Dec. 26, 1967 A. J. NELSON 3,359,741

DEEP WATER SUPPORT SYSTEM

Filed March 11, 1966 3 Sheets-Sheet 1

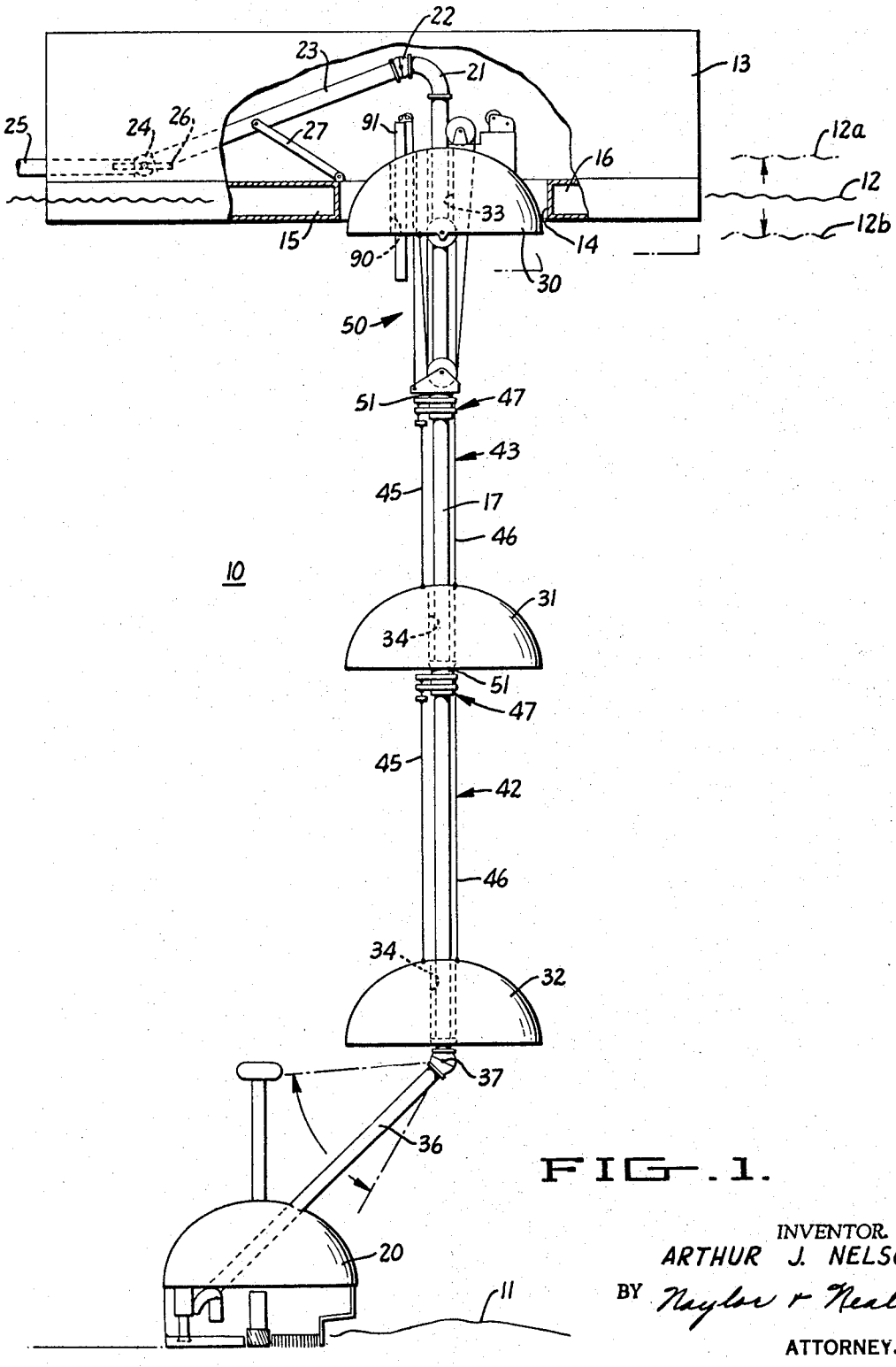


FIG. 1.

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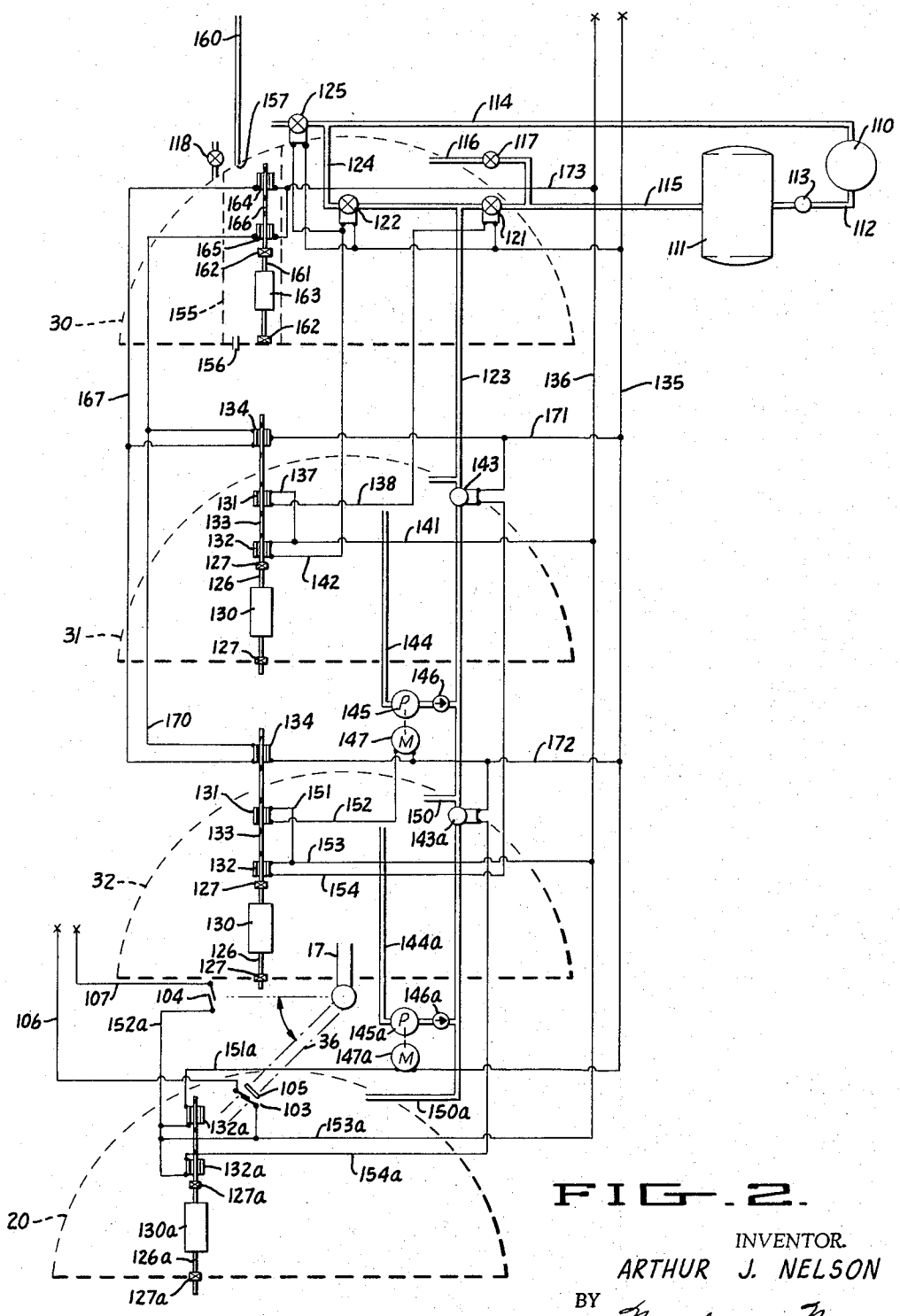


FIG. 2.

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DEEP WATER SUPPORT SYSTEM

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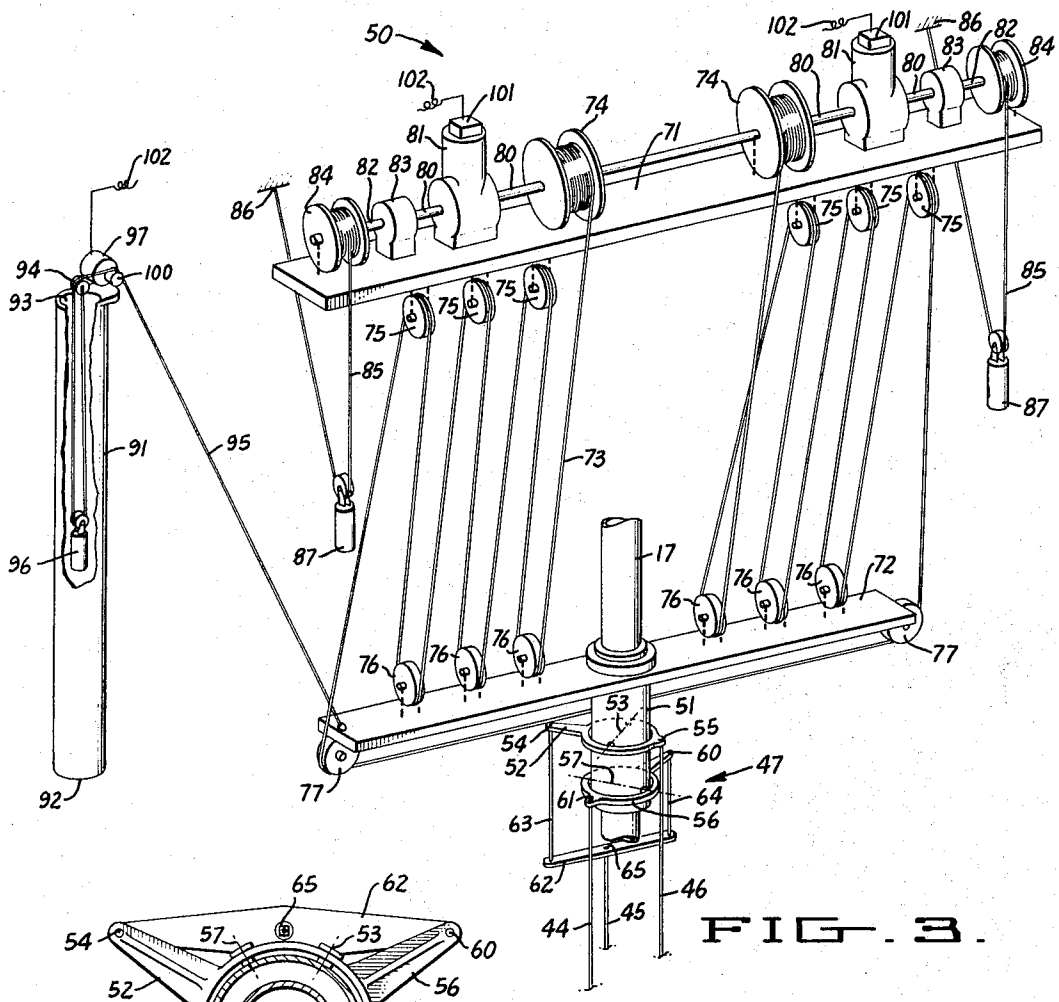


FIG. 3.

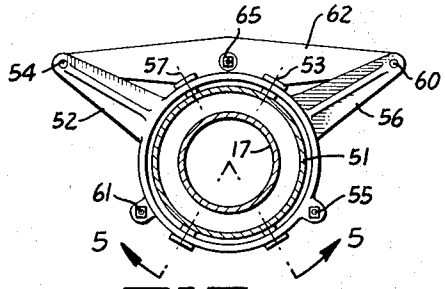


FIG. 4

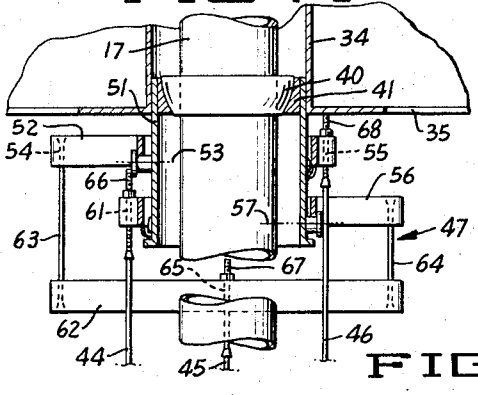


FIG. 5.

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3,359,741

DEEP WATER SUPPORT SYSTEM

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Filed Mar. 11, 1966, Ser. No. 533,627
14 Claims. (Cl. 61—46)

The present invention relates to a system for supporting objects in submerged condition in a body of liquid, and more particularly is directed to such a system adapted to buoyantly support an elongated array of objects in submerged stable condition. The invention is especially concerned with a system adapted for use at sea to automatically sustain the absolute position of the objects with respect to an established datum, irrespective of changes in the supported mass and/or adverse sea conditions.

In recent years, it has become increasingly evident that underwater working techniques must be developed to take advantage of the many resources found at sea. Prime among these resources presently known are petroleum and mineral deposits found at or beneath the floor of the sea. It is also anticipated that, as technology develops, other valuable resources will be discovered in the sea.

In order to effectively recover resources from the sea, it is necessary that practical means of supporting various objects in submerged condition be developed. Among the most immediate of these objects which it is necessary to support are conduits facilitated to convey resources from the floor of the sea to convenient collection stations. Although the support of such conduits might seem relatively simple, it has posed extreme problems due to the depths typically encountered at sea and the resultant conduit lengths necessitated. These problems are aggravated by various factors, such as: adverse sea condtions, varying density of the resource product being recovered, practical limitations on the strength and capacity of conduit and support components, and unexpected conditions resulting from failure of equipment associated with the conduits.

According to the present invention, it has been found that the foregoing problems and aggravating factors can best be treated by providing a system whereby the conduit or other elongated array desired to be supported is disposed under tension in a substantially vertical orientation. The preferred form of the system employs both intermediate submerged pontoon structure and surface stabilizing structure to effect the support. Ancillary to these structures the invention incorporates monitoring means to continuously sense varying conditions and control means associated with this monitoring means to maintain the structures in a condition effecting support at a selected elevation relative to a fixed datum, such as the ocean floor. Naturally, the invention also provides for the construction of the support system in a manner to withstand the rigors of sea service.

It is, accordingly, a principal object of the present invention to provide a support system to satisfy the needs of modern underwater technology and particularly technology relating to the recovery of resources from locations on or beneath the floor of the sea.

Another and more specific object of the invention is to provide an underwater support system capable of effecting the stable support of submerged objects under continuously varying conditions.

Yet another object of the invention is to provide an elongated underwater support system incorporating elongated support elements which are continuously maintained under relatively uniform tensile loads.

Still another and more general object of the invention

is to provide an underwater support system well adapted for supporting any of the various objects which it may be desired to dispose in submerged condition at sea. With respect to this object, it is noted that although the exemplary embodiment of the invention disclosed herein is shown cooperating with a harvesting system of the type disclosed in my co-pending application, Ser. No. 533,623, filed Mar. 11, 1966, the invention will find any number of other applications.

In its more basic aspects, the system of the present invention may be defined as a series of interrelated elements adapted to support an elongated array of objects in a substantially vertically disposed condition submerged at sea. The basic system comprises: a substantially vertically disposed elongated tension transmitting structure secured in supporting relationship to the objects of the array; at least one intermediate pontoon structure secured to the tension transmitting structure intermediate the end portions thereof to support, at least partially, the load of the array disposed therebelow; and, stabilizing structure secured to the upper end portion of the tension transmitting structure to support, at least in part, the composite load of the array unsupported by the intermediate pontoon structure. The intermediate pontoon structure comprises a chamber of selectively variable buoyancy; buoyancy monitoring means to sense the degree of buoyancy of the chamber; and, buoyancy control means to vary the buoyancy of the chamber responsive to the buoyancy monitoring means so as to maintain the intermediate pontoon structure in a condition supporting the portion of the array therebelow to a predetermined partial degree.

The foregoing and other objects and the more specific characteristics of the present invention will become more apparaent when viewed in light of the following description and accompanying drawings, wherein:

FIG. 1 is an elevational view, partially in section, illustrating the overall arrangement of an embodiment of the inventive system;

FIG. 2 is an elevational schematic view illustrating the buoyancy control circuitry employed with the arrangement of FIG. 1;

FIG. 3 is a perspective view, partially in section, illustrating the condition responsive block and tackle structure adjustably securing the stabilizing pontoon structure of the inventive system to the tension transmitting structure thereof;

FIG. 4 is a sectional plan view of the equal tensioning arrangement employed in the tension transmitting structure of the invention; and,

FIG. 5 is a sectional view taken on a plane designated by the line 5—5 of FIG. 4.

Referring now to FIG. 1, therein is shown a body of water **10** having a floor **11** and a surface **12**. The surface **12** is designated by phantom lines at **12***a* and **12***b* to illustrate deviations therein which may result from wave or tidal action. A barge **13** is buoyantly supported on the surface **12** and has extending therethrough a circular well **14**. Closed buoyant chambers **15** and **16** surround the well **14** and are isolated therefrom to provide for buoyancy of the barge.

In the exemplary embodiment illustrated in FIG. 1, the buoyancy system of the present invention is shown supporting a conduit **17** extending between the barge **13** and a harvester **20** disposed in proximate contact with the floor **11**. The harvester **20** is of the type more fully disclosed in my aforementioned co-pending application, Ser. No. 533,623. It is to be understood that the barge **13**, conduit **17** and harvester **20** are shown herein primarily to exemplify an environment in which the inventive support system may be used. From the subsequent discussion,

it will become apparent that the system is not limited to use with these specific components.

The exemplary environment illustrated in FIG. 1 also includes discharge conduit structure supported on the barge **13** and coupled in fluid communication with the conduit **17**. This structure includes coupled fluid conveying components comprising: an elbow **21**; a first ball joint **22**; a first conduit section **23**; a second ball joint **24**; and, a second conduit section **25**. Support of this structure on the barge **13** is provided by a track **26** mounting the ball joint **24** on the barge for free rectilinear movement longitudinally thereof and a rigid arm **27** pivotally secured at the respective ends thereof to the conduit section **23** and a portion of the barge hull. Through the latter arrangement, as the barge **13** is vertically displaced relative to the conduit **17**, movement with respect to the ball joint **22** is confined to a substantially vertical line. During this movement, the ball joint **24** slides rectilinearly on the track **26** and the arm **27** pivots about its connection with the barge **13** and the conduit section **23**. A more detailed disclosure of this support arrangement is found in my aforementioned co-pending application Ser. No. 533,623.

Referring now more specifically to the improved inventive support system, a stabilizing pontoon **30** is buoyantly supported at the surface **12** within the well **14** for vertical movement relative to the barge **13**. Detailed structure to provide for the guiding of the stabilizing pontoon **30** within the well **14** is also disclosed in my aforementioned co-pending application Ser. No. 533,623. From the subsequent discussion, it will be seen that the stabilizing pontoon **30**, together with submerged intermediate pontoons disposed therebelow and ancillary tension transmitting structure function to support the conduit **17** without transmitting any appreciable degree of support force to the barge **13**. In FIG. 1, two intermediate pontoons designated, respectively, by the numerals **31** and **32**, are shown disposed below the stabilizing pontoon **30**. Although only two intermediate pontoons have been shown for exemplary purposes, from the subsequent discussion it will become apparent that any number of such pontoons could be utilized without departing from the invention. The specific number of pontoons employed in a particular system would be dependent upon the support capacity of each pontoon and the cumulative load to be supported by the system.

Pontoon structure

Each of the pontoons **30**, **31**, and **32** comprises an inverted cup-shaped vessel of generally semi-spherical configuration having a closed upper surface and a bottom open to fluid communication with the body of water **10**. An open ended conduit section sealingly secured to and extending through the upper surface of each of the pontoons provides for passage of the conduit **17** therethrough. In the stabilizing pontoon **30**, the conduit section is designated by the numeral **33** and in the intermediate pontoons **31** and **32**, which are identical to each other, the conduit sections are designated by the numerals **34**. The lower support arrangement for these conduit sections is exemplified by the illustration of one of the sections **34** in FIG. 5, wherein it is shown secured to spider-like structure **35** extending across the lower portion of the pontoon. The spider-like structure **35** does not interfere materially with the open bottomed characteristic of the pontoons.

Through the aforedescribed pontoon structure, the stabilizing pontoon **30** and each of the intermediate pontoons are provided with a vessel of selectively variable buoyancy. Specifically, by varying the amount of air, or other gas, contained in the open bottomed pontoons, the buoyancy therefore may be selectively varied. Variance of each pontoon is effected, as will subsequently become apparent, by structure providing for the selective charging and discharging of gas from the pontoons.

At this point it is noted that the harvester **20** incorporates open bottomed pontoon structure similar in operation to that of the pontoons **30**, **31** and **32**. Although the pontoon structure of the harvester is schematically shown herein for the purpose of exemplification, it is to be understood that the specifics of this harvester form part of the subject matter of my aforementioned co-pending application Ser. No. 533,623. Attention is directed to the fact, however, that the harvester **20** is coupled to the conduit **17** by a swingable conduit section **36** mounted for swinging movement by a fluid communicating ball joint **37**. From the susbequent discussion, it will be seen that swinging of the conduit section **36** may be used, in part, to control the operation of the inventive support system.

The intermediate pontoons **31** and **32** are each secured in supporting relationship to the conduit **17** through the arrangement illustrated in FIG. 5. This arrangement comprises a frusto-spherical collar **40** fixed to and extending radially from the conduit **17** and a mating annular frusto-spherical socket member **41** fixed to the conduit sections of each of the pontoons. The support thus provided facilitates a degree of flexibility between the conduits **17** and the intermediate pontoons, since the collars **40** and members **41** may move universally relative to each other.

From the following discussion, it will be seen that the above described support connections between the intermediate pontoons and the conduit **17** function to secure the tension transmitting structure in supporting relationship to the conduit **17**. The manner in which the stabilizing pontoon **30** is secured in supporting relationship to the conduit **17** will also be developed in the subsequent discussion.

Tension transmitting structure

The tension transmitting structure in the illustrated embodiment comprises cable segments **42** and **43** secured, respectively, between the intermediate pontoons **31** and **32** and the stabilizing pontoon **30** and intermediate pontoon **31**. Each of the segments **42** and **43** is comprised of similar elements and, for the sake of simplicity, corresponding elements in each segment will be designated by like numerals. The segments **42** and **43** each comprise: three cables **44**, **45**, and **46**; and, a tension equalizing device **47** secured to the uppermost ends of the cables (see FIGS. 3, 4, and 5). The cables of the segment **42** are secured in tension transmitting relationship by connection of the lowermost ends thereof to the pontoon **32** and connection of the equalizing device **47** at the uppermost end thereof to the pontoon **31**. The cables of the segment **43** are secured in tension transmitting relationship by connection of the lowermost ends thereof to the pontoon **31** and connection of the equalizing device **47** at the uppermost end thereof to the stabilizing pontoon **30** through a crane mechanism **50**. Connection of the equalizing device **47** to the pontoon **31** and crane mechanism **50**, respectively, is similarly effected through sleeves **51** fixed to these elements in loose coaxial relationship around the conduit **17**.

Each of the equalizing devices **47** comprises: a first substantially horizontally disposed beam **52** pivotally mounted on the sleeve **51** for movement about a first axis **53** extending substantially normal to and through the longitudinal centerline of the conduit **17**, said first beam having cable connectors **54** and **55** on the end portions thereof spaced, respectively, from the first axis by distances in a two to one ratio relative to each other; a second substantially horizontally disposed beam **56** pivotally mounted on the sleeve **51** for movement about a second axis **57** extending substantially normal to and through the longitudinal centerline of the conduit **17** in vertically spaced relationship to the first axis **53**, said second beam having cable connectors **60** and **61** on the end portions thereof spaced, respectively, from the axis **57** in a two to one ratio relative to each other; a third substantially horizontally disposed beam **62** freely suspended by connection of the end portions thereof, respectively, with the connectors **54** and **60** by cables **63** and **64**, said third beam having a cable connector **65** midway between the con-

nected end portions thereof; and, bolts **66**, **67**, and **68** fixedly secured to the cables **44**, **45**, and **46**, respectively, and adjustably received in the cable connectors **61**, **65**, and **55**, respectively. The cable connectors on the respective beams comprise openings extending therethrough. Cables **63** and **64** are fixed directly to these openings, whereas cables **44**, **45**, and **46** are adjustably secured thereto through the aforedescribed bolts **66**, **67**, and **68**, respectively, and nuts cooperating therewith (see FIG. 5). The adjustable securing of the latter cables is provided to facilitate installation and to compensate for elastic stretch which may take place in the cables **44**, **45**, and **46**.

Through the geometric interrelationship of the equalizer device components, equal tension is continuously maintained in the cables **44**, **45**, and **46**. Furthermore, since these cables are symmetrically positioned at equal angularly spaced locations around the conduit **17** (see FIG. 4), imbalance of support for the conduit is avoided. To illustrate the operation of the equalizing device, it is noted that with equal weights, designated as *w* for convenience, applied to each of the cables **45**, **46**, and **47**, loads will be transmitted through the following equalizer elements in the indicated units of *w*.

63—½*w*
64—½*w*
53—1½*w*
57—1½*w*

Crane mechanism

The crane mechanism **50** basically comprises a head block support **71** fixedly mounted on the stabilizing pontoon **30**; a tail block support **72** fixedly secured to the sleeve **51** of the equalizing device secured to cable segment **43**; and, a continuous cable **73** reeved around pulleys **75** and **76** on the respective head and tail block supports to haul drums **74** mounted on the stabilizing pontoon **30** in fixed relationship with respect to the head block **71**. From FIG. 3, it will be seen that the crane mechanism comprises a balanced block and tackle system symmetrically disposed on either side of the conduit **17**. Since the block and tackle elements to either side of the conduit **17**, such as the haul drums **74**, correspond identically in structure and operation, like numerals will be used for designation of corresponding elements. It is noted that in the diagrammatic representation of FIG. 3, the haul drums **74** and associated drive train structures cooperating therewith appear mounted on the head block support **71** for purposes of diagrammatic illustration. This illustration technique has been employed for simplification purposes, since the head block support **71** and the haul drums **74** and associated drive train structure are all fixedly mounted on the stabilizing pontoon **30**. From FIG. 1, however, it can be seen that the haul drum and its associated drive structure are actually elevated on the stabilizing pontoon relative to the head block support.

From the haul drums **74**, the continuous cable **73** is directed first around opposed aligned sheaves **75** and **76**, respectively, on the head block and tail block supports and then around equalizing sheaves **77** mounted beneath the tail block support. The latter sheaves provide for balance continuity between the block and tackle segments to either side of the conduit **17**. The drive train structure for the haul drums **74** comprises: a common drive shaft **80** keyed to the drums; a pair of motors **81** drivingly engaged with the shaft **80** through hydraulic clutch and gear box devices (the latter devices are not illustrated); shafts **82** mounted to either end of the shaft **80** in axial alignment therewith; selectively operable clutches **83** interposed between the ends of the shaft **80** and the shafts **82** to establish driving interengagement therebetween; and, counterbalance drums **84** keyed to the shafts **82**. The drums **84** each have connected thereto and reeved therearound a counterbalance cable **85** extending to a fixed connection **86** with the stabilizing pontoon **30**, which cable has supported intermediate the ends thereof a counterbalance weight **87**. The counterbalance cables **85** are reeved around the counterbalance drums cooperating therewith in a direction opposite to that at which the cable **73** is reeved around the haul drums **74**. Thus, when the clutches **83** are engaged, the counterweights **87** function to balance the load transmitted to the haul drums **74** by the cable **73**.

In the preferred form, the counterweights **87** each have a weight equal to twice the minimum support stress on the cable **73**. Thus, since half of the counterbalance weight is transmitted to the counterbalance drums **84**, this weight maintains the drive train assembly statically balanced when the cable **73** is in the condition of minimum support stress. As a result, the crane motors **81** need only provide the energy necessary to overcome stresses in the cable **73** from additional supported load, acceleration, and frictional resistance in the various crane mechanism members.

In operation, the crane motors **81** continuously run to support any residual load applied to the cable **73** in excess of that balanced by the weights **87**. Naturally, during this operation, the clutches **83** are engaged to couple the shafts **82** in driving engagement with the shaft **80**. The hydraulic couplings incorporated into the motors **81** provide for the continuous running of the motors, even when it is not desired to support residual load therethrough or haul in on the cable **73**. This arrangement has the advantage that the motors are always ready for instant use and control thereof may be readily effected through the hydraulic clutches cooperating therewith. The control system for the hydraulic clutches will be developed in the subsequent discussion.

Crane control system

The support system of the present invention, as will become more apparent in the following discussion, is designed so that each intermediate pontoon **31** will support slightly less than the load disposed therebelow. As a result, the composite load unsupported by the intermediate pontoons is transmitted to the stabilizing pontoon **30**. This interrelationship of load support is deliberately maintained so that the cable segments **42** and **43** and the crane mechanism **50** are continuously held under tension. As a result of this interrelationship, however, to maintain the conduit **17** at a fixed elevation relative to the floor **11**, it is necessary to provide a crane control system to accommodate elevational variances in both the floor **11** and the surface **12**. It is to this system that the present control system applies.

Control of the crane responsive to variances in the surface **12** is accomplished through submergence monitoring structure mounted on the stabilizing pontoon **30** and a control mechanism coupled between this structure and the crane mechanism **50** to provide for operation of the crane mechanism responsive to the condition of the submergence monitoring structure. The submergence monitoring structure comprises: an open ended well **90** sealingly secured to and extending vertically through the stabilizing pontoon **30**; a cylindrical float **91** slidably received within the well **90** and having a closed lower end **92** and an open upper end **93**; a sheave **94** mounted on the float **91** above the open upper end **93**; a cable **95** trained over the sheave **94** and secured at one end to the tail block support **72** and at the other end to the upper end of the float **91**; and, a weight **96** sheave supported on the cable **95** within the float **91**. Through this arrangement, the float **91** is free to float on the surface **12** irrespective of the submerged condition of the stabilizing pontoon **31**. Submergence monitoring is continuously effected through the cable **95**, since this cable is drawn into and out of the float **91** as the elevation of the tail block support **72** varies relative to the float.

The control mechanism associated with the aforedescribed submergence monitoring structure comprises: a

selsyn transmitter mounted on the float 91 and having a drive sheave 100 in reeved engagement with the cable 95; selsyn receivers 101 mounted on each of the motors 81 in controlling association with the hydraulic clutches incorporated thereinto to effect bypassing of the clutch fluid and resultant clutch disengagement upon the receipt of a signal by the receivers 101 from the transmitter 97; and, conventional control circuitry 102 (schematically illustrated in FIG. 3) controllably coupling the transmitter 97 and the receivers 101. The sprocket 100 is coupled in driving relationship to the selsyn transmitter 97 through a ratchet clutching mechanism (not illustrated) which provides for activation of the transmitter only upon payout of the cable 95 from the float 91. The latter occurrence results whenever the stabilizing pontoon 30 is raised relative to the tail block support 72 in response to tidal or wave action. Upon this occurrence, the selsyn transmitter 97 activates the receivers 101 to bypass clutch fluid in the hydraulic clutches incorporated into the motors 81. The latter operation, in turn, permits the load on the tail block support 72 to payout the cable 73 from the haul drums 74. Thus, the stabilizing pontoon is permitted to be raised with wave or tidal action while the submerged apparatus secured to the tail block support 72 is held steady. Naturally, due to the one way action of the transmitter 97, as wave or tidal action lowers the stabilizing pontoon relative to the tail block support 72, the motors 81 drive the haul drums 74 to take up the cable 73.

Control of the crane mechanism 50 responsive to variances in the floor 11 is effected through means of position monitoring structure adapted to sense variances in vertical displacement between the harvester 20 and the lower end of the conduit 17; and, position control means associating this position monitoring structure with the crane mechanism. The position monitoring structure is schematically represented in FIG. 2 and simply comprises a pair of normally opened vane operated magnetic switches 103 and 104 mounted on the harvester 20 and a vane operator 105 for these switches mounted on the swingable conduit section 36. Through this arrangement, raising of the conduit 17 relative to the harvester 20 functions to close the switch 103. Similarly, lowering of the conduit 17 relative to the harvester 20 functions to close the switch 104. Naturally, as can be seen from FIG. 2, the switches 103 and 104 are spaced apart sufficiently that limited movement of the conduit 17 relative to the harvester 20, and resultant swinging of the conduit section 36, may take place without closing either of the switches.

The control mechanism associating the switches 103 and 104 with the crane mechanism 50 comprises circuitry, 106 and 107, respectively, coupling the switches in controlling relationship with the hydraulic couplings of the motors 81. Although this circuitry is only shown partially in FIG. 3, it is to be understood that it may take any of the forms well known to those skilled in the electrical art. The circuitry is arranged so that closing of the switches 103 and 104, respectively, functions alternatively to either pay out or haul in the cable 73. Haul in is effected by charging the hydraulic couplings with fluid, while payout is effected by bypassing fluid from the hydraulic couplings.

As a result of the position monitoring arrangement provided by the switches 103 and 104, the crane mechanism 50 is operated to maintain the conduit 17 within predetermined distances from the floor 11. Thus, it may be said that the support system maintains the conduit at a fixed elevation relative to the datum established by the floor level.

Buoyancy control structure

From the foregoing description of the stabilizing pontoon 30 and the intermediate pontoons 31 and 32, it was seen that these pontoons each comprise open bottomed vessels capable of entrapping a gaseous medium, such as air, therein. Although the details of the harvester 20 are in part the subject of applicant's aforementioned co-pending application Ser. No. 533,623, it is noted that the harvester also incorporates an open bottomed vessel capable of entrapping a gaseous medium therein. The latter characteristic is not, however, intended to form a part of the present invention.

The buoyancy control system of the present invention operates by selectively varying the volume of gaseous medium, namely air, in the exemplary embodiment illustrated, entrapped in each of the pontoons 30, 31 and 32. The main source of air in the embodiment diagrammatically illustrated in FIG. 2 comprises a compressor 110 having the discharge thereof coupled in fluid communication with a storage tank 111 by a conduit 112. The latter arrangement is conventional in that it includes a check valve 113 interposed in the conduit 112 to prevent the passage of air from the tank 111 to the compressor 110 and a pressure control valve (not illustrated) incorporated into the storage tank 111 to effect control of the compressor 110. The compressor 110 and tank 111 are connected in fluid communication with discharging and charging conduits for the pontoons through means of conduits 114 and 115, respectively. The latter conduit has a branch 116 leading to fluid communication with the interior of the stabilizing pontoon 30 through a manually controlled charging valve 117. It is through the valve 117 and a similar manually controlled discharging valve 118 coupled in fluid communication with the pontoon 30 that the volume of air trapped in the vessel of the pontoon is controlled. This control is effected to maintain the pontoon at a predetermined degree of buoyancy under a specific load.

Alternatively operable electrically controlled valves 121 and 122 are interposed in the conduit 115 and provide, respectively, through a conduit 123 for the charging of air into and the discharging of air from the intermediate pontoon 31. Specifically, when the valve 121 is opened, air is charged into the pontoon 31 from the tank 111. Similarly, when the valve 122 is opened, air is discharged therethrough to a conduit 124 leading to the conduit 114. The latter conduit has disposed therein downstream from the connection of the conduit 124 in fluid communication with the atmosphere an electrically operated valve 125 wired to operate opposite the valve 122. Through this arrangement, air is provided to the compressor 110 either from the conduit 124 or from atmosphere and compressed air is recirculated to increase efficiency of the overall system.

The charging and discharging of air from each of the intermediate pontoons is effected through means of buoyancy monitoring structure for each of the pontoons and buoyancy control means operated responsive to the conditions sensed by the monitoring structure. Since the buoyancy monitoring structure for each intermediate pontoon corresponds, like numerals will be used to designate corresponding elements in each intermediate pontoon. Referring now to FIG. 2, the structure in each of the intermediate pontoons is shown therein as comprising: a rod 126 received for free axial movement between a pair of bearings 127; a float 130 fixed to the rod 126 between the bearings 127; a pair of magnetically operated switches 131 and 132 received loosely around the rod 126 in vertically spaced relationship; a switch actuating blade 133 fixed to the shaft 126 intermediate the switches 131 and 132; and, a solenoid coil 134 loosely received around the shaft 126. Although the solenoid coil 134 does not perform a part of the monitoring function, it is so structurally related to the monitoring structure that its mention at this time seems appropriate. It is to be understood that, with the exception of the shaft 126 and the elements fixed thereto, the various components of the monitoring structure and the solenoid 134 are fixedly mounted with-

in and on the intermediate pontoons with electrical apparatus above liquid level.

Since the buoyancy control means cooperating with the uppermost intermediate pontoon **31** differs from that of the lower intermediate pontoon **32**, the structure and operation of these means will be described separately. It is here pointed out, however, that although only one lower intermediate pontoon has been shown beneath the uppermost intermediate pontoon, any number of lower intermediate pontoons could be utilized without departing from the spirit of the invention. In the event that more lower intermediate pontoons are utilized, the interrelationship of buoyancy monitoring structure and buoyancy control means would correspond identically to that between the uppermost intermediate pontoon **31** and the lower intermediate pontoon **32**.

The buoyancy control means for each of the intermediate pontoons is electrically operated through means of a pair of main leads **135** and **136**. These leads extend to an electrical power supply typically supported either on the stabilizing pontoon **30** or the barge **13**. Reference is made to FIG. 2 for a schematic illustration of the leads **135** and **136** and the various circuitry cooperating therewith.

Referring now to the buoyancy control means for the intermediate pontoon **31**, this comprises: the valves **121** and **122**; electrical leads **137** and **138** controllably connecting the switch **131** to the valve **121**; and, electrical leads **141** and **142** controllably connecting the switch **132** to the valve **122**. With this arrangement, when the water level in the intermediate pontoon **31** raises the float **130** to a position wherein the blade **133** closes the switch **131**, the valve **121** is opened, thus admitting air into the vessel of the intermediate pontoon **31** and lowering the water level therein. Similarly, when the water level in the intermediate pontoon **31** permits the float **130** to drop to a position wherein the blade **130** closes the switch **132**, the valve **122** is opened, thus venting or discharging air from the vessel of the intermediate pontoon **31** and raising the water level therein. It can thus be seen that the water level within the pontoon **31**, and the resultant buoyancy thereof, is maintained within predetermined limits. The exact positioning of these limits can readily be adjusted by select positioning of the float **130**.

Referring now to the buoyancy control means for the lower intermediate pontoon **32**, this comprises: an electrically operable valve **143** interposed in the conduit **123** beneath the opening thereof into the intermediate pontoon **31**; a conduit **144** extending in fluid communication between the interior of the intermediate pontoon **31** and the conduit **123**; a compressor **145** and check valve **146** interposed in the conduit **144** to provide one way flow therethrough to the conduit **123**; a submersible electric motor **147** coupled in driving relationship with the compressor **145**; a conduit section **150** establishing fluid communication between the conduit **123** and the interior of the pontoon **32**; and, electrical circuitry controllably connected between the switches **131** and **132**, respectively, of the pontoon **32** and the motor **147** and valve **143**. The latter circuitry comprises electrical leads **151** and **152** establishing electrical connection between the switch **131** and the motor **147** and electrical leads **153** and **154** establishing electrical connection between the switch **132** and the valve **143**. With this arrangement, when the water level in the pontoon **32** raises the float **130** to a position closing the switch **131**, the compressor **145** is activated, thus pumping air from the pontoon **31** into the pontoon **32** and increasing the buoyancy of the latter pontoon. Similarly, when the level of water in the pontoon **32** permits the float **130** to lower to a position wherein the blade **133** closes the switch **132**, the valve **143** is opened, thus permitting air to discharge or vent from the pontoon **32** into the pontoon **31**. As a result of this arrangement, the buoyancy of the pontoon **32** is maintained within predetermined limits similarly to that of the pontoon **31**.

The foregoing charging and discharging arrangement for the lower intermediate pontoon **32** has the advantage that air introduced into the lower intermediate pontoon is compressed in stages. Specifically, the air is first compressed for introduction into the intermediate pontoon **31** by the compressor **110** and then compressed for introduduction into the pontoon **32** by the compressor **145**. As a result, the capacity required of each compressor is maintained within reasonable limits. It is to be understood that if additional lower intermediate pontoons are employed, the same stepwise compression arrangement existing between the pontoons **31** and **32** would be utilized. In such an expanded arrangement, it is preferable to provide each successively lower compressor with slightly less capacity, thus assuring that the lower pontoon will not charge so rapidly as to impart compressive forces to the load being supported.

It is here again noted that the capacity and control structure for each of the intermediate pontoons is so adjusted that each intermediate pontoon is capable of only partially supporting the load therebeneath. Thus, compressive forces in the supported load are avoided and some composite unsupported load is always transmitted to the stabilizing pontoon **30**.

The harvester **20** has cooperating therewith buoyancy monitoring structure and buoyancy control means corresponding in structure and operation to that for the intermediate pontoon **32**. For the sake of simplicity, the various components cooperating with the harvester **20** which correspond to those cooperating with the intermediate pontoon **32** have been designated by like numerals followed by the subscript *a*. Specifically, these components are designated as follows: **126***a*, **127***a*, **130***a*, **131***a*, **132***a*, **143***a*, **144***a*, **145***a*, **146***a*, **147***a*, **150***a*, **151***a*, **152***a*, **153***a*, and **154***a*. With this arrangement, the buoyancy of the harvester **20** is maintained within predetermined limits and air supply for this buoyancy is obtained through the same stepwise compression arrangement utilized for the lower intermediate pontoon **32**. It is to be understood, however, that the harvester **20** is not designed to support the load of the conduit **17**.

In addition to the aforedescribed buoyancy control structure associated with each of the pontoons, the stabilizing pontoon is provided with support condition monitoring structure to sense the load of the conduit **17** supported thereby and maintain this load within predetermined limits. This condition monitoring structure comprises: a float compartment tank **155** vertcally disposed in the stabilizing pontoon **30** and having a lower port **156** in fluid communication with the body of water on which the pontoon is supported and an upper port **157** communicating with the atmosphere through an upstanding pipe **160**; a rod **161** mounted in the tank **155** by bearings **162** for free axial movement; a float **163** fixed to the rod **161** intermediate the bearings; a pair of magnetically operated switches **164** and **165** received around the rod **161** in vertically spaced relationship; and, a switch actuating blade **166** fixed to the rod **161** intermediate the switches **164** and **165** for movement into activating condition with respect to either of the switches.

The operation of the support condition monitoring structure is coordinated with that of the buoyancy control structure for each of the intermediate pontoons through electrical circuitry adapted to energize the solenoids **134** to either depress or raise the floats **130** responsive to the condition of the switches **164** and **165**. This circuitry comprises: an electrical lead **167** extending from the switch **164** to one side of the solenoids **134**; an electrical lead **170** extending from the switch **165** to the other side of the solenoids **134**; electrical leads **171** and **172** connecting the solenoids **134** to the main power lead **135**; and, an electrical lead **173** connecting the switches **164** and **165** to the main power lead **136**. This circuitry is arranged so that closing of the switch **164** functions to raise the rods **126**, while closing of the switch **165** functions to

lower the rods **126**. As a result of this arrangement, when the stabilizing pontoon is in an elevated condition indicating that it is not supporting the desired degree of load, the buoyancy monitoring structure of the intermediate pontoons **31** and **32** is forced to a position simulating excessive buoyancy and, thus, the buoyancy of the intermediate pontoons is decreased and the composite load transmitted to the stabilizing pontoon for support is increased. When an excessively submerged condition of the stabilizing pontoon is sensed by closing of the switch **164**, a condition of insufficient buoyancy is simulated in the intermediate pontoons **131** and **132** by raising of the rod **136**. This, in turn, functions to increase the buoyancy of the intermediate pontoon and decrease the composite load transmitted to the stabilizing pontoon **30**.

Through the aforedescribed support condition monitoring structure and the coordinating means cooperating therewith, the load transmitted to the stabilizing pontoon is maintained within predetermined limits. The restricted port **156** in the lower end of the float tank **155** functions to dampen the responsiveness of the float **163**, thus avoiding operation of the support condition monitoring structure responsive to sudden variations in the load supported thereby, as might result from sudden wave action. The provision of the extension pipe **160** assures that the tank **155** is continuously vented while the entrance of water through the vent port **157** is avoided.

With the continued admittance of air to the intermediate pontoons **31** and **32** under the influence of the solenoids **134**, the water level in the intermediate pontoons will eventually reach a level where the weight of the float **130** will transfer to the rod **126**. This weight is so designed as to be more than the solenoid can support and, therefore, upon this occurrence the switches **131** will open, thus terminating the charging of air into the intermediate pontoons. The continued venting of air from the intermediate pontoons under the influence of the solenoids **134** similarly eventually results in a condition where the floats **130** raise the rods **126** to a position opening the switches **132**. At this point, the venting of air from the intermediate pontoons responsive to the condition monitoring structure is, naturally, terminated.

At this point it is noted that variations between the buoyant capacity of the intermediate pontoons may result due to different water levels established by variances in the compressor rates and other causes, possibly minor leaks, et cetera. Periodically, this imbalance can be rectified by artificially establishing a light load condition at the stablizer pontoon through utilization of the aforedescribed support monitoring structure. Specifically, this is accomplished by manually depressing the float **163** to a position venting the intermediate pontoons to the maximum water level, thus tensioning the supported load to a maximum. After this condition has been assumed for a period of time, it can be assumed that all pontoons are ballasted to a maximum level. When this condition is reached, release of the float **163** will activate the compressors of the system and return the intermediate pontoons to a balanced condition.

From the foregoing description it is believed apparent that the present invention enables the accomplishment of the objects initially set forth herein. It is to be understood, however, that the invention is not intended to be limited to the specific details of the exemplary embodiment herein described. For example, it is considered well within the province of the invention that the specific physical characteristics of the system components may be varied and that loads of various types might be supported.

What is claimed is:

1. In an elongated array of objects disposed substantially vertically in a body of liquid, an improved support system comprising:

(a) a substantially vertically disposed elongated tension transmitting structure secured in supporting relationship to the objects of said array;

(b) at least one intermediate pontoon means secured to said tension transmitting structure intermediate the end portions thereof to support, at least partially, the load of said array disposed therebelow, said pontoon means having:

(1) a chamber of selectively variable buoyancy;

(2) buoyancy monitoring means to sense the degree of buoyancy of said chamber; and,

(3) buoyancy control means to vary the buoyancy of said chamber responsive to said buoyancy monitoring means to maintain said intermediate pontoon means in a condition supporting the portion of said array therebelow to a predetermined partial degree;

(c) stabilizing pontoon means secured to the upper end portion of said tension transmitting structure to support, at least in part, the composite load of said array unsupported by said intermediate pontoon means.

2. An improved support system according to claim **1**, including:

(a) adjustment means secured to said tension transmitting structure to selectively vary the relative vertical position at which the stabilizing pontoon means is secured to the upper portion of said structure;

(b) submergence monitoring means operatively associated with the stabilizing pontoon means to sense the degree of submergence thereof in said body of water; and,

(c) submergence control means responsive to said submergence monitoring means and controllably associated with said adjustment means to maintain the stabilizing pontoon means secured to the tension structure in a surfaced condition.

3. In an elongated array according to claim **2**, further including an element disposed in close proximity to the floor of said body of water, the improved support system further comprising:

(a) linking structure secured between said element and the tension transmitting structure;

(b) position monitoring means operatively associated with said element and tension transmitting structure to sense vertical displacement therebetween; and

(c) position control means responsive to said position monitoring means and controllably associated with said adjustment means to maintain said vertical displacement within predetermined limits.

4. An improved support system according to claim **1**, including:

(a) support condition monitoring means operatively associated with said stabilizing pontoon means to sense the load of said array supported thereby; and,

(b) coordinating means cooperatively associated with said condition monitoring means and the buoyancy control means of said intermediate pontoon means to effect operation of said control means responsive to the load sensed by said condition monitoring means so that said load is maintained within predetermined limits.

5. An improved support system according to claim **1**, wherein:

(a) a plurality of said intermediate pontoon means are secured, respectively, to said tension transmitting means at vertically spaced locations intermediate the end portions thereof;

(b) said intermediate pontoon means are each secured in supporting relationship to the objects of said array therebelow; and,

(c) said tension transmitting structure comprises:

(1) first flexible cable segments secured, respectively, between adjacent of said intermediate pontoon means; and,

(2) a second flexible cable segment secured between the uppermost of said intermediate pon-

toon means and said stabilizing pontoon means.

6. An improved support system according to claim 5, wherein, in each of said intermediate pontoon means:

(a) said chamber is defined by an inverted cup-shaped vessel having a closed upper surface and an open bottom;

(b) said buoyancy monitoring means comprises a water displaceable float disposed in said vessel and float position detectors cooperating therewith to detect deviation of said float from predetermined extremities of displacement; and,

(c) said buoyancy control means comprises alternatively operable gaseous medium charging and discharging structure secured in fluid communication with the interior of said vessel and controllably associated with said detectors to selectively charge gaseous medium into or discharge gaseous medium from said vessel.

7. An improved support system according to claim 6, including:

(a) a prime source of gaseous medium maintained under a pressure sufficient to facilitate the introduction thereof into the uppermost of said intermediate pontoon means;

(b) first conduit means coupling said source in fluid supplying communication with the charging structure of the uppermost of said intermediate pontoon means; and,

(c) second conduit means coupling the vessel of each of said intermediate pontoon means in fluid communication with the charging and discharging structure of the intermediate potoon means immediately therebelow, whereby:

(1) gaseous medium charged into the vessels of each of the intermediate pontoon means below the uppermost thereof is supplied from the vessel of the intermediate pontoon means immediately thereabove; and,

(2) gaseous medium discharged from the vessels of each of the intermediate pontoon means below the uppermost thereof is vented into the vessel of the intermediate pontoon means immediately thereabove.

8. An improved support system according to claim 7, wherein:

(a) the charging structure of the uppermost of said intermediate pontoon means comprises a valve adapted to selectively open and close said first conduit means to fluid communication with the vessel of the uppermost of said intermediate pontoon means; and,

(b) the charging structure of each intermediate pontoon means below the uppermost thereof comprises a pump adapted to selectively compress and convey gaseous medium from the vessel of the intermediate pontoon means thereabove to the vessel thereof through said second conduit means; and,

(c) the discharging structure of each of said intermediate pontoon means below the uppermost thereof comprises a valve adapted to selectively open and close the vessel of the intermediate pontoon means thereabove to the vessel thereof through said second conduit means.

9. In an elongated array according to claim 5, wherein the array comprises a continuous member, the improved support system wherein:

(a) said first cable segments each comprise:

(1) at least three intermediate cables disposed symmetrically around and extending longitudinally of said member in equal angularly spaced relationship; and,

(2) first equalizing means secured to and continuously maintaining equal tension in said intermediate cables;

(b) said second cable segment comprises:

(1) at least three stabilizing cables disposed symmetrically around and extending longitudinally of said member in equal angularly spaced relationship; and,

(2) second equalizing means secured to and continuously maintaining equal tension in said stabilizing cables;

(c) said adjustment means comprises a block and tackle comprising:

(1) head and tail blocks secured, respectively, to said stabilizing pontoon means and second cable segment; and,

(2) a take-up cable trained around said head and tail blocks.

10. An improved support system according to claim 9, wherein:

(a) the intermediate cables of each of said first segments extend between opposed sides of immediately adjacent intermediate pontoon means;

(b) the intermediate cables of each of said first segments are secured between opposed sides of immediately adjacent intermediate pontoon means by a fixedly secured connection to one of said intermediate pontoon means and a connection through one of said first equalizing means to the other of said intermediate pontoon means;

(c) on each of said other intermediate pontoon means said first equalizing means comprise:

(1) a first substantially horizontally disposed beam pivotally secured to said intermediate pontoon means for movement about a first axis extending substantially normal to and through the longitudinal centerline of said continuous member, said first beam having first and second connectors on the end portions thereof spaced, respectively, from said first axis by distances in a two-to-one ratio relative to each other;

(2) a second substantially horizontally disposed beam pivotally secured to said intermediate pontoon means for movement about a second axis extending substantially normal to and through the longitudinal centerline of said continuous member in vertically spaced relationship to said first axis, said second beam having first and second connectors on the end portions thereof spaced, respectively, from said second axis by distances in a two-to-one ratio relative to each other; and,

(3) a third beam substantially horizontally disposed, freely suspended by connection of the end portions thereof respectively, with the first connectors of said first and second beams through tension transmitting elements and having a cable connector mid-way between the connected end portions thereof;

(d) the three intermediate cables of each of said first segments are secured through each of said equalizing means by connections, respectively, to said second connector of said first beam, said second connector of said second beam and said cable connector of said third beam.

11. An improved support system according to claim 9, wherein said adjustment means further comprises:

(a) haul means operatively secured to said take-up cable to selectively vary the length thereof trained around said head and tail blocks and thus vary the relative vertical position at which the stabilizing pontoon means is secured to the upper portion of the tension transmitting structure; and,

(b) counterbalance means operatively associated with said haul means to balance, at least partially, the weight supported by said take-up cable.

12. In a system comprising:

(a) a support member;

(b) a suspended member; and,

(c) three tension transmitting support elements secured between said members;

an improved structure securing said elements to one of said members to maintain equal tension therein, comprising:

(1) a first beam disposed substantially normal to said tension transmitting support elements and pivotally secured to said one member for movement about a first axis disposed substantially normal to said support elements, said first beam having first and second connectors on the end portions thereof spaced, respectively, from said first axis by distances in a two-to-one ratio relative to each other;

(2) a second beam disposed substantially normal to said tension transmitting support elements and pivotally secured to said one member in spaced relationship to said first beam for movement about a second axis disposed substantially normal to said support elements, said second beam having first and second connectors on the end portions thereof spaced, respectively, from said second axis by distances in a two-to-one ratio relative to each other;

(3) a third beam freely suspended substantially normal to said tension transmitting support elements by connection of end portions thereof, respectively, to the first connectors of said first and second beams through tension transmitting elements and having an intermediate connector mid-way between the connected end portions thereof; and,

(4) means connecting said three tension transmitting support elements, respectively, to said second connector of said first beam, said second connector of said second beam and said intermediate connector of said third beam.

13. In an installation comprising:

(A) a series of gas containing stations disposed, respectively, at succeedingly greater depths in a body of liquid, said stations each having:

(1) contiguous wall means defining an upwardly closed chamber containing a volume of gas, said wall means being subject, externally, to pressure by said body; and,

(2) opening means disposed through a lower portion of said wall means to establish fluid communication between said body and volume and subject said volume to pressure corresponding, substantially, to the pressure externally of said wall means;

(B) a gas supply source disposed above the uppermost of said stations, said source being capable of providing gas under a pressure sufficient for the introduction thereof into the chamber of said uppermost chamber; and,

(C) means to effect the introduction of gas into the chamber of the uppermost station from said source and the discharging of gas from said chamber responsive to the liquid level therein to maintain said level within a predetermined range;

an improved system for supplying gas and discharging gas from the chambers of said stations comprising:

(a) a single fluid conducting conduit extending between said stations, said conduit having:

(1) first and second conduit means connected thereto for each of said stations above the lowermost thereof, said means extending, independently, into fluid communication with the chamber of the station therefor with said means for each station being disposed with the second thereof connected to said single conduit below the first thereof; and,

(2) third conduit means connected thereto beneath the lowermost connection thereto of said second conduit means and extending into fluid communication with the chamber of the lowermost of said stations;

(b) remotely operable independent shut-off valve means interposed, respectively, in said single conduit between the connection thereto of the first and second conduit means for each of said stations above the lowermost thereof;

(c) remotely operable independent discharge means interposed in each of said second conduit means to selectively effect the pumping of gas therethrough to said single conduit; and,

(d) liquid level control means operatively associated with the chamber of each of said stations below the uppermost thereof, said means being adapted to, selectively:

(1) open and close the valve means immediately thereabove responsive to the attainment of first predetermined liquid level conditions in the chamber operatively associated therewith; and,

(2) activate and de-activate the discharge means immediately thereabove responsive to the attainment of second predetermined liquid level conditions in the chamber operatively associated therewith.

14. In an elongated array of objects interconnected in tension transmitting relationship and disposed substantially vertically in a body of liquid, an improved support system comprising:

(a) at least one intermediate pontoon means secured to said array in tension transmitting relationship intermediate the end portions thereof to support, at least partially, the load of said array disposed therebelow, said pontoon means having:

(1) a chamber of selectively variable buoyancy;

(2) buoyancy monitoring means to sense the degree of buoyancy of said chamber; and,

(3) buoyancy control means to vary the buoyancy of said chamber responsive to said buoyancy monitoring means to maintain said intermediate pontoon means in a condition supporting the portion of said array therebelow to a predetermined partial degree;

(b) stabilizing pontoon means secured to the upper end portion of said array in tension transmitting relationship to support, at least in part, the composite load of said array unsupported by said intermediate pontoon means.

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