

FLEXIBLE SEAWALL FOR COASTAL RESERVOIRS

RELATED APPLICATION

[0001] This application claims the benefit of priority to the Singapore application no. 10202302520Q filed September 8, 2023, which is incorporated herein by reference in its entirety for all purposes.

TECHNICAL FIELD

[0002] The present disclosure relates to very large floating structures and more particularly to a coastal reservoir.

BACKGROUND

[0003] The traditional reservoir construction generally requires natural low-lying areas such as valleys and basins to form a height difference with surrounding retaining structures, while coastal areas generally lack the conditions for building traditional reservoirs due to flat terrain. Further, the traditional methods of constructing seawalls for coastal reservoirs are resource intensive, costly and technically challenging.

SUMMARY

[0004] In one aspect, the present application discloses a seawall. The seawall includes a floatable structure. The floatable structure includes opposing ends and a base characterized by a length defined between opposing ends. The seawall includes one or more water ballast compartments defined in the floatable structure. The seawall includes one or more membranes. Each of the one or more membranes includes a water-impermeable flexible panel having a first edge and a second edge. The first edge may be coupled with the base along the length. The second edge may be anchored to a seabed.

[0005] The seawall may include a base that is coupled with two or more membranes. The two or more of the plurality of membranes may be parallel and spaced apart from one another to form respective water-impermeable flexible layers of a multi-layered barrier.

[0006] The seawall may be configured with the multi-layered barrier including one or more columns of water. Each of the one or more columns of water may be defined between adjacent ones of the two or more membranes.

[0007] In another aspect, a seawall may include a plurality of floatable structures, one or more water ballast compartments defined in each of the plurality of floatable structures, an anchoring member, and one or more membranes. Each of the plurality of floatable structures may have opposing ends and a base characterized by a length defined between the opposing ends. The plurality of floatable structures may be coupled to one another at respective ones of the opposing ends. The anchoring member may be disposed in/or a seabed. Each of the one or more membranes may be a water-impermeable flexible panel having a first edge and a second edge. The first edge may be coupled with the base along the first length. The second edge may be anchored to the seabed by the anchoring member. Contacting side edges of respective membranes of adjacent ones of the plurality of floatable structures are joined to one another in a continuous sealed joint.

[0008] The base of each of the plurality of floatable structures may be coupled with two or more of the membranes. The two or more of the plurality of membranes may be parallel and spaced apart from one another to form respective water-impermeable flexible layers of a multi-layered barrier.

[0009] The multi-layered barrier may include one or more columns of water, each of the one or more columns of water being defined between adjacent ones of the two or more membranes.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 schematically illustrates a coastal reservoir according to embodiments of the present disclosure;

[0011] FIG. 2A is a schematic diagram of a modular unit according to an embodiment of the present disclosure;

[0012] FIG. 2B is a schematic diagram of the modular unit of FIG. 2A showing a plurality of membranes deformed by water currents;

[0013] FIG. 3A is a schematic side view of the seawall;

[0014] FIG. 3B is a schematic view of the seawall from another side view;

[0015] FIG. 4A is a schematic diagram of anchoring members according to various embodiments of the present disclosure;

[0016] FIG. 4B schematically illustrates one example of a plurality of floatable structures coupled to the anchoring member of FIG. 4A;

[0017] FIG. 4C schematically illustrates one example of the plurality of floatable structures coupled to the anchoring member and a plurality of membranes;

[0018] FIG. 5 schematically illustrates one section of a coastal reservoir formed by a flexible seawall in accordance with embodiments of the present disclosure; and

[0019] FIG. 6 is a schematic flow diagram illustrating a method of stabilizing the seawall 100 in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION

[0020] The following detailed description is made with reference to the accompanying drawings, showing details and embodiments of the present disclosure for the purposes of illustration. Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments, even if not explicitly described in these other embodiments. Additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0021] The term “and/or” includes any and all combinations of one or more of the associated listed items.

[0022] The terms “about” and “approximately” as applied to a stated numeric value encompasses the exact value and a reasonable variance and the terms “generally” and “substantially” are to be understood in a comparable manner, unless otherwise specified. For example, in the context of various embodiments, the term “about” or “approximately” as applied to a stated numeric value will be generally understood by one skilled in the art to encompass the exact value and a reasonable variance as generally understood in the relevant technical field, e.g., within 10% of the specified value.

[0023] The word “exemplary” is used herein to mean “serving as an example, instance, or illustration.” Any embodiment described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other embodiments. As used herein, the singular “a”, “an”, and “the” may be construed as including the plural “one or more” unless apparent from the context to be otherwise.

[0024] Terms such as “first” and “second” are used in the description and claims only for the sake of brevity and clarity, and do not necessarily imply a priority or order, unless required by the context.

[0025] Floatable Structure

[0026] **FIG. 1** schematically illustrates an example of a very large floating structure (VLFS) that may be constructed according to embodiments of the present disclosure to serve various functions, including but not limited to serving as a coastal reservoir 102. The proposed coastal reservoir 102 is useful in many aspects. For example, the coastal reservoir 102 can be used to reduce or mitigate urban flooding by serving as a water catchment area, e.g., to store excess rainfall and surface runoff water during a high tide. In addition, the coastal reservoir 102 can be part of a freshwater supply, e.g., the water in the reservoir may be diluted by rainwater or processed by a desalination plant.

[0027] The proposed coastal reservoir 102 includes a seawall 100 that extends from the land 910 and encloses a body of coastal water 930. For example, ends of the coastal reservoir 102 may be connected to the land 910. In some examples, the ends of the coastal reservoir 102 are conceivably connected to different islands. For the sake of brevity, as used herein, the terms “water” 970, “sea water”, “coastal water”, and the like, may be used interchangeably. The seawall 100 may be described as a floating structure in that it is not constructed on a pile.

[0028] The coastal reservoir 102 may include one or more gravity piers 110 and/or one or more bridges 120. The gravity pier 110 includes one or more load-bearing walls or columns, and may be constructed using conventional piling techniques involving driving load-bearing supports into the seabed. The gravity pier 110 is constructed to be able to resist horizontal loads from winds and waves. The gravity pier 110 may serve as a transit point for connecting the seawall 100 to a

bridge 120. The one or more bridges 120 may serve as a connection between the seawall 100 and the land 910.

[0029] The coastal reservoir 102 may be formed by one or more seawalls 100 (or seawall sections), in which each seawall 100 (or seawall section) includes a plurality of interconnected modular units 200. The seawall 100 may be disposed offshore to define an inner body 220 of water 970 between the seawall 100 and the land 910 (or the enclosed body of coastal water 930) and an outer body 240 of water 970 on the other side of the seawall 100 (e.g., the open sea 940 in some examples).

[0030] The modular units 200 may be prefabricated (e.g., on land) and assembled (e.g., interconnected) in the coastal waters. As used herein, the terms modular units and prefabricated floating seawall modules (PFSM) may be used interchangeably. The modular unit 200 of the present disclosure may be used to construct one or more seawalls 100 that form the whole or a part of a variety of VLFS. In some examples, the modular unit 200 may be used to form a pier or a breakwater. In particular, the modular unit 200 may be used to construct a coastal reservoir 102.

[0031] **FIG. 2A** and **FIG. 2B** are schematic diagrams of the modular unit 200 according to an embodiment of the present disclosure. **FIG. 3A** and **FIG. 3B** are different side views to better illustrate aspects of the modular unit 200 and the seawall 100 formed by a plurality of the modular units 200.

[0032] The modular unit 200 includes a floatable structure 300 with a base 340. The modular unit 200 includes one or more membranes 400 coupled to the base 340 of the floatable structure 300.

[0033] The floatable structure 300 may be of various shapes and dimensions. In the non-limiting example illustrated, the floatable structure may be made of concrete and steel. A top surface 220 of the floatable structure 300 may be used for roads, rail transportation, or other facilities.

[0034] The floatable structure 300 may be generally described as having a first side 321 and a second side 322 that are spaced apart along a transverse direction 103 by a width ("W") (**FIG. 3A**). For the sake of brevity and to aid understanding, in use, the first side 321 may also be referred to as the coast side or the side that

faces the land 910. Correspondingly, the second side 322 may also be referred to as the sea side or the side that faces the open sea 940. The floatable structure 300 may include at least one sloping side 325 at the sea side 322 that serves as an inter-tidal zone. In some examples, the sloping side 325 may include vegetation that arise as a function of the inter-tidal zone.

[0035] The floatable structure 300 includes opposing ends 351/352, e.g., a first end 351 and a second end 352 that are spaced apart along the longitudinal direction 101 by a length ("L") (**FIG. 3B**). Shear keys 370 and corresponding shear key sockets 372 may be installed on the first end 351 and second end 352 of the floatable structure 300. Two floatable structures may be joined by mating the longitudinal exterior walls (first end 351 and second end 352), with the shear keys 370 being received by the corresponding shear key sockets 372. Sealing strips may be provided between the mating first end 351 and second end 352 to ensure a sealed joint between adjacent floatable structures 300.

[0036] Self-adjustments

[0037] The interior of the floatable structure 300 may be divided into multiple compartments 350. One or more of the compartments 350 may be configured as one or more water ballast compartments 360 defined in the floatable structure 300.

[0038] An upper compartment of the floatable structure 300 may be used mainly for utilities and ventilation. The floatable structure 300 may include one or more compartments 350 configured for use as roads or road tunnels. Selected one or more compartments 350 located on either side of the road tunnels may be configured to serve as ventilation channels or emergency evacuation channels. It is also conceived that one or more compartments 350 may be used as storage facilities. It is also conceived that one or more compartments 350 may be used for residential and/or commercial use. It is also conceived that one or more compartments 350 may be used for industrial and/or agricultural use, etc.

[0039] The floatable structure 300 includes one or more compartments that serve as one or more water ballast compartments 360 or water chambers for ballasting. For example, lower compartments may be selected for use as water chambers and equipped with water pumps 362 and drainage pipes 364.

[0040] With the tidal movement, the buoyancy of the floatable structure 300 is adjusted by taking water 970 (from the surroundings) into the water ballast compartments 360 or by discharging water out of the water ballast compartments 360. The water pumps 362 may be controllably operated to discharge water from and/or take water into selected ones of the water ballast compartments 360, keeping the elevation of the floatable structures 300 as constant as possible.

[0041] A bottom compartment of the floatable structure 300 may be configured as a one-way drainage channel 365. The drainage channel 365 may extend across the width (W) of the floatable structure 300, e.g., with an intake point at the coast side (first side 321) and a drainage gate 366 at the sea side (second side 322). When the water level in the coastal reservoir (water level of the enclosed body of coastal water) is higher than that of the sea, water from the coastal reservoir can be discharged into the sea via the drainage channel 365. When the water level of the sea is sensed to be higher than that of the coastal reservoir, the drainage channel 365 or the drainage gate 366 may be closed in response.

[0042] In alternative embodiments, at least one of the one or more compartments 350 may be configured as a water ballast compartment 360. The water ballast compartment 360 may be proximally disposed to the base 340. Optionally, the one or more compartments may be configured as one or more water ballast compartments 360. The one or more water ballast compartments 360 may be symmetrically distributed between each of the first side 321 (coast side) and the second side 322 (sea side) of the seawall 100.

[0043] In some embodiments, the water ballast compartments 360 may be equipped with one or more pumps 362, e.g., water pumps and drainage pumps, etc. The one or more pumps 362 may be coupled with a respective inlet of the one or more water ballast compartments 360 to control vertical stability and vertical movement of the floatable structure 300 by adjusting water ballast using the pumps 362.

[0044] In some embodiments, the seawall 100 may include a drainage channel 365 defining a fluid communication path between the first side 321 (coast side) and the second side 322 (sea side) of the floatable structure 300, the fluid

communication path may be extended through a width (W) of the floatable structure 300.

[0045] In some embodiments, the seawall 100 may include a plurality of sensors 600 (**FIG. 3A**). At least one of the plurality of sensors 600 may be installed at an external surface of a first side 321 of the floatable structure and at least one other of the plurality of sensors 600 may be installed at an external surface of a second side 322 of the floatable structure 300. In some embodiments, the plurality of sensors 600 may be configured to sense a water level difference between respective water levels at the first side (coast side) 321 of the floatable structure 300 and at the second side (sea side) 322 of the floatable structure 300.

[0046] In some embodiments, the seawall 100 may include a controller 620. In some embodiments, the controller 620 may be operated to be in signal communication with the one or more sensors 600 and the one or more pumps 362. In some embodiments, the controller 620 may be configured to adjust a water level in the one or more water ballast compartments 360 via controllable operation of the one or more pumps 362 in response to the water level difference sensed by the one or more sensors 600.

[0047] In some embodiments, the controller 620 may be configured to determine a change in the respective water levels sensed at the first side 321 and the second side 322 of the floatable structure 300.

[0048] In some embodiments, the controller 620 may be configured to responsively adjust the water level in the one or more water ballast compartments 360 via the controllable operation of the one or more pumps 362. In some embodiments, the sensors and the controller 620 may be configured to detect the mean water levels change, and the pumps are worked to adjust the ballast to reach a balance between external forces (e.g., from sea currents and from the counteracting water ballasting) with unchanged tension of tendon.

[0049] In some embodiments, the seawall 100 may further include a drainage gate 366 coupled with the drainage channel 365, the drainage gate 366 being switchable by the controller 620 between an opened state and a closed state. In some examples, the drainage gate 366 is configured to be switched from a closed state to an opened state when the water level at the first side 321 is higher than that

of the second side 322 of the floatable structure 300. In some examples, the drainage gate 366 is configured to be switched from an opened state to a closed state when the water level of the second side 322 is higher than that of the first side 321 to maintain the average water level difference between the first side 321 and the second side 322. For example, **FIG. 2B** illustrates a situation in which the water level is higher at the first side 321 than at the second side 322, in which case the membranes 400 may deform toward the second side 322. As needed, the drainage gate 366 may be opened (as shown in **FIG. 2B**) to mitigate excessive pressure differences. If the water level is higher at the second side 322 than at the first side 321, the flexibility and deformable membranes 400 can help to mitigate excessive pressure differences without the aid of a drainage gate on the first side. For example, the plurality of membranes may be deformable toward the sea side of the seawall if the respective water levels are higher at the coast side than at the sea side, and the same plurality of membranes may be deformable toward the coast side of the seawall if the respective water levels are higher at the sea side than at the coast side. As illustrated, further balancing can be enabled with the aid of the water ballast compartments that open to only one side (e.g., either the first side 321 or the second side 322) of the seawall 100, such that the body of water 970 in the reservoir and the open sea does not mix.

[0050] Membrane

[0051] In some embodiments, the seawall 100 may include a plurality of membranes 400, each of the plurality of membranes 400 may be a water-impermeable flexible panel having opposing edges respectively coupled to an anchoring member 190 and the base 340. In some embodiments, each of the plurality of membranes 400 may be coupled along the length of the base 340. In some examples, the membrane 400 may be selected from the anti-fouling material comprises anti-fouling material to resist the accumulation of marine organism such as algae, barnacles, and mollusks on its surface, thereby maintaining its functionality and longevity in the marine environments.

[0052] In some embodiments, the base 340 may be coupled with two of the plurality of membranes 400, selected from the plurality of membranes. In some embodiments, the two of the plurality of membranes 400 may be parallel and

spaced apart from one another to form respective water-impermeable flexible layers of a multi-layered barrier 490. In some embodiments, the base 340 may be coupled with two or more of the plurality of membranes 400, the two or more of the plurality of membranes 400 may be parallel and spaced apart from one another to form respective water-impermeable flexible layers of a multi-layered barrier 490.

[0053] In some embodiments, the multi-layered barrier 490 may include respective water-impermeable flexible layers of membranes 400 defining a column of water 970 therebetween. In some examples, the multi-layered barrier 490 includes two layers of the membranes 400 with a column 950 of water 970 between the two membranes 400. In another example, as illustrated in **FIG. 3A**, the multi-layered barrier 490 includes three membranes 400 defining two columns 950 of water 970 between two successive and spaced apart membranes 400, in which the membranes 400 are spaced apart along the transverse direction 103.

[0054] Alternatively, the seawall 100 may include anchoring members 190 with an elongate body (e.g., pipes) in which the elongate body is disposed in/on the seabed 960 to define the longitudinal direction 101. The seawall 100 will be constructed to extend along the longitudinal direction 101. Each floatable structure 300 is coupled with one or more membranes 400, in which the membranes 400 of the same floatable structure 300 are parallel to one another, with the membranes 400 being spaced apart from one another along the transverse direction 103. The transverse direction 103 is non-parallel to the longitudinal direction 101.

[0055] **FIG. 3B** shows the plurality of membranes 400 may include a contiguous sheet (made up of joined membranes 400) extending along an entirety of the seawall 100. The contiguous sheet is elastically deformable away from a flat, planar shape (e.g., as shown in **FIG. 3A**).

[0056] The one or more flexible membranes 400 are each anchored to/on the seabed 960. The one or more flexible membranes 400 may flex and/or deformed in accordance with forces applied on the membranes 400 by waves or currents in the water 970, e.g., the sea water. The membranes 400 may be elastically deformable away from a flat, planar shape. In the example of **FIG. 2B** illustrated, both membranes are shown to be similarly deformed. In actual case, the deformations may be dissimilar and result in a more complex curved surface.

[0057] In some embodiments, each of the plurality of membranes 400 may be formed of a stab-resistant material. In some embodiments, each of the plurality of membranes 400 may be formed of a reinforced composite. In some examples, the reinforced composite may be selected from the group consisting of synthetic rubber reinforced with synthetic polymers, synthetic rubber reinforced with synthetic fibre or natural rubber reinforced with metal mesh. In some preferred embodiments, the reinforced composite is neoprene rubber sheet with nylon reinforcement. The neoprene rubber sheet may be laminated with a nylon fabric layer, providing enhanced strength and durability while maintaining flexibility. In some preferred embodiments, the reinforced composite is EPDM (ethylene propylene diene monomer) rubber sheet with polyester fabric reinforcement. The EPDM rubber sheet may be combined with a polyester fabric layer, enhancing tensile strength and tear resistance while retaining flexibility. In some preferred embodiments, the reinforced composite is natural rubber sheet with metal mesh reinforcement. A natural rubber sheet embedded with a metal mesh provides exceptional puncture resistance and durability while maintaining flexibility.

[0058] In some embodiments, the anchoring member 190 may include an elongate body. In some embodiments, one of the opposing edges of each of the plurality of membranes may form a continuous sealed coupling along with the elongate body.

[0059] In some embodiments, the seawall 100 may further include one or more tension leg foundations 192, each of the one or more tension leg foundations 192 being coupled with the floatable structures 300. The tension leg foundations 192 provide tensile resistance to the floatable structures 300 to further stabilize the seawall 100, e.g., the floatable structure 300 will not exhibit rolling motion owing to the confinement of the tension leg foundations 192.

[0060] Installation

[0061] **FIG. 4A to FIG. 4C** schematically illustrate another advantageous aspect of the seawall 100. The seawall 100 may be assembled from a plurality of modular units. Each modular unit may include a floatable structure 300 that is based on a prefabricated frame structure made of concrete and steel. The modular units may be precast onshore, e.g., at a pre-casting yard on the shore, and then transported

by a barge to a designated coastal location for assembly.

[0062] At the selected location for the flexible seawall 100, the proposed method includes installing anchoring members 190 and tension leg foundations 192 are embedded into the seabed 960 (**FIG. 4A**). The anchoring members 190 and the tension leg foundations 192 will be used for anchoring the membranes 400 and the floatable structures 300 respectively.

[0063] One or more gravity piers 110 may be constructed at a given interval to serve as a horizontal support for the seawall 100.

[0064] A plurality of floatable structures 300 may be transported to the designated location using a barge. The base 340 of each floatable structure 300 may be secured to the tension leg foundations 192 using anchoring cable 194. Adjacent floatable structures 300 may be coupled by inserting the shear key 370 of one floatable structure 300 into the shear key sockets 372 of another floatable structure 300. A sealing strip on the longitudinal outer wall of the two floatable structures 300 may be used for sealing and waterproofing (**FIG. 4B**). Provision for using an additional sealing layer for the joint from the outside of the floatable structures 300 can also be made.

[0065] The floatable structure 300 only form the top section of the seawall 100. The bottom section of the seawall 100 is formed by one or more layers of membranes 400. Preferably, the bottom section of the seawall 100 is formed by two or more layers of membranes 400. Each membrane 400 may be a reinforced impermeable membrane. The top (first edge 411) of the membrane 400 is connected to the base 340 of the floatable structure 300. The bottom (second edge 412) of the membrane 400 is anchored into the seabed 960 with a required embedded depth (d) to form a complete watertight structure to completely separate the water 970 in the coastal reservoir 102 from water 970 in the open sea 940.

[0066] Referring to **FIG. 4C**, the second edge (lower edge) 412 of the membrane 400 may be inserted into the embedded anchoring member 190. The first edge (top edge) 411 of the membranes 400 (selected from waterproof multi-layer reinforced materials) are coupled to the base 340 of the respective floatable structure 300. Two contacting side edges 450 of the membranes 400 of adjacent floatable structures 300 are connected to one another to form a continuous sealed joint 452,

such that two membranes 400 form an extended contiguous water-impermeable flexible panel. The contacting side edges 450 of two membranes 400 may be joined using preinstalled adhesive strips.

[0067] Various infrastructures may be built/provided at the top surface 310 of the seawall 100, e.g., road pavements, green slopes on both sides, etc. The water pumps 362, the drainage pipes 364, sensors, and other ancillary facilities in the various compartments 350 can then be installed.

[0068] As illustrated schematically in **FIG. 5**, with the stabilizing capabilities described above, despite being a floating structure, the seawall 100 is envisioned to be sufficiently stable for use as infrastructure 800 such as but not limited to transportation infrastructures such as roads and tunnels, building infrastructures, and/or infrastructures for warehousing, distribution, and/or other commercial or industrial applications, etc.

[0069] It can be appreciated that, in order to accommodate such infrastructures and serve the purpose of a coastal reservoir, the seawall 100 may be required to be of a substantial size or what is referred to as a VLFS. According to various embodiments of the present disclosure, the proposed seawall 100 includes a controller 620 and a computer-readable memory, in which the controller 620 is configured to execute instructions stored in the computer-readable memory and execute a method 700 of stabilizing the seawall. Referring to **FIG. 6**, the method 700 includes monitoring real-time responses of at least one section of the seawall 100 in terms of a rolling balance / rolling imbalance, a horizontal balance, and a vertical balance of the seawall 100. In some embodiments, the method 700 includes monitoring real-time responses of the seawall 100 in terms of selected floatable structures 300. In some embodiments, the method 700 includes monitoring real-time responses of the seawall 100 in terms of all floatable structures 300 in a section of the seawall 100.

[0070] Based on the monitoring (measurements acquired from the sensors), the controller 620 is configured to determine whether or not the floatable structure 300 is balanced in roll or whether the floatable structure 300 is characterized by a rolling balance / rolling imbalance (e.g., step 710). If the floatable structure 300 is determined to be balanced in the roll directions, no corrective action is required.

Continuous or intermittent monitoring may continue.

[0071] If the floatable structure 300 is determined to be characterized by a rolling imbalance, the controller 620 is configured to re-balance the floatable structure 300. In this example, the re-balancing includes measuring the difference between the average water level at the reservoir side or the coast side (e.g., first side 321) and the sea side (e.g., second side 322) (e.g., step 720 of method 700).

[0072] The re-balancing may further include adjusting the water levels of the water ballast compartments at selected ones of the water ballast compartments at the reservoir side (e.g., first side 321) and/or the sea side (e.g., second side 322) (e.g., step 730) in response to the difference measured.

[0073] The roll balance may be maintained by adjusting the water ballasts at the sea side and at the reservoir side. Horizontal forces are automatically balanced by arched flexible seawall modules and gravity piers. Vertical forces are automatically balanced by tension legs and tension leg foundations.

[0074] According to various embodiments of the present disclosure, a seawall 100 includes a floatable structure 300. The floatable structure 300 includes opposing ends 351/352 and a base 340 characterized by a length (L) defined between opposing ends 351/352. The seawall 100 includes one or more water ballast compartments 360 defined in the floatable structure 300. The seawall 100 includes one or more membranes 400. Each of the one or more membranes 400 includes a water-impermeable flexible panel having a first edge 411 and a second edge 412. The first edge 411 may be coupled with the base 340 along the length (L). The second edge 412 may be anchored to a seabed 960.

[0075] In some embodiments, the seawall 100 may include a base 340 that is coupled with two or more membranes 400. The two or more of the plurality of membranes 400 may be parallel and spaced apart from one another to form respective water-impermeable flexible layers of a multi-layered barrier 490.

[0076] In some embodiments, the seawall 100 may be configured with the multi-layered barrier 490 including one or more columns 950 of water 970. Each of the one or more columns 950 of water 970 may be defined between adjacent ones of the two or more membranes 400.

[0077] In some embodiments, the seawall 100 may further include a plurality of

sensors 600. The plurality of sensors 600 may be installed at respective external surfaces of a first side 321 of the floatable structure 300 and a second side 322 of the floatable structure 300. The plurality of sensors 600 may be configured to sense a water level difference between respective water levels at the first side 321 of the floatable structure 300 and at the second side 322 of the floatable structure 300. The seawall 100 may include one or more pumps 362 coupled with a respective inlet/outlet of the one or more water ballast compartments 360. The seawall 100 may include a controller 620. The controller 620 in operation may be in signal communication with the one or more sensors 600 and the one or more pumps 362. The controller 620 may be configured to adjust a water level in the one or more water ballast compartments 360 via controllable operation of the one or more pumps 362 in response to the water level difference sensed by the one or more sensors 600.

[0078] In some embodiments, the seawall 100 may be configured with the one or more water ballast compartments 360 being symmetrically distributed at each of the first side 321 and the second side 322.

[0079] In some embodiments, the seawall 100 may further include a drainage channel 365 defining a fluid communication path between the first side 321 and the second side 322. The fluid communication path may extend through a width (W) of the floatable structure 300.

[0080] In some embodiments, the seawall 100 may further include a drainage gate 366 coupled with the drainage channel 365. The drainage gate 366 may be switchable by the controller 620 between an opened state and a closed state. The drainage gate 366 in the opened state may be configured to enable a water discharge from the first side 321 to the second side 322 via the fluid communication path.

[0081] In some embodiments, the controller 620 in operation may be configured to: determine a change in the respective water levels sensed; based on the change, determine if an adjustment in the respective water levels is required; and, via controllable operation of the one or more pumps 362, make the adjustment to the respective water levels in the one or more water ballast compartments 360.

[0082] The seawall 100 may further include an anchoring member. The

anchoring member may include an elongate body. The second edge 412 of each of the one or more membranes 400 may form a continuous sealed coupling with the anchoring member along the elongate body.

[0083] In some embodiments, the one or more membranes 400 may include a contiguous sheet extending along an entirety of the seawall 100, the contiguous sheet being elastically deformable away from a planar shape.

[0084] In some embodiments, each of the one or more membranes 400 may be formed of a stab-resistant material.

[0085] In some embodiments, each of the one or more membranes 400 may be formed of a reinforced composite.

[0086] In some embodiments, each of the floatable structure 300 may include a prefabricated frame defining one or more compartments 350. At least one of the one or more compartments 350 may be configured as the one or more water ballast compartments 360.

[0087] According to various embodiments, the seawall 100 may include a plurality of floatable structures 300, one or more water ballast compartments 360 defined in each of the plurality of floatable structures 300, an anchoring member 190, and one or more membranes 400. Each of the plurality of floatable structures 300 may have opposing ends and a base 340 characterized by a length defined between the opposing ends. The plurality of floatable structures 300 may be coupled to one another at respective ones of the opposing ends. The anchoring member may be disposed in/on a seabed. Each of the one or more membranes 400 may be a water-impermeable flexible panel having a first edge 411 and a second edge 412. The first edge 411 may be coupled with the base 340 along the first length. The second edge 412 may be anchored to the seabed by the anchoring member. Contacting side edges of respective membranes 400 of adjacent ones of the plurality of floatable structures 300 are joined to one another in a continuous sealed joint 452.

[0088] In some embodiments, the base 340 of each of the plurality of floatable structures 300 may be coupled with two or more of the membranes 400. The two or more of the plurality of membranes 400 may be parallel and spaced apart from one another to form respective water-impermeable flexible layers of a multi-layered

barrier 490.

[0089] In some embodiments, the multi-layered barrier 490 may include one or more columns 950 of water 970, each of the one or more columns 950 of water 970 being defined between adjacent ones of the two or more membranes 400.

[0090] In some embodiments, the seawall 100 may further include a plurality of sensors 600. The plurality of sensors 600 may be configured to sense a water level difference between respective water levels at a coast side / first side 321 of the seawall 100 and at a sea side / second side 322 of the seawall 100. The seawall 100 may include one or more pumps 362 coupled with a respective inlet/outlet of the one or more water ballast compartments 360. The seawall 100 may include a controller 620. The controller 620 in operation may be in signal communication with the one or more sensors 600 and the one or more pumps 362, in which the controller 620 may be configured to adjust a water level in the one or more water ballast compartments 360 via controllable operation of the one or more pumps 362 in response to the water level difference sensed by the plurality of sensors 600.

[0091] In some embodiments, the one or more water ballast compartments 360 may be symmetrically distributed at each of the coast side / first side 321 and the sea side / second side 322.

[0092] In some embodiments, the seawall 100 may further include one or more drainage channels 365 defining a respective fluid communication path between the coast side / first side 321 and the sea side / second side 322. The respective fluid communication path may extend through a width (W) of any one or more of the plurality of floatable structures 300.

[0093] In some embodiments, the seawall 100 may further include a respective drainage gate 366 coupled with each of the one or more drainage channels 365. The respective drainage gate may be switchable by the controller 620 between an opened state and a closed state, in which the respective drainage gate in the opened state may be configured to enable a water discharge from the first side 321 to the second side 322 via the fluid communication path.

[0094] In some embodiments, for any one or more of the plurality of floatable structures 300, the controller 620 in operation may be further configured to determine a change in the respective water levels sensed at the first side 321 and

the second side 322 of the one or more of the plurality of floatable structures 300; based on the change, determine if the one or more of the plurality of floatable structures 300 is exhibiting a rolling imbalance; and via controllable operation of the one or more pumps 362, responsively adjust the water level in the one or more water ballast compartments 360 of the one or more of the plurality of the floatable structures 300, e.g., to compensate for any rolling imbalance.

[0095] In some embodiments, the anchoring member 190 may include an elongate body, in which one of the opposing edges of each of the plurality of membranes 400 forms a continuous sealed coupling along with the elongate body.

[0096] In some embodiments, the seawall 100 in which each of the plurality of membranes 400 includes a contiguous sheet that is elastically deformable away from a planar shape.

[0097] In some embodiments, the plurality of membranes 400 may be deformable toward the sea side of the seawall 100 if the respective water levels are higher at the coast side than at the sea side.

[0098] In some embodiments, the plurality of membranes 400 may be deformable toward the coast side of the seawall 100 if the respective water levels are higher at the sea side than at the coast side.

[0099] In some embodiments, each of the plurality of membranes 400 may be formed of a stab-resistant material.

[00100] In some embodiments, each of the one or more membranes 400 may include an anti-fouling material.

[00101] In some embodiments, each of the plurality of membranes 400 may be formed of a reinforced composite.

[00102] In some embodiments, each of the plurality of floatable structures 300 may include a prefabricated frame defining one or more compartments 360, in which at least one of the one or more compartments 360 may be configured as the one or more water ballast compartments 360.

[00103] In some embodiments, the seawall 100 may further include one or more gravity piers 110. Each of the one or more gravity piers 110 may be coupled with one or more of the plurality of the floatable structures 300.

[00104] In some embodiments, the seawall 100 may further include one or more

tension leg foundations 192. Each of the one or more tension leg foundations 192 may be coupled with one or more of the plurality of the floatable structures 300.

[00105] In some embodiments, the seawall 100 may enclose a body of coastal waters to form a coastal reservoir 102.

[00106] In some embodiments, the sea side of the seawall 100 may include at least one sloping side 325. The at least one sloping side 325 may serve as an inter-tidal zone.

[00107] In some embodiments, the seawall 100 may include any one or more of infrastructures 800 on/in any one or more of the plurality of floatable structures 300. The any one or more infrastructures 800 may include any one or more of the following: a transportation infrastructure, a building infrastructure, and a logistics infrastructure.

[00108] All examples described herein, whether of apparatus, methods, materials, or products, are presented for the purpose of illustration and to aid understanding, and are not intended to be limiting or exhaustive. Modifications may be made by one of ordinary skill in the art without departing from the scope of the claimed invention.

CLAIMS

1. A seawall comprising:
a floatable structure, the floatable structure having opposing ends and a base characterized by a length defined between opposing ends;
one or more water ballast compartments defined in the floatable structure;
and
one or more membranes, each of the one or more membranes being a water-impermeable flexible panel having a first edge and a second edge, the first edge being coupled with the base along the length,
wherein the second edge is anchored to a seabed.
2. The seawall as recited in claim 1, wherein the base is coupled with two or more membranes, the two or more of the plurality of membranes being parallel and spaced apart from one another to form respective water-impermeable flexible layers of a multi-layered barrier.
3. The seawall as recited in claim 2, wherein the multi-layered barrier comprises one or more columns of sea water, each of the one or more columns of water being defined between adjacent ones of the two or more membranes.
4. The seawall as recited in any one of claims 1 to 3, further comprising:
a plurality of sensors, the plurality of sensors being installed at respective external surfaces of a first side of the floatable structure and a second side of the floatable structure, the plurality of sensors being configured to sense a water level difference between respective water levels at the first side of the floatable structure and at the second side of the floatable structure;
one or more pumps coupled with a respective inlet/outlet of the one or more water ballast compartments; and
a controller, the controller in operation being in signal communication with the one or more sensors and the one or more pumps,
wherein the controller is configured to adjust a water level in the one or more

water ballast compartments via controllable operation of the one or more pumps in response to the water level difference sensed by the one or more sensors.

5. The seawall as recited in claim 4, wherein the one or more water ballast compartments are symmetrically distributed at each of the first side and the second side.

6. The seawall as recited in claim 4 or claim 5, further comprising a drainage channel defining a fluid communication path between the first side and the second side, the fluid communication path extending through a width of the floatable structure.

7. The seawall as recited in claim 6, further comprising a drainage gate coupled with the drainage channel, the drainage gate being switchable by the controller between an opened state and a closed state,

wherein the drainage gate in the opened state is configured to enable a water discharge from the first side to the second side via the fluid communication path.

8. The seawall as recited in any one of claims 4 to 7, wherein in operation the controller is further configured to:

determine a change in the respective water levels sensed;

based on the change, determine if an adjustment in the respective water levels is required; and

via controllable operation of the one or more pumps, make the adjustment to the respective water levels in the one or more water ballast compartments.

9. The seawall as recited in any one of claims 1 to 8, further comprising an anchoring member, wherein the anchoring member comprises an elongate body, and wherein the second edge of each of the one or more membranes forms a continuous sealed coupling with the anchoring member along the elongate body.

10. The seawall as recited in any one of claims 1 to 9, wherein each of the one or more membranes comprises a contiguous sheet extending along an entirety of the seawall, the contiguous sheet being elastically deformable away from a planar shape.
11. The seawall as recited in any one of claims 1 to 10, wherein each of the one or more membranes is formed of a stab-resistant material.
12. The seawall as recited in any one of claims 1 to 11, wherein each of the one or more membranes is formed of a reinforced composite.
13. The seawall as recited in any one of claims 1 to 12, wherein each of the floatable structure comprises a prefabricated frame defining one or more compartments, and wherein at least one of the one or more compartments is configured as the one or more water ballast compartments.
14. A seawall comprising:
a plurality of floatable structures, each of the plurality of floatable structures having opposing ends and a base characterized by a length defined between the opposing ends, the plurality of floatable structures being coupled to one another at respective ones of the opposing ends;
one or more water ballast compartments defined in each of the plurality of floatable structures;
an anchoring member, the anchoring member being disposed in/or a seabed; and
one or more membranes, each of the one or more membranes being a water-impermeable flexible panel having a first edge and a second edge, the first edge being coupled with the base along the first length, the second edge being anchored to the seabed by the anchoring member,
wherein contacting side edges of respective membranes of adjacent ones of the plurality of floatable structures are joined to one another in a continuous sealed joint.

15. The seawall as recited in claim 14, wherein the base of each of the plurality of floatable structures is coupled with two or more of the membranes, the two or more of the plurality of membranes being parallel and spaced apart from one another to form respective water-impermeable flexible layers of a multi-layered barrier.

16. The seawall as recited in claim 15, wherein the multi-layered barrier comprises one or more columns of sea water, each of the one or more columns of sea water being defined between adjacent ones of the two or more membranes.

17. The seawall as recited in any one of claims 14 to 16, further comprising:
a plurality of sensors, the plurality of sensors being configured to sense a water level difference between respective water levels at a coast side of the seawall and at a sea side of the seawall;
one or more pumps coupled with a respective inlet/outlet of the one or more water ballast compartments; and
a controller, the controller in operation being in signal communication with the one or more sensors and the one or more pumps,
wherein the controller is configured to adjust a water level in the one or more water ballast compartments via controllable operation of the one or more pumps in response to the water level difference sensed by the plurality of sensors.

18. The seawall as recited in claim 17, wherein the one or more water ballast compartments are symmetrically distributed at each of the coast side and the sea side.

19. The seawall as recited in claim 17 or claim 18, further comprising one or more drainage channels defining a respective fluid communication path between the coast side and the sea side, the respective fluid communication path extending through a width of any one or more of the plurality of floatable structures.

20. The seawall as recited in claim 19, further comprising a respective drainage gate coupled with each of the one or more drainage channels, the respective drainage gate being switchable by the controller between an opened state and a closed state,

wherein the respective drainage gate in the opened state is configured to enable a water discharge from the first side to the second side via the fluid communication path.

21. The seawall as recited in any one of claims 17 to 20, wherein in operation the controller is further configured to:

for any one or more of the plurality of floatable structures, determine a change in the respective water levels sensed at the first side and the second side of the one or more of the plurality of floatable structures;

based on the change, determine if the one or more of the plurality of floatable structures is exhibiting a rolling imbalance; and

via controllable operation of the one or more pumps, responsively adjust the water level in the one or more water ballast compartments of the one or more of the plurality of the floatable structures.

22. The seawall as recited in any one of claims 14 to 21, wherein the anchoring member comprises an elongate body, and wherein one of the opposing edges of each of the plurality of membranes forms a continuous sealed coupling along with the elongate body.

23. The seawall as recited in any one of claims 14 to 22, wherein each of the plurality of membranes comprises a contiguous sheet that is elastically deformable away from a planar shape.

24. The seawall as recited in claim 23, wherein the plurality of membranes are deformable toward the sea side of the seawall if the respective water levels are higher at the coast side than at the sea side.

25. The seawall as recited in claim 23, wherein the plurality of membranes are deformable toward the coast side of the seawall if the respective water levels are higher at the sea side than at the coast side.

26. The seawall as recited in any one of claims 14 to 25, wherein each of the plurality of membranes is formed of a stab-resistant material.

27. The seawall as recited in any one of claims 14 to 26, wherein each of the one or more membranes comprises an anti-fouling material.

28. The seawall as recited in any one of claims 14 to 27, wherein each of the plurality of membranes is formed of a reinforced composite.

29. The seawall as recited in any one of claims 14 to 28, wherein each of the plurality of floatable structures comprises a prefabricated frame defining one or more compartments, and wherein at least one of the one or more compartments is configured as the one or more water ballast compartments.

30. The seawall as recited in any one of claims 14 to 29, further comprising one or more gravity piers, each of the one or more gravity piers being coupled with one or more of the plurality of the floatable structures.

31. The seawall as recited in any one of claims 14 to 30, further comprising one or more tension leg foundations, each of the one or more tension leg foundations being coupled with one or more of the plurality of the floatable structures.

32. The seawall as recited in any one of claims 14 to 31, wherein the seawall encloses a body of coastal waters to form a coastal reservoir.

33. The seawall as recited in any one of claims 17 to 32, wherein the sea side of the seawall comprises at least one sloping side, the at least one sloping side serving as an inter-tidal zone.

34. The seawall as recited in any one of claims 14 to 33, wherein the seawall comprises any one or more of infrastructures on/in any one or more of the plurality of floatable structures, the any one or more infrastructures being any one or more of the following: a transportation infrastructure, a building infrastructure, and a logistics infrastructure.