

MULTI-STAGE COMING OFF LOCATION TECHNOLOGY

Background

[0001] This disclosure relates generally to mobile offshore units. More particularly, but not by way of limitation, this disclosure relates to a system for extracting self-elevating vessels during a coming off location operation.

[0002] Self-elevating vessels are used in the offshore industry to perform drilling operations to access hydrocarbon reservoirs in the seabed, provide accommodation to offshore personnel, perform offshore wind farm installation, assist in performing related construction activities, etc. Self-elevating vessels can refer to, for example, jackups, liftboats, jackup barges, mobile offshore drilling units (MODUs), mobile offshore production units (MOPUs) and the like.

[0003] Generally, a self-elevating vessel comprises a hull and one or more legs extending downward from or through the hull. The hull is buoyant and adapted to float in water. The legs are designed to support the hull in an elevated state. The legs may extend through openings provided in the hull or may be attached to the sides of the hull. An elevating system may be rigidly attached to the hull to allow the legs to move vertically in relation to the hull to elevate (or lower) the hull. A self-elevating vessel has two primary states in which it operates: (i) an afloat state in which footings of all the legs are off the seabed and the entire vessel structure is supported by the buoyancy of the hull; and (ii) an elevated state in which the legs are lowered into the seabed to be firmly supported by the seabed and the hull is elevated above the waterline with a positive airgap between the hull and the waterline. When the vessel is moved in the afloat state to a desired offshore location and the state of the vessel is changed at the location from the afloat state to the elevated state, such an operation is commonly referred to as a “going on location” operation. Conversely, when the vessel is to be moved away from the offshore location and the state of the vessel is to be changed from the elevated state back to the afloat state, such an operation is commonly referred to as a “coming off location” operation.

Summary

[0004] The following summary is included in order to provide a basic understanding of some aspects and features of the claimed subject matter. This summary is not an extensive overview and as such it is not intended to particularly identify key or critical elements of the claimed subject matter or to delineate the scope of the claimed subject matter. The sole purpose of this summary is to present some concepts of the claimed subject matter in a simplified form as a prelude to the more detailed description that is presented below.

[0005] According to a first aspect of the present disclosure, there is provided a system including: a first interface configured to receive sensor output indicative of a positional displacement of a self-elevating vessel; memory; and one or more processors communicatively coupled to the memory and the first interface, wherein the one or more processors are configured to execute program instructions stored in the memory for causing the one or more processors to: obtain data of first and second sets of conditions corresponding to the self-elevating vessel, determine a first permissible operating range of the self-elevating vessel based on a first structural analysis of the self-elevating vessel under the data of the first set of conditions, the first permissible operating range corresponding to a first hull draft level of the self-elevating vessel, determine a structural utilization ratio of the self-elevating vessel based on a second structural analysis of the self-elevating vessel under the data of the first and second sets of conditions, determine it is safe to lower the self-elevating vessel from an elevated state having a positive airgap to the first hull draft level that eliminates the positive airgap as a first stage in a coming off location operation of the self-elevating vessel when the structural utilization ratio is less than a predetermined value, obtain first positional displacement data from the first interface subsequent to the one or more processors determining that it is safe to lower the self-elevating vessel to the first hull draft level, the first positional displacement data separate from the structural utilization ratio of the self-elevating vessel and corresponding to the positional displacement of the self-elevating vessel while the self-elevating vessel is at the first hull draft level, present the first positional displacement data in relation to the first permissible operating range of the self-elevating vessel, and indicate it is safe to lower the self-elevating vessel from the first hull draft level to a second, deeper, hull draft level as a second stage in the coming off location operation of the self-elevating vessel when the first positional displacement data separate from the structural utilization ratio of the self-elevating vessel indicates that the positional displacement of the self-elevating vessel while at the first hull draft level is within the first permissible operating range.

[0006] According to a second aspect of the present disclosure, there is provided a non-transitory computer readable recording medium having a computer readable program stored thereon that is executable by one or more processors to perform operations including: receiving sensor output indicative of a positional displacement of a self-elevating vessel; obtaining data of first and second sets of conditions corresponding to the self-elevating vessel; determining a first permissible operating range of the self-elevating vessel based on a first structural analysis of the self-elevating vessel under the data of the first set of conditions, the first permissible operating range corresponding to a first hull draft level of the self-elevating vessel; determining a structural utilization ratio of the self-elevating vessel based on a second structural analysis of the self-elevating vessel under the data of the first and second sets of conditions; determining it is safe to lower the self-elevating vessel from an elevated state having a positive airgap to the first hull draft level that eliminates the positive airgap as a first stage in a coming off location operation of the self-elevating vessel when the structural utilization ratio is less than a predetermined value; obtaining, subsequent to determining that it is safe to lower the self-elevating vessel to the first hull draft level, first positional displacement data separate from the structural utilization ratio of the self-elevating vessel and indicative of the positional displacement of the self-elevating vessel while the vessel is at the first hull draft level; presenting the first positional displacement data in relation to the first

permissible operating range of the self-elevating vessel; and indicating it is safe to lower the self-elevating vessel from the first hull draft level to a second, deeper, hull draft level as a second stage in the coming off location operation of the self-elevating vessel when the first positional displacement data separate from the structural utilization ratio of the self-elevating vessel indicates that the positional displacement of the self-elevating vessel while at the first hull draft level is within the first permissible operating range.

[0007] According to a third aspect of the present disclosure, there is provided a self-elevating vessel including: a hull adapted to float; a plurality of legs extending substantially perpendicular to the hull; and a multi-stage coming off location system, including: a positional displacement sensor that senses a positional displacement of the self-elevating vessel; memory; and one or more processors communicatively coupled to the memory, wherein the one or more processors are configured to execute program instructions stored in the memory for causing the one or more processors to: obtain data of first and second sets of conditions corresponding to the self-elevating vessel, determine a first permissible operating range of the self-elevating vessel based on a first structural analysis of the self-elevating vessel under the data of the first set of conditions, the first permissible operating range corresponding to a first hull draft level of the self-elevating vessel, determine a structural utilization ratio of the self-elevating vessel based on a second structural analysis of the self-elevating vessel under the data of the first and second sets of conditions, determine it is safe to lower the self-elevating vessel from an elevated state having a positive airgap to the first hull draft level that eliminates the positive airgap as a first stage in a coming off location operation of the self-elevating vessel when the structural utilization ratio is less than a predetermined value, obtain first positional displacement data from the positional displacement sensor subsequent to the one or more processors determining that it is safe to lower the self-elevating vessel to the first hull draft level, the first positional displacement data separate from the structural utilization ratio of the self-elevating vessel and corresponding to the positional displacement of the self-elevating vessel while the self-elevating vessel is at the first hull draft level, present the first positional displacement data in relation to the first permissible operating range of the self-elevating vessel, and indicate it is safe to lower the self-elevating vessel from the first hull draft level to a second, deeper, hull draft level as a second stage in the coming off location operation of the self-elevating vessel when the first positional displacement data separate from the structural utilization ratio of the self-elevating vessel indicates that the positional displacement of the self-elevating vessel while at the first hull draft level is within the first permissible operating range.

Brief Description of the Drawings

[0008] FIG. 1 shows, in profile view, a self-elevating vessel in an elevated state in accordance with one or more embodiments.

[0009] FIG. 2 shows, in profile view, a self-elevating vessel in a transition state after having commenced a coming off location operation in accordance with one or more embodiments.

[0010] FIG. 3 shows, in profile view, a self-elevating vessel in an afloat state in accordance with one or more embodiments.

[0011] FIG. 4 shows, in block diagram form, a control system in accordance with one or more embodiments.

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[0012] FIG. 5 shows, in flowchart form, operations of the control system in accordance with one or more embodiments.

[0013] FIG. 6 shows permissible operating ranges in accordance with one or more embodiments.

[0014] FIG. 7 shows a screen shot of a graphical user interface (GUI) in accordance with one or more embodiments.

Detailed Description

[0015] This disclosure pertains to an improved self-elevating vessel and systems and computer-readable media for improving operations thereof. Techniques disclosed herein look to aid personnel, and to automate, coming off location operations for self-elevating vessels. In particular, a structural analysis of the self-elevating vessel can be performed based on conditions of the self-elevating vessel (*e.g.*, site conditions where the self-elevating vessel is stationed, vessel conditions, and/or environmental conditions). Permissible operating ranges (*e.g.*, watch circles) defining maximum permissible limits of hull motion (displacement) in the water may be determined for multiple hull draft levels based on the vessel's physical limits identified by the structural analysis. A maximum utilization ratio for the self-elevating vessel under actual environmental conditions (*e.g.*, as-measured wave heights with directionality, wave spread, period, and composition information of wave energy - both wind-driven and swells) measured using onboard instrumentation may be found and used to make an initial assessment as to whether it is safe to lower the vessel into the water (*i.e.*, to begin coming off location or leg pulling operations). In finding the utilization ratio, as-measured environmental conditions may be used rather than relying on highly subjective human-observations or generic wave forecasts. Upon lowering the vessel into the water, additional onboard instrumentation may be used to track the response of the hull due to the environment and if the response is within the previously determined permissible operating ranges, leg pulling operations may be continued. As-measured hull motions at multiple hull drafts may be compared against corresponding watch circles to determine whether the as-measured conditions are within acceptable operating limits of the vessel for carrying out the coming off location operations in multiple stages. Thus, personnel can more accurately determine if the vessel's legs can safely be pulled from the seabed.

[0016] In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the disclosed concepts. As part of

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this description, some of this disclosure's drawings represent structures and devices in block diagram form in order to avoid obscuring the novel aspects of the disclosed concepts. In the interest of clarity, not all features of an actual implementation may be described. Further, as part of this description, some of this disclosure's drawings may be provided in the form of flowcharts. The boxes in any particular flowchart may be presented in a particular order. It should be understood however that the particular sequence of any given flowchart is used only to exemplify one embodiment. In other embodiments, any of the various elements depicted in the flowchart may be deleted, or the illustrated sequence of operations may be performed in a different order, or even concurrently. In addition, other embodiments may include additional steps not depicted as part of the flowchart. Moreover, the language used in this disclosure has been principally selected for readability and instructional purposes, and may not have been selected to delineate or circumscribe the inventive subject matter, resort to the claims being necessary to determine such inventive subject matter. Reference in this disclosure to "one embodiment" or to "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the disclosed subject matter, and multiple references to "one embodiment" or "an embodiment" should not be understood as necessarily all referring to the same embodiment.

[0017] It will be appreciated that in the development of any actual implementation (as in any software and/or hardware development project), numerous decisions must be made to achieve a developers' specific goals (*e.g.*, compliance with system- and business-related constraints), and that these goals may vary from one implementation to another. It will also be appreciated that such development efforts might be complex and time-consuming, but would nevertheless be a routine undertaking for those of ordinary skill in the design and implementation of display systems having the benefit of this disclosure.

[0018] FIG. 1 shows a self-elevating vessel **100** in an elevated state according to one embodiment. Self-elevating vessel **100** may be a jackup rig (as shown in FIG. 1), liftboat, jackup barge, mobile offshore drilling unit (MODU), mobile offshore production unit (MOPU), mobile offshore windfarm installation unit and the like. As shown in FIG. 1, vessel **100** includes hull **110**, one or more legs **120**, elevating systems **130**, and control system **170**. Hull **110** is buoyant and adapted to support the weight of vessel **100** including legs **120** and any onboard cargo. When vessel **100** is in the elevated state, hull **110** is raised above waterline **150** with a positive airgap between hull **110** and waterline **150**. In the elevated state, the weight of vessel

100 is supported by legs **120** that have been lowered into seabed **140**. Legs **120** may be provided with footings (*e.g.*, spudcans and the like) **160** that are adapted to penetrate into seabed **140**. Once preloaded, legs **120** can support vessel **100** by transmitting loads between vessel **100** and seabed **140**. Elevating systems **130** may be fixedly attached to hull **110** to raise and lower hull **110** relative to legs **120** so as to transition vessel **100** from an elevated state to an afloat state and vice versa. An exemplary implementation of elevating systems **130** may include a rack-and-pinion mechanism. When vessel **100** is in the elevated state, elevating systems **130** may be operated to lower hull **110** into the water until the buoyancy of hull **110** is sufficient to extract and raise legs **120**. Further, elevating systems **130** may be operated to lock legs **120** into a position relative to hull **110** once vessel **100** has completed its transition to the elevated state (or to the afloat state).

[0019] The process of transitioning vessel **100** from the elevated state to the afloat state, commonly referred to as coming off location, is illustrated in a transition state shown in FIG. 2. There is a time between when hull **110** is above waterline **150** and legs **120** support hull **110** in the elevated state (FIG. 1) and when buoyancy of hull **110** supports vessel **100** in the afloat state with legs **120** no longer in contact with seabed **140** (FIG. 3). During this transition period, the environment may cause motions of hull **110** or vessel **100** due to loads that may occur on one or more parts of vessel **100**. More specifically, cyclic wave-induced loads may cause loading of legs **120** and elevating systems **130** to oscillate about their mean values due to static and buoyancy loads and steady wind/current-induced loads. Wave loads acting on the hull **110** or vessel **100** may transmit through elevating system **130** and legs **120** to seabed **140** as internal loads and may affect one or more parts of the vessel **100**. Further, inertial loads transferred from their point of origin through elevating system **130** and legs **120** to seabed **140** may be induced by the cyclic nature of waves. These loads can damage one or more parts of vessel **100**, and thus, allowable structural limits of load the vessel **100** can bear during coming off location operations must be established.

[0020] In one embodiment, control system **170** may be utilized for determining the feasibility of a coming off location operation for vessel **100** under given conditions. In addition, in some embodiments, control system **170** may also control at least a part of the coming off location operation. Control system **170** may operate to, for example, determine if vessel **100** is within predetermined acceptable operating limits for extracting vessel **100** off location based on a utilization ratio determined for given environmental, site and vessel **100** conditions and

based on comparison of hull **110** motion data with permissible operating ranges. In one embodiment, control system **170** may be provided onboard vessel **100** to assist operating personnel in controlling operation of vessel **100** when coming off location. In one or more other embodiments, control system **170** may be partially provided onboard vessel **100** and partially on land (*e.g.*, at a service center communicatively coupled to the onboard control system **170**). Control system **170** may be coupled with onboard instrumentation (not specifically shown in FIG. **1**) to obtain environmental information and motion information like surge, sway, heave, yaw, pitch and roll of vessel **100** when vessel **100** is subject to meteorology and (physical) oceanography (metocean) conditions (*e.g.*, wind, current, wave energy). Control system **170** may also be coupled with land- and/or satellite-based instrumentation (*e.g.*, weather data from satellites). In general, control system **170** may assist operating personnel in determining whether it is safe to come off location under given conditions by predicting whether structural loads exerted on vessel **100** in a given environment are within acceptable operating limits during the transition period for coming off location.

[0021] More specifically, control system **170** may perform structural analysis and establish the permissible operating ranges for coming off location by determining actual allowable structural limits of loads the vessel **100** can bear. Based on the determined acceptable operating limits, when vessel **100** is in the elevated state as shown in FIG. **1**, control system **170** may initially output an indication to assist operating personnel in determining whether it is safe to lower vessel **100** into the water to begin a coming off location operation under given environmental, site and vessel conditions. The conditions may be actual, as-measured conditions measured using onboard instrumentation. In one embodiment, the control system **170** may first indicate it is safe to lower hull **110** to an intermediate hull draft (as shown in, for *e.g.*, FIG. **2**) that is less (or shallower) than a load-line hull draft (as shown in, for *e.g.*, FIG. **3**) of hull **110**. While hull **110** is lowered to the intermediate hull draft, the control system **170** may again use onboard instrumentation to determine real-time hull motion (*e.g.*, surge and sway motion of the hull) and compare the observed hull motion against established permissible operating ranges to determine whether the vessel's behavior is within the allowable structural limits. As used herein, and as shown in FIGS. **2-3**, the term "hull draft" refers to the distance hull **110** is submerged in water under different conditions of legs **120**. Based on this comparison, the control system **170** may further indicate it is safe to lower the hull **110** to a lower elevation or maximum hull draft to extract legs **120** from seabed **140** (*e.g.*, a load-line

hull draft of vessel **100** in the afloat state or a hull draft that is more than the load-line hull draft). Hull **110** may be lowered to a large draft (*e.g.*, more than the load-line hull draft) in order to develop sufficient excess buoyancy and leg pulling force so as to retrieve or withdraw legs **120** from seabed **140**. Also, soil stiffness at a given site from where vessel **100** is to be extracted may be layered with low stiffness near seabed **140** and to a considerable depth below, thereby causing large leg penetrations into the seabed. At such sites, larger leg-pulling forces may be required and therefore more of hull **110** may be required to be in the water. These sites may also require a longer time to get legs **120** unstuck from seabed **140**.

[0022] FIG. 4 shows a block diagram of control system **170** in accordance with one or more embodiments. As shown in FIG. 4, control system **170** includes computing device **400**, a plurality of N signal processing units (SPUs), and a plurality of N sensors. In the example illustrated in FIG. 4, the N signal processing units include SPU 1 **470A**, SPU 2 **470B**, and SPU N **470N**, and the N sensors include sensor 1 **480A**, sensor 2 **480B**, and sensor N **480N**. Sensors 1-N **480A-480N** may be coupled with computing device **400** via SPUs 1-N **470A-470N**, respectively. Alternately, plural sensors may be coupled with computing device **400** via the same signal processing unit. Computing device **400** may include processor module **410**, memory **420**, storage device **430**, input interface **440**, output interface **450**, and network interface **460**. One or more components of control system **170** may be portable. For example, all of computing device **400**, sensors 1-N **480A-480N**, and SPUs 1-N **470A-470N** may be portable and movable from vessel **100** to another vessel. Further, control system **170** may be provided on vessel **100**. Alternately, one or more components of the control system **170** may be provided on vessel **100** and other components of control system **170** may be provided at one or more locations remote from the vessel **100** (*e.g.*, a land-based remote monitoring center or as part of a cloud-based network).

[0023] Sensors 1-N **480A-480N** may include one or more of a global positioning system (GPS) sensor, wind anemometer, navigation radar, sea surface scanning and measuring devices, motion sensor, motion reference unit (MRU), or other metocean sensor. Sensors 1-N **480A-480N** may sense different conditions corresponding to vessel **100**. For example, sensors 1-N **480A-480N** may sense one or more of metocean conditions (*e.g.*, wave energy, wave spectrum, wave height, wave period, wind speed, current speed, draft, salinity, air temperature, humidity); orientation conditions (*e.g.*, directions from which wave energy – both wind-driven and swell – is coming from in a sea state relative to vessel's **100** heading); site conditions (*e.g.*,

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soil properties of seabed **140** over which vessel **100** is stationed, water depth at the location of vessel **100**, leg penetration depth indicative of how deep into seabed **140** legs **120** of vessel **100** penetrate); and vessel conditions (*e.g.*, hull draft, inclination of hull **110**, airgap between hull **110** and waterline **150**). Sensors 1-N **480A-480N** may be provided on hull **110**, legs **120**, or on footings **160**. Alternately, one or more of sensors 1-N **480A-480N** may be provided at a location distal to vessel **100** and communicatively coupled to computing device **400**. Sensors 1-N **480A-480N** may sense motion information (positional displacement) of one or more portions of the vessel **100** in response to the metocean conditions such as wind, wave and current. For example, one or more of sensors 1-N **480A-480N** may sense motions about each of the hull's six-degrees of freedom (surge, sway, heave, yaw, pitch and roll) to calculate displacement of the hull **110**. Computing device **400** may receive information from sensors 1-N **480A-480N** via a wired connection or a wireless connection. In one embodiment, sensors 1-N **480A-480N** include one or more MRUs that capture hull **110** motion data at periodic intervals and a sea surface scanning and measuring device. Data captured by the MRU may be processed and analyzed prior to being output to a user. The MRU may measure rotational velocities and translational accelerations which may be converted to hull **110** motions based on a constant of integration. The MRU may be provided onboard vessel **100** so that it is positioned at a center of floatation (COF) of vessel **100** to measure motion (*e.g.*, surge and sway) of hull **110**. Another MRU may be provided in a different part of vessel **100** to compensate for calculation of airgap performed by the sea surface scanning and measuring device (*e.g.*, point-down wave height measurement device). Sensors 1-N **480A-480N** may further include a navy grade navigation radar. Data output from the navigation radar may be processed by a corresponding signal processing unit (*i.e.*, radar processing unit) to detect objects (*e.g.*, ship) in a vicinity of vessel **100**. Further, video output from the navigation radar based on a sweep operation may be processed by the radar processing unit to identify wave energy information (*e.g.*, wave height, wave direction, wave period) that may be displayed and used during the coming off location operation. The radar may be positioned onboard vessel **100** so that a sweep angle of the radar may be at least 50°.

[0024] In one embodiment, computing device **400** may be a general purpose computer system such as a desktop, laptop, notebook or tablet computer system. Computing device **400** may also be a portable electronic device such as a Personal Digital Assistant (PDA) or a smartphone. Processor module **410**, memory **420**, storage device **430**, input interface **440**,

output interface **450**, and network interface **460** may be coupled to each other via system bus, backplane, or fabric. Processor module **410** may include one or more processing units each of which may include at least one central processing unit (CPU) and zero or more graphics processing units (GPUs); each of which in turn may include one or more processing cores. Each processing unit may be based on reduced instruction-set computer (RISC) or complex instruction set-computer (CISC) architectures or any other suitable architecture. Processor module **410** may be a single processor element, a system-on-chip, an encapsulated collection of integrated circuits (ICs), or a collection of ICs affixed to one or more substrates. Memory **420** may include one or more different types of media (typically solid-state) used by processor module **410**. For example, memory **420** may include memory cache, read-only memory (ROM), and/or random access memory (RAM). Storage device **430** may include one or more non-transitory storage mediums including, for example, magnetic disks (fixed, floppy, and removable) and tape, optical media such as CD-ROMs and digital video disks (DVDs), and semiconductor memory devices such as Electrically Programmable Read-Only Memory (EPROM), and Electrically Erasable Programmable Read-Only Memory (EEPROM). Memory **420** and storage device **430** may be used to retain media (*e.g.*, audio, image and video files), structural analysis data, mathematical models, finite element models, hydrodynamic models, vessel **100** data, site data, metocean data, hull **110** motion data, structural analysis results data, algorithms, computer program instructions or code organized into one or more modules and written in any desired computer programming language, and any other suitable data. When executed by processor module **410** such computer program code may implement one or more of the methods and actions described herein. In one embodiment, computing device **400** may further include a logging **490A** process for time-based storage of data generated by sensors 1-N **480A-480N**. Thus, information generated by sensors 1-N **480A-480N** including output GUI (screen) data representing the data generated by sensors 1-N **480A-480N** and audio/video data may be subject to time-based storage in storage device **430**. For example, metocean data (including radar video data) obtained by sensors 1-N **480A-480N** and pinion load data indicating pinion load in elevating systems **130** determined based on a power output level of a motor of elevating systems **130** when pulling legs **120** out of seabed **140** may be subject to time-based storage. The logged data may be quickly and securely accessible for subsequent analysis, reporting, informed decision-making, and calibration of models that are used in performing the structural analysis to determine acceptable operating limits of vessel **100**. For

example, logging **490A** process may be implemented using a historian data log that is compliant with the Object Linking and Embedding (OLE) for Process Control (OPC) standard.

[0025] Further, computing device **400** includes output interface **450** that may be a display (*e.g.*, a liquid crystal display (LCD) or another type of display) that allows users to view images and other output generated by computing device **400**. Output interface **450** may include a touch screen which allows users to interact with a graphical user interface (GUI) generated by one or more programs executed on computing device **400**. In addition, or in the alternative, computing device **400** may transmit images to a display of another device, for example, a separate control system on vessel **100** or a device distal to vessel **100**. Output interface **450** may include any audio, visual and/or other sensory interface that can be used by control system **170** to communicate information to the user. Computing device **400** may further include broadcast **490B** process for broadcasting, via network interface **460** data obtained from sensors 1-N **480A-480N** to multiple devices onboard vessel **100** and/or at one or more locations remote from vessel **100** (*e.g.*, devices at onshore locations or other offshore locations). For example, computing device **400** may broadcast the data so that the data is securely accessible via a network such as the Internet. Computing device **400** may also include one or more input interfaces **440** (*e.g.*, one or more of a keypad, mouse, touchpad, touchscreen, one or more switches, buttons, and the like) to allow a user to interact with computing device **400**. It may be understood that a GUI may be a type of a user interface that allows a user to interact with computing device **400** and/or control system **170** through, for example, graphical icons, visual indicators, and the like. In one embodiment, input interface **440** may receive via network interface **460** data or instructions for operating vessel **100** during the coming off location operation. For example, the input interface **440** may receive metocean data that may be used for controlling operation of vessel **100**. Alternately, or in addition, input interface **440** may also receive instructions from a remote location for operating vessel **100** during the coming off location operation based on data of sensors 1-N **480A-480N** sent to the remote location via output interface **450**. In one embodiment, logging **490A**, data display, broadcast **490B** and other functions (*e.g.*, troubleshooting) provided by computing device **400** may be implemented using respective virtual machines running simultaneously and independently on computing device **400**. In addition, computing device **400** may include network interface **460** to allow computing device **400** to interface with various other electronic devices and/or sensors 1-N **480A-480N**. Network interface **460** may include a Bluetooth interface, a local area network (LAN) or

wireless local area network (WLAN) interface, an Ethernet connection or the like. The network interface **460** may use any suitable technology (*e.g.*, wired or wireless) and protocol (*e.g.*, Transmission Control Protocol (TCP), Internet Protocol (IP), User Datagram Protocol (UDP), Internet Control Message Protocol (ICMP), Hypertext Transfer Protocol (HTTP), Post Office Protocol (POP), File Transfer Protocol (FTP), Internet Message Access Protocol (IMAP), Modbus protocol, Process Field Net protocol (PROFINET), and Process Field Bus protocol (PROFIBUS)).

[0026] Referring to FIG. 5, coming off location operation **500** illustrates actions control system **170** may take in accordance with one or more embodiments. Coming off location operation **500** begins at block **505** where control system **170** obtains data that is used in performing structural analysis of vessel **100**. The data may be obtained from one or more sources including sensors 1-N **480A-480N**, input interface **440**, memory **420**, storage device **430**, and network interface **460**. In one embodiment, the data may include one or more of the site conditions, the vessel conditions and (assumed) environmental conditions.

[0027] At block **510** the control system **170** performs a structural analysis of vessel **100** based on the data of site conditions, vessel conditions and (assumed) environmental conditions obtained at block **505**. The structural analysis may include using a quasi-static structural analysis with dynamic amplification factors to predict stress levels and hull motions when hull **110** is in the water with legs **120** either fully stuck or partially stuck during the coming off location operation. The structural analysis may account for one or more of soil properties of seabed **140** on which vessel **100** is stationed, water depth at the location of vessel **100**, leg penetration depth indicative of how deep into seabed **140** legs **120** of vessel **100** penetrate, airgap between hull **110** and waterline **150**, hull **110** draft level, amplitude and direction of dominant wave energy – wind-driven or swell, inclination of hull **110**, stiffness of elevating systems **130**, and structural capacity of legs **120**, hull **110** and the elevating systems **130**. Wave energy may be thought of as including wind-driven wave components and swell components. In one embodiment, the structural analysis may be performed using regular waves when swells are dominant in the vessel's **100** local environment. The structural analysis may be performed using random waves when wind-driven waves are dominant in the vessel's **100** local environment. Alternately, the structural analysis may be performed using combinations of swells and wind-driven waves with different directions and periods. Control system **170** may determine whether the swells are dominant or the wind-driven waves are dominant based on

data received from sensors 1-N **480A-480N**. Alternately, this information may be provided by the user.

[0028] The structural analysis may further include performing a finite element analysis based on a mathematical model of vessel **100** to determine loads acting on vessel **100** under various assumed environmental conditions (*e.g.*, wind speeds, wave energy, wave period, wave height, current, directions relative to vessel **100** from which the wind, wave and current energy are coming from) and specific site and vessel conditions (*e.g.*, soil properties of seabed **140** over which vessel **100** is stationed, water depth at the location of vessel **100**, leg penetration depth indicative of how deep into seabed **140** legs **120** of vessel **100** penetrate, airgap between hull **110** and waterline **150**). The finite element analysis may include finite elements (*e.g.*, beam elements, plate elements, and the like) that are representative of vessel's **100** entire structure. For example, while loads are being applied to the system due to the various assumed environmental conditions, the interaction of legs **120** with elevating systems **130** may be modeled when legs **120** are being pulled out of seabed **140** from fully stuck (at full penetration depth of legs **120** into seabed **140**) or partially unstuck (less than the full penetration of legs **120** into seabed **140**) positions during the coming off location operation. The structural analysis may further include performing hydrodynamic analysis of the vessel **100**. For example, a hydrodynamic model may be created to compute the forces acting on the vessel **100** under the assumed environmental conditions. In performing the structural analysis, different soil stiffness conditions and damping values corresponding to one or more parts of vessel **100** or vessel/soil system may be assumed to predict hull **110** motions and wave loads on vessel **100** inducing the hull motions. For example, during a coming off location operation, soft clay conditions of the soil where vessel **100** is positioned may require large hull **110** overdraft and leg-by-leg pull-out efforts (due to, *e.g.*, footings **160** being stuck). A site having soft clay soils with deep leg penetration and lengthy leg pulling operations presents risks associated with high pulling forces and extended exposure to the environment. Therefore, different soil stiffness models may be developed with respect to all legs **120** of vessel **100** being fully stuck or one or more legs being partially unstuck, and the structural analysis of vessel **100** may be performed based on the determined soil stiffness models. Maximum allowable structural limits of load the vessel **100** can bear may then be determined based on the analysis.

[0029] Once the conditions that produce the maximum allowable structural limits of load the vessel **100** can bear are identified, permissible wave height data may be prepared and these

limiting conditions may be used to establish permissible hull offset envelopes at various hull **110** draft levels while legs **120** are being pulled for extraction, thereby determining one or more permissible operating ranges of vessel **100** at different hull drafts and/or foundation conditions (*e.g.*, number of legs **120** fully/partially stuck/unstuck in seabed **140**) (block **515**). Thus, the permissible operating ranges of vessel **100** for coming off location may be determined based on actual allowable structural limits of load the vessel **100** can bear. That is, the permissible operating ranges for coming off location may be determined based on the structural analysis that is specific to the vessel **100**. Permissible operating ranges may also be determined based on assumed load and foundation conditions that represent the worst case condition (*e.g.*, soil stiffness and/or number of legs **120** fully/partially stuck/unstuck). Still further, the permissible operating ranges may be determined based on the vessel's **100** proximity to other infrastructure where vessel **100** is located. For example, the permissible operating ranges may be set to prevent contact between vessel **100** and any structural features of any proximal infrastructure (*e.g.*, a platform). The permissible operating range(s) determined at block **515** may be displayed on a display.

[0030] At block **520** the control system **170** may obtain given site and vessel conditions (*e.g.*, soil properties of seabed **140** on which vessel **100** is stationed, water depth at the location of vessel **100**, and/or leg penetration depth indicative of how deep into seafloor **140** legs **120** of vessel **100** penetrate) and given environmental conditions (*e.g.*, wind, current, wind-driven wave and swell energy, wind-driven wave and swell period, wind-driven wave and swell height, directions relative to vessel **100** the energy is coming from, a measure of how concentrated, or narrow-banded, the wind-driven wave and swell energy is in the vicinity of corresponding peak period) and determine a structural utilization ratio (Unity Check or "UC") based on the given site, vessel and environmental conditions. The given site and environmental conditions may be actual as-measured conditions obtained using onboard instrumentation (*e.g.*, one or more sensors **1-N 480A-480N**). In one embodiment, a maximum acceptable value for the structural utilization ratio may be 100% or 1.0 (*i.e.*, "unity"). The structural utilization ratio may indicate whether the obtained site and environmental conditions may cause the vessel **100** to exceed its acceptable operating limits.

[0031] In one embodiment, the structural analysis may be performed well before coming off location operations are begun and results thereof indicating acceptable operating limits of vessel **100** (*i.e.*, allowable structural limits of load the vessel **100** can bear) under different site

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and vessel conditions (*e.g.*, soil properties of seabed **140** on which vessel **100** is stationed, water depth at the location of vessel **100**, leg penetration depth indicative of how deep into seabed **140** legs **120** of vessel **100** penetrate, hull draft, inclination of hull **110**, stiffness of elevating systems **130**, and the structural capacity of legs **120**, hull **110** and the elevating systems **130**) and assumed environmental conditions (*e.g.*, wave energy, wave period, wave height, wind, current, directions relative to the vessel **100** the energy is coming from) may be stored as a matrix of structural responses in storage device **430**. For example, the analytical results may be stored in a lookup table in conjunction with the various site and vessel conditions and the assumed environmental conditions. At block **520** the control system **170** may then interpolate from the available stored matrix of results data to produce a condition-specific structural utilization ratio for vessel **100** under the given site, vessel and environmental conditions. Alternatively, the structural analysis at block **510** may be performed in real-time either on-board vessel **100** or with the assistance of an off-vessel system and the permissible operating ranges (block **515**) and structural utilization ratio (block **520**) may be determined based on the structural analysis performed in real-time. The environmental conditions obtained at block **520** may be as-measured or actual conditions at the site of vessel **100** obtained using onboard instrumentation (*e.g.*, one or more sensors 1-N **480A-480N**). Thus, control system **170** may determine actual wave energy using onboard instrumentation. The control system **170** may then determine a site-specific structural utilization ratio for a given combination of wind-driven waves and swells with different directions and periods. Alternately, the environmental conditions may be representative of a forecast of metocean conditions indicating what the conditions are predicted to be over a predetermined future period. The metocean conditions may be obtained from sensors 1-N **480A-480N** or from an external source. Determination of the structural utilization ratio is further illustrated in GUI **700** of FIG. 7.

[0032] At block **525** the control system **170** determines whether the structural utilization ratio is less than or equal to a predetermined value. In one embodiment, vessel **100** may be in the elevated state at blocks **505-525** with hull **110** above waterline **150** as shown in Fig. 1. Based on the determination result at block **525**, hull **110** may be lowered into the water. Thus, if control system **170** determines that the structural utilization ratio is less than or equal to a predetermined value (“YES” at block **525**), control system **170** may indicate it is safe to lower vessel **100** from the elevated state to a first hull draft level (block **535**). The first hull draft level may be an intermediate hull draft level which is less than a load-line hull draft level of hull

110. For example, the intermediate hull draft level of hull **110** may be 8-10 feet. If control system **170** determines that the calculated structural utilization ratio is greater than the predetermined value (“NO” at block **525**), control system **170** may indicate it is unsafe to continue the coming off location operation (*i.e.*, it is unsafe to lower vessel **100** into water from the elevated state. Coming off location operations are not to be carried out until environmental conditions improve) (block **530**). For example, at block **530** control system **170** may generate an alarm that may be displayed on a display to indicate that coming off location operations are not to be carried out or continued. Control system **170** at block **530** may also be programmed to automatically maintain vessel **100** at the elevated state or to begin raising vessel **100** to the elevated state without any operation by a user. In one embodiment, at block **535** control system **170** may be programmed to automatically begin lowering vessel **100** from the elevated state to the first hull draft level without any operation by a user. In another embodiment, control system **170** may simply signal the user that it is safe to lower vessel **100** into the water at block **535**.

[0033] At block **540** the control system **170** may obtain positional displacement data of hull **110** while hull **110** is at the first hull draft level. The positional displacement data may be measured by instrumentation onboard vessel **100** (*e.g.*, sensors 1-N **480A-480N**) while hull **110** is at the first hull draft level. Further, at block **540** watertight integrity of hull **110** may be checked for a predetermined period of time (*e.g.*, 30 mins), during which control system **170** may obtain the positional displacement information of hull **110** at the first hull draft level. The watertight integrity check may encompass checking if there is any damage to hull **110** that may cause hull **110** to take on water and checking for leakage in sea valves connected to hull **110**. In one embodiment, surge/sway motion values for the hull **110** may be obtained as the positional displacement data. The surge/sway motion values may be real-time as-measured values provided by sensors 1-N **480A-480N** (*e.g.*, MRU). The positional displacement data may be measured at block **540** for at least a predetermined period of time. For example, the positional displacement data may be measured for at least 10 minutes. The positional displacement data may also be measured periodically. For example, the displacement data may be measured every second.

[0034] At block **545** the obtained positional displacement data at the first hull draft level may be compared with a first permissible operating range (determined, for example, at block **515**) to determine whether the obtained positional displacement data at the first hull draft level is within a threshold defined by the first permissible operating range. By way of example, the

positional displacement data at the first hull draft level may be determined to be within a threshold defined by the first permissible operating range when hull **110** motion data are within the threshold defined by the first range. In other words, if any current hull **110** motion data are outside the threshold defined by the first range, it may be determined that the positional displacement data at the first hull draft level is not within the threshold. The positional displacement data at the first hull draft level and the first permissible operating range may be presented on a display to assist a user in the comparison. In one embodiment, the user may then make the determination regarding whether the obtained positional displacement data at the first hull draft level is within the threshold. In another embodiment, the control system **170** may make the determination regarding whether the obtained positional displacement data at the first hull draft level is within the threshold without any assistance of the user and output a result of the determination via the output interface **450**. At block **545** the comparison may be performed for a predetermined period of time (for *e.g.*, throughout the period for performing the watertight integrity check) while results of the comparison are being continuously output to the user.

[0035] If it is determined that the obtained positional displacement data at the first hull draft level is within a threshold defined by the first permissible operating range (“YES” at block **545**), control system **170** may indicate it is safe to lower vessel **100** from the first hull draft level to a second hull draft level (block **555**). The second hull draft level may be a maximum hull draft level which is equal to or more than the load-line hull draft level of hull **110**. For example, the maximum hull draft level of hull **110** may be 3-4 feet greater than the load-line hull draft level of hull **110** or, in one specific example, around 21 feet. Further, at block **555** the control system **170** may be programmed to automatically begin lowering vessel **100** from the first hull draft level to the second hull draft level upon confirming that the watertight integrity check has been completed successfully, without any operation by a user. In another embodiment, at block **555** the control system **170** may simply signal the user that it is safe to lower the vessel **100** further down to the second hull draft level. On the other hand, if it is determined that the obtained positional displacement data at the first hull draft level is not within a threshold defined by the first permissible operating range (“NO” at block **545**), control system **170** may indicate it is unsafe to continue the coming off location operation (*i.e.*, it is unsafe to lower vessel **100** from the first hull draft level to the second (deeper) hull draft level) (block **550**). At block **550**, control system **170** may further indicate vessel **100** should be raised from the first hull draft level to the elevated state having the positive airgap. In one

embodiment, at block **550** the control system **170** may be programmed to automatically begin elevating vessel **100** from the first hull draft level to a hull draft level shallower than the first hull draft level or to the elevated state without any operation by a user. In another embodiment, control system **170** may simply signal the user to jack vessel **100** up from the first hull draft level to a hull draft level shallower than the first hull draft level or to the elevated state out of the water at block **550**. If the positional displacement data exceeds the threshold defined by the first permissible operating range, it does not mean vessel **100** is being overstressed. Instead, it means that if operations move to the next stage to reach the second (deeper) hull draft level, the expectation is that the stress levels on legs **120** and/or elevating systems **130** will be higher than the allowable structural limits of load the vessel **100** can bear. In this case, the coming off location operation may not be continued.

[0036] At block **560** the control system **170** may obtain positional displacement data of hull **110** while hull **110** is at the second hull draft level. The positional displacement data may be measured by instrumentation onboard vessel **100** (e.g., sensors 1-N **480A-480N**) while hull **110** is at the second hull draft level. In one embodiment, surge/sway motion values for hull **110** may be obtained as the positional displacement data. The surge/sway motion values may be real-time as measured by sensors 1-N **480A-480N**. The positional displacement data may be measured periodically. For example, the displacement data may be measured every second.

[0037] At block **565** the obtained positional displacement data at the second hull draft level may be compared with a second permissible operating range (determined, for example, at block **515**) to determine whether the obtained positional displacement data at the second hull draft level is within a threshold defined by the second permissible operating range. By way of example, the positional displacement data at the second hull draft level may be determined to be within a threshold defined by the second permissible operating range when hull **110** motion data are within the threshold defined by the second range. In other words, if any current hull **110** motion data are outside the threshold defined by the second range, it may be determined that the positional displacement data at the second hull draft level is not within the threshold. The second permissible operating range may be different from (e.g., larger than) the first permissible operating range. In one embodiment, when it is determined that the obtained positional displacement data at the first hull draft level is within the threshold defined by the first range (“YES” at block **545**), positional displacement data while vessel **100** is being lowered from the first hull draft level to the second hull draft level may be obtained and

compared with the second permissible operating range to determine ongoing safety of the leg pulling operations. In an alternate embodiment, the positional displacement data while the vessel **100** is being lowered from the first hull draft level to the second hull draft level may be obtained and compared with a permissible operating range other than the first and second permissible operating ranges. The positional displacement data at the second hull draft level and the second permissible operating range may be displayed on a display to assist a user in the comparison. In one embodiment, the user may then make the determination regarding whether the obtained positional displacement data at the second hull draft level is within the threshold. In another embodiment, control system **170** may make the determination regarding whether the obtained positional displacement data at the second hull draft level is within the threshold without any assistance of the user and output a result of the determination via output interface **450**. At block **565**, the comparison may be performed for a predetermined period of time while results of the comparison are being continuously output to the user.

[0038] If it is determined that the obtained positional displacement data at the second hull draft level is within a threshold defined by the second permissible operating range (“YES” at block **565**), control system **170** may indicate it is safe to continue the coming off location operation (block **575**). If it is determined that the obtained positional displacement data at the second hull draft level is not within a threshold defined by the second permissible operating range (“NO” at block **565**), control system **170** may indicate it is unsafe to continue the coming off location operation (*i.e.*, it is unsafe to keep vessel **100** in the water at the second hull draft level) (block **570**). Control system **170** at block **570** may further indicate to a user to raise vessel **100** from the second hull draft level to a hull draft level shallower than the second hull draft level or to the first hull draft level or to the elevated state having a positive airgap. In one embodiment, at block **570** the control system **170** may be programmed to begin elevating vessel **100** from the second hull draft level to a hull draft level shallower than the second hull draft level or to the first hull draft level or to the elevated state automatically without any operation by a user. In this case, before elevating vessel **100**, control system **170** may also be programmed to lower any legs **120** that may have been raised from their pre-loaded position off seabed **140**. In another embodiment, at block **570** the control system **170** may simply signal the user to jack vessel **100** up to a hull draft level shallower than the second hull draft level or to the first hull draft level or completely out of water in the elevated state. In this case, before elevating vessel **100**, control system **170** at block **570** may also signal the user to lower any legs **120** that may

have been raised from their pre-loaded position off seabed **140**. Further, at block **575** the control system **170** may be programmed to continue coming off location operations of the vessel **100** automatically without any operation by a user. In this case, control system **170** at block **575** may be further programmed to begin raising legs **120** off seabed **140** automatically without any user operation. In another embodiment, at block **575** the control system **170** may simply signal the user that it is safe to continue the coming off location operations of vessel **100**. In this case, control system **170** may further signal the user to begin pulling legs **120** off seabed **140**.

[0039] FIG. **6** shows exemplary permissible operating ranges **600** (*e.g.*, as determined at block **515** of FIG. **5**) in accordance with one or more embodiments. The permissible operating ranges **600** may be displayed as watch circles for use during different stages of the coming off location operation. The watch circles may visually display the permissible operating ranges (*i.e.*, limit of displacement) for hull **110** motion (*e.g.*, surge and sway motions of hull **110**) for different hull draft conditions and/or vessel **100** foundation conditions (*e.g.*, number of legs **120** that are fully/partially stuck/unstuck). In one embodiment, as shown in FIG. **6**, the abscissa represents a sway motion of hull **110** (measured in feet) while the ordinate represents a surge motion of hull **110** (measured in feet). Two (or one or three or more) watch circles may be displayed. Watch circle **610** may correspond to a permissible operating range for positional displacement of hull **110** while at a first hull draft level and/or a first foundation condition. Watch circle **620** may correspond to a permissible operating range for positional displacement of hull **110** while at a second hull draft level and/or a second foundation condition. Thus, multiple watch circles may be provided for the same hull draft level and different foundation conditions. For example, one watch circle may be generated for use at the start of coming off location operations when all legs **120** are fully stuck and another watch circle may be generated for use when the legs **120** are no longer fully stuck.

[0040] In one embodiment, positional displacement data **630** may be displayed superimposed on the watch circles to facilitate comparison of the positional displacement data against the appropriate watch circle. Positional displacement data **630** may indicate real-time surge/sway motions of hull **110** relative to a predetermined hull position. Positional displacement data **630** may be periodically obtained from sensors 1-N **480A-480N** at a predetermined interval (*e.g.*, every second) and displayed in real-time. Further, as shown in FIG. **6**, plural positional displacement data points may be simultaneously displayed corresponding to a most recent predetermined period of time, thereby facilitating hull motion

predictions based on the displayed data points and an understanding of variations and/or trends in the motions over time. In the positional displacement data **630** shown in FIG. **6**, a largest dot may represent a current positional displacement and a smallest dot may represent a positional displacement associated with a specified time in the past. Although illustrated in FIG. **6** as watch circles, the permissible operating ranges may be represented in any reasonable way so long as comparison of the real-time as-measured hull motions with the corresponding permissible operating ranges during a coming off location operation can be facilitated.

[0041] Positional displacement data **630** shown in FIG. **6** may convey to the user how close vessel **100** is to the defined acceptable operating limit, based on the corresponding site-specific watch circles. Conventionally, personnel responsible for extraction of vessel **100** would have to use their best judgement and experience to estimate the metocean conditions and expected loads on legs **120** and elevating systems **130**. With the techniques described herein, actual hull **110** response measurements (surge/sway motions) from onboard instrumentation may be compared against the corresponding watch circle, removing most of the subjective analysis and conservatism of conventional coming off location assessments. Further, when comparing the as-measured motions at an intermediate hull draft level with a corresponding watch circle, if the as-measured motions happen to exceed the predicted values, as long as the as-measured motions do not also exceed the watch circle at maximum hull draft when all legs are fully stuck, the stress levels on vessel **100** are still below the allowable structural limits, since the intermediate watch circle is established based on the expected hull motions at a maximum hull draft level. Still further, if the as-measured hull **110** motion data at the intermediate hull draft level indicates displacement outside the intermediate watch circle, the vessel **100** can be jacked back up fairly quickly without damage to the vessel **100**. By using as-measured hull **110** motions and comparing them against corresponding permissible operating ranges, the coming off location assessment fully accounts for whether the sea state is dominated by wind-driven waves or swells and also fully accounts for soil conditions and wave spreading. Conventionally, since a single set of limiting values were used for defining the acceptable operating limits for coming off location, these limits would have to be the most conservative. However, since the allowable structural limits for coming off location vary considerably based on different conditions (*e.g.*, water depth, wave period, direction of environment, and the like) and since the present technique develops the allowable structural limits based on the different conditions,

the acceptable operating limits can be developed that allow for a greater range of conditions for which the vessel **100** can be taken off location.

[0042] FIG. 7 shows a screen shot of graphical user interface (GUI) **700** in accordance with one or more embodiments. GUI **700** may be displayed on a display in conjunction with making a decision for coming off location. GUI **700** may include one or more user interactive screens that allow for a user to interact with a program of control system **170** executing one or more of the operations described in FIG. 5. GUI **700** may indicate to a user that computing device **400** is available to receive input values **710A-740B** from a user (*e.g.*, via input interface **440**) to control GUI **700**. In one embodiment, GUI **700** may receive one or more of input values **710A-740B** from one or more sensors 1-N **480A-480N**. For example, GUI **700** may receive input values **720B-740B** as actual, as-measured values from the navigation radar. Alternately, GUI **700** may receive input values **720B-740B** as forecast values of what the conditions are predicted to be over a predetermined future period.

[0043] As illustrated, input value **710A** corresponds to water depth (*e.g.*, the depth of water from waterline **150** to seabed **140**) and input value **710B** corresponds to a leg penetration amount (*e.g.*, leg penetration depth indicative of how deep into seabed **140** legs **120** of vessel **100** are penetrated). It should be noted that input value **710B** may correspond to, for example, an input for multiple leg **120** penetration values, a single (*e.g.*, average) penetration value for all legs **120**, and/or independent inputs for one or more leg **120** penetration values, which may be of use when different legs **120** may have one or more different leg penetration values. Input values **720A-C** correspond to orientation conditions of vessel **100** and may be represented by three (3) parameters - a rig heading **720A** (*e.g.*, a compass direction in which the rig's bow or nose is pointed), a direction of wind-driven waves **720B**, and a direction of swells **720C** (*e.g.*, directions from which the wind-driven waves and swells are coming relative to the vessel's **100** heading or relative to true North). As shown in FIG. 7, input values **720A-C** may also be displayed visually. Input values **730A-C** and **740A-B** may correspond to wave energy (which may be thought of as including wind-driven wave components **730A-C** and swell components **740A-B**) and may be represented by the following parameters - significant wave height (H_s), peak spectral period (T_p), peakedness parameter (γ), maximum wave height (H_{max}), and zero-crossing period (T_z).

[0044] Input values **710A-740B** may be manually entered by the user into GUI **700**. Alternately or in addition, computing system **400** may obtain one or more of input values **710A-**

740B as actual, as-measured values from the onboard instrumentation (*e.g.*, sensors 1-N **480A-480N**) and/or storage device **430** and automatically enter them into GUI **700**. While input values **710A-740B** are illustrated in FIG. 7, it is appreciated that a fewer number or greater number of input values may be displayed in connection with GUI **700**. Additionally and/or alternately, other conditions separate from or in addition to those described above may correspond to input values **710A-740B**. Operational commands **760** and **780** may also be present in GUI **700**. Operational command **760** may correspond to an instruction to calculate UC and offset to instruct control system **170** to determine the structural utilization ratio (UC) and the one or more permissible operating ranges based on one or more of input values **710A-740B**. Operational command **780** may correspond to an instruction to control system **170** to output offset data (*e.g.*, watch circle data) to a predetermined location **790** that may be provided by the user.

[0045] Prior to commencing the coming off location operation, when the user activates operational command **760** (*e.g.*, a button to calculate UC and Offset), control system **170** may output one or more permissible operating ranges that are determined based on at least input values **710A-B**. For example, control system **170** may produce watch circles (as shown in FIG. 6) at one or more hull draft levels and/or foundation conditions (*e.g.*, number of legs **120** fully/partially stuck/unstuck in the seabed **140**) to be used while legs **120** of vessel **100** are being pulled for extraction. Further, when the user operates on operational command **760**, control system **170** may determine a maximum structural utilization ratio of vessel **100** under the conditions specified by input values **710A-740B**. Control system **170** may output the determined structural utilization ratio as output values **770A-B**. Output value **770A** may be represented as a percentage value to be compared against a maximum acceptable value (*e.g.*, 100%). In GUI **700** shown in FIG. 7, since the calculated structural utilization ratio is 41% (*i.e.*, less than or equal to the maximum acceptable value of 100%), control system **170** may output indication **770B** (*e.g.*, “OK”) indicating that it is safe to continue the coming off location operation and lower vessel **100** into the water. When the user operates operational command **780** (*e.g.*, a button to output data), a file containing data corresponding to the calculated permissible operating ranges is output to a predetermined location **790** that may be selectable by the user. For example, the file may be a Microsoft Excel® file containing coordinate pairs for generating the one or more watch circles on a display of computing device **400**. (EXCEL is a registered trademark of the Microsoft Corporation.)

[0046] In one embodiment, in order to improve the structural analysis (at block **510** of FIG. **5**) that goes into determining the permissible operating ranges and the structural utilization ratio, confirmations or deviations of observed conditions/responses may be logged to calibrate the mathematical models used in performing the structural analysis. Such calibration may result in more accurate mathematical models, thereby increasing the accuracy of the predictions on the response of vessel **100** under different conditions and the resulting permissible operating ranges. As more and more data representing actual motions for site-specific soils and environmental conditions (e.g., wind, wave, current and their individual directions relative to vessel **100** heading) is collected, the mathematical models may be refined to better predict the structural limits of vessel **100**. For example, assumed soil stiffness conditions and damping values for one or more parts of vessel **100** may be adjusted based on a comparison between hull **110** motions predicted during the structural analysis and actual hull **110** motions as-measured by the onboard instrumentation during coming off location operations. In one embodiment, one or more of the following data points may be logged for calibration of the structural analysis models: loads on elevating systems **130**, hull draft levels, hull inclinations, maximum wave height, period, direction, indication of whether the seas were wind-driven wave dominated or swell dominated, position of one or more of legs **120**, start/end of jacking, start/end of jetting, and vessel **100** displacement motions.

[0047] It is to be understood that the above description is intended to be illustrative, and not restrictive. The material has been presented to enable any person skilled in the art to make and use the disclosed subject matter as claimed and is provided in the context of particular embodiments, variations of which will be readily apparent to those skilled in the art (e.g., some of the disclosed embodiments may be used in combination with each other). Accordingly, the specific arrangement of elements shown in FIGS. **1-4**, the arrangement of steps or actions shown in FIG. **5** or the arrangement of (input/output) data shown in FIGS. **6** and **7** should not be construed as limiting the scope of the disclosed subject matter. The scope of the invention therefore should be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms “including” and “in which” are used as the plain-English equivalents of the respective terms “comprising” and “wherein.”

Claims

1. A system comprising:
 - a first interface configured to receive sensor output indicative of a positional displacement of a self-elevating vessel;
 - memory; and
 - one or more processors communicatively coupled to the memory and the first interface, wherein the one or more processors are configured to execute program instructions stored in the memory for causing the one or more processors to:
 - obtain data of first and second sets of conditions corresponding to the self-elevating vessel,
 - determine a first permissible operating range of the self-elevating vessel based on a first structural analysis of the self-elevating vessel under the data of the first set of conditions, the first permissible operating range corresponding to a first hull draft level of the self-elevating vessel,
 - determine a structural utilization ratio of the self-elevating vessel based on a second structural analysis of the self-elevating vessel under the data of the first and second sets of conditions,
 - determine it is safe to lower the self-elevating vessel from an elevated state having a positive airgap to the first hull draft level that eliminates the positive airgap as a first stage in a coming off location operation of the self-elevating vessel when the structural utilization ratio is less than a predetermined value,
 - obtain first positional displacement data from the first interface subsequent to the one or more processors determining that it is safe to lower the self-elevating vessel to the first hull draft level, the first positional displacement data separate from the structural utilization ratio of the self-elevating vessel and corresponding to the positional displacement of the self-elevating vessel while the self-elevating vessel is at the first hull draft level,
 - present the first positional displacement data in relation to the first permissible operating range of the self-elevating vessel, and
 - indicate it is safe to lower the self-elevating vessel from the first hull draft level to a second, deeper, hull draft level as a second stage in the coming off location

operation of the self-elevating vessel when the first positional displacement data separate from the structural utilization ratio of the self-elevating vessel indicates that the positional displacement of the self-elevating vessel while at the first hull draft level is within the first permissible operating range.

2. The system according to claim 1, wherein the one or more processors are further configured to obtain second positional displacement data from the first interface, the second positional displacement data corresponding to the positional displacement of the self-elevating vessel while the self-elevating vessel is at the second hull draft level or is being lowered from the first hull draft level to the second hull draft level.

3. The system according to claim 2, wherein the one or more processors are further configured to:

determine a second permissible operating range of the self-elevating vessel based on the first structural analysis of the self-elevating vessel under the data of the first set of conditions, the second permissible operating range corresponding to the second hull draft level,

present the second positional displacement data in relation to the second permissible operating range of the self-elevating vessel, and

indicate it is safe to maintain the self-elevating vessel at the second hull draft level when the second positional displacement data indicates that the positional displacement of the self-elevating vessel while at the second hull draft level is within the second permissible operating range.

4. The system according to claim 3, wherein the one or more processors are further configured to automatically maintain the self-elevating vessel at the second hull draft level when the second positional displacement data indicates that the positional displacement of the self-elevating vessel is within the second permissible operating range.

5. The system according to claim 3 or 4, wherein the one or more processors are further configured to indicate that the self-elevating vessel be raised from the second hull draft level to a

higher elevation when the second positional displacement data indicates that the positional displacement of the self-elevating vessel is not within the second permissible operating range.

6. The system according to claim 5, wherein the one or more processors are further configured to automatically raise the self-elevating vessel from the second hull draft level to the higher elevation when the second positional displacement data indicates that the positional displacement of the self-elevating vessel is not within the second permissible operating range.

7. The system according to any one of claims 1 to 6, wherein the one or more processors are further configured to automatically lower the self-elevating vessel from the elevated state having the positive airgap to the first hull draft level that eliminates the positive airgap when the structural utilization ratio is less than the predetermined value.

8. The system according to any one of claims 1 to 7, wherein the one or more processors are further configured to automatically lower the self-elevating vessel from the first hull draft level to the second hull draft level when the first positional displacement data indicates that the positional displacement of the self-elevating vessel while at the first hull draft level is within the first permissible operating range.

9. The system according to any one of claims 1 to 8, wherein the one or more processors are further configured to indicate that the self-elevating vessel be raised from the first hull draft level to a higher elevation when the first positional displacement data indicates that the positional displacement of the self-elevating vessel while at the first hull draft level is not within the first permissible operating range.

10. The system according to claim 9, wherein the one or more processors are further configured to automatically raise the self-elevating vessel from the first hull draft level to the higher elevation when the first positional displacement data indicates that the positional displacement of the self-elevating vessel while at the first hull draft level is not within the first permissible operating range.

11. The system according to any one of claims 1 to 10, wherein the first interface is configured to receive the sensor output that indicates surge and sway motion of the self-elevating vessel.
12. The system according to any one of claims 1 to 11, further comprising one or more motion reference units for determining the positional displacement of the self-elevating vessel based on a center of floatation of the vessel.
13. The system according to any one of claims 1 to 12, wherein a first one of the one or more processors is located at a land-based remote monitoring center and a second one of the one or more processors is located on-board the self-elevating vessel.
14. The system according to any one of claims 1 to 13, wherein each of the first and second sets of conditions include at least one of site conditions, vessel conditions, orientation conditions, and metocean conditions of the self-elevating vessel, wherein the site conditions include at least one of soil properties of seabed on which the self-elevating vessel is stationed, water depth where the self-elevating vessel is stationed, and an initial leg penetration depth indicative of how deep into the seabed legs of the self-elevating vessel penetrate, wherein the vessel conditions include at least one of hull draft level, hull inclination, elevating system stiffness, number of legs of the self-elevating vessel that are fully stuck in seabed, and structural capacity of one or more of the legs, hull and the elevating system of the self-elevating vessel, wherein the orientation conditions include at least one of a heading direction of the self-elevating vessel and wave energy directions, wherein the metocean conditions include at least one of wave energy spectrum, wave period, wave height, wind speed, and current speed.
15. The system according to any one of claims 1 to 14, wherein the structural analysis of the self-elevating vessel includes at least one of a finite element analysis and a hydrodynamic analysis of the self-elevating vessel.
16. The system according to any one of claims 1 to 15, wherein the one or more processors are further configured to display a first watch circle for visually representing the first permissible operating range of the self-elevating vessel to a user, wherein the one or more processors are

further configured to broadcast the first watch circle representing the first permissible operating range to a portable electronic device.

17. The system according to any one of claims 1 to 16, further comprising one or more sensors that sense as-measured orientation conditions and metocean conditions corresponding to the self-elevating vessel as the second set of conditions.

18. The system according to claim 17, wherein the system is portable.

19. A non-transitory computer readable recording medium having a computer readable program stored thereon that is executable by one or more processors to perform operations comprising:

receiving sensor output indicative of a positional displacement of a self-elevating vessel;
obtaining data of first and second sets of conditions corresponding to the self-elevating vessel;

determining a first permissible operating range of the self-elevating vessel based on a first structural analysis of the self-elevating vessel under the data of the first set of conditions, the first permissible operating range corresponding to a first hull draft level of the self-elevating vessel;

determining a structural utilization ratio of the self-elevating vessel based on a second structural analysis of the self-elevating vessel under the data of the first and second sets of conditions;

determining it is safe to lower the self-elevating vessel from an elevated state having a positive airgap to the first hull draft level that eliminates the positive airgap as a first stage in a coming off location operation of the self-elevating vessel when the structural utilization ratio is less than a predetermined value;

obtaining, subsequent to determining that it is safe to lower the self-elevating vessel to the first hull draft level, first positional displacement data separate from the structural utilization ratio of the self-elevating vessel and indicative of the positional displacement of the self-elevating vessel while the vessel is at the first hull draft level;

presenting the first positional displacement data in relation to the first permissible operating range of the self-elevating vessel; and
indicating it is safe to lower the self-elevating vessel from the first hull draft level to a second, deeper, hull draft level as a second stage in the coming off location operation of the self-elevating vessel when the first positional displacement data separate from the structural utilization ratio of the self-elevating vessel indicates that the positional displacement of the self-elevating vessel while at the first hull draft level is within the first permissible operating range.

20. A self-elevating vessel comprising:

a hull adapted to float;

a plurality of legs extending substantially perpendicular to the hull; and

a multi-stage coming off location system, comprising:

a positional displacement sensor that senses a positional displacement of the self-elevating vessel;

memory; and

one or more processors communicatively coupled to the memory, wherein the one or more processors are configured to execute program instructions stored in the memory for causing the one or more processors to:

obtain data of first and second sets of conditions corresponding to the self-elevating vessel,

determine a first permissible operating range of the self-elevating vessel based on a first structural analysis of the self-elevating vessel under the data of the first set of conditions, the first permissible operating range corresponding to a first hull draft level of the self-elevating vessel,

determine a structural utilization ratio of the self-elevating vessel based on a second structural analysis of the self-elevating vessel under the data of the first and second sets of conditions,

determine it is safe to lower the self-elevating vessel from an elevated state having a positive airgap to the first hull draft level that eliminates the positive

airgap as a first stage in a coming off location operation of the self-elevating vessel when the structural utilization ratio is less than a predetermined value, obtain first positional displacement data from the positional displacement sensor subsequent to the one or more processors determining that it is safe to lower the self-elevating vessel to the first hull draft level, the first positional displacement data separate from the structural utilization ratio of the self-elevating vessel and corresponding to the positional displacement of the self-elevating vessel while the self-elevating vessel is at the first hull draft level,

present the first positional displacement data in relation to the first permissible operating range of the self-elevating vessel, and

indicate it is safe to lower the self-elevating vessel from the first hull draft level to a second, deeper, hull draft level as a second stage in the coming off location operation of the self-elevating vessel when the first positional displacement data separate from the structural utilization ratio of the self-elevating vessel indicates that the positional displacement of the self-elevating vessel while at the first hull draft level is within the first permissible operating range.