seabed **1154** is also seen as part of the marine environment **56**. In **Figure 11A**, the mooring system **1150** is shown suspended above the seabed **1154**. Arrows **11A** demonstrate lowering of the mooring system **1150** onto the seabed **1154**. Once in place, the permanent mooring lines **1152** will extend from the seabed **1154** up to a tower. More specifically, the anchor **160** will be attached to the seabed **1154**, and the permanent mooring line **1152** will extend up from the anchor **160** and attach to the tower.

[0178] In order to secure the anchor **160** at the correct position relative to the tower, a positioning template **1110** is employed. The positioning template **1110** is preferably a heavy steel skid configured to rest on the seabed **1154**. The positioning template **1110** may be a modified version of a drilling template normally installed along the seabed **1154** and through which wells are drilled. In connection with the method for deploying a mooring system **1150**, the template **1110** is placed on the seabed **1154**. This is shown at bracket **1120**. The positioning template **1110** is placed along the seabed **1154** at a position below where the tower will later be deployed for operation.

[0179] Next, a setting line **1152'** is lowered into the marine environment **56**. This setting line **1152'** is also indicated at bracket **1120**. The setting line **1152'** may be a portion of mooring line **1152** having a predetermined length. Alternatively, the setting line **1152'** may be a temporary measuring line. Either way, the setting line **1152'** is attached to the anchor **160** at end **158** of the anchor **160**. However, the anchor **160** is not yet attached to the seabed **1154**.

[0180] The setting line **1152'** is next connected to the positioning template **1110**. To accommodate this step, a guide bracket **1112** is provided along the positioning template **1110**. The guide bracket **1112** is shown at an end of the template **1110** in **Figure 11B**.

[0181] **Figure 11B** presents an expanded view of a portion of bracket **1120** of **Figure 11A**. The expanded area is indicated in **Figure 11A** at **11B**. Referring to **Figure 11B**, a side view of the guide bracket **1112** and of the positioning template **1110** is provided. The guide bracket **1112** provides a pivoting connection between the template **1110** and the setting line **1152'**. A first joint **1155(1)** of the setting line **1152'** is shown connected to the guide bracket **1112**.

[0182] The length of the setting line **1152'** to the first joint **1155(1)** is dimensioned to provide an accurate spacing between the template **1110** and the anchor **1160**. Taking advantage of the rigid nature of the setting line **1152'**, the anchor **1160** is completely lowered in the marine environment **56** to the seabed **1154** at the appropriate distance from the positioning template **1110**. The anchor **1160** is secured to the seabed **1154** either gravitationally or by means of pile or suction attachments.

[0183] The above process for positioning an anchor **1160** is repeated using the setting line **1152'**. In this respect, the setting line **1152'** is disconnected from each anchor **1160** as it is placed on the seabed **1154**. Multiple anchors **1160** are thereby properly positioned for future connection to the tower. The positioning template **1110** may then be removed and, optionally, transported away.

[0184] Once the anchors **1160** are secured to the seabed **1154**, a tower such as tower **106'** is brought on-site. The tower is brought into an upright position. Mooring lines **1152**

may then be connected between the tower and the respective anchors **1160**. The positioning template **1110** allowed the anchors **1160** to be placed with a high degree of accuracy so that the mooring lines **1152** readily connect to the tower.

[0185] Once the tower is fully connected, the operator increases the draft of the tower. The drilling structure is then floated over the tower and connected. The tower may be partially de-ballasted to achieve a desired pre-tension in the mooring lines **1152**.

[0186] **Figure 11C** and **11D** together provide a unified flow chart for a method **1160** for deploying a mooring system for a floating structure. The mooring system may be in accordance with mooring system **1150** of **Figure 11**A or mooring system **1250** of **Figure 12**A. The floating structure may be, for example, the drilling unit **100** of **Figure 12A**. In this respect, the floating structure generally includes a platform on which operations are performed in a marine environment. The floating structure also includes a tower for providing ballast and stability below a water line in the marine environment.

[0187] The method **1160** includes placing a positioning template on a seabed at an offshore work site, such as a drill site. This is shown at Box **1162** of **Figure 11C**. The positioning template is placed below the intended location of the tower at the drill site. The method **1160** also includes providing a setting line. This is indicated at Box **1162**. The setting line has a first end, a second end, and a plurality of substantially rigid links joined together using linkages. Each link comprises at least one elongated, metallic member.

[0188] The method **1160** also includes connecting the first end of the setting line to the positioning template, and then connecting the second end of the setting line to an anchor. These steps are provided in Boxes **1166** and **1168**, respectively. The anchor is used to secure the setting line and, later, a mooring line as connected to the floating structure.

[0189] The method **1160** also includes securing the anchor along the seabed. This is presented in Box **1170**. The manner of securing is dictated by the type of anchor employed. For example, if the anchor just has a block base, the anchor may be gravitationally secured by just setting the anchor onto the seabed. If the anchor employs suction piles, then the anchor is secured by removing soil below the seabed and countersinking the suction pile. The anchor is secured according to the first length.

[0190] The method **1160** further includes disconnecting the first end of the setting line from the positioning template, and disconnecting the second end of the setting line from the anchor. These steps are provided in Box **1172** and **1174**, respectively. In this way, the setting line is free. It is noted here that the setting line may be a temporary measuring line used for properly spacing the anchor from the template. Alternatively, the setting line may be a portion of a permanent mooring line having a predetermined length. In either instance, the steps **1164** through **1174** are repeated for successive anchors so as to properly space a plurality of anchors around the positioning template. The process of repeating the steps is shown at Box **1176**.

[0191] The method **1160** also comprises providing a permanent mooring line. This is shown at Box **1178**. The mooring line has a first end, a second end, and a plurality of substantially rigid links joined together using linkages. The mooring line may be, for example, in accordance with line **150** of **Figure 1,** line **1152** of **Figure 11A,** or line **1250** of **Figure 12A**.

[0192] The method **1160** also includes operatively connecting the second end of the mooring line to a respective anchor. This is shown at Box **1180** of **Figure 11D**. The method **1160** further includes operatively connecting the first end of the mooring line to the floating structure. This step is provided in Box **1182**. Preferably, the respective first ends are connected to the floating structure at a top portion of the tower.

[0193] Steps **1178** through **1182** are then repeated for each of the successive anchors. Preferably, each permanent mooring line that is installed is capable of withstanding at least about 100 Mega-Newtons of force from a moving ice sheet. In one aspect, the force from the moving ice sheet has a horizontal component, and each mooring line is capable of withstanding at least about 500 Mega-Newtons of horizontal force.

[0194] The inventions described herein are not restricted to offshore structures used to support drilling rigs. The inventions are suitable for any type of offshore vessel operating in arctic waters in which there is a need for protection against dynamic masses of ice. Examples include production support, arctic research vessels, and strategic locations for military or civilian logistics support in arctic waters.

[0195] While it will be apparent that the inventions herein described are well calculated to achieve the benefits and advantages set forth above, it will be appreciated that the inventions are susceptible to modification, variation and change without departing from the spirit thereof. Improvements to maintaining a floating vessel "on location" in the presence of heavy ice conditions typical of the "high arctic" are offered.

CLAIMS:

1. A mooring system for a floating vessel, the floating vessel having a platform for conducting operations in a marine environment, and a floating tower for providing ballast and stability below a water line in the marine environment, the mooring system comprising:

a plurality of anchors disposed around the tower along a seabed; and

a plurality of mooring lines, each mooring line having a first end operatively connected to the tower and a second end operatively connected to a respective anchor, each mooring line comprising at least two substantially rigid links joined together using pivoting connections such that the pivoting connections provide relative motion between adjoining links along a single plane.

2. The mooring system of claim 1, wherein each link is at least five meters in length.

3. The mooring system of claim 1, wherein the mooring system has the capacity to maintain station-keeping for the vessel in the presence of ice forces greater than about 100 Mega-Newtons.

4. The mooring system of claim 1, wherein:

the ice forces have a horizontal component; and

each mooring line is capable of withstanding at least about 500 Mega-Newtons of horizontal force.

5. The mooring system of claim 1, wherein the floating vessel has an axi-symmetric shape.

6. The mooring system of claim 1, wherein:

the floating vessel is a floating drilling unit; and

the operations are offshore drilling operations or production operations.

7. The mooring system of claim 6, wherein each of the plurality of anchors comprises a weighted block held on the seabed by gravity, or a frame structure with a plurality of pile-driven pillars or suction pillars secured to the earth proximate the seabed.

8. The mooring system of claim 6, wherein:

each link comprises a plurality of elongated members disposed parallel to one another.

9. The mooring system of claim 8, wherein the plurality of elongated members comprise either two or more eyebars or two or more substantially hollow tubular members.

10. The mooring system of claim 6, wherein:

the first end of each of the plurality of mooring lines is connected to the tower proximate an upper end of the tower; and

each of the first ends is selectively connectable to the tower at two or more different depths along the upper end of the tower so as to adjust the floating position of the drilling unit within the marine environment.

11. The mooring system of claim 10, wherein the first end of each of the plurality of mooring lines is connected to the tower by means of a selectively pivoting link having a first end pinned to the tower at a first point, and a second end which is selectively:

pinned to the tower at a second lower point to increase draft of the floating vessel, and

not pinned to the tower at the second lower point to decrease draft of the floating vessel, depending on the marine conditions.

12. The mooring system of claim 10, wherein:

the first end of each of the plurality of mooring lines is connected to the caisson by means of a radial connector that lands in a slot to permit pivoting motion for the respective mooring lines to the tower; and

a first slot is provided at each of the two or more different depths along the upper end of the caisson.

13. The mooring system of claim 6, wherein each of the plurality of anchors comprises a plurality of connection points for selectively connecting each respective mooring line along a corresponding anchor, thereby adjusting the distance of the caisson from the connection point.

14. The mooring system of claim 6, wherein:

the platform is supported by a drilling hull having a frusto-conical shape; and

the drilling unit further comprises a neck connecting the drilling structure to the caisson.

15. The mooring system of claim 6, further comprising:

a plurality of secondary mooring lines, each line having a first end connected to the caisson proximate a bottom end of the caisson, and

a second end connected to a respective anchor.

16. The mooring system of claim 15, wherein each of the secondary mooring lines is fabricated from chains, wire ropes, synthetic ropes or pipes.

17. The mooring system of claim 6, further comprising:

a template adapted to temporarily receive the first end of each of a plurality of setting lines, each setting line having a predetermined length such that the template may be placed on the seabed directly under the tower, and

each of the anchors may be positioned around the template at a proper radius.

18. The mooring system of claim 17, wherein the setting line is either a portion of a mooring line having a predetermined length or a temporary measuring line.

19. The mooring system of claim 6, wherein selected links within each of the plurality of mooring lines receives material that increases buoyancy.

20. The mooring system of claim 19, wherein the selected joints comprise syntactic foam to increase buoyancy.

21. The mooring system of claim 19, wherein the selected joints comprise a material to increase buoyancy, which is wrapped around the selected links or attached to the selected links.

22. The mooring system of claim 6, further comprising:

at least one thruster placed proximate a bottom of the tower adapted to further provide ballast and stability of the tower below the water line.

23. The mooring system of claim 6, wherein:

each of the plurality of mooring lines is connected between the tower and the anchor in a state of substantial tension; and

an angle of at least two of the plurality of mooring lines relative to the water line is selected to reduce movement of the drilling unit, wherein the angle is selected by considering the dimensions of the tower and the distance of the mooring lines from the anchor to the tower.

24. A method for deploying a mooring system for a floating structure, comprising:

(A) placing a positioning template on a seabed at an offshore work site;

(B) providing a setting line, the setting line having a first end, a second end, and a plurality of substantially rigid links joined together using linkages, each link comprising at least one elongated, metallic member;

(C) connecting the first end of the setting line to the positioning template;

(D) connecting the second end of the setting line to an anchor;

(E) securing the anchor along the seabed according to the first length;

(F) disconnecting the first end of the setting line from the positioning template and the second end of the setting line from the anchor;

(G) repeating steps (A) through (F) for successive anchors such that a plurality of anchors is placed around the positioning template;

(H) providing a permanent mooring line, the mooring line having a first end, a second end, and a plurality of substantially rigid links joined together using linkages;

(I) operatively connecting the second end of the mooring line to an anchor;

(J) operatively connecting, a first end of the mooring line to the floating structure; and

(K) repeating steps (H) through (J) for each of the successive anchors.

25. The method of claim 24, wherein:

the floating structure is a floating drilling unit comprising:

a platform for providing drilling operations in a marine environment, and a tower adapted to provide ballast and stability below a water line in the marine environment;

the work site is a drill site where drilling and production operations take place;

the positioning template is placed below the intended location of the tower at the drill-site; and the first end of each of the respective permanent mooring lines is operatively connected to the tower.

26. The method of claim 25, wherein each of the anchors comprises either a weighted block held on the seabed by gravity, or a frame structure with pile-driven pillars or suction pillars secured to the earth proximate the seabed.

27. The method of claim 25, wherein:

each link comprises a plurality of elongated metallic members disposed parallel to one another; and

the links are joined together using a pivoting connector.

28. The method of claim 27, wherein the plurality of elongated metallic members comprise either two or more eyebars or two or more substantially hollow tubular members.

29. The method of claim 28, wherein:

the first end of each of the plurality of mooring lines is connected to the tower proximate an upper end of the tower; and

each of the first ends is selectively connectable to the tower at two or more different depths along the upper end of the tower so as to adjust the floating height of the floating drilling unit.

30. The method of claim 25, wherein each permanent mooring line is capable of withstanding at least about 100 Mega-Newtons of force from a moving ice sheet.

31. The method of claim 30, wherein:

the force from the moving ice sheet has a horizontal component; and

each permanent mooring line is capable of withstanding at least about 500 Mega-Newtons of horizontal force.

32. The method of claim 25, wherein selected links within each of the plurality of permanent mooring lines receives material that increases buoyancy.

33. A method for relocating a floating structure, the floating structure comprising a platform for providing operations in a marine environment and a tower for providing ballast and stability below a water line in the marine environment, the method comprising:

disconnecting the tower from the platform;

lowering the tower within the marine environment to a depth below the depth of an oncoming ice sheet; and

moving the floating structure to a new location in the marine environment;

wherein the floating structure is originally stationed in the arctic marine environment by means of a mooring system, the mooring system comprising:

a plurality of mooring lines having a first end operatively connected to the tower and a second end, with each mooring line comprising at least two substantially rigid links joined together using pivoting connections that permit the mooring lines to kinematically collapse as the tower is lowered into the marine environment, and a plurality of anchors placed along the seabed, each anchor securing a respective mooring line at the second end of the mooring line.

34. The method of claim 33, wherein:

the floating structure is an offshore drilling unit comprising a drilling structure and the tower;

the platform provides drilling operations in the marine environment; and

the operations are drilling or production operations.

35. The method of claim 34, wherein selected links within each of the plurality of mooring lines receives a material that increases buoyancy such that mooring lines more easily kinematically collapse to accommodate the reduced distance from the respective anchors to the tower as the tower is lowered to the seabed.

36. The method of claim 34, wherein:

each of the plurality of links is at least about thirty meters in length; and

each of the mooring lines comprises no more than three linkages.

37. The method of claim 34, wherein each of the plurality of anchors comprises either a weighted block held on the seabed by gravity, or a frame structure with pile-driven pillars or suction pillars secured to the earth proximate the seabed.

38. The method of claim 34, wherein:

each joint comprises either at least one eyebar, or a plurality of elongated, substantially hollow tubular members.

39. The method of claim 34, wherein the links are joined using pins.

40. The method of claim 34, wherein each mooring line is capable of withstanding at least about 100 Mega-Newtons of force from a moving ice sheet.

41. The method of claim 40, wherein:

the force from the moving ice sheet has a horizontal component; and

each permanent mooring line is capable of withstanding at least about 500 Mega-Newtons of horizontal force.

42. A mooring system for a floating vessel, the floating vessel having a platform for conducting operations in a marine environment, and a floating tower for providing ballast and stability below a water line in the marine environment, the floating tower being constructed and arranged to detachably connect to the floating vessel, the mooring system comprising:

a plurality of anchors disposed around the tower along a seabed;

a plurality of primary mooring lines, each primary mooring line having a first end connected to the tower proximate to a top end of the tower and a second end operatively connected to a respective anchor; and

a plurality of secondary mooring lines, each secondary mooring line having a first end connected to the tower proximate a bottom end of the tower and a second end connected to a respective anchor.

43. The mooring system of claim 42, wherein each mooring line comprises at least two substantially rigid links joined together using pivoting connections such that the pivoting connections provide relative motion between adjoining links along a single plane, the at least two substantially rigid links disposed along the length between the first end and the second end of the mooring line.

44. The mooring system of claim 42, wherein the floating vessel is a floating drilling unit and the operations are offshore drilling operations or production operations.

45. The mooring system of claim 44, wherein each of the first ends of the primary mooring lines is selectively connectible to the tower at two or more different depths along the

top end of the tower so as to adjust the floating position of the drilling unit within the marine environment.

46. The mooring system of claim 42, wherein each of the secondary mooring lines is fabricated from chains, wire ropes, synthetic ropes or pipes.

47. The mooring system of claim 42, wherein at least one primary mooring line, of the plurality of primary mooring lines, includes a pivoting connector disposed along the length between the first end and the second end of the at least one primary mooring line.

48. A mooring system comprising:

a floating vessel;

a floating tower, the floating tower configured to provide ballast and stability disposed below a water line in a marine environment and arranged to detachably connect to the floating vessel;

a plurality of anchors disposed around the tower along a seabed;

a plurality of primary mooring lines with first ends connected to the tower proximate to a top end of the tower and second ends operatively connected to the plurality of anchors, at least one of the plurality of primary mooring lines includes at least one pivoting connector disposed along the length between a first end and a second end of the at least one of the plurality of primary mooring lines; and

a plurality of secondary mooring lines having first ends connected to the tower proximate a bottom end of the tower and second ends connected to the plurality of anchors.

49. The mooring system of claim 48, wherein each of the plurality of primary mooring lines, includes a pivoting connector disposed along the length between the first end and the second end of each of the plurality of primary mooring lines.

50. The mooring system of claim 45, wherein the marine environment is an arctic marine environment.

51. The mooring system of claim 42, wherein at least one of the plurality of primary mooring lines includes at least two pivoting connectors disposed along the length between the first end and the second end of the at least one of the plurality of primary mooring lines.

52. The mooring system of claim 51, wherein each of the plurality of primary mooring lines includes at least two pivoting connectors disposed along the length between the first end and the second end the primary mooring line.

53. The mooring system of claim 42, wherein each of the plurality of primary mooring lines are in a state of substantial tension when the tower is connected to the floating vessel.

54. The mooring system of claim 42, wherein the system is configured to maintain the tower in an upright position.

55. The mooring system of claim 51, wherein the at least one of the plurality of primary mooring lines includes at least three pivoting connectors disposed along the length between the first end and the second end of the at least one of the plurality of primary mooring lines.

56. The mooring system of claim 48, wherein the at least one of the plurality of primary mooring lines includes at least two pivoting connectors disposed along the length between the first end and the second end of the at least one of the plurality of primary mooring lines.

57. The mooring system of claim 42, wherein the plurality of secondary mooring lines are configured to counter-act tilting loads experienced by the floating tower.

58. The mooring system of claim 48, wherein the plurality of secondary mooring lines are configured to counter-act tilting loads experienced by the floating tower.

59. A mooring system for a floating vessel, the floating vessel having a platform for conducting operations in a marine environment, and a floating tower for providing ballast and stability below a water line in the marine environment, the floating tower being constructed and arranged to detachably connect to the floating vessel, the mooring system comprising:

a plurality of anchors disposed around the tower along a seabed;

a plurality of primary mooring lines, each primary mooring line having a first end connected to the tower proximate to a top end of the tower and a second end operatively connected to a respective anchor, each primary mooring line comprises at least two substantially rigid links joined together using pivoting connections such that the pivoting connections provide relative motion between adjoining links along a single plane, the at least two substantially rigid links disposed along the length between the first end and the second end of the mooring line; and

a plurality of secondary mooring lines, each secondary mooring line having a first end connected to the tower proximate a bottom end of the tower and a second end connected to a respective anchor.

60. A mooring system comprising:

a floating vessel;

a floating tower, the floating tower configured to provide ballast and stability disposed below a water line in a marine environment and arranged to detachably connect to the floating vessel;

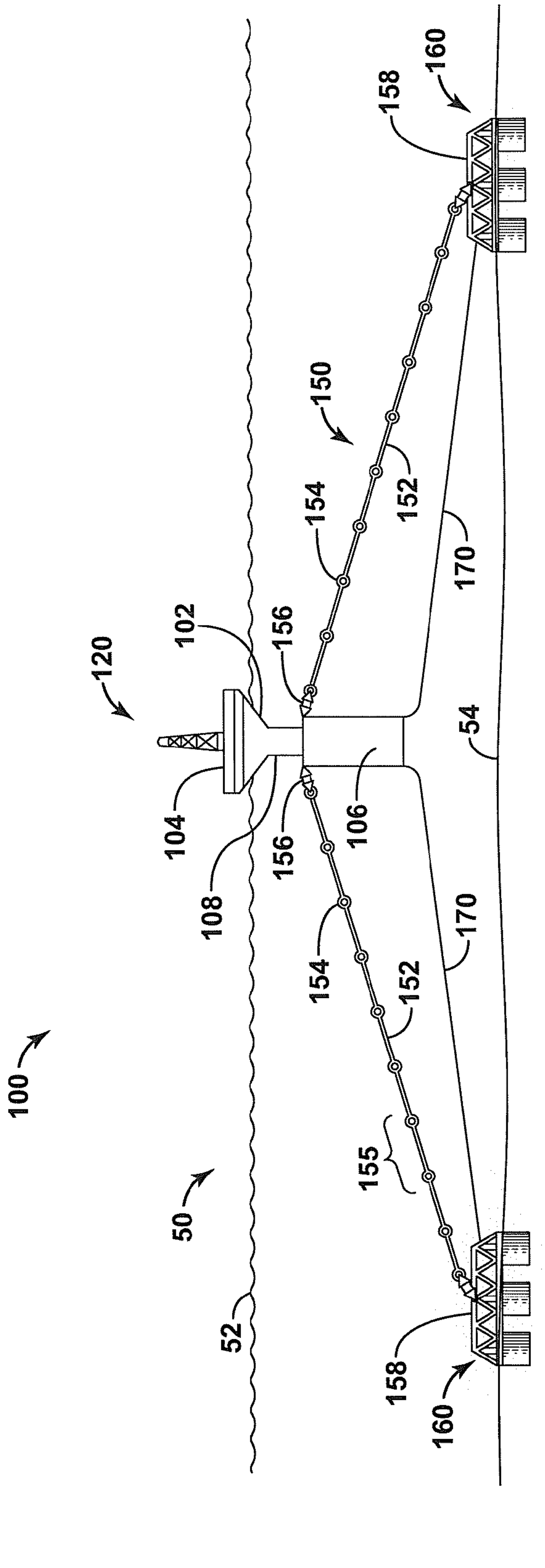
a plurality of anchors disposed around the tower along a seabed;

a plurality of primary mooring lines with first ends connected to the tower proximate to a top end of the tower and second ends operatively connected to the plurality of anchors, at least one of the plurality of primary mooring lines includes at least one pivoting connector disposed along the length between a first end and a second end of the at least one of the plurality of primary mooring lines such that the pivoting connection provides relative motion along a single plane; and

a plurality of secondary mooring lines having first ends connected to the tower proximate a bottom end of the tower and second ends connected to the plurality of anchors.

61. The mooring system of claim 60, wherein the at least one of the plurality of primary mooring lines includes at least two pivoting connectors disposed along the length between the first end and the second end of the at least one of the plurality of primary mooring lines.

1/20


100
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160

FIG. 1

2/20

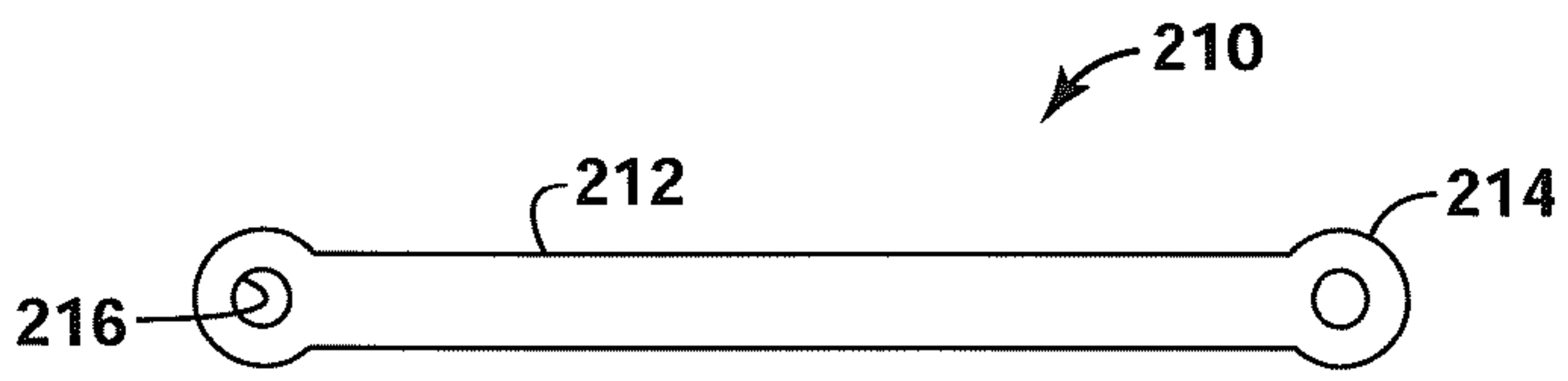


FIG. 2A

FIG. 2B

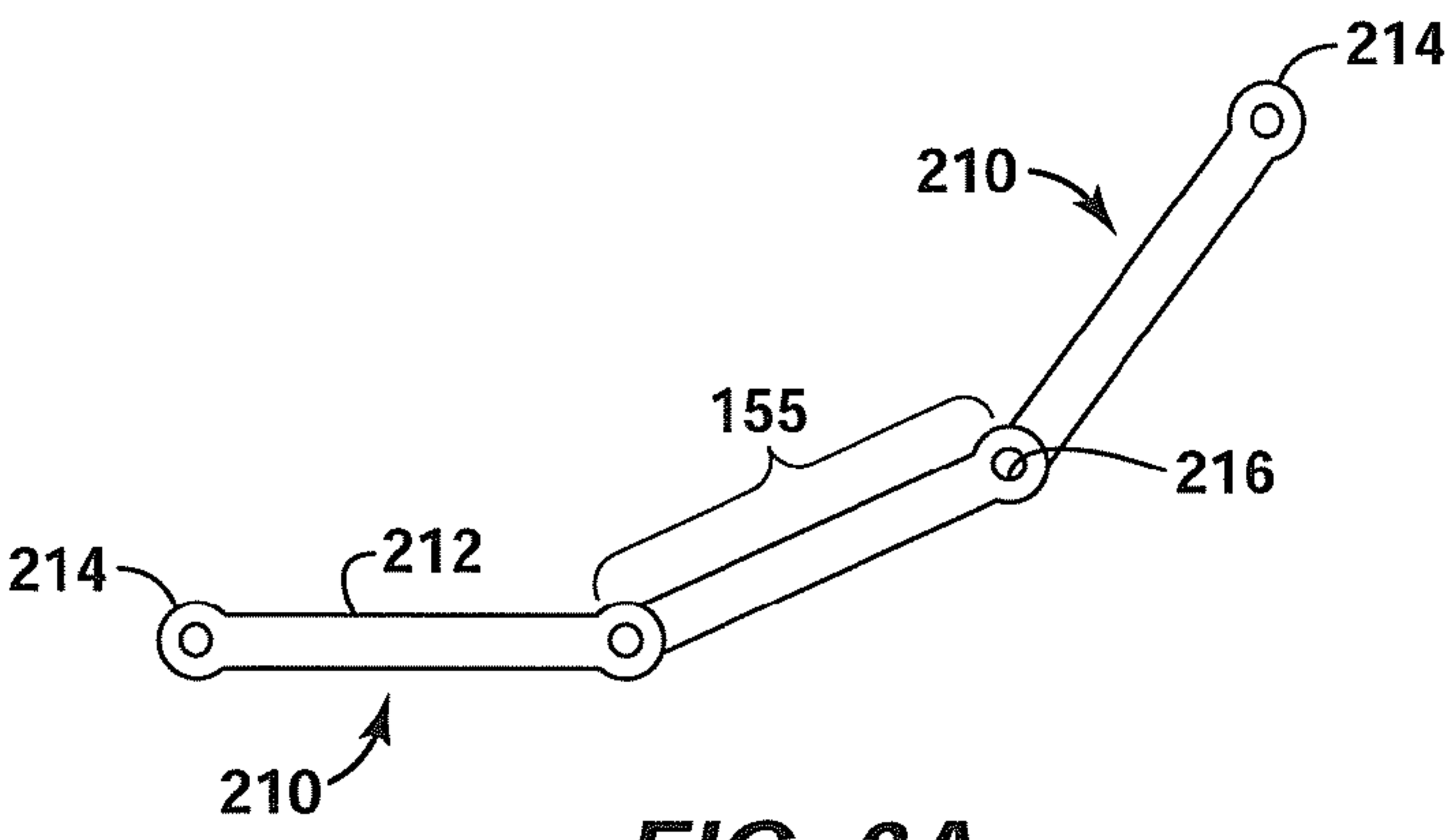


FIG. 3A

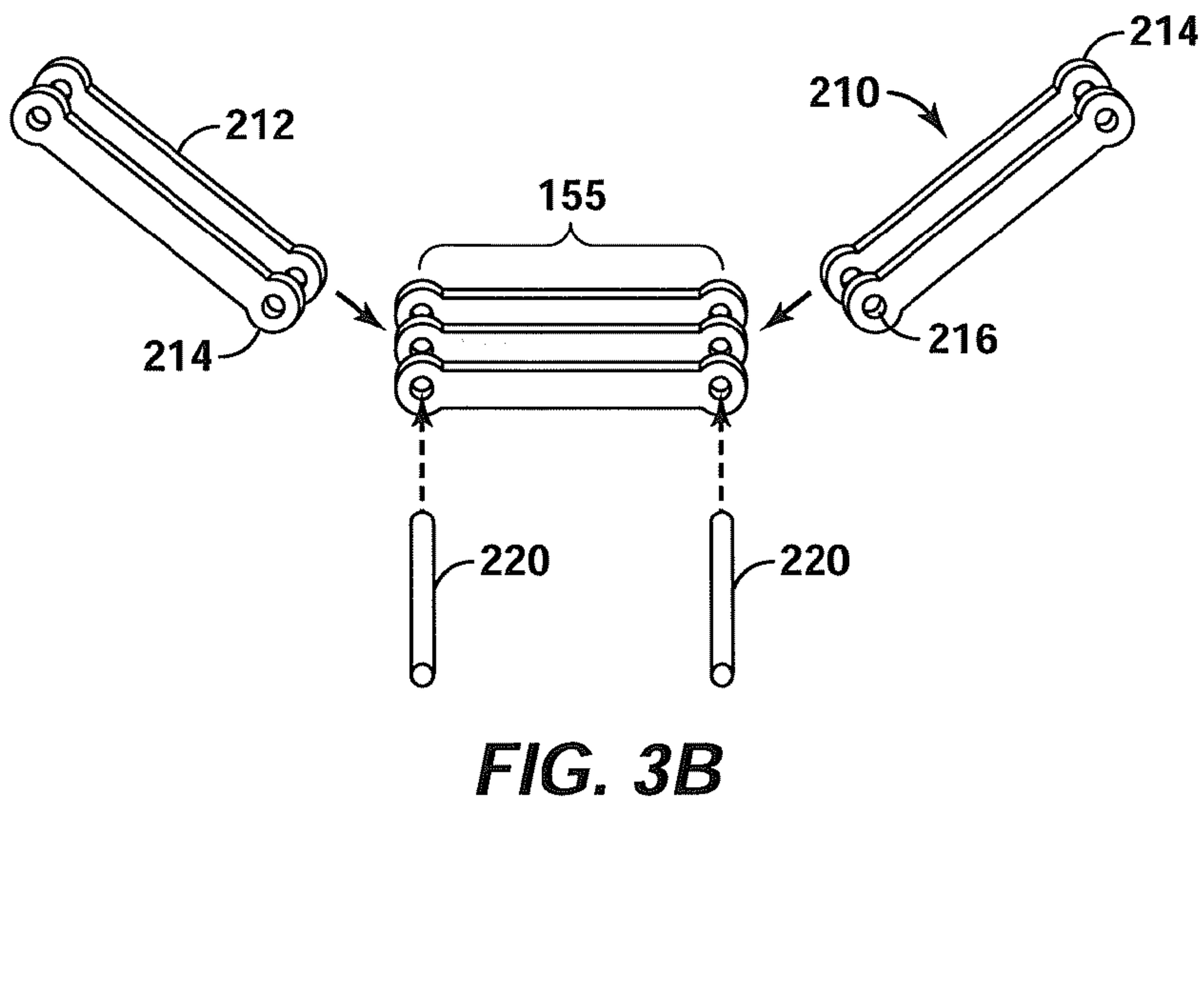


FIG. 3B

3/20

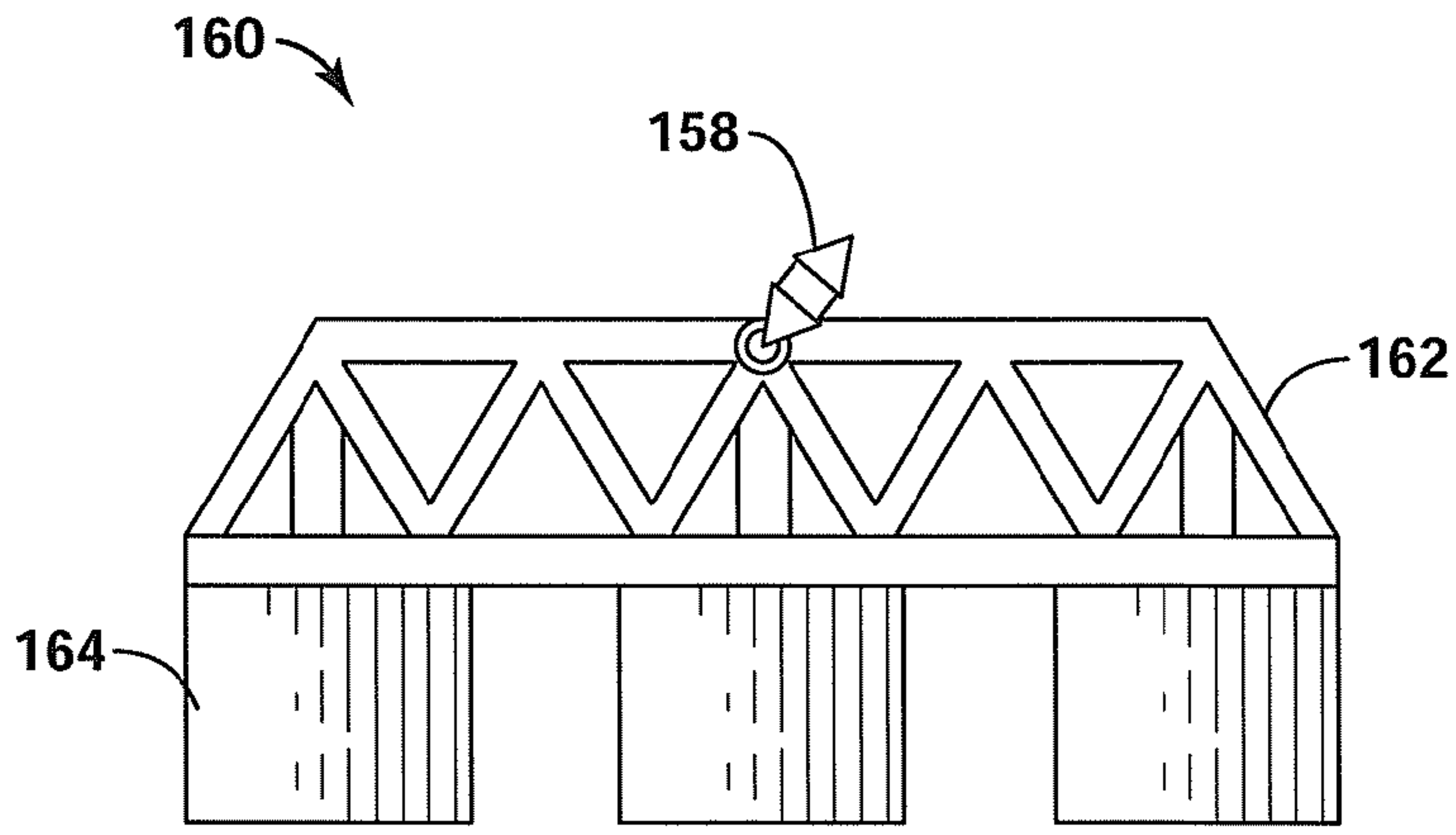


FIG. 4A

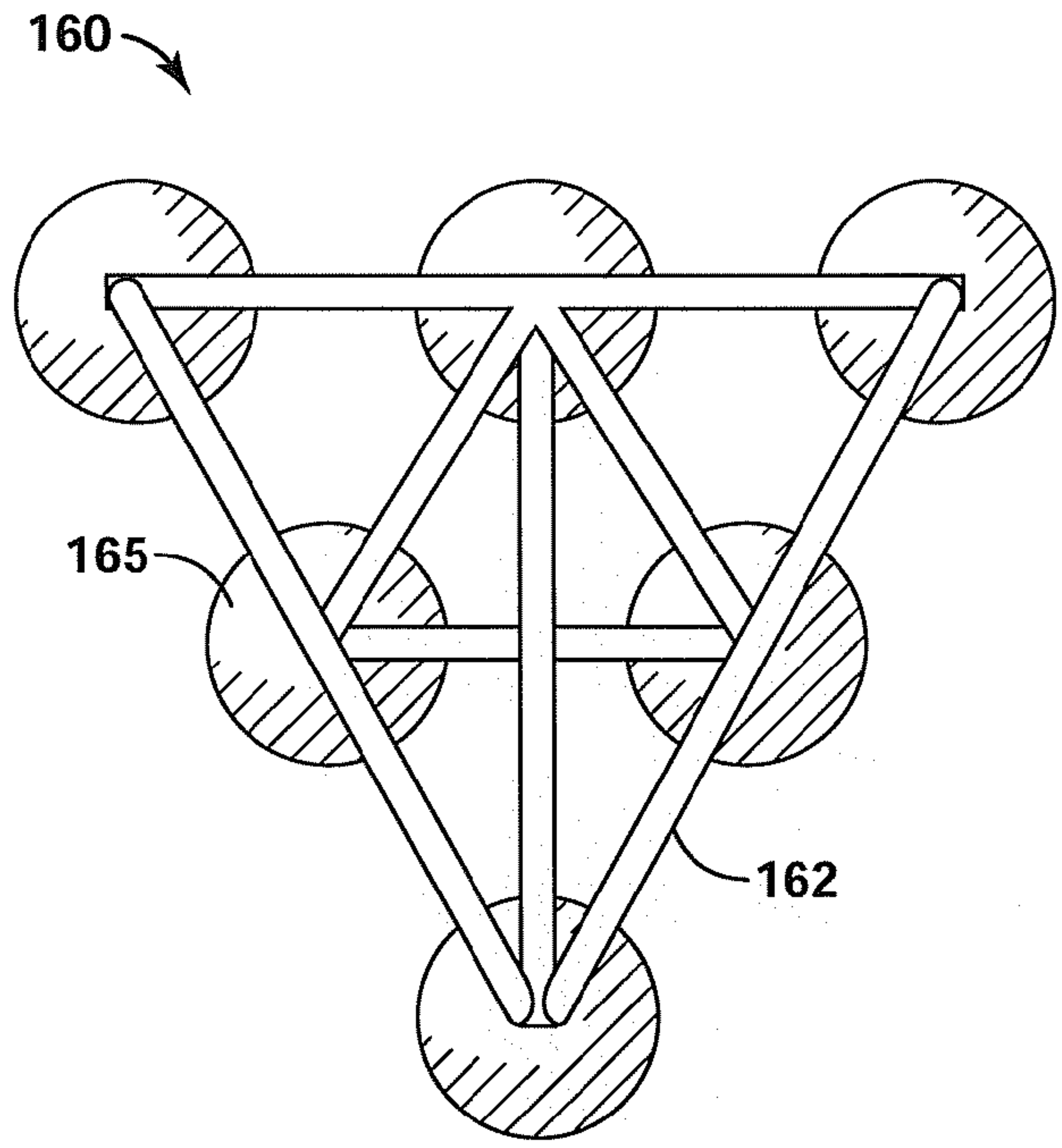


FIG. 4B

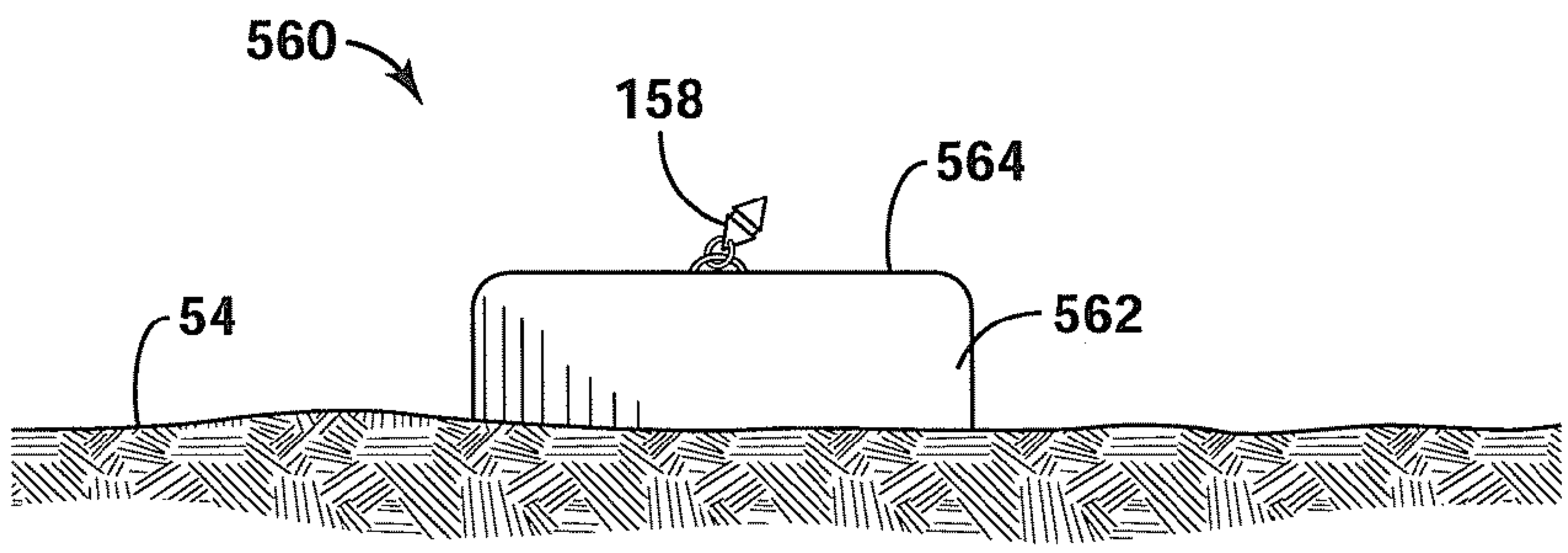


FIG. 5A

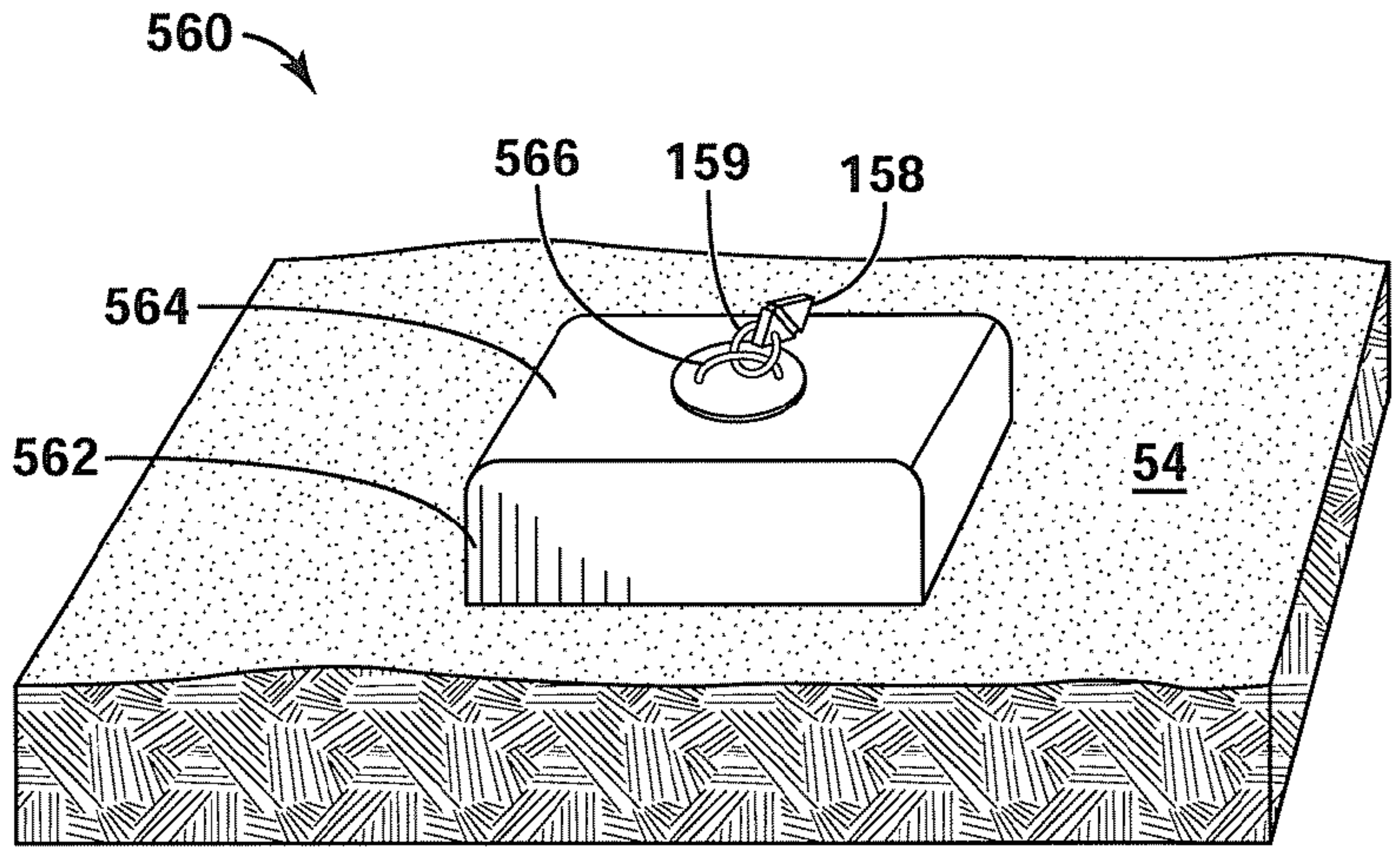


FIG. 5B

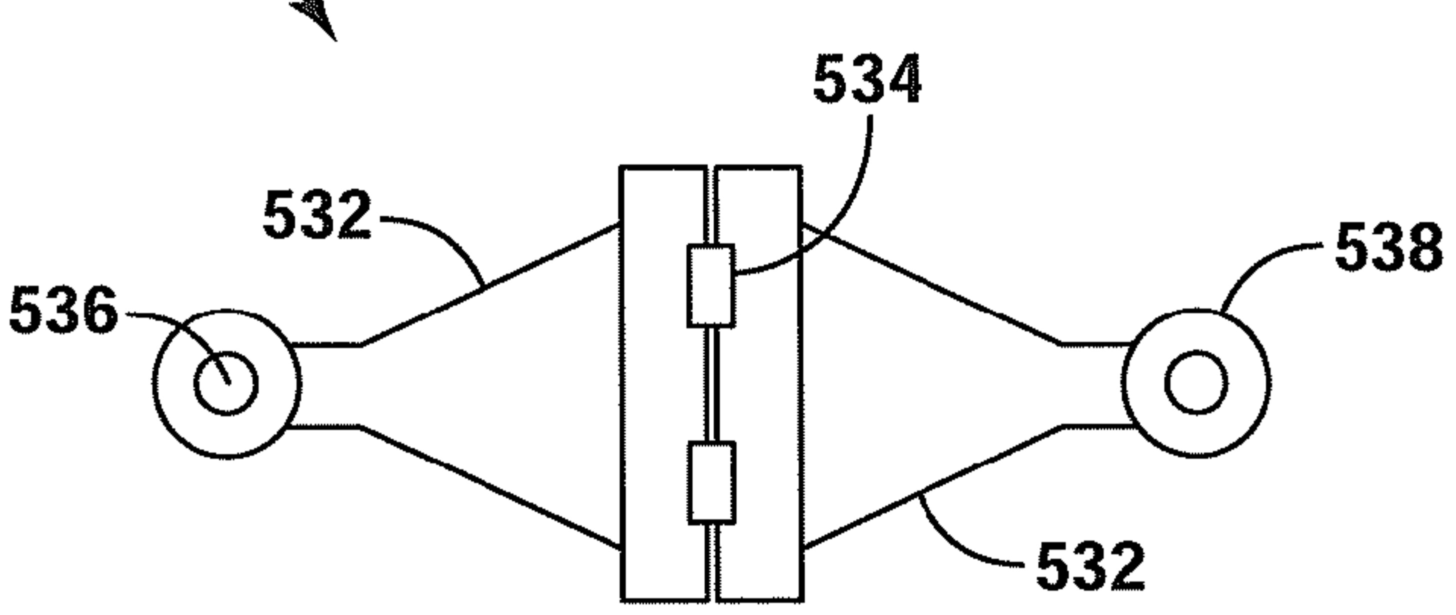


FIG. 5C

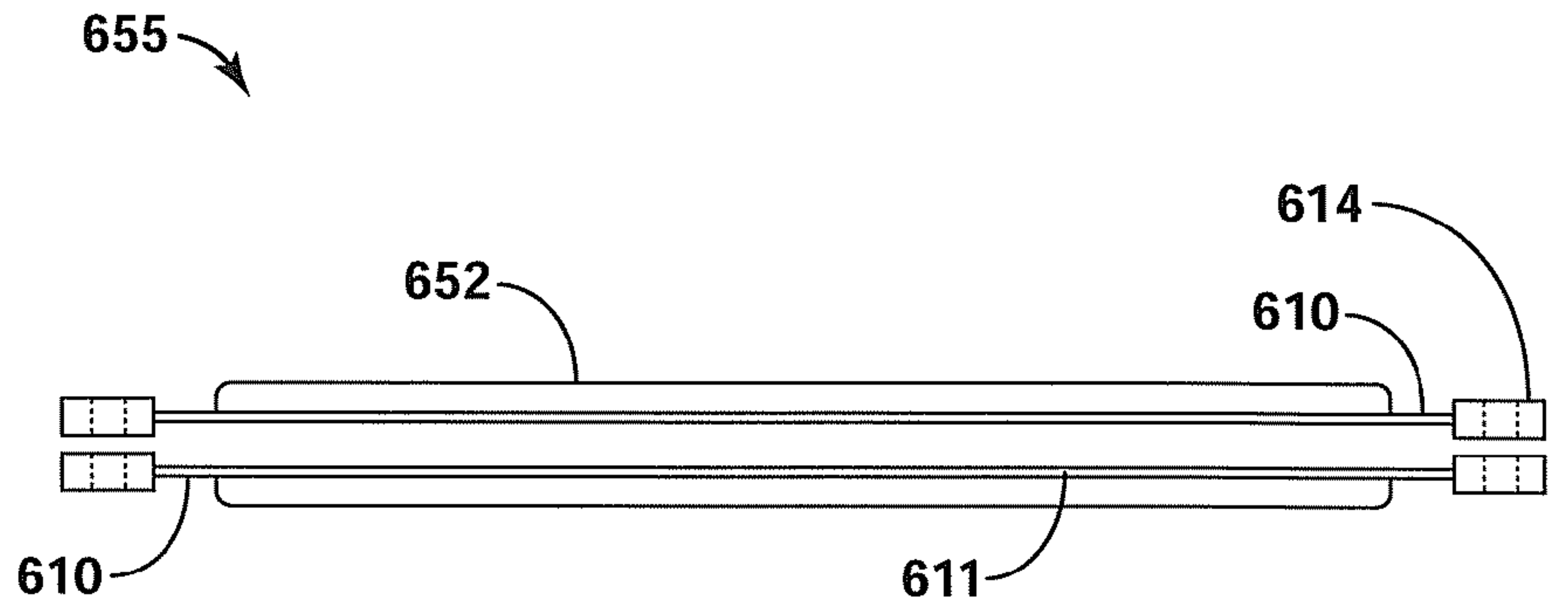


FIG. 6A

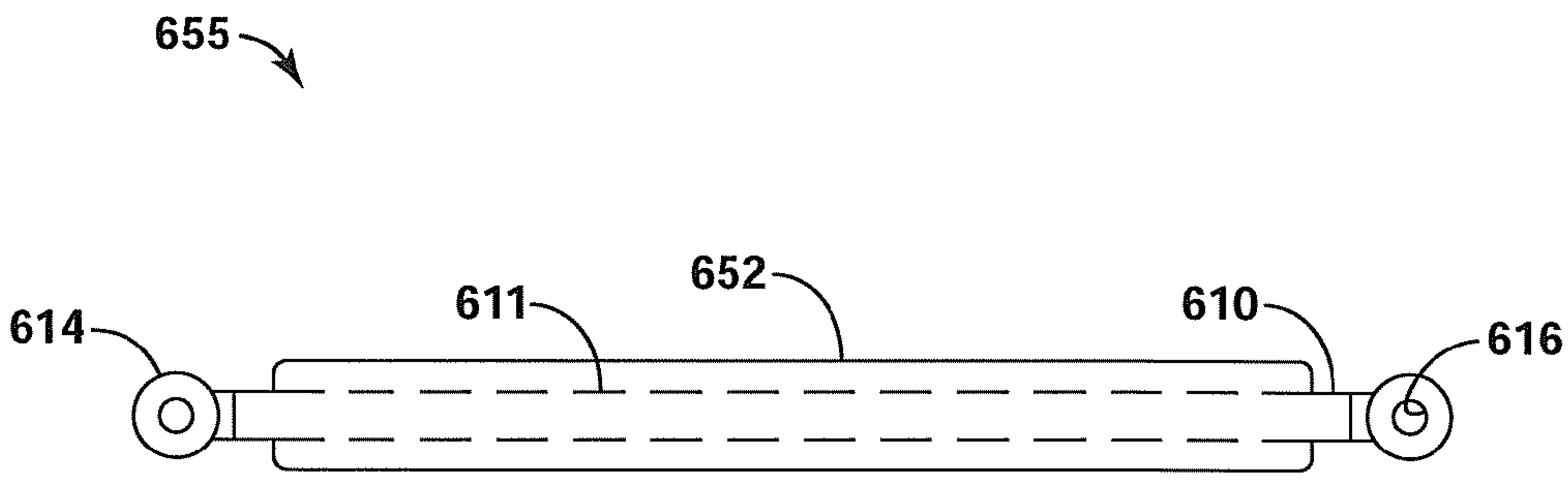


FIG. 6B

6/20

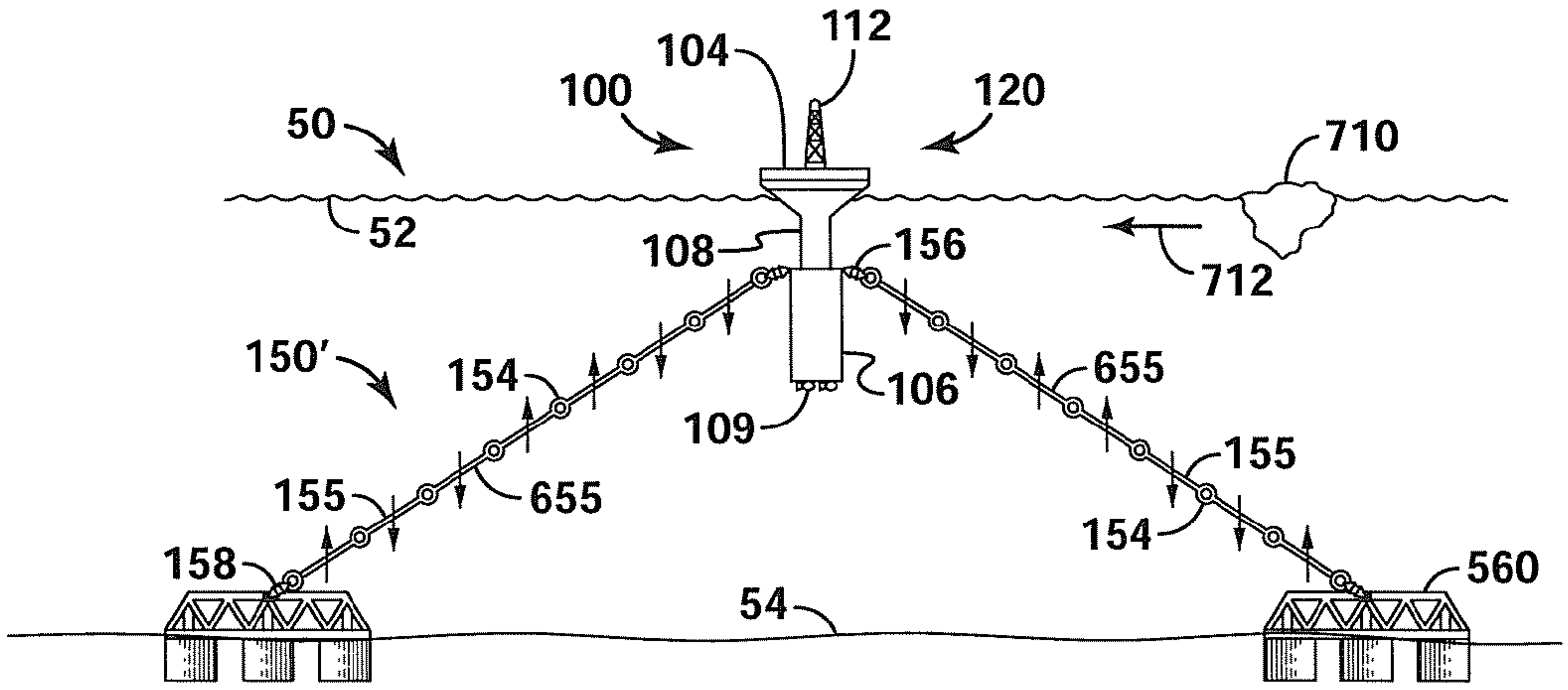


FIG. 7A

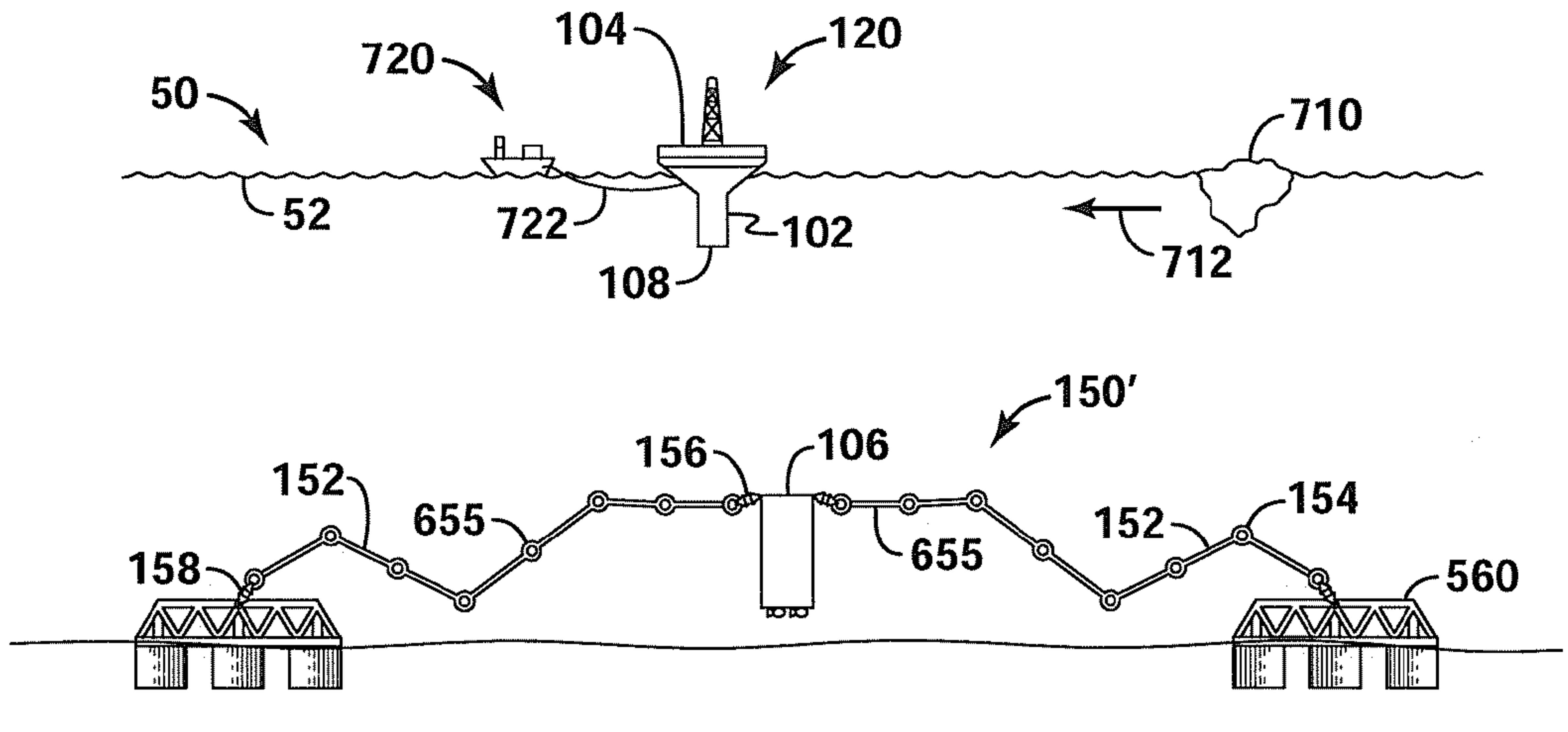


FIG. 7B

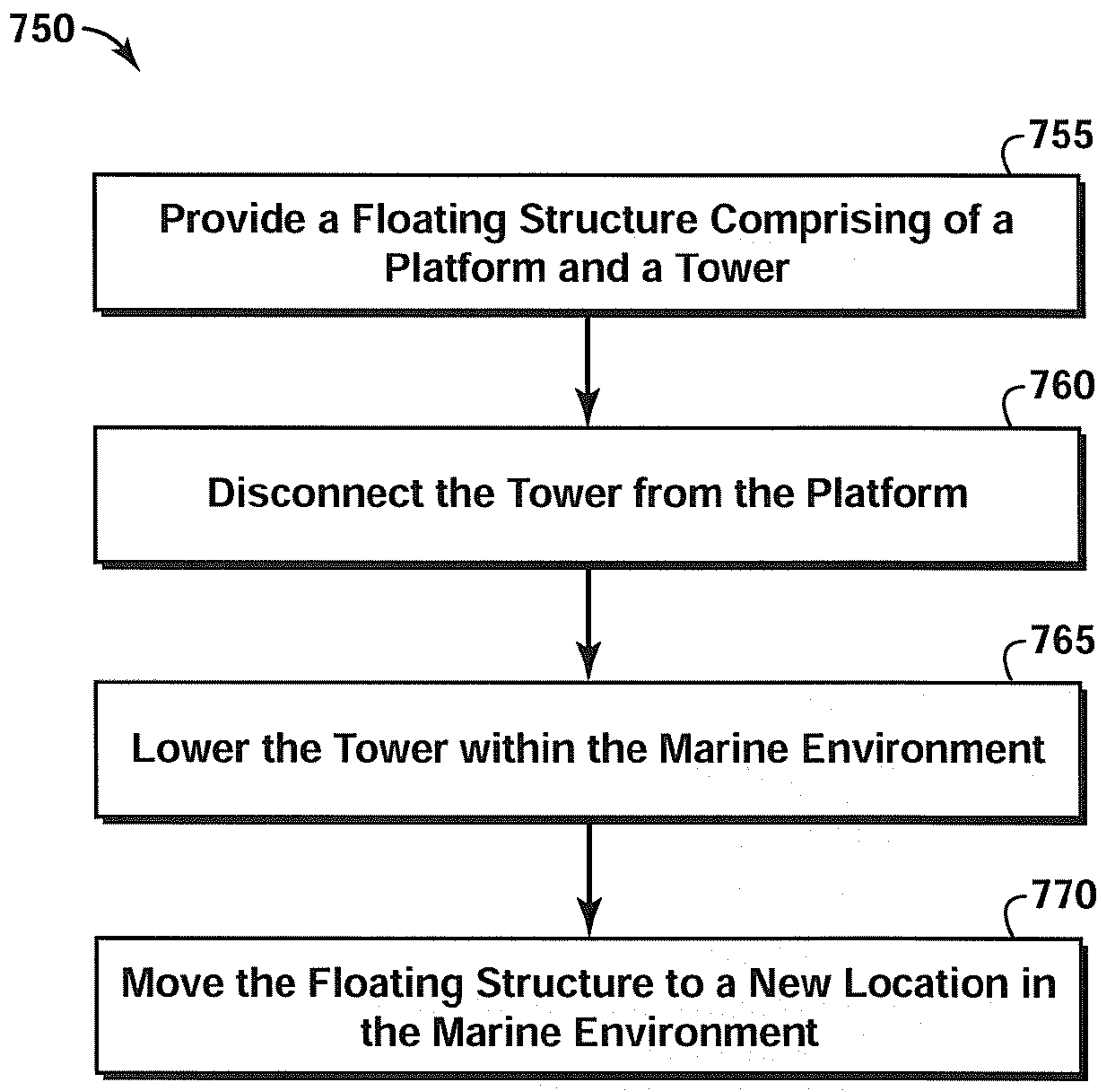

750
755
Provide a Floating Structure Comprising of a Platform and a Tower
760
Disconnect the Tower from the Platform
765
Lower the Tower within the Marine Environment
770
Move the Floating Structure to a New Location in the Marine Environment

FIG. 7C

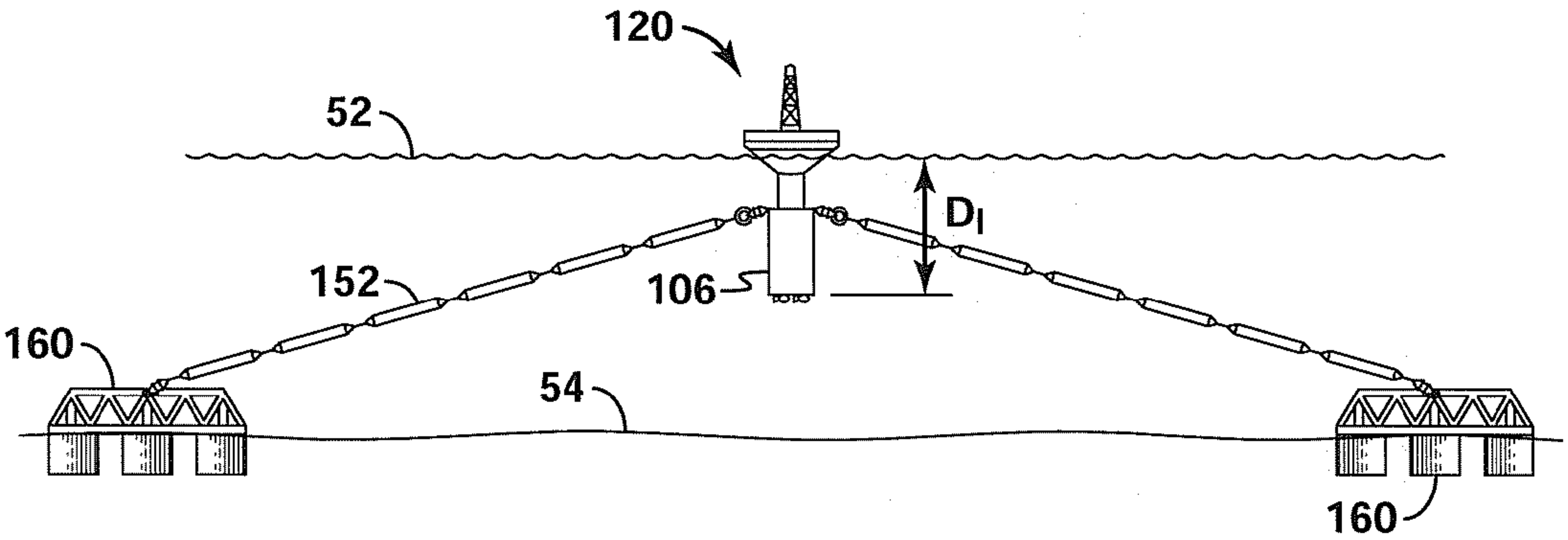


FIG. 8A

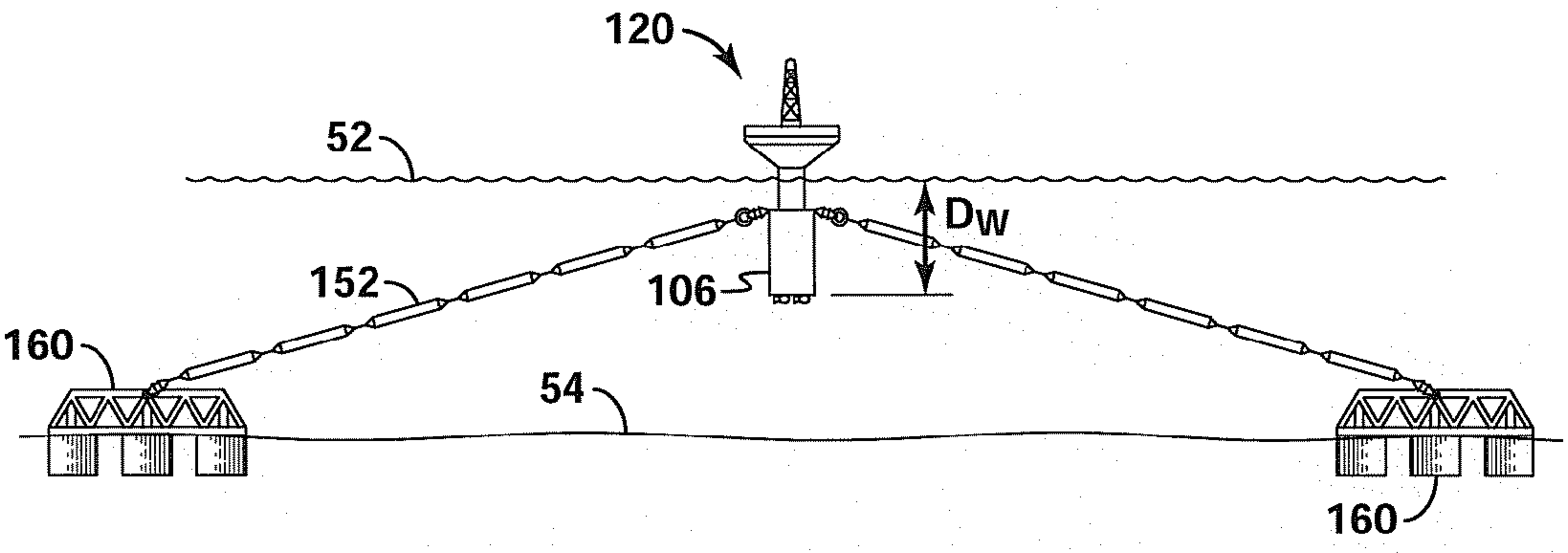


FIG. 8B

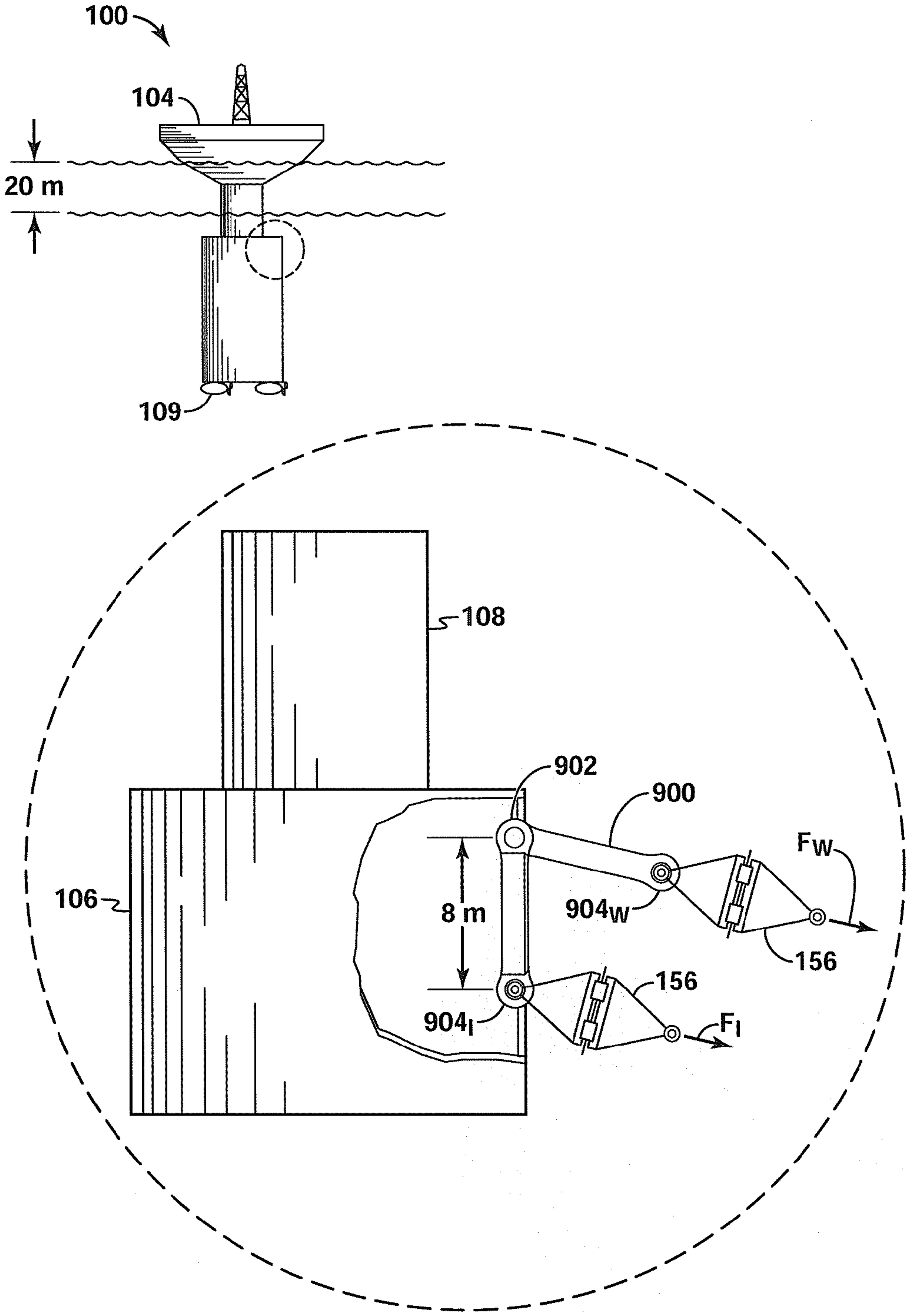


FIG. 9

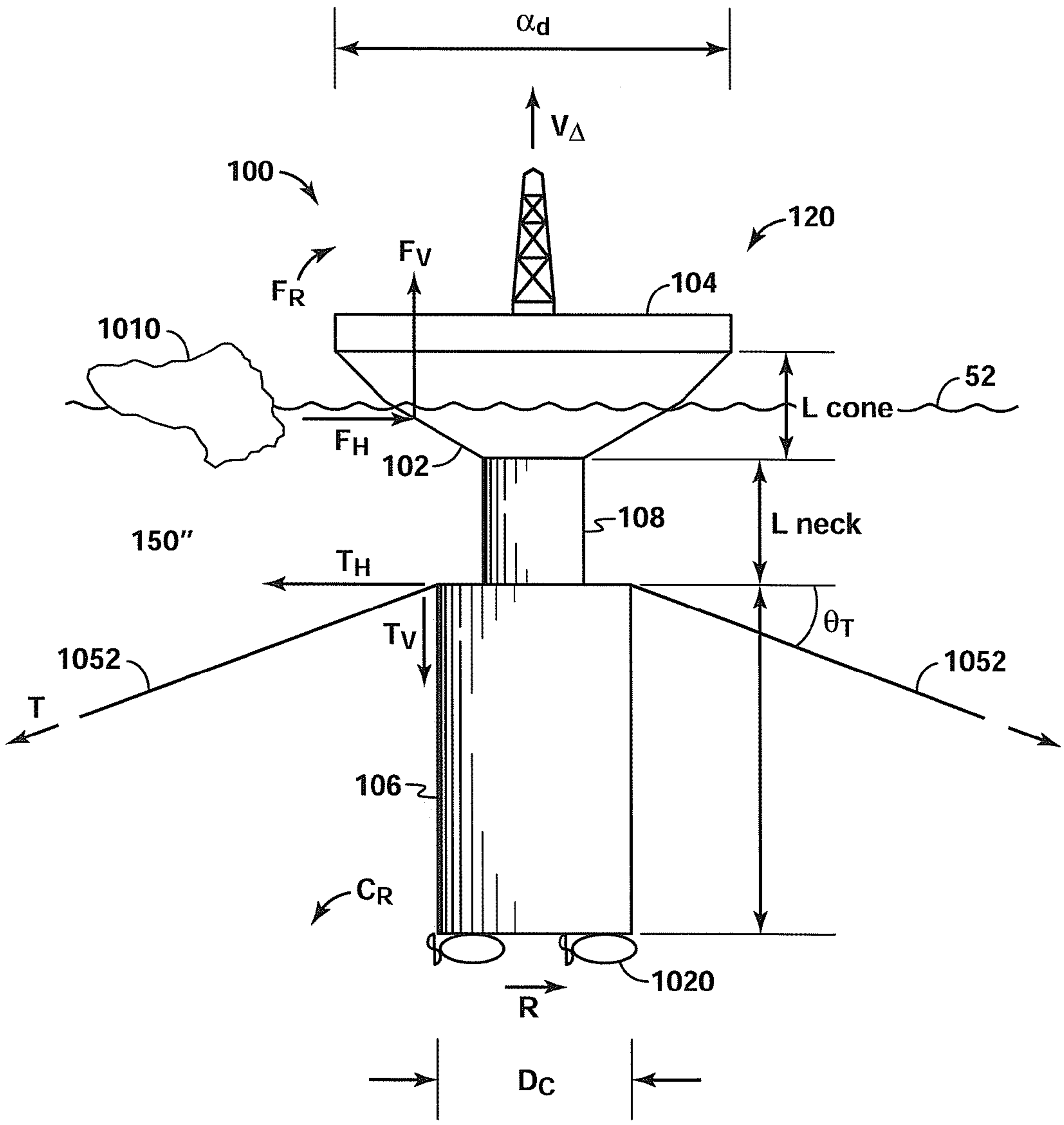

α_d
V_Δ
100
120
F_V
F_R
104
1010
52
L cone
F_H
102
108
L neck
150″
T_H
θ_T
T_V
1052
1052
T
106
C_R
1020
R
D_C

FIG. 10

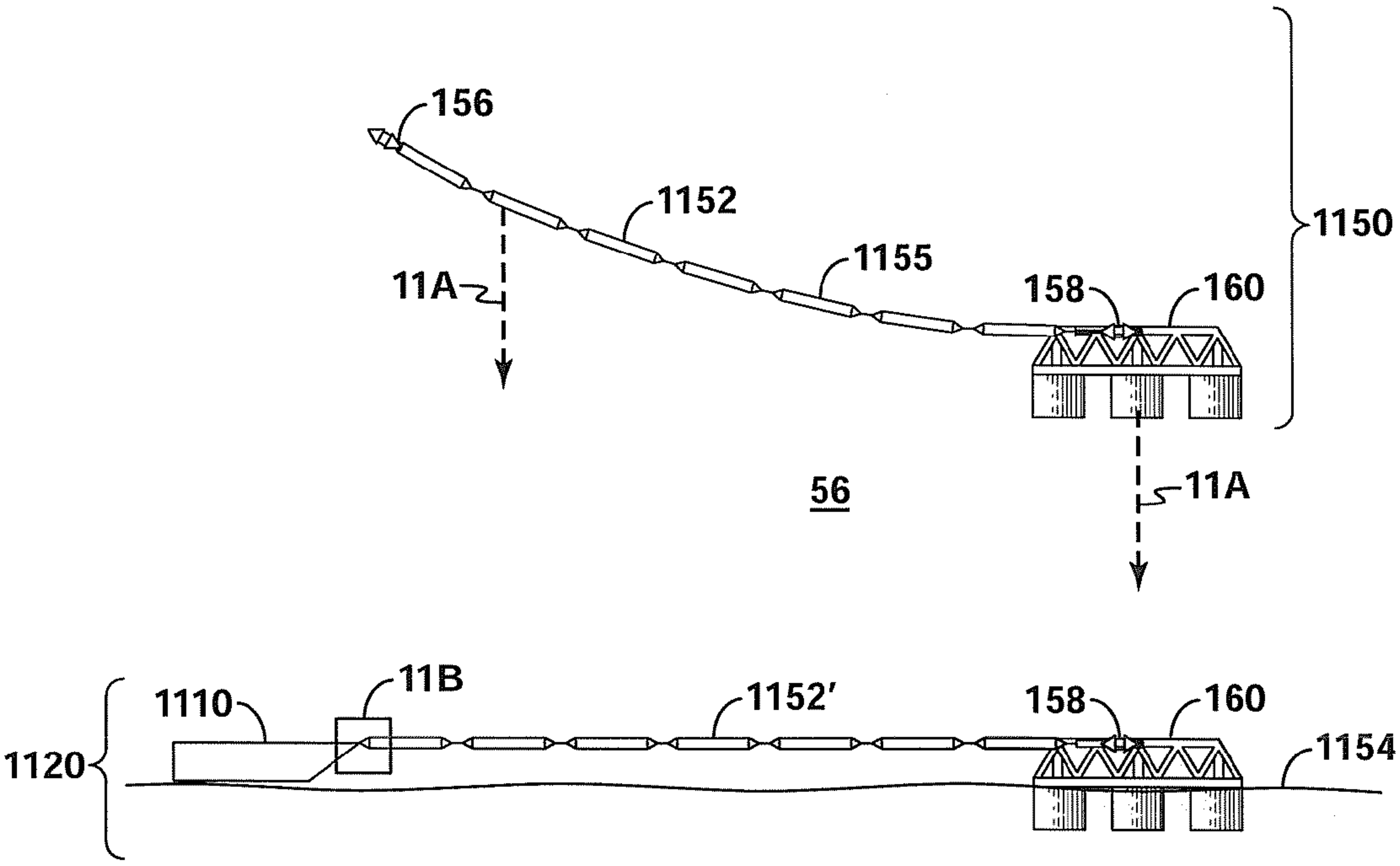


FIG. 11A

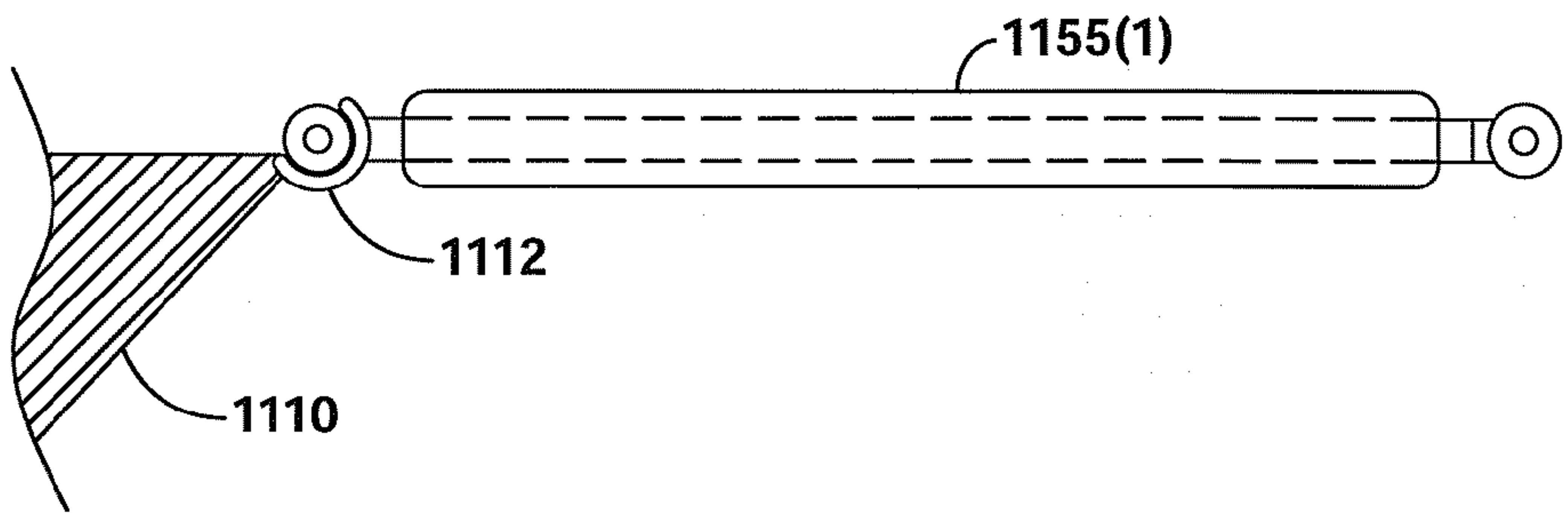


FIG. 11B

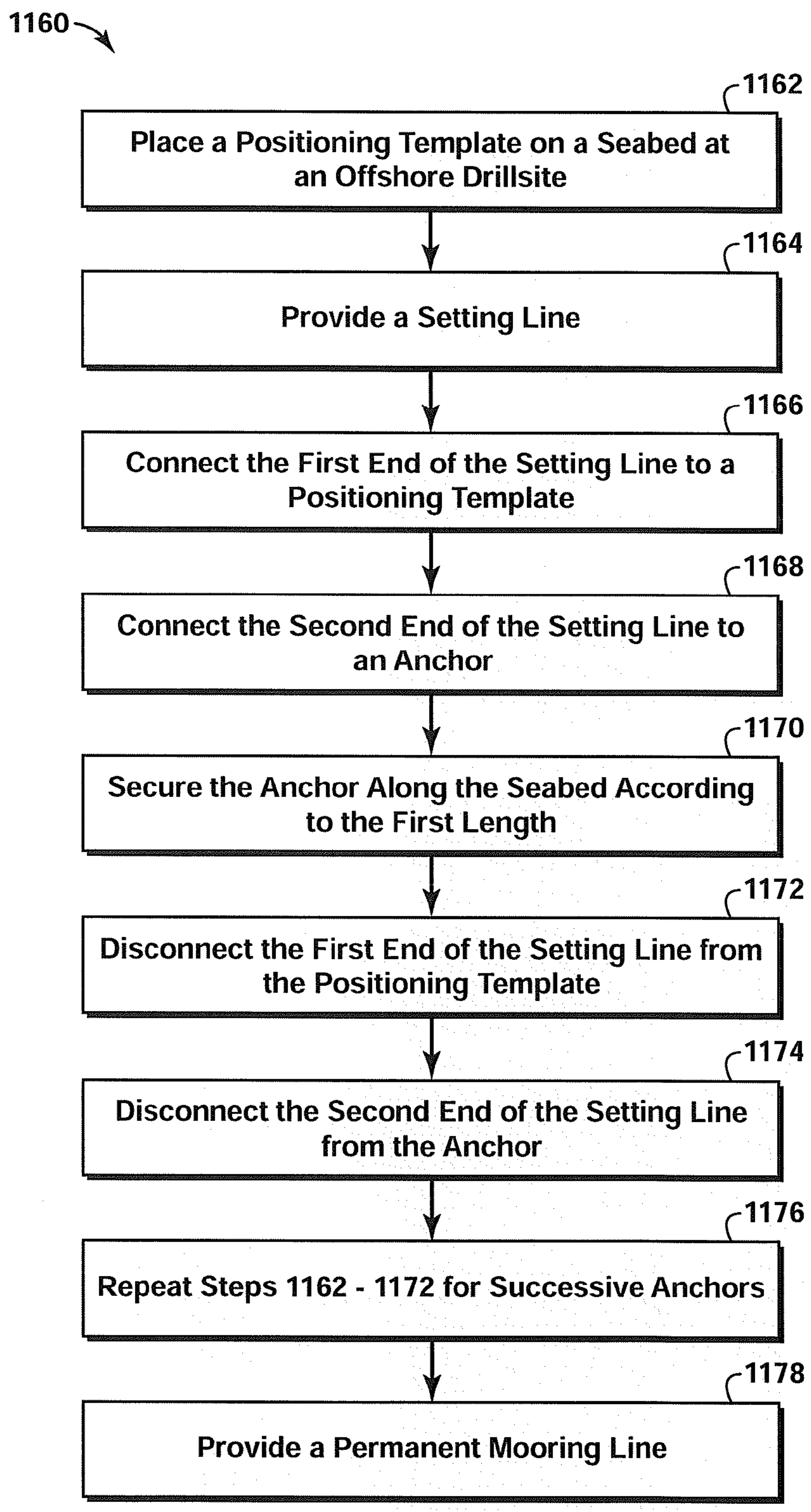

1160
1162
Place a Positioning Template on a Seabed at an Offshore Drillsite
1164
Provide a Setting Line
1166
Connect the First End of the Setting Line to a Positioning Template
1168
Connect the Second End of the Setting Line to an Anchor
1170
Secure the Anchor Along the Seabed According to the First Length
1172
Disconnect the First End of the Setting Line from the Positioning Template
1174
Disconnect the Second End of the Setting Line from the Anchor
1176
Repeat Steps 1162 - 1172 for Successive Anchors
1178
Provide a Permanent Mooring Line

FIG. 11C

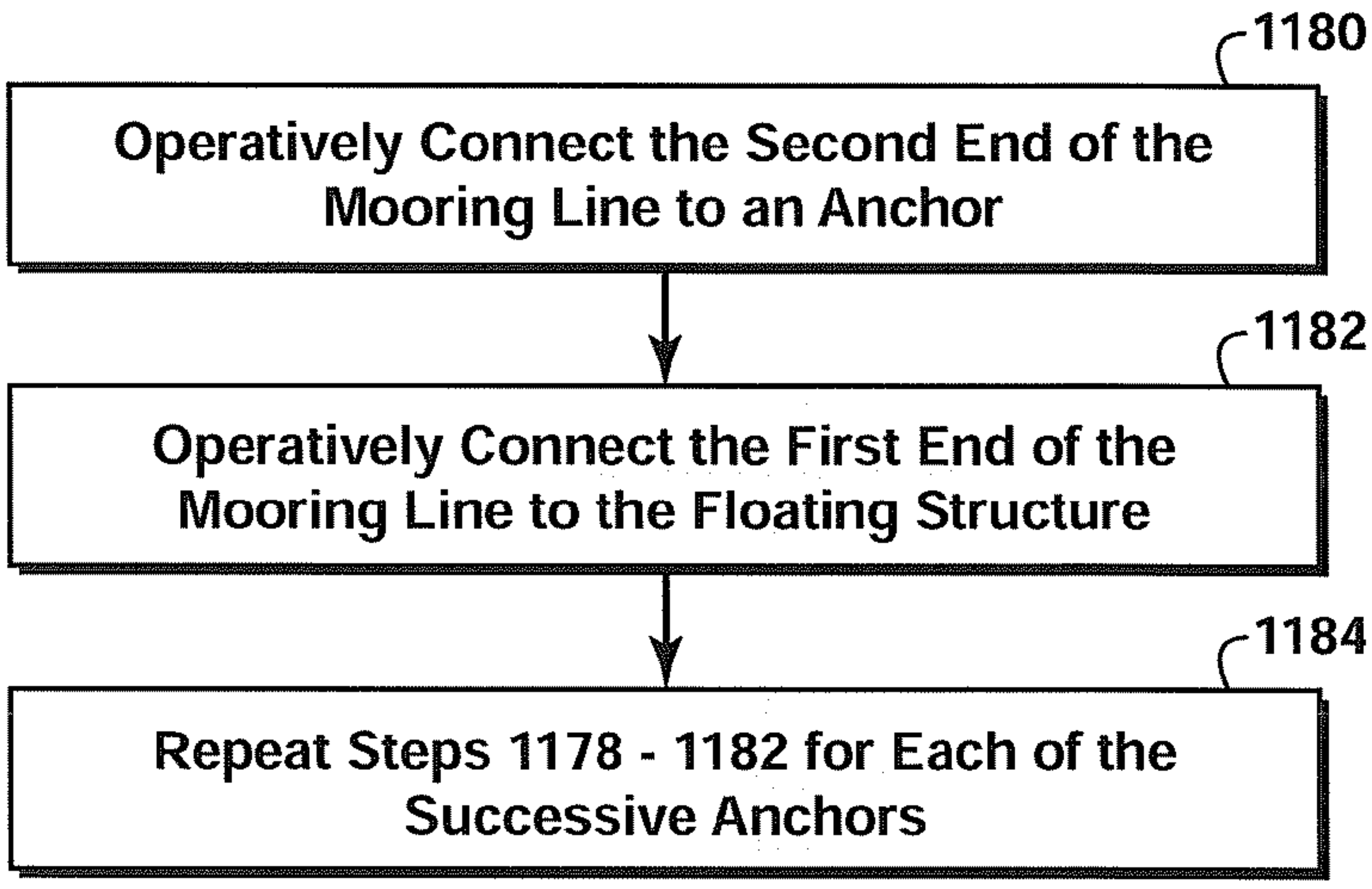

1180
Operatively Connect the Second End of the Mooring Line to an Anchor
1182
Operatively Connect the First End of the Mooring Line to the Floating Structure
1184
Repeat Steps 1178 - 1182 for Each of the Successive Anchors

FIG. 11D

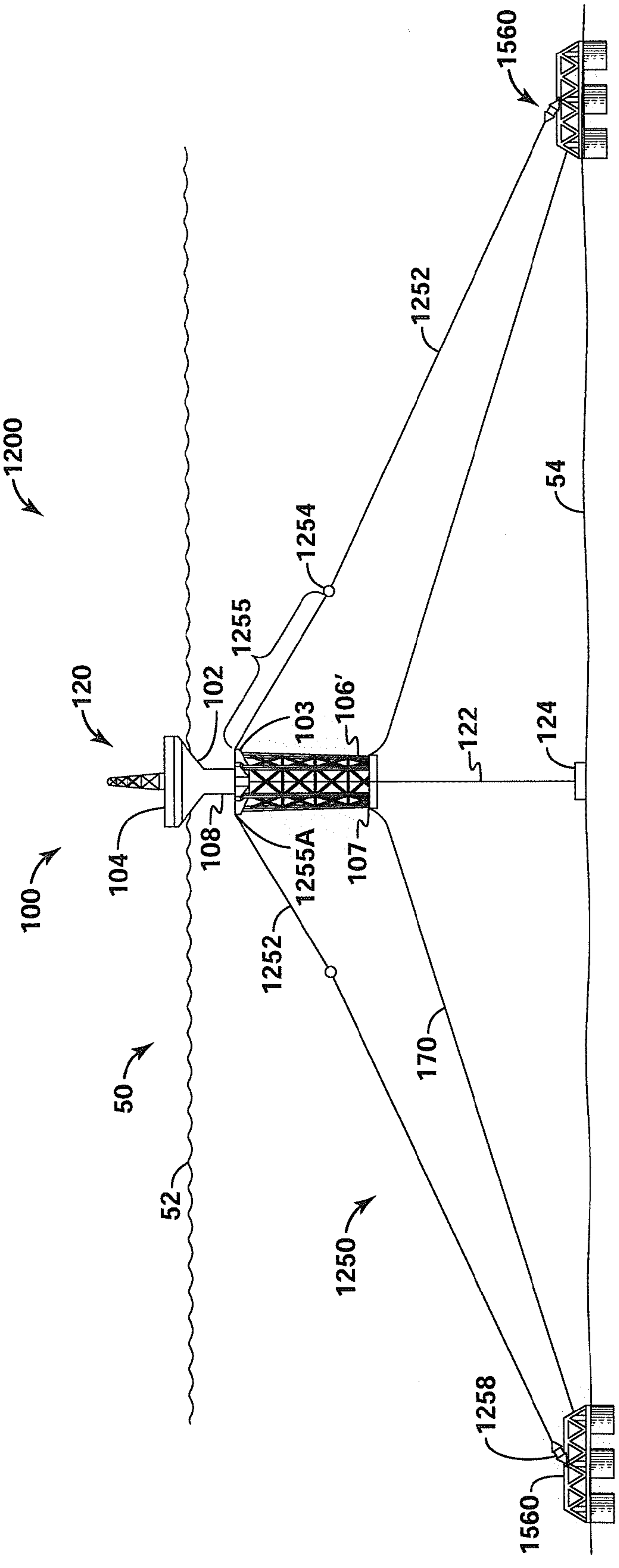
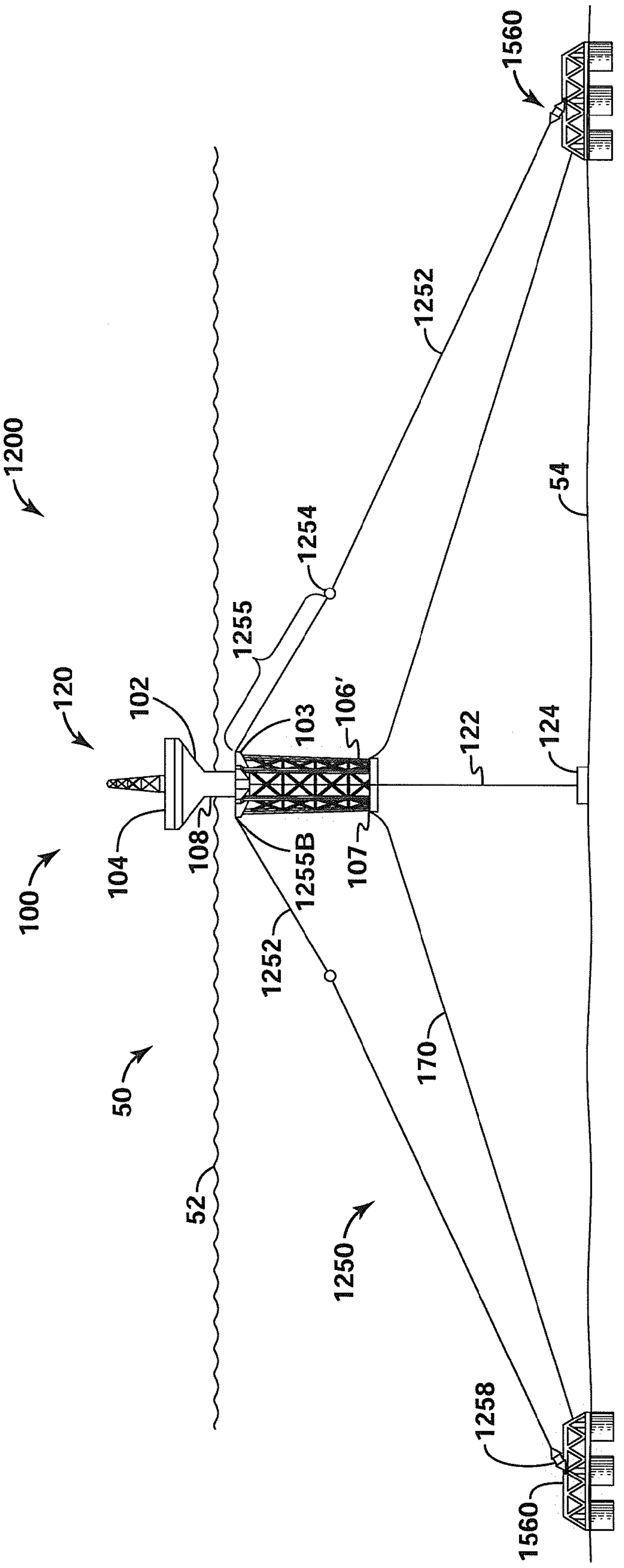

1560
1252
1200
54
1254
1255
120
102
103
106'
122
124
104
108
1255A
107
100
1252
170
50
52
1250
1258
1560

FIG. 12A


1560
1252
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1254
1255
120
102
103
106′
122
124
104
108
1255B
107
100
1252
170
50
52
1250
1258
1560

FIG. 12B

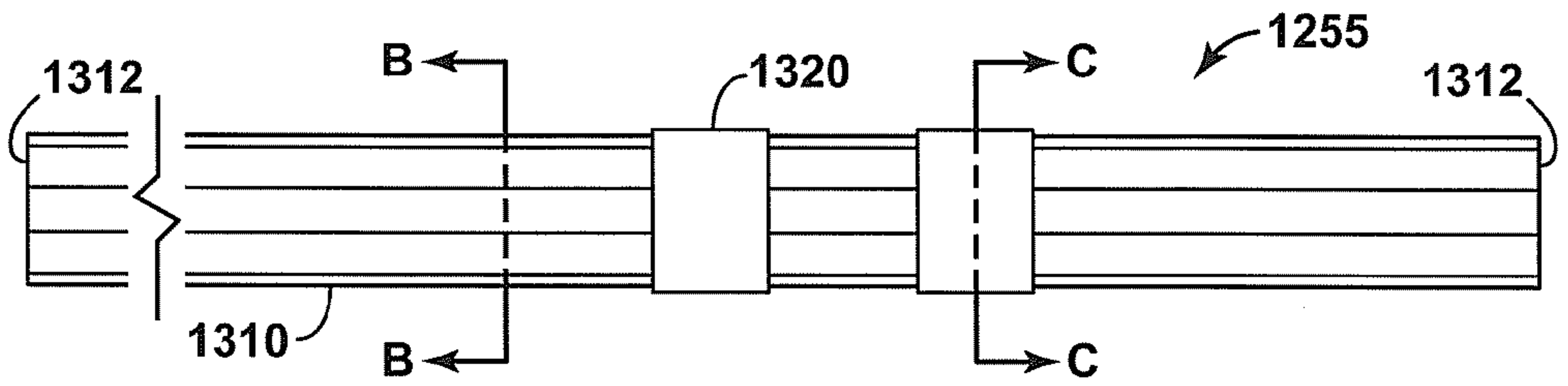


FIG. 13A

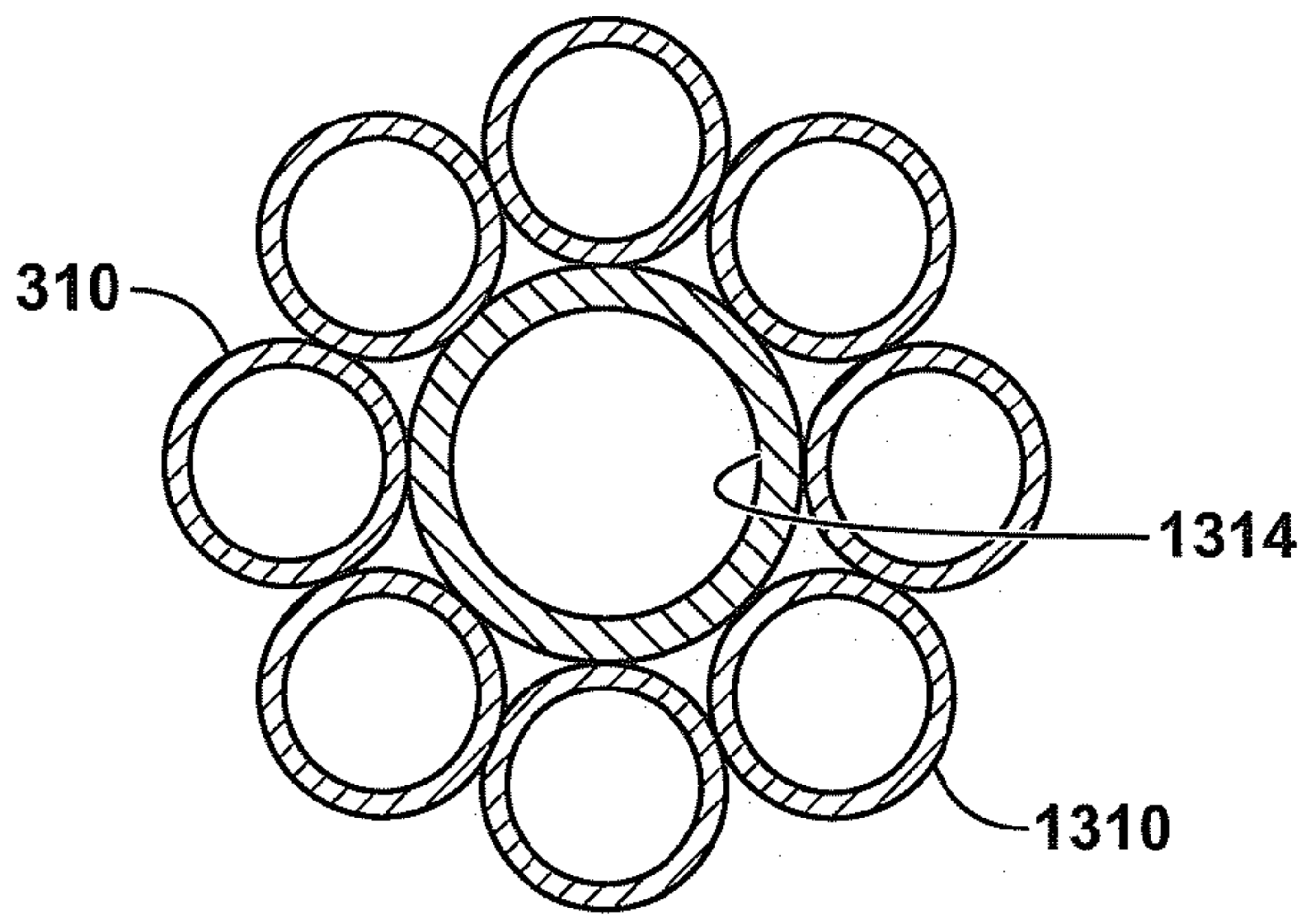


FIG. 13B

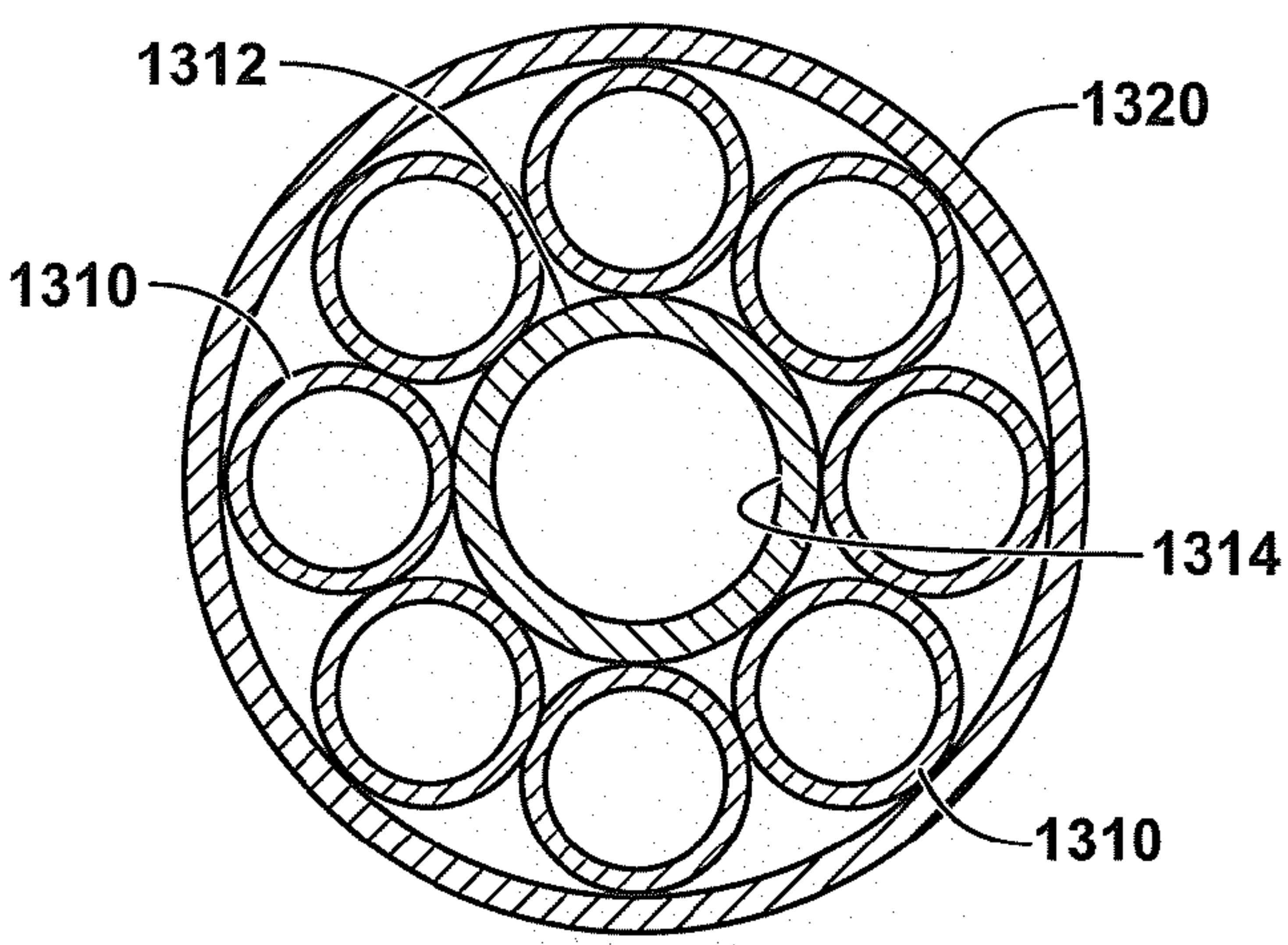


FIG. 13C

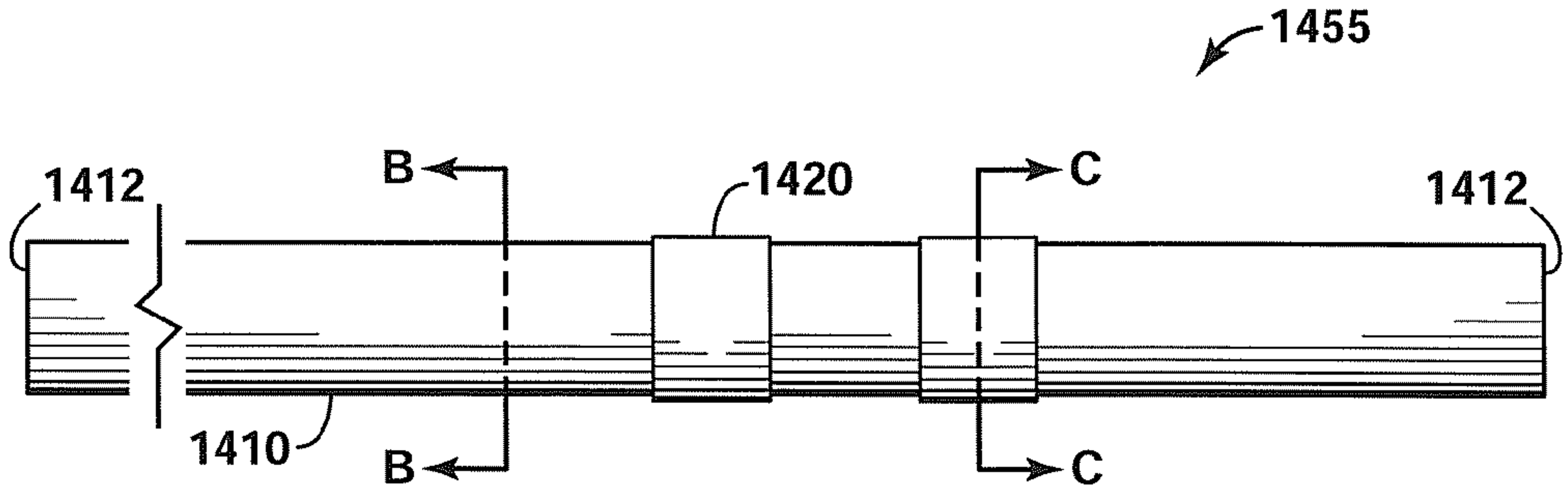


FIG. 14A

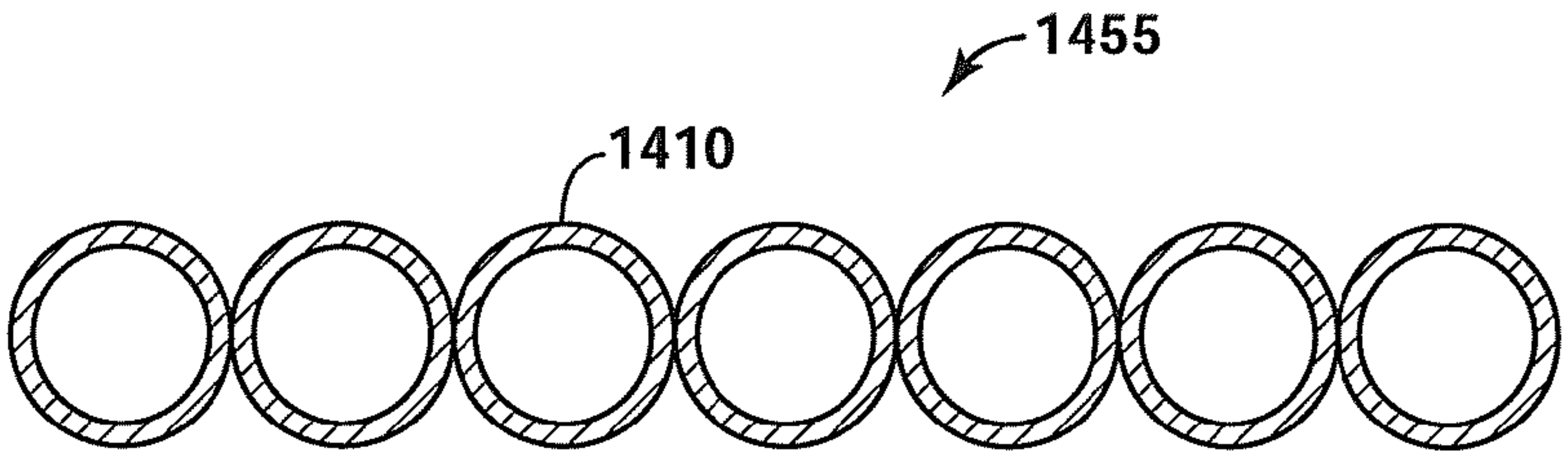


FIG. 14B

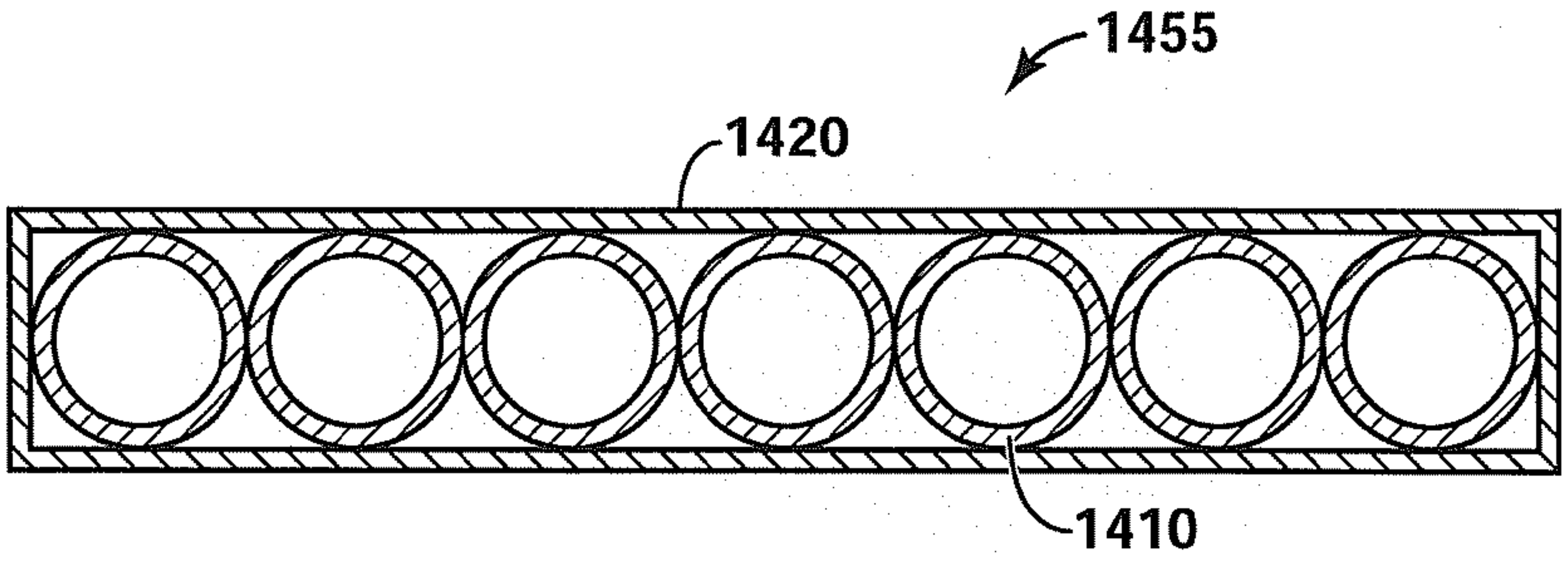


FIG. 14C

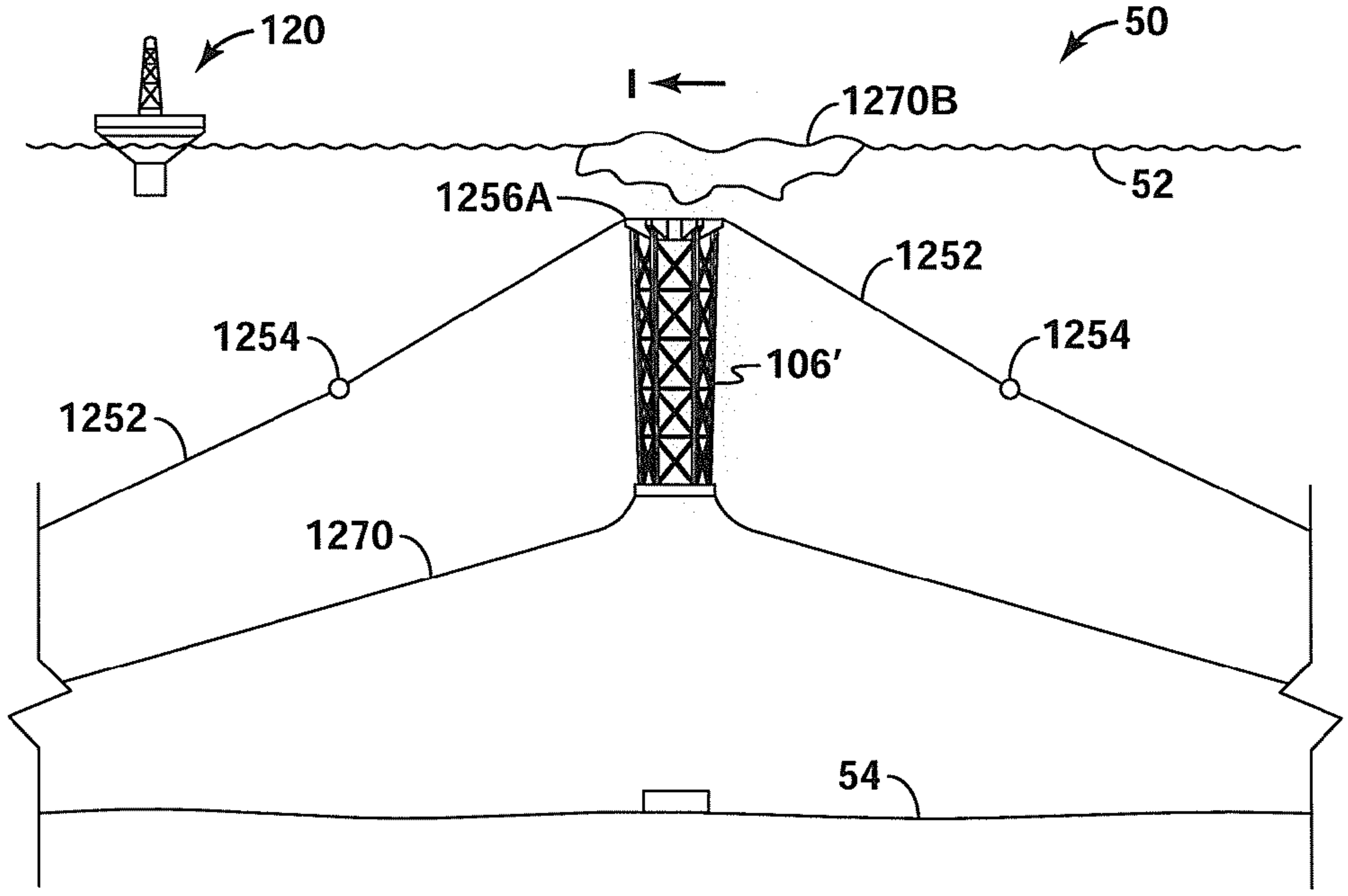


FIG. 15A

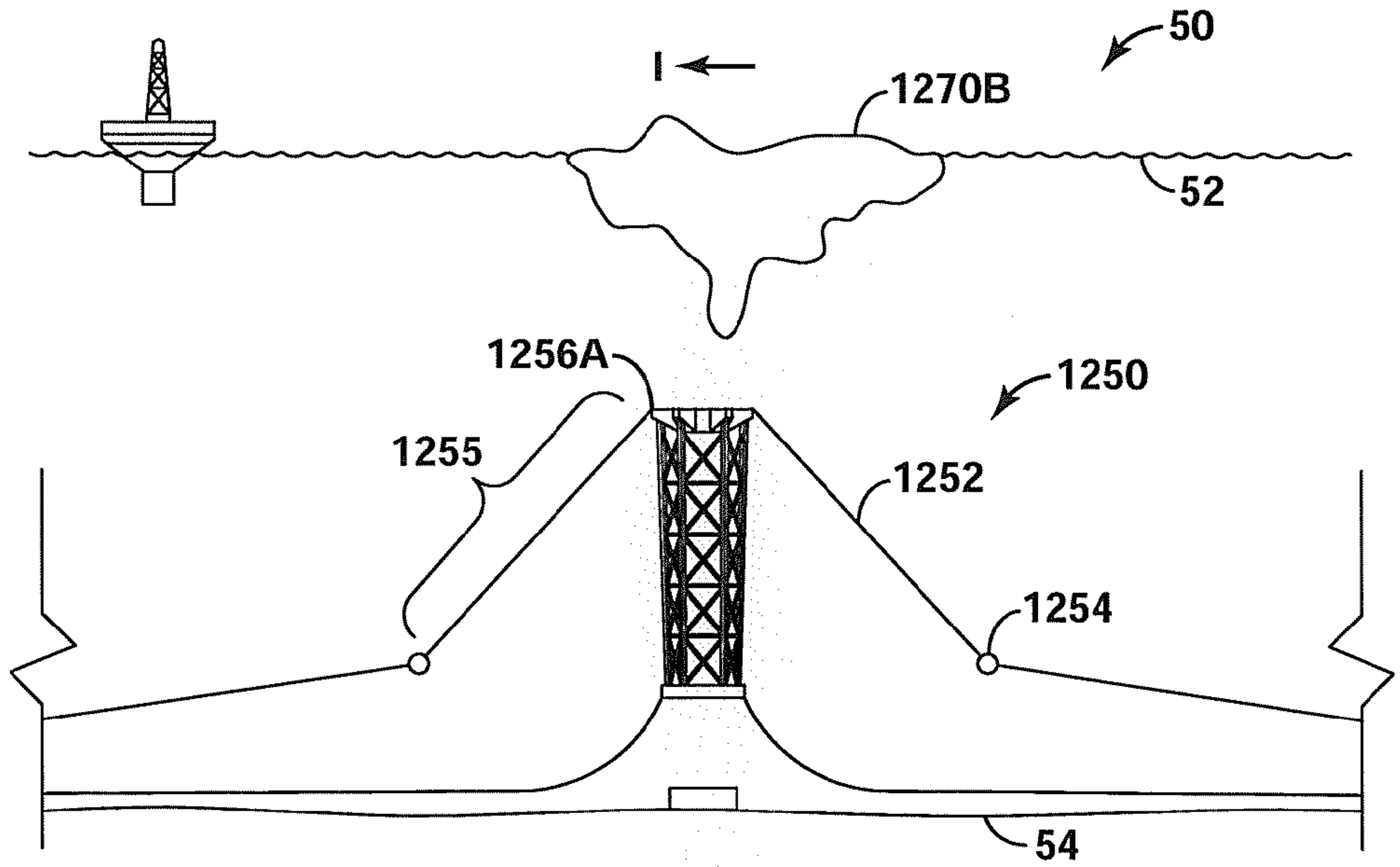


FIG. 15B

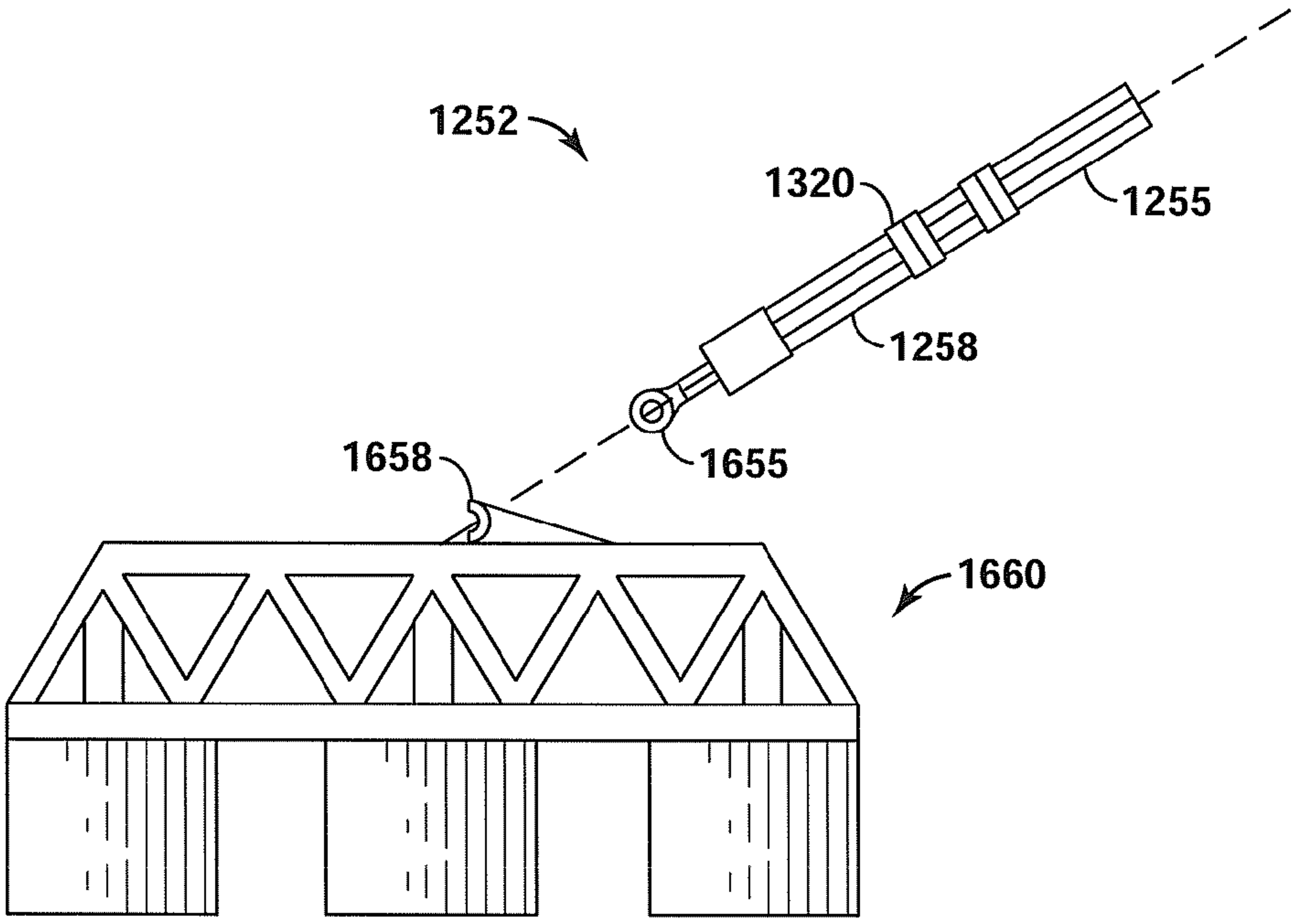


FIG. 16A

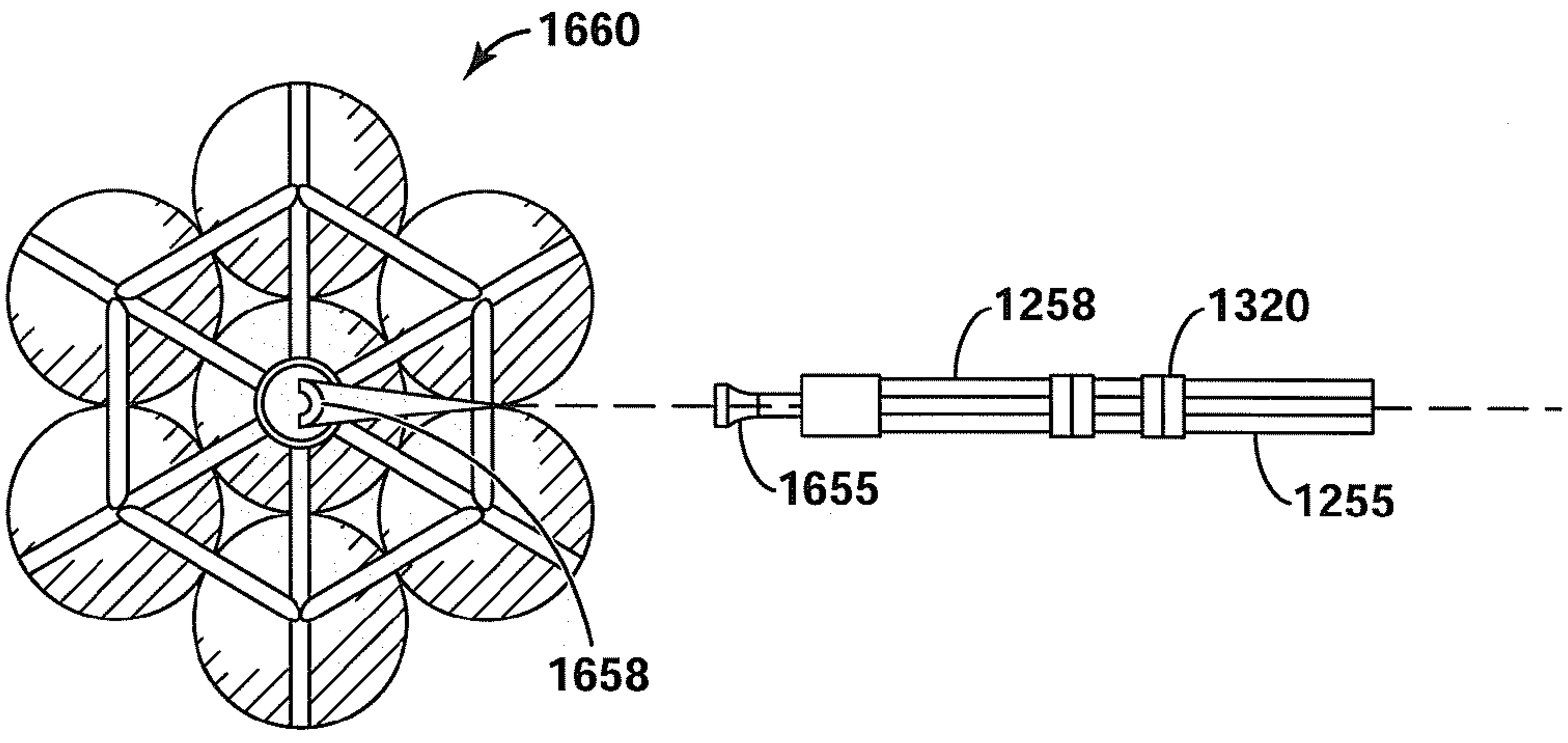


FIG. 16B

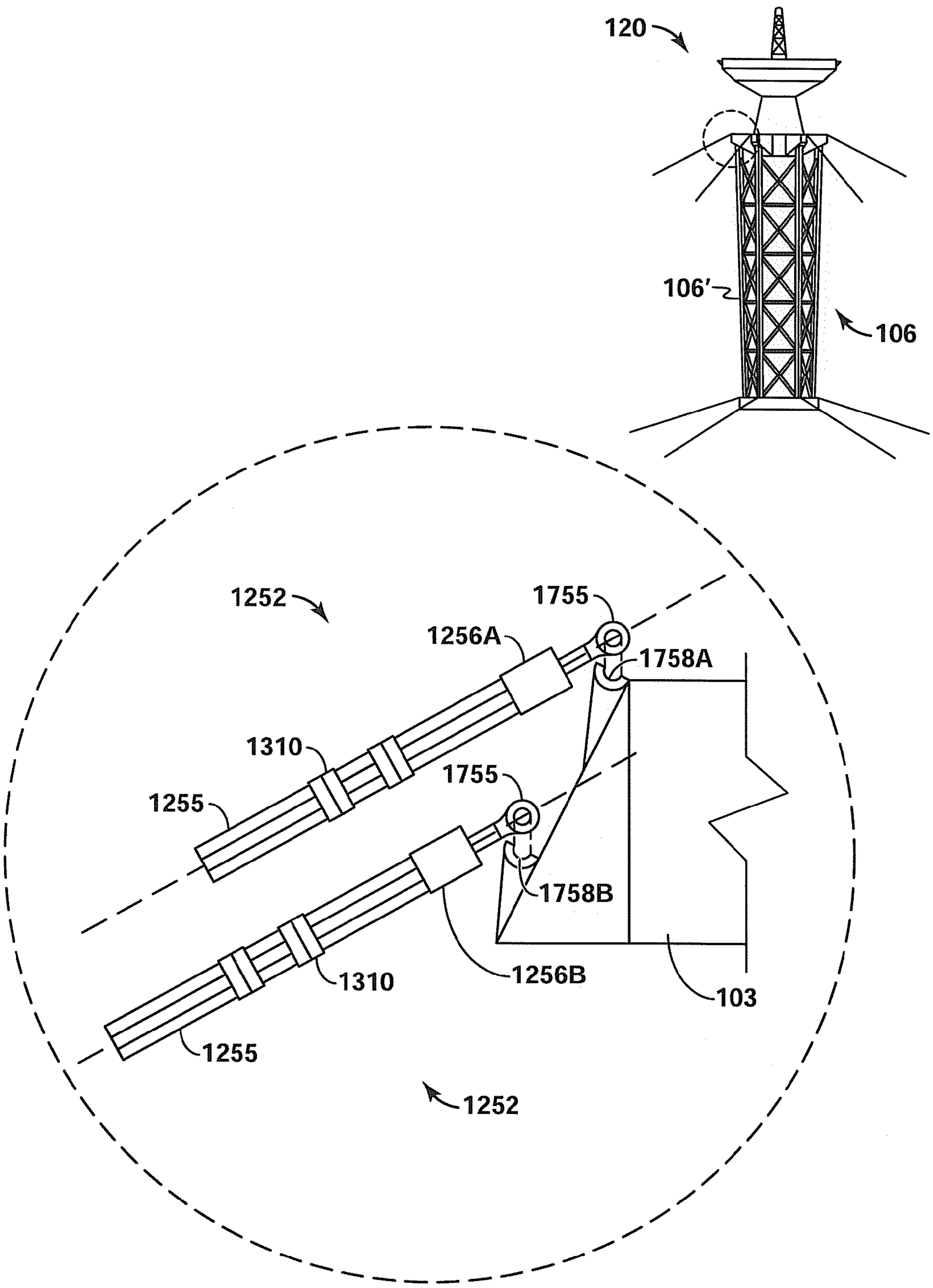
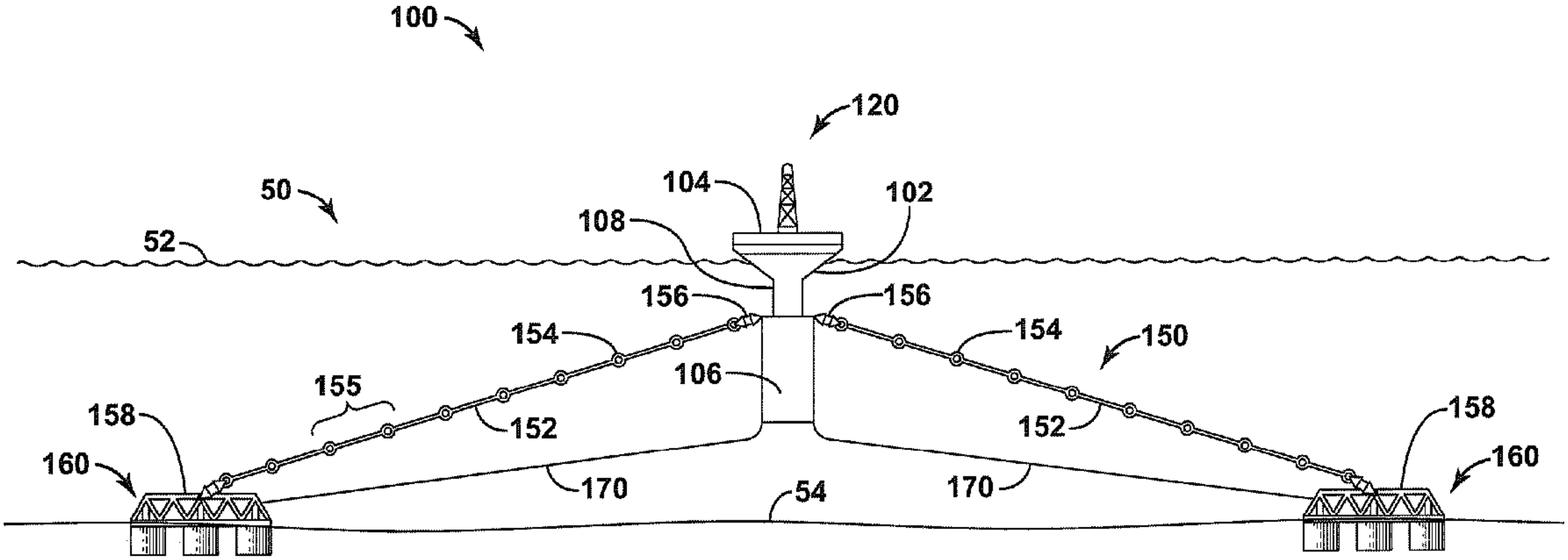

120
106'
106
1252
1755
1256A
1758A
1310
1755
1255
1758B
1310
1256B
103
1255
1252

FIG. 17


100
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170