United States Patent [19]

Willke et al.

[11] **3,743,247**

[45] **July 3, 1973**

[54] **LEG SUPPORTED OFFSHORE STRUCTURE WITH JACKING APPARATUS**

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[73] Assignee: **Armco Steel Corporation,** Middletown, Ohio

[22] Filed: **May 11, 1971**

[21] Appl. No.: **142,168**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 876,781, Nov. 14, 1969, Pat. No. 3,606,251.

[52] U.S. Cl. **254/89,** 254/95

[51] Int. Cl. **B66f 7/12**

[58] **Field of Search** 254/89, 95, 97; 61/46.5

[56] **References Cited**

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Assistant Examiner—Robert C. Watson
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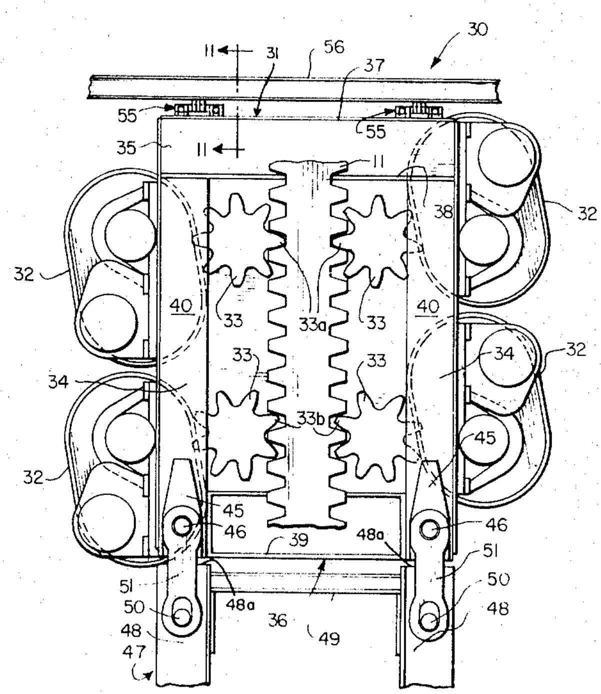
[57] **ABSTRACT**

Offshore platforms and like structures of the leg-and-jacking unit type, where the jacking units are based on racks and pinions, are improved by mounting the jacking units with freedom of horizontal movement relative to the vessel in directions in the plane of the rack, and by providing additional means to restrain the jacking units against movement in directions generally perpendicular to the plane of the rack. Such features allow the jacking units to accept small angular displacements of the legs, and small relative movements between the vessel and the legs in directions lateral with respect to the legs, without losing precise meshed engagement of the pinions with the rack teeth and without application of excessive stress.

14 Claims, 19 Drawing Figures



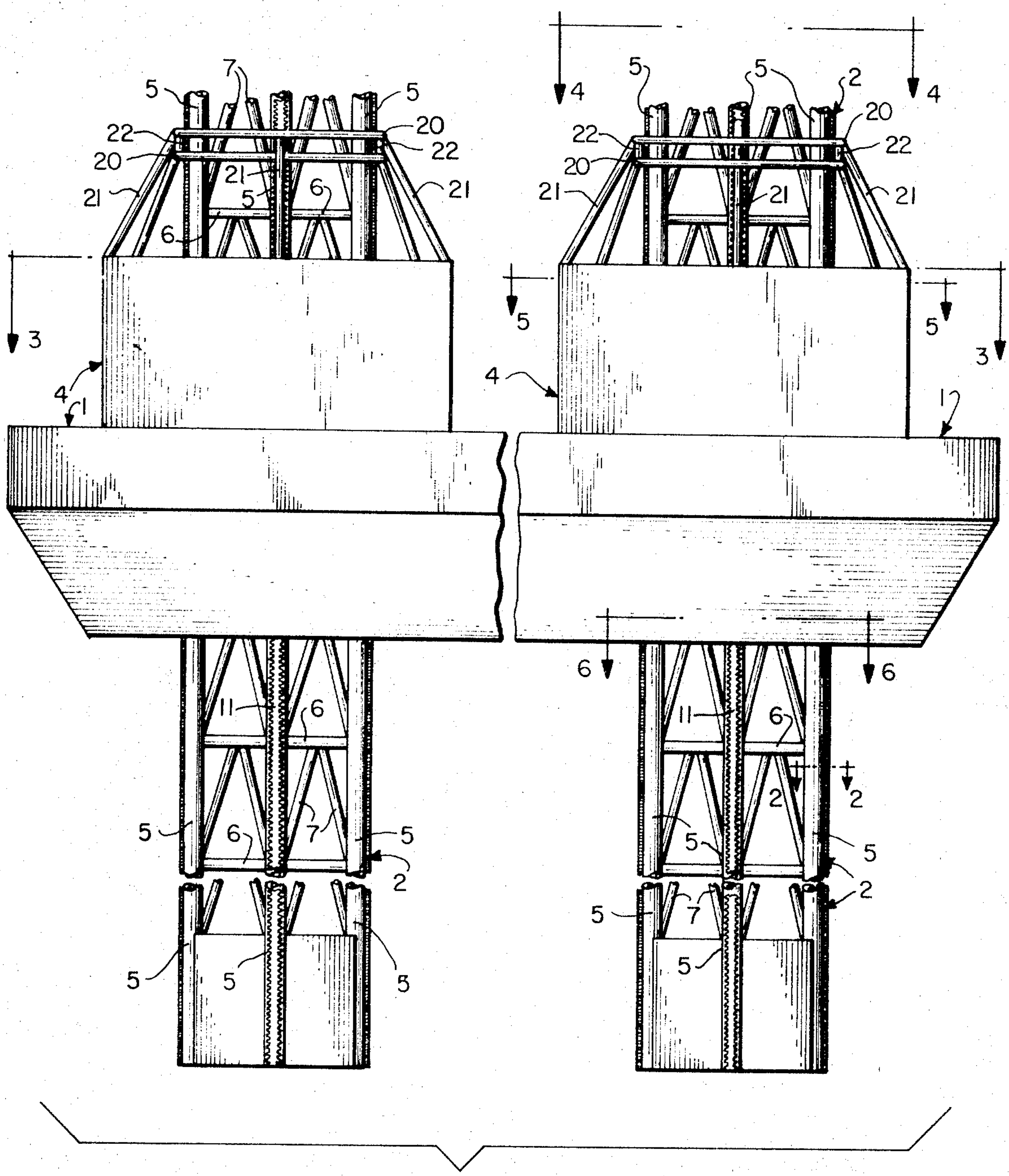


FIG. 1

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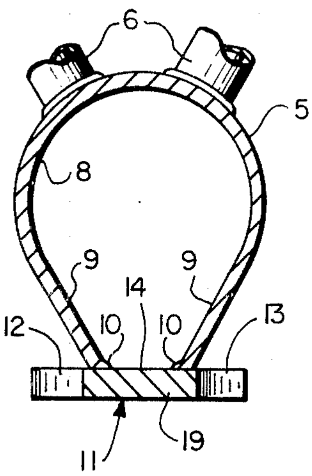

FIG. 2

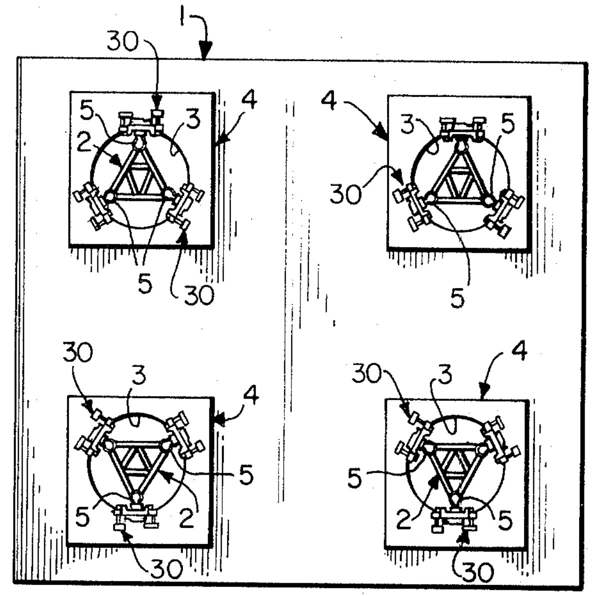

FIG. 3

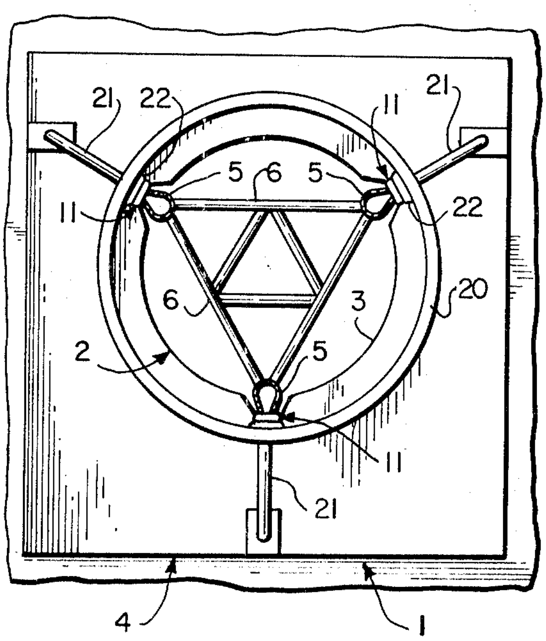

FIG. 4

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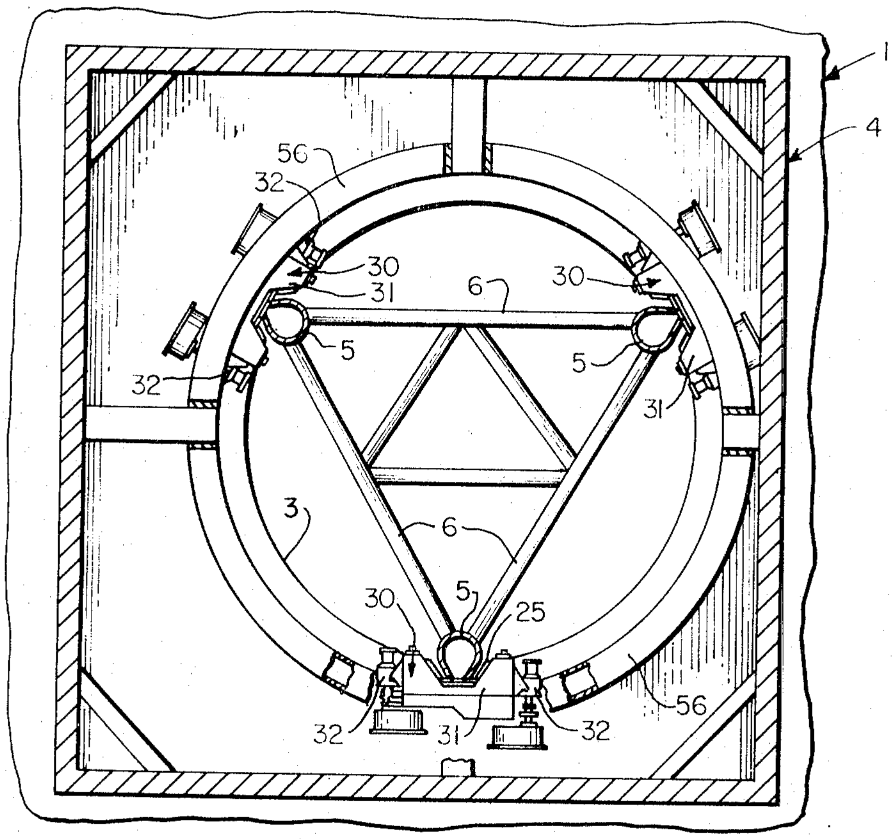

FIG. 5

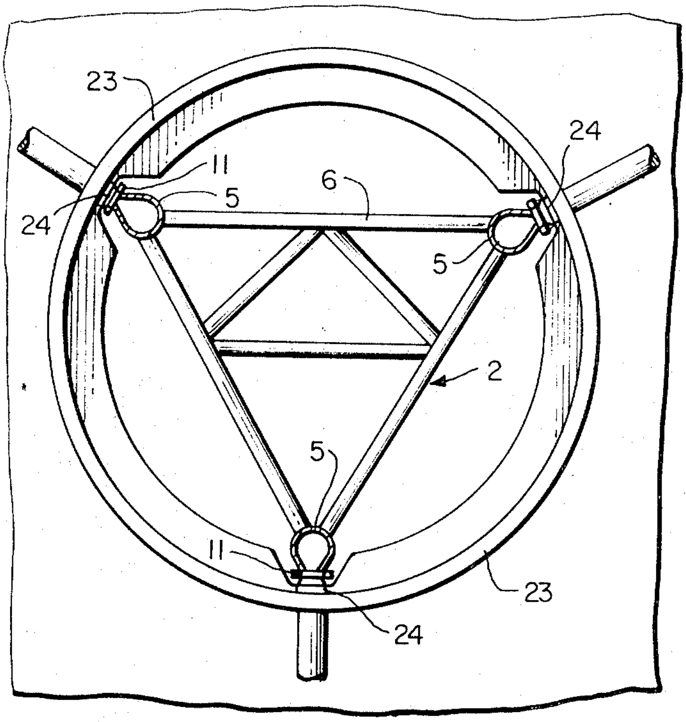

FIG. 6

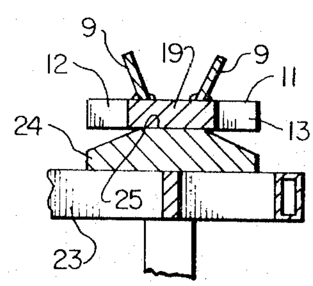

FIG. 7

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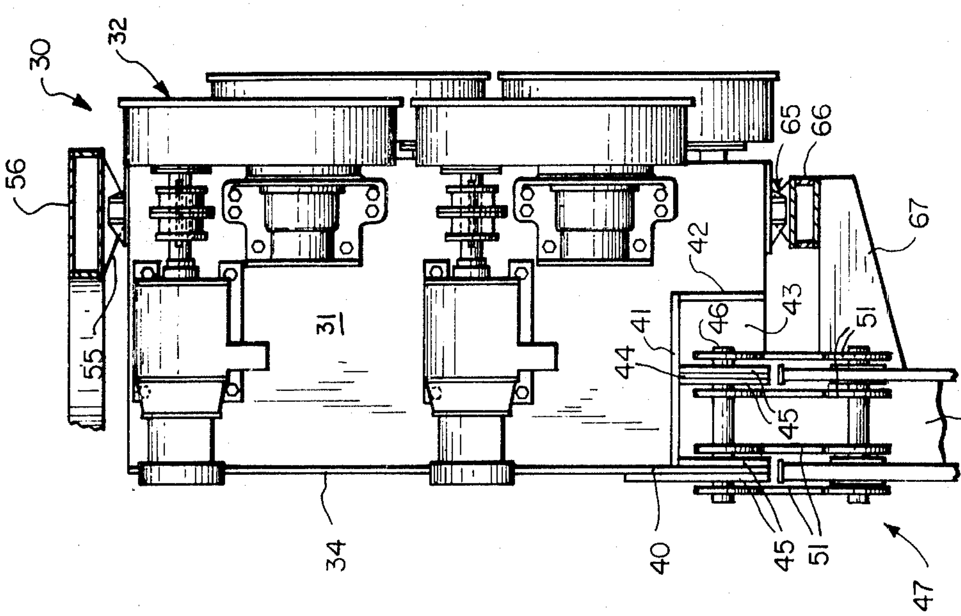

FIG. 9

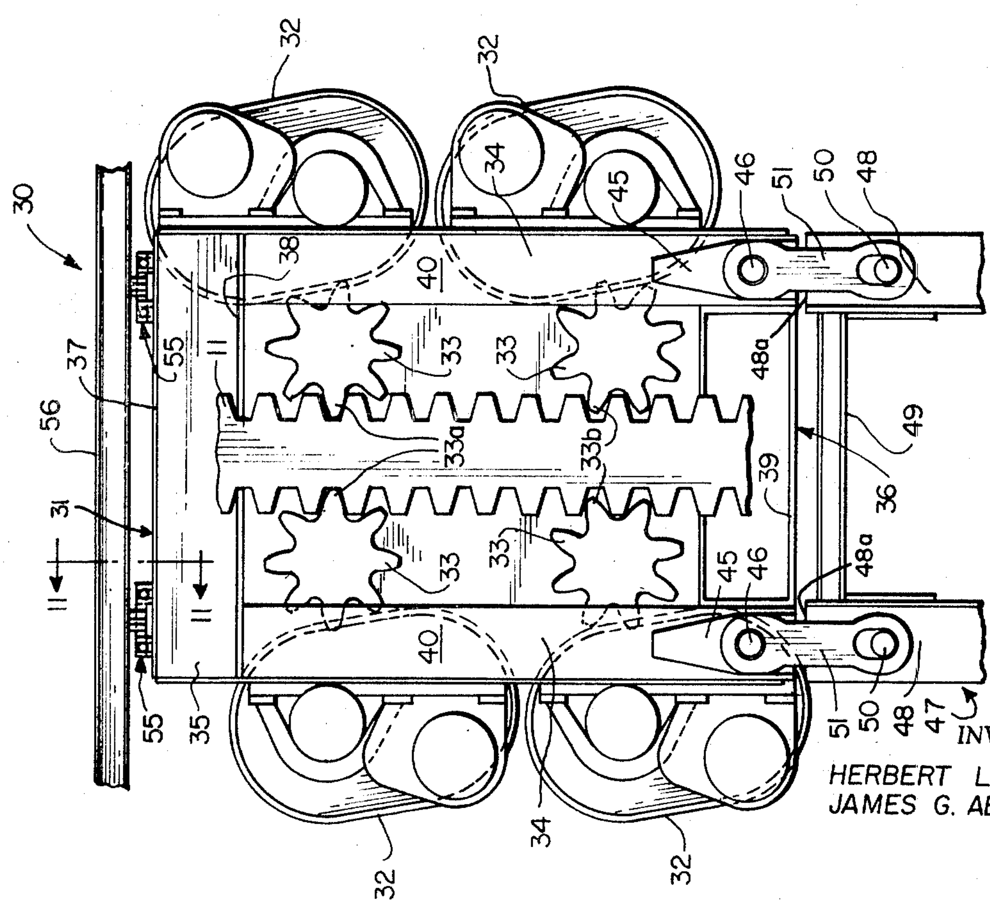

FIG. 8

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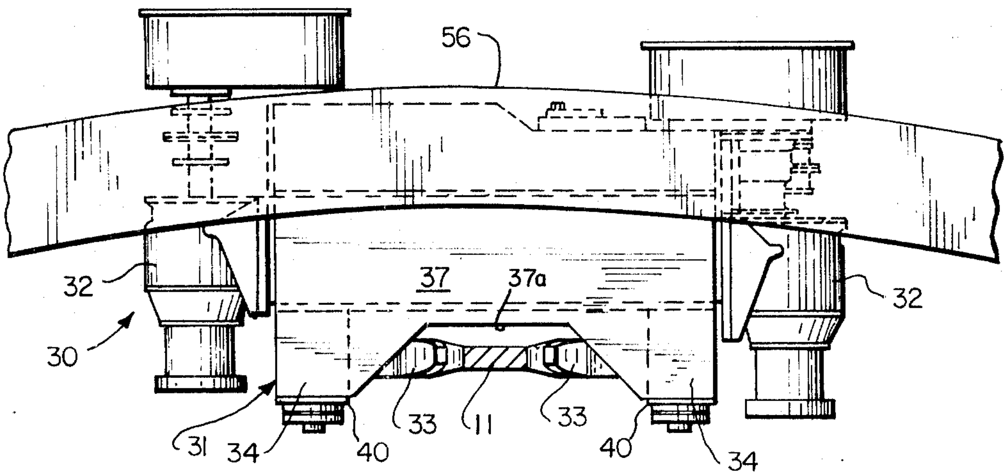

FIG. 10

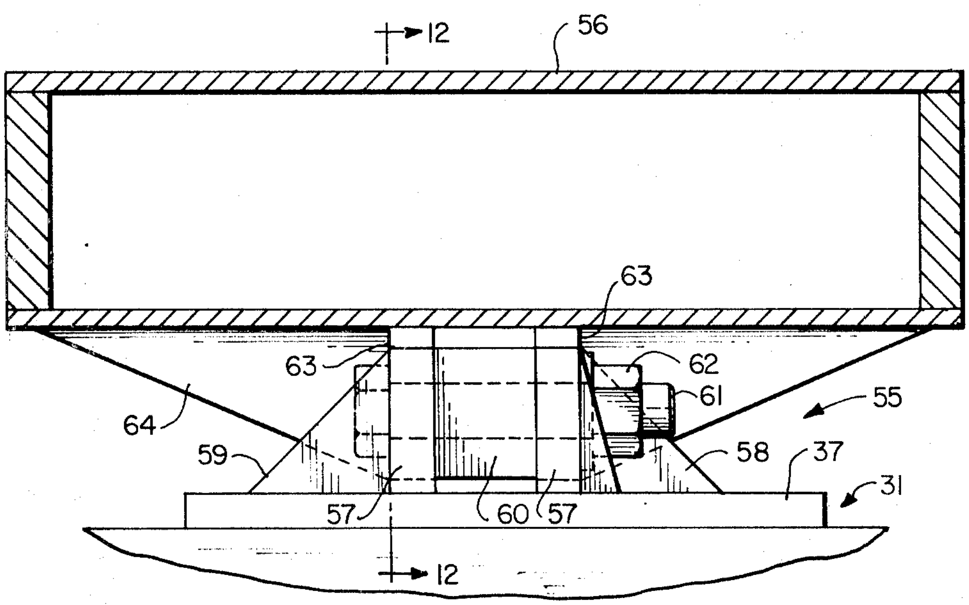

FIG. 11

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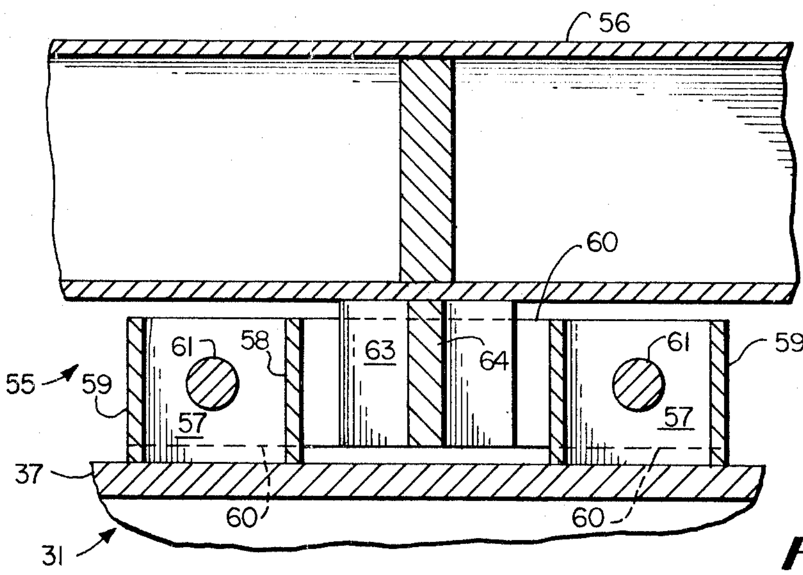

FIG. 12

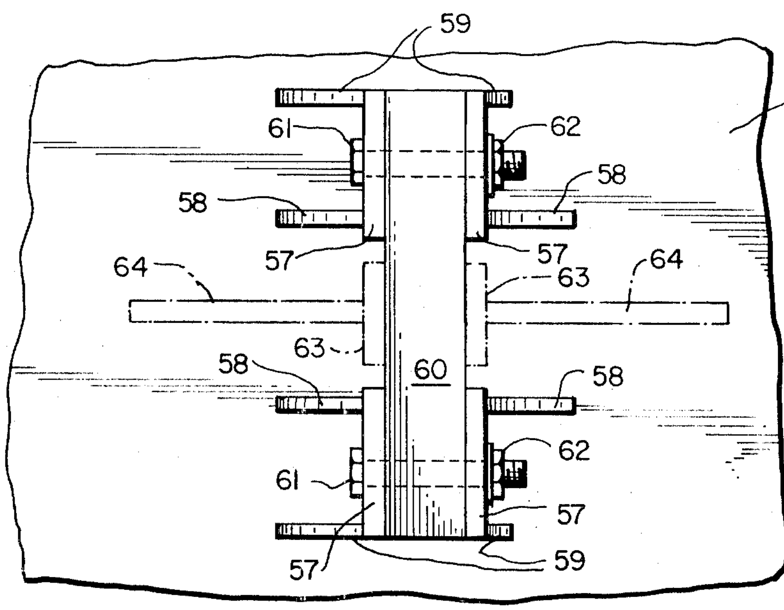

FIG. 13

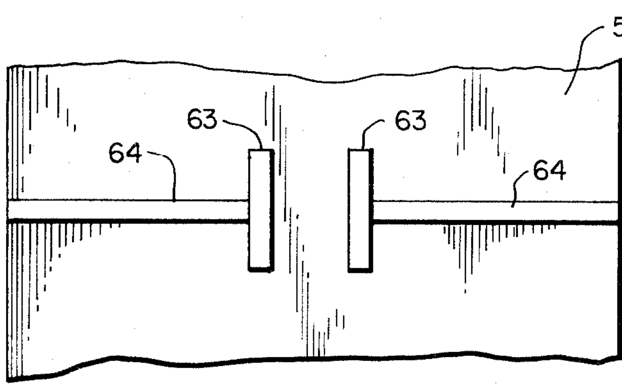

FIG. 14

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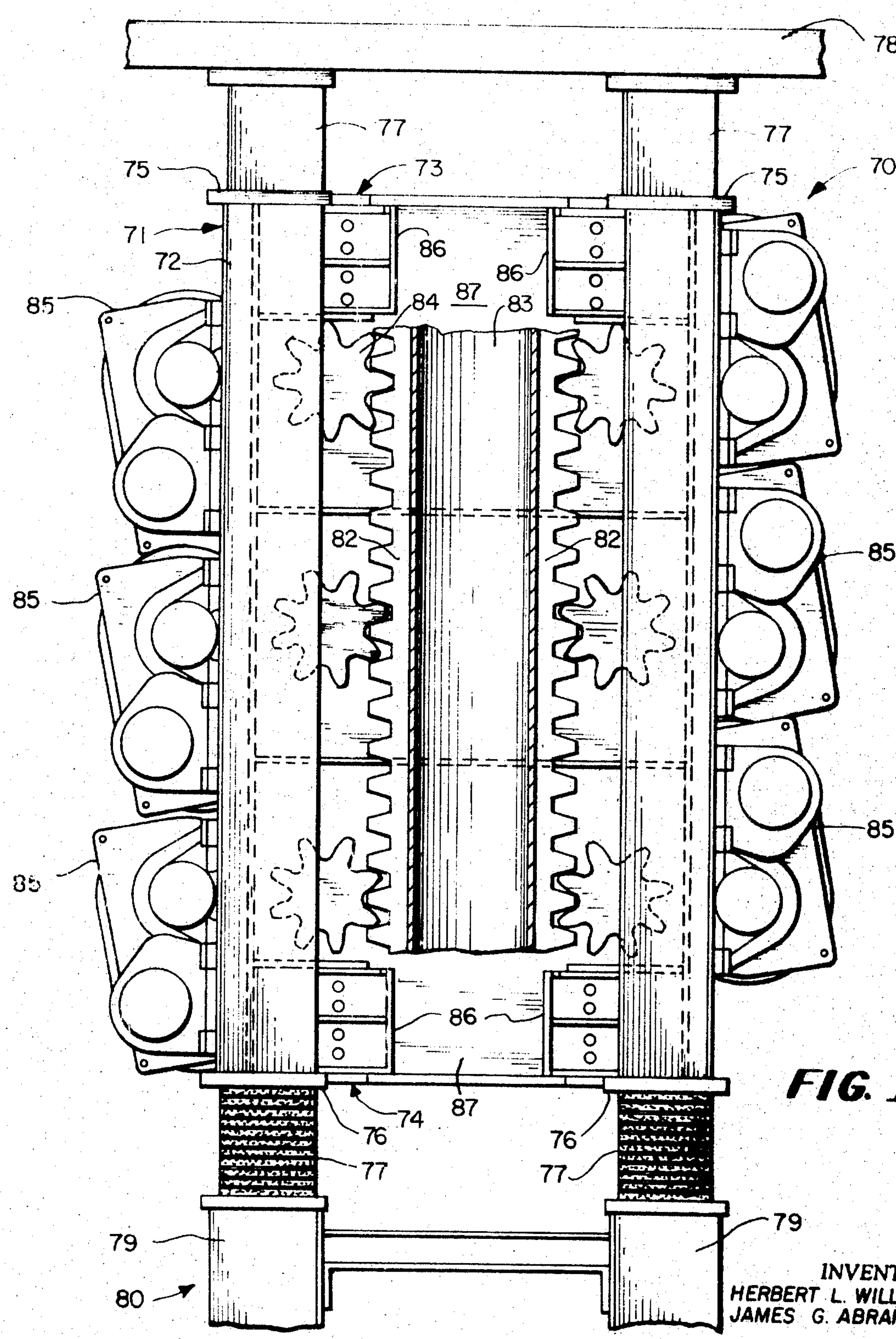

FIG. 15

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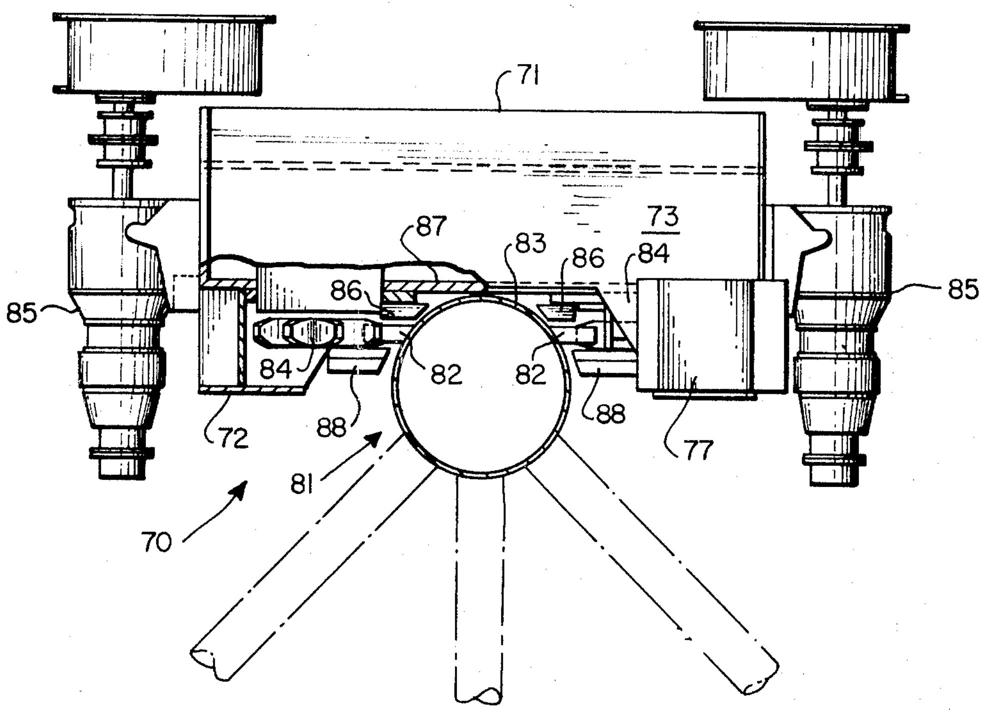

FIG. 16

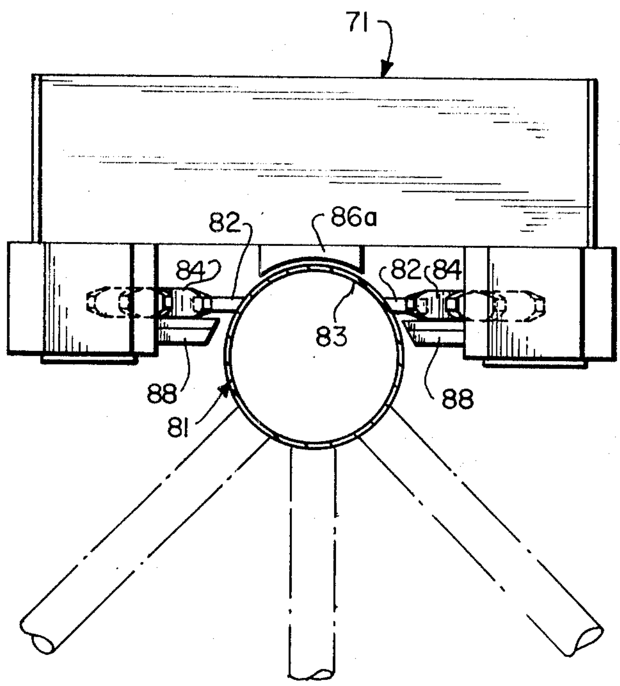

FIG. 17

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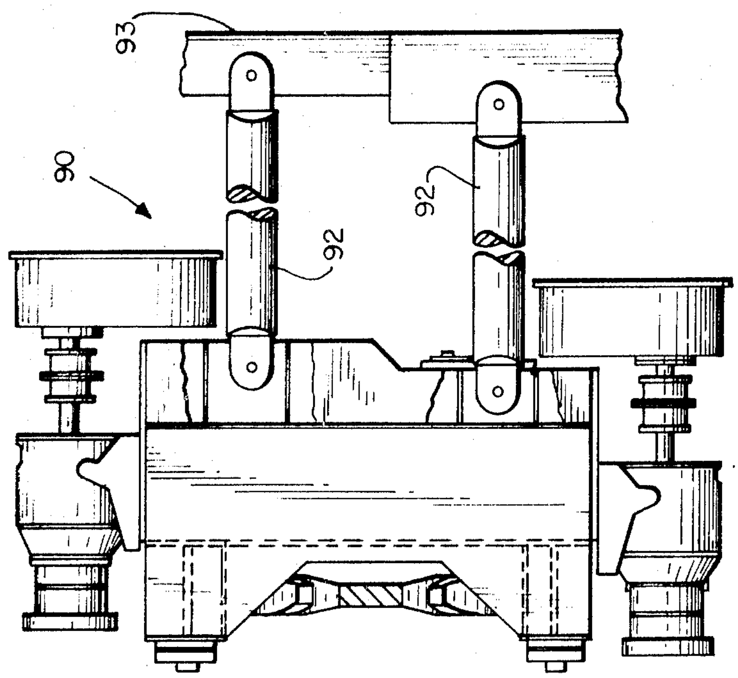

FIG. 19

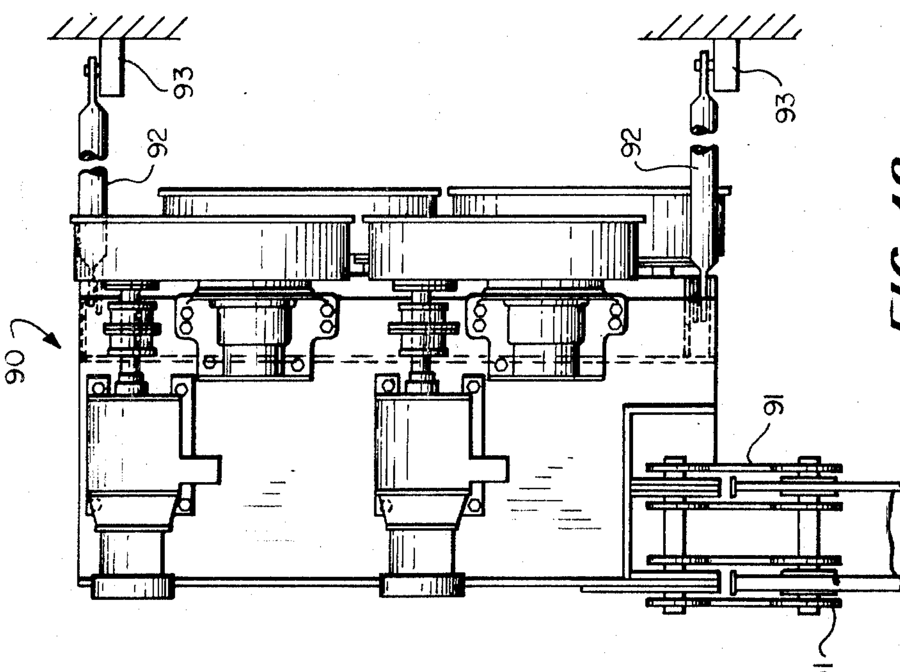

FIG. 18

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LEG SUPPORTED OFFSHORE STRUCTURE WITH JACKING APPARATUS

This application is a continuation-in-part of our copending application Ser. No. 876,781, filed Nov. 14, 1969, now U.S. Pat. No. 3,606,251.

This invention relates to offshore platforms and like installations wherein a structure, such as a vessel, is supported on upright legs by a rack and pinion apparatus in a fashion such that the supported structure can be adjusted vertically relative to the legs.

Offshore platforms as commonly constructed employ a vessel as the main platform structure, the vessel being equipped with a plurality of upright legs and a jacking mechanism, typically of the rack-and-pinion type, being provided to interconnect the legs and the vessel in such fashion that, when the vessel is launched, the legs can be jacked up so that the vessel can be floated to the installation site, the legs then being lowered into engagement with the bottom of the body of water, and the vessel then being jacked up to a position in which it is supported above the surface of the body of water. In some such installations, the legs are equipped with racks having a single set of rack teeth facing away from the leg, and the jacking units include a plurality of pinions lying generally in the plane of the rack. The structure disclosed in U. S. Pat. No. 2,924,077, issued Feb. 9, 1960, to R. G. LeTourneau, is typical for such installations. Our copending application Ser. No. 876,781 describes offshore platforms and the like in which each of the legs is equipped with at least one elongated rack means presenting two mutually parallel oppositely facing sets of rack teeth, the vessel or other structure to be supported being provided with jacking units each including at least one pair of pinions spaced apart and disposed in meshed engagement each with a different set of teeth of one of the rack means, the pinions being mounted for rotation about parallel axes which are rigidly fixed against lateral movement relative to the jacking unit so that, the pinions being opposed across the rack means, any force tending to disengage one of the pinions from its respective set of rack teeth is opposed by reason of the fact that the pinion is engaged with the opposite set of rack teeth. Installations of this latter type have the important advantage that positive meshed engagement between the pinions of the jacking units and the rack means of the legs is assured.

Offshore platforms employing jacking systems of the rack-and-pinion type have achieved wide success in actual practice. Despite this success, it has been found that such installations have heretofore presented a problem arising primarily from the fact that, during jacking, the legs may assume positions which are not precisely perpendicular with respect to the vessel. And, to complicate the problem, small relative movements, between the legs and the vessel, occur in directions lateral with respect to the legs. Because of the very great loads involved and which must be supported through the rack and pinion apparatus, it has been common practice to secure the jacking units rigidly to the vessel, so that misalignments resulting, e.g., from small angular displacements or small lateral displacements of the legs, and therefore the racks, must be accommodated by a structure which is essentially rigid and noncompliant. This situation has resulted in the pinions becoming less than perfectly meshed with the cooperating rack teeth, and in application of stresses to the structure which are highly undesirable.

It is accordingly a general object of the invention to provide structures of the type described in which small angular and lateral displacements of the legs relative to the structure to be supported thereon can be accommodated without loss of proper engagement of the pinions with the rack teeth and without developing undesirable forces in the structure.

Another object is to provide structures of the type described in which the jacking units are so arranged that the entire jacking unit is allowed a small freedom of movement in directions such as to accommodate displacements and irregularities of the racks.

A further object is to devise such structures in which the jacking units are connected to the vessel, or other structures to be supported by the legs, via means presenting a limited compliance with respect to the forces tending to result from small angular and lateral displacements of the legs relative to the vessel or the like.

Generally stated, offshore platforms and the like according to the invention embody jacking units in which the pinions are carried by a rigid frame and the frame is connected to the vessel, or like structure to be supported, by means allowing freedom of movement in horizontal directions which are parallel to the plane of the rack means, additional means being provided to prevent undue relative movement between the jacking units and the legs in directions generally perpendicular to the plane of the rack means. Mounting of the jacking units for limited freedom of movement is accomplished by use of linkages or resilient compression pads. The additional means employed to prevent undue relative movement between the jacking units and the legs in directions generally perpendicular to the plane of the rack means can act between the jacking units and the vessel, or between the jacking units and the rack means. According to one embodiment, links support the jacking unit on the vessel with freedom for horizontal movement relative to the vessel in directions parallel to the plane of the rack means, and additional means acts to fix the jacking unit against movement relative to the vessel in directions perpendicular to the plane of the rack means. In such structures, relative movement between the jacking unit and the leg in directions perpendicular to the plane of the rack means is allowed because the teeth of the pinions can slide over the faces of the rack teeth. According to another embodiment, the jacking units are supported on the vessel by resilient compression pads which allow the jacking unit to move relative to the vessel in all horizontal directions, and additional means are provided to prevent or limit relative movement between the jacking units and the rack means in directions perpendicular to the plane of the rack means. Both embodiments thus afford via the jacking units two degrees of freedom of relative horizontal movement between the legs and the vessel and accordingly accommodate all horizontal displacements regardless of the angle between the direction of the displacement and the plane of the respective rack means.

In order that the manner in which the foregoing and other objects are achieved according to the invention can be understood in detail, particularly advantageous embodiments thereof will be described with reference to the accompanying drawings, which form part of the original disclosure of this application, and wherein:

FIG. 1 is a side elevational view of an offshore platform incorporating one embodiment of the invention;

FIG. 2 is a transverse sectional view, taken on line 2—2, FIG. 1, showing the transverse cross-sectional configuration of a column member of one of the leg structures of the platform of FIG. 1;

FIG. 3 is a top plan view of the platform of FIG. 1;

FIG. 4 is a view, mainly in top plane elevation, taken generally on line 4—4, FIG. 1;

FIG. 5 is a horizontal sectional view taken generally on line 5—5, FIG. 1, with portions broken away for clarity and some parts appearing in top plan elevation;

FIG. 6 is a fragmentary horizontal sectional view taken generally on line 6—6, FIG. 1, with some parts appearing in top plan elevation;

FIG. 7 is an enlarged transverse sectional view illustrating a guide shoe employed in the platform of FIG. 1;

FIG. 8 is a front elevational view of one of the jacking units and its associated mounting means, employed in the platform of FIG. 1;

FIG. 9 is a side elevational view of the jacking unit of FIG. 8 and its associated mounting and supporting means, with parts shown in vertical cross section;

FIG. 10 is a top plan elevational view of the structure shown in FIGS. 8 and 9, with the rack member shown in horizontal cross section;

FIG. 11 is a fragmentary vertical sectional view taken on line 11—11, FIG. 8, with some parts appearing in side elevation;

FIG. 12 is a fragmentary vertical sectional view taken on line 12—12, FIG. 11;

FIG. 13 is a top plan view of stop means carried by the jacking unit of FIG. 8 and forming part of the structure shown in FIGS. 11 and 12;

FIG. 14 is a bottom plan view of stop means separate from the jacking unit but forming part of the structure shown in FIGS. 11 and 12;

FIG. 15 is a front elevational view, similar to FIG. 8, of a jacking unit mounted according to another embodiment of the invention, the associated column portion appearing in vertical cross section;

FIG. 16 is a top plan view of the unit of FIG. 15, portions being broken away for clarity and the associated column portion appearing in horizontal cross section;

FIG. 17 is a view similar to FIG. 16 and illustrating a modified form of the embodiment shown in FIGS. 15 and 16;

FIG. 18 is a side elevational view of a jacking unit mounted according to a further embodiment of the invention; and

FIG. 19 is a top plan view of the unit of FIG. 17.

Turning now to the drawings in detail, the invention is illustrated as incorporated in an offshore platform comprising a structure 1 to be supported and a plurality of upright leg structures 2. For illustrative purposes, the structure 1 has been shown as a buoyant hull of simple rectangular plan configuration, equipped with four of the leg structures with each leg structure disposed adjacent a different corner of the hull. To accommodate each leg, the hull is provided with a plurality of openings which extend completely through the hull from bottom to top and are indicated generally at 3, FIG. 3. Above each opening 3, a jack house 4 is mounted on the deck of the hull and projects upwardly for a substantial distance, surrounding the corresponding leg.

In this embodiment, each leg structure 2 comprises three tubular column members 5, the column members being mutually parallel and spaced apart laterally to define a triangle with each column member located at a different one of the apices. Column members 5 are interconnected by horizontal brace members 6 and diagonal, generally longitudinal brace members 7 extending between each adjacent pair of sets of horizontal brace members.

The column members 5 are all identical, having the transverse cross section seen in FIG. 2. Each column member is formed from relatively thick metal stock generally in the fashion common for the manufacture of heavy wall pipe, and includes a circular wall portion 8 which extends for approximately 270°, and two flat portions 9 which project as tangential extensions of the circular portions 8 and thus converge outwardly to terminate in two parallel straight edges 10.

Each column member 5 is completed by a dual rack member 11 which, in this embodiment, is in the form of a heavy flat metal bar of elongated rectangular transverse cross section. Two sets of rack teeth 12 and 13 are provided, each extending along a different one of the two small sides of the rectangular rack member. The crest-to-crest width of rack member 11 is only slightly less than the diameter of circular portion 8 of column member 5. The root-to-root width of rack member 11 is significantly greater than the transverse space between the edge portions 10 of column member 5. Accordingly, with the longitudinal center line of rack member 11 extending parallel to the longitudinal axis of column member 5 in a location spaced equally from the two edge portions 10, the two edge portions 10 can both be engaged with one flat face 14 of the body of the rack, as seen in FIG. 2. The two edge portions 10 of the column member are welded to surface 14 of the rack member so that the relatively heavy rack member 11 is thus integrated into the column member of the leg structure, not only closing the space between edge portions 10 but also constituting a load-bearing portion of the column member. From FIG. 2, it will be seen that the teeth 12 and 13 project in a common plane which extends across the converging planes of portions 9 of column member 5 in such fashion that each set of rack teeth is spaced outwardly from the column member by a distance sufficient to establish free access to the rack teeth for establishing the rack-and-pinion relationship hereinafter described. It is also to be noted that the outer face 19 of the central portion of the rack member is freely exposed for sliding engagement with guide shoes, later described.

As seen in FIGS. 1 and 4, a vertically spaced pair of horizontally extending circular support members 20 is supported above each jack house 4, as by frame members 21. Secured to the inner periphery of support members 20 are three guide shoes 22, the three shoes 22 being equally spaced and so located that each shoe will be aligned with the path of travel of a different one of the dual rack members 11. Similarly, at the bottom of each opening 3, the hull 1 is provided with a rigidly mounted, circularly extending, horizontal support member 23, FIG. 6. Three guide shoes 24 are secured to the inner periphery of support member 23, each guide shoe 24 being aligned vertically below a different one of the guide shoes 22 and, therefore, centered on the path of travel of a different one of the rack members 11. As seen in FIG. 7, guide shoes 24 are so dimensioned and located that the active face 25 of the guide shoe is held in a position to slidably engage the outer face 19 of the corresponding rack member 11. The relationship between the upper guide shoes 22 and the rack members is the same as that shown in FIG. 7 for the lower guide shoes.

The upper and lower sets of guide shoes just described serve to generally maintain proper positional relationship between the leg structures 2 and the vessel. However, in order to maintain freedom of relative vertical movement between the legs and the vessel, a small radial space is provided between the guide shoes and the corresponding rack members of the leg structures. Typically, such spaces allow a freedom of lateral movement between the legs and the guide shoes on the order of one-half inch. Accordingly, assuming that the vessel is afloat and the leg structures have been run down and seated on the floor of the body of water, it is clear that the vessel can move, under the influence of wave and wind forces, on the order of one-half inch laterally of the leg structures before such movement is stopped by engagement of the appropriate guide shoes and rack members. Similarly, recognizing that the upper and lower guide shoes are spaced apart by a distance which may be on the order of fifty feet, it is possible for the leg structures to be displaced from the perpendicular, relative to the plane of the vessel, by a small angle typically on the order of several minutes.

For each dual rack member 11, there is provided a jacking unit indicated generally at 30, FIG. 3, and shown in detail in FIGS. 8–10. In this embodiment, all of the jacking units 30 are identical. Each unit 30 has a rigid frame 31 which carries motor and gear reduction units 32 arranged to drive pinions 33. Pinions 33 are arranged in pairs with the axes of rotation for each pair of pinions being mutually parallel, horizontal and spaced apart in a horizontal plane extending transversely across frame 31. The motor and gear reduction units 32 and pinions 33, with their associated shafts and bearings (not shown) can be constructed and arranged as disclosed in our aforementioned copending application Ser. No. 876,781, the arrangement being such that the axes of rotation of the pinions are rigidly constrained against lateral movement. A plurality of pairs of the pinions 33 are provided, with the pairs being aligned vertically one above the other. The pinions of each pair are spaced apart by a distance such that the dual rack member 11 is accommodated between the two pinions with each pinion being in operative meshed relation with a different one of the sets of rack teeth 12 and 13.

At the front of the jacking unit, frame 31 includes two vertical box beams 34, arranged each at a different side of the frame, a top cross beam 35, and a bottom cross beam 36. Top cross beam 35 is defined in part by the top plate 37 and a horizontal plate 38, plates 37 and 38 being notched to provide space for passage of rack member 11, as indicated, for example, at 37*a* in FIG. 10. Similarly, bottom cross beam 36 is defined by horizontal plates 39 which are notched to provide space for the rack member. As will be clear from FIG. 10, all of the pinions 33 lie in a common vertical plane and, in the finished installation, the dual rack member 11 lies in the same plane as the pinions, this plane being spaced inwardly from the front plates 40 of the box beams 34.

While the top cross beam 35 extends for the full width of frame 31, lower cross beam 36 terminates at the adjacent side walls of the vertical beams 34. As seen in FIG. 9, suitable plates 41, 42 define a recess 43 at the lower end of each vertical beam 34. The front wall plates 40 of beams 34 project downwardly to a point slightly below the bottom of frame 31, and rear plates 44 of beams 34 project similarly through the recesses 43. The lower end portions of plates 40 and 44 are strengthened by being laminated with additional plates 45, FIG. 9. The downwardly projecting end portions of plates 40 and 44, so reinforced, are provided with horizontally aligned circular apertures to receive a pivot pin 46.

A supporting structure, indicated generally at 47, is rigidly mounted on the deck of the vessel 1 and includes two vertical posts 48 each generally aligned with a different one of the vertical beams 34 of frame 31 of the corresponding jacking unit, there being one supporting structure 47 for each jacking unit. At their upper ends, vertical posts 48 are interconnected by a cross beam 49. The posts 48 are defined by side, front and back plates. Near its upper end, each post 48 is provided with apertures in the front and back plates which are horizontally aligned and accommodate a pivot pin 50.

Each jacking unit 30 is connected to the corresponding supporting structure 47 by eight link members 51. Considering one side of the jacking unit as viewed in FIG. 9, the link members 51 are arranged in two pairs, one pair being spaced apart to accommodate therebetween the bottom ends of front plates 40 of beams 34 and the upper ends of corresponding plates of the vertical post 48. A second pair of the links 51 is spaced apart to accommodate the lower end of rear plate 44 of vertical beam 34 and the corresponding rear plate of post 48. This arrangement is, of course, repeated at the opposite side of the jacking unit. Each link member 51 is provided with apertures respectively embracing the pivot pins 46 and 50.

From FIG. 8, it will be seen that the jacking unit can be aligned vertically with the supporting structure 47 so that the front beams 34 of frame 31 of the jacking unit extend upwardly in vertical alignment with the respective posts 48 of the supporting structure. The upper ends of posts 48 are flat transverse surfaces and the depending lower end portions of plates 40 and 44 of beams 34 terminate in flat transverse surfaces capable of engaging the upper ends of posts 48 in flush sliding relation. The pivot pin-accommodating apertures in the lower ends of link members 51 are enlarged vertically so that, while the pivot pins 50 are snugly embraced by the walls of such apertures with regard to lateral relative movement, the apertures in the links allow a significant amount of vertical movement of the links relative to the lower pivot pins. Such enlargement of the lower apertures of the links is adequate to enable the jacking units to descend, when the weight of the associated leg 2 is applied to the jacking unit (as during raising or lowering of the legs when the vessel is afloat) far enough to bring the lower ends of plates 40, 44 into direct engagement with the upper end surfaces 48*a*, FIG. 8 of the vertical posts 48. HOwever, when forces are applied to the jacking units which tend to place the link members 51 in tension (as when the vessel 1 is being raised on legs 2), the frames 31 of the jacking units are raised slightly above the supporting structures 47, so that the relationship seen in FIG. 8 exists. Under both conditions, the connections between frames 31 and supporting structures 47 afforded by link members 51 and the cooperating pivot pins allows the frames, and therefore the entire jacking units, to shift laterally, relative to vessel **1**, in directions which are parallel to the plane of the rack members **11** (i.e., the plane containing the two sets of rack teeth **12, 13**) and transverse thereto. The dimensions of the link members and the relative positions of the pivot pins respectively on the supporting structures **47** and the frames **31** are such that the freedom of movement of frames **31** so provided is adequate to allow the jacking units to shift with the rack members when the legs are inclined, or when the vessel moves laterally relative to the legs, within the limits afforded by the guide shoes **22, 24**.

With the jacking units thus mounted, the link members **51** and their associated pivot pins and supports constitute freedom of motion means with respect to horizontal forces acting in the planes of the respective rack members. Since the pinions of each pair of pinions **33** are opposed across the respective rack member and meshed therewith, the jacking units and rack members act essentially as if they were combined rigidly with respect to horizontal forces in the plane of the rack members. Accordingly, it is not necessary to provide support for the jacking units, other than is provided by link members **51**, in horizontal directions in the plane of the rack members. Recognizing, however, that forces acting in directions perpendicular to the plane of the rack member can result in a like relative movement between the jacking unit and the rack, since the pinion teeth and rack teeth are in sliding engagement in such directions, the invention embodies additional retaining means to limit movement of the jacking units relative to their respective racks in horizontal directions perpendicular to the plane of the rack. In the embodiment of the invention shown in FIGS. **1–14**, a plurality of such additional means, indicated generally at **55** and shown in detail in FIGS. **11–14**, are employed.

As will be understood from FIGS. **1, 5** and **8**, each jack house **4** is equipped with a horizontal frame member **56** which is rigidly secured to the jack house structure and extends across the tops of the frames **31** of all of the jacking units, member **56** being spaced slightly above the top plates **37** of the frames. Each retaining means **55** includes cooperating elements fixed respectively to the top of the corresponding frame **31** and the lower face of the frame member **56**.

As seen in FIG. **13**, the retaining elements secured to the frame **31** include two pairs of relatively short rectangular plates **57**, the plates **57** of each pair being parallel and lying in planes which are parallel to the common plane of the pinions and rack member. The plates **57** of each pair are spaced apart in a direction perpendicular to the plane of the rack and pinions. Plates **57** are secured directly to frame plate **37**, as by welding, and are rigidified by braces **58** and **59**. The plates **57** of each pair are respectively aligned with the corresponding plates **57** of the other pair so that the two pairs of plates can accommodate a stop bar **60** which is of rectangular transverse cross-section and is of such length as to extend for the full distance between the outer ends of the respective plates **57**. Block **60** is carried by bolts **61** which extend through aligned openings in the respective plates **57** and the corresponding end portion of block **60** and are secured in place by nuts **62**. Block **60** is snugly accommodated between the respective pairs of plates **57**.

As seen in FIG. **14**, the elements secured to horizontal frame member **56** include two rectangular plates **63** which are secured directly to the bottom surface of member **56**, as by welding, and are rigidified by plate-like brace members **64**. PLates **63** are parallel and spaced apart by a distance equal to the width of block **60** plus a small working clearance. The dimension of plates **63**, in the direction of the length of frame member **56**, is substantially less than the space between the adjacent edges of the aligned ones of plates **57**. Thus, as shown in broken lines in FIG. **13**, plates **63** can occupy positions between the aligned ones of plates **57**, with the adjacent edges of the respective plates **57** and **63** being spaced apart by a small distance. As seen in FIGS. **12** and **13**, the vertical dimensions of plates **57** and **63** are slightly less than the vertical space between the bottom face of frame member **56** and the surface of plate **37**.

In the assembled device, the retaining means **55** constitute interconnections between the tops of frames **31**, on the one hand, and frame member **56**, on the other hand. As to forces acting on the jacking units in directions at right angles to the planes of the respective rack means, the snug engagement of blocks **60** between the pairs of plates **57** fixes the jacking units against movement in such directions relative to the vessel. As to forces acting on the jacking units in directions parallel to the plane of the respective rack means, the fact that blocks **60** are free to move lengthwise, sliding relative to plates **57**, allows a freedom of lateral movement limited by engagement of the adjacent edges of plates **63** and the respective plates **57**. This limiting action with respect to lateral movement is provided at the top of frame **31** to supplement the limitations applied to such movements as a result of engagement of the pinions with the rack member and as a result of engagement of the lower ends of beams **34** with the upper ends of support posts **48**.

Advantageously, each jacking unit **30** is also provided with two additional retaining means **65** which are substantially identical with retaining means **55** but are located at the bottom of frame **31**, the lower set of retaining elements being supported by a horizontal bar **66** secured on rearwardly projecting arms **67** carried by the posts **48** of the supporting structure **47**, FIG. **9**.

Considering FIGS. **3–6**, it will be noted that each leg structure **2** includes three column members **5** spaced apart in triangular fashion, and that there is a jacking unit **30** associated with each of the three column members. Though the triangular disposition of the respective column members and jacking units might at first appear inherently to restrain the movement of any one of the three jacking units relative to the column member with which it is associated, it must be noted that movement of any of the three jacking units in, e.g., a direction parallel to the plane of the rack means with which that jacking unit is associated will result in a force at the other two column members which can be considered as having two components, one in the plane of the rack means of such other column member, the other at right angles thereto. This force is resolved partly by relative sliding movement between the teeth of the jacking unit pinions and the teeth of the rack means, and partly by the compliance of the mounting means for the respective jacking unit with respect to forces acting in the plane of the rack means with which the jacking unit is associated.

FIGS. 15 and 16 illustrate another embodiment of the invention. Here, each jacking unit 70 comprises a rigid frame 71 constructed generally in the fashion hereinbefore described with reference to frame 31, FIG. 8, and comprising vertical box beams 72 at the front sides of the frame, a top end plate 73, and a bottom end plate 74. Top plate 73 includes thickened rectangular portions 75 each centered on a different one of the vertical beams 72. Similarly, the bottom plate 74 includes two rectangular thickened portions 76 each centered on the bottom of one of the beams 72. In this embodiment, the freedom of motion means comprises four compression columns 77. Two such columns are engaged between portions 75 of the top plate 73 of frame 71 and a horizontal frame member 78 which is rigidly secured to the vessel 1 and which extends in a location above the upper ends of the jacking unit. The remaining two compression columns 77 are disposed between the thickened portions 76 of bottom end plate 74 and the respective upper ends of posts 79 of a support structure 80 which is secured to the deck of vessel 1. Each compression column 77 comprises alternate steel plates and bodies of an elastomeric material laminated into an integral structure. Such columns can be, e.g., on the order of 30 inch in height, with the elastomeric lamina being on the order of 1 inch in thickness and the steel plates being on the order of 1/4 inch in thickness. Accordingly, such columns offer great strength in compression, and can be resiliently deformed axially and, to a limited degree, transversely. Accordingly, the compression columns 77 offer the same freedom of relative movement between the jacking units and the vessel as do the link mechanisms of the embodiment shown in FIGS. 1-14. However, the compression columns 77 also provide freedom of movement for the jacking units in directions other than those which are parallel to the plane of the rack teeth.

In this embodiment, the legs of the structure each comprise a plurality of cylindrical column members 81 and the rack means each comprise two rack bars 82 which are welded directly to the outer surface of the column member and lie in a common plane which extends chordwise with respect to the circular transverse cross section of the column member. Accordingly, an arcuate portion 83 of the wall of the column member 81 constitutes the intermediate or body portion of the rack means, the outer surface of portion 83 therefore corresponding to surface 19 of the rack means illustrated in FIG. 2.

Each jacking unit 70 includes three pairs of pinions 84 with the pairs of pinions being aligned vertically one above the other as seen in FIG. 15. Save for the difference in number of pinions, the meshed relationship between the pinions and the teeth presented by rack bars 82 is the same as hereinbefore described with reference to the embodiments of FIGS. 1–14. Frame 71 carries a plurality of motor and gear reduction units 85, each unit 85 being connected to drive a different one of the pinions 84 in the manner disclosed in our copending application Ser. No. 876,781. now U.S. Pat. No. 3,606,241.

In the embodiment of FIGS. 15 and 16, the additional means acting to prevent the jacking unit from being shifted toward or away from the rack means comprises guide members carried by the frame 71 of the jacking unit and cooperating directly with portions of the rack means. Thus, two pairs of guide members 86 are secured to frame 71, one pair adjacent the top of the frame and the other adjacent the bottom thereof. Members 86 lie in a common plane which is parallel to the plane of the rack bars and located between the rack bars and front plate 87 of the frame. One guide member 86 of each pair overlaps a different one of the rack bars 82. Also secured to frame 71 are two pairs of guide members 88, one pair at the top of the frame and one at the bottom thereof. Guide members 88 lie in a common plane which is parallel to the plane of the rack bars and located on the side of the rack bars opposite front plate 87 of the the frame. One member 88 of each pair overlaps a different one of the rack bars 82. Should the jacking unit 70 tend to move toward the leg of which column member 81 forms a part, such movement is stopped by engagement of members 86 with the respective rack bars 82. Similarly, relative movement in the opposite direction is stopped by engagement of members 88 with the rack bars 82.

FIG. 17 illustrates an alternative arrangement in which the guide members 86 of the structure shown in FIG. 16 are eliminated in favor of two members 86*a* secured directly to front plate 87 of frame 71, one at the top of the frame and one at the bottom, the members 86*a* being centered with respect to the pairs of pinions 84 and thus opposed to portion 83 of column 81. In this embodiment, movement of the jacking unit 70 toward the leg is stopped by engagement of member 86*a* with portion 83 of column member 81. Advantageously, the faces of members 86*a* directed toward the column member are of arcuate transverse cross-section to provide a wide area of contact with the column member portion 83.

FIGS. 18 and 19 illustrate yet another embodiment of the invention, wherein the jacking units indicated generally at 90 are equipped with link members 91 to provide freedom of motion, in horizontal directions parallel to the plane of the rack means, in the fashion described in detail with reference to FIGS. 8–10. In this embodiment, however, the additional means for essentially preventing relative horizontal movement between the jacking units and the associated rack means and leg structure in directions perpendicular to the plane of the rack means comprises two pairs of horizontally extending link members 92. Link members 92 are arranged with one pair located at the top of the jacking unit and the other pair located at the bottom of the jacking unit, one end of each link being pivoted directly to the frame of the jacking unit and the other end being pivoted to a support member, indicated at 93, rigidly secured to the vessel, all of the pivotal axes being vertical. As in the case of the link members described with reference to FIGS. 8–10, link members 92 are equal in effective length, so that a parallelogram type of linkage is provided. Accordingly, though the link members 92 allow the jacking units 90 and the vessel to move relative to each other in directions which are transverse to the rack means and lie in the plane of the rack means, the link members 92 essentially eliminate any relative movement between the jacking units and the vessel in directions perpendicular to the rack means, save for such small movements in those directions which are inherent in the operation of the parallelogram linkage.

In all embodiments of the invention, it is advantageous to have the pairs of pinions spaced apart longitudinally along the rack member by distances such that the phase of tooth engagement for each successive pair of pinions is different from that of the next adjacent pair of pinions, as will be clear from FIGS. **8** and **15.** Thus, the pairs of pinions are spaced apart longitudinally of the rack member by distances which are fractional multiples of the circular pitch of the pinion. Accordingly, teeth **33**a, FIG. **8,** of the pinions of one pair are, e.g., fully meshed with the appropriate rack teeth when teeth **33**b of the next adjacent pair of pinions are significantly less than fully engaged with the appropriate rack teeth. The difference in phase of tooth engagement, pair-to-pair, depends upon the number of pairs of pinions employed, being less when the number of pairs increases.

What is claimed is:

1. In an offshore installation of the type comprising a structure to be supported, a plurality of upright legs for supporting the structure in vertically adjustable fashion, a plurality of upper guide members for each of the legs, and a plurality of lower guide members for each of the legs, the upper and lower guide members being spaced apart by a substantial vertical distance and being in vertical alignment and so disposed relative to the legs as to allow free relative vertical movement between the legs and structure to be supported while constraining relative movement between the legs and the structure to be supported in directions lateral with respect to the legs, the effective spacing between the guide members and the legs being such that the legs can cant at very small angles relative to the structure to be supported and that the structure to be supported can move laterally relative to the legs through distances on the order of a fraction of an inch, the combination of

a plurality of rack means each having two sets of parallel oppositely facing rack teeth,

each of said rack means being rigidly secured to one of the legs in such fashion that both of said sets of teeth are spaced outwardly from the leg to which the rack means is secured;

a plurality of jacking units carried by the structure to be supported and each cooperating with a different one of said rack means, each of said jacking units comprising

a frame having an upper end and a lower end, and

a plurality of pairs of pinions each mounted on said frame for rotation about a fixed axis, said axes of each of said pairs of pinions being mutually parallel and spaced apart, each pinion of said pairs of pinions being operatively meshed with a different one of said two sets of rack teeth of the corresponding one of said rack means, such meshed relation of said pinions with said rack teeth, and the fact that said axes are fixed relative to said frame, causing any force tending to disengage one pinion of said pairs of pinions by movement away from the corresponding set of rack teeth to be opposed by engagement of the other pinion of the pair of pinions with its corresponding set of rack teeth, said pairs of pinions being spaced one above the other so that, said pinions being meshed with the corresponding rack means and said pairs of pinions being spaced over a significant portion of the corresponding rack means, the fact that the axes of rotation of said pinions are rigidly fixed by said frame constraining relative angular displacement between the rack means and said frame in directions parallel to the plane of said rack teeth to values less than would be allowed by the upper and lower guide means; and

mounting means interconnecting at least one of said upper and lower ends of said frame of each of said jacking units and a rigid member of the structure to be supported, said mounting means comprising

freedom of motion means arranged to allow said jacking units to move, relative to the structure to be supported, at least in directions which are parallel to the plane of said rack teeth of the corresponding one of said rack means and transverse to such rack means; and

retaining means connected to said frame of each of said jacking units and arranged to at least limit movement of said jacking units in directions perpendicular to the plane of said rack teeth of the corresponding one of said rack means.

2. The combination defined in claim **1,** wherein said freedom of motion means comprises link members each pivotally connected to both said frame of the respective jacking unit and a rigid part of the structure to be supported.

3. The combination defined in claim **2,** wherein

said link members of each of said mounting means are connected to one end of said frame of the respective jacking unit, and

said retaining means comprises cooperating stop elements fixed respectively to the other end of said frame and a member secured to the structure to be supported.

4. The combination defined in claim **3,** wherein

said link members are secured to the bottom end of said frame.

5. The combination defined in claim **1,** wherein

said retaining means for each of said jacking units comprises

two elements spaced apart in a direction perpendicular to the plane of the rack teeth of the respective rack means and secured to one of said frame of the jacking unit and the structure to be supported, and

a member secured to the other one of said frame and the structure to be supported and disposed between said elements.

6. The combination defined in claim **5,** wherein

said retaining means further comprises

two additional elements spaced apart in a direction parallel to the plane of said rack teeth and secured to said other one of said frame and the structure to be supported,

one of said first-mentioned two elements being disposed between said two additional elements.

7. The combination defined in claim **1** and further including

support means secured to the structure to be supported, and

frame means secured to the structure to be supported and spaced above said support means,

said frames of said jacking units being disposed between said support means and said frame means,

said retaining means comprising for each of said jacking units

a first set of cooperating elements secured respectively to the top of said frame of the respective jacking unit and to said frame means, and a second set of cooperating elements secured respectively to the bottom of said frame and to said support means.

8. The combination defined in claim **7** and wherein said freedom of motion means comprises link members each having one end pivoted to said lower end of said frame and the other end pivoted to said support means, said ends of said link members being pivoted about axes perpendicular to the plane of said teeth of the corresponding one of said rack means.

9. The combination defined in claim **1**, wherein said retaining means comprises for each of said jacking units

a first pair of members carried by said frame and each overlapping a different one of the two sets of teeth of said rack means on the side thereof opposite said frame, and

a second pair of members carried by said frame and each overlapping a different one of the two sets of teeth of said rack means on the side thereof adjacent said frame.

10. The combination defined in claim **1**, wherein said retaining means comprises for each of said jacking units

means carried by said frame of the respective jacking unit and presenting a surface directed toward the longitudinally extending central portion of the rack means with which the jacking unit is associated, and

two members carried by said frame and each overlapping a different one of the two sets of rack teeth of said rack means on the side thereof opposite said surface.

11. The combination defined in claim **1**, wherein said retaining means comprises for each of said jacking units a plurality of horizontally extending link members each pivoted at one end to said frame of the respective jacking unit and at the other end to the structure to be supported.

12. The combination defined in claim **1** and further including

support means secured to the structure to be supported,

said freedom of motion means comprising for each of said jacking units

first and second link members spaced apart horizontally and each projecting upwardly from said support means,

a first pair of horizontal pivot pins carried by said frame of said jacking unit at said bottom end thereof, the upper ends of said link members having openings in which said first pair of pivot pins are respectively engaged to pivotally connect said links to said bottom end of said frame, and

a second pair of horizontal pivot pins carried by said support means, the lower ends of said link members having openings in which said second pair of pivot pins are respectively engaged to pivotally connect said links to said support means,

said link members being of the same effective length;

said support means and said frame of the jacking unit having opposed horizontal surfaces capable of sliding engagement with each other,

at least one of said openings of each of said link members being elongated, lengthwise of the link member, to provide lost motion connections to allow the jacking unit to move toward said support means and bring said horizontal surfaces into engagement when the relative forces on the jacking unit and the structure to be supported are such as to tend to place said link members under compression.

13. The combination defined in claim **1**, wherein each pair of pinions is spaced, longitudinally of the cooperating rack means, from the next adjacent pair of pinions by a distance such that the pinions of one pair engage the rack means with a different phase of tooth engagement than do the pinions of the next pair.

14. In an offshore platform, the combination of

a platform structure;

a plurality of upright legs,

said platform structure defining a plurality of openings and each of said legs extending freely through one of said openings,

each of said legs comprising a plurality of mutually parallel elongated hollow column members of curvi-linear transverse cross section and means rigidly interconnecting said column members;

a plurality of rack means, each of said rack means comprising

two elongated rack bars each having a set of rack teeth,

said rack bars of each of said rack means being rigidly secured throughout its length to the wall of one of said column members with both of said rack bars lying in a common plane which is parallel to and spaced laterally from the longitudinal central axis of said column member and which extends chordwise with respect to the transverse cross section thereof,

an elongated portion of the wall of said column member interconnecting said rack bars and constituting the main body portion of said rack means;

a plurality of jacking units each operatively associated with a different one of said rack means, each of said jacking units comprising

a frame,

a plurality of pairs of pinions, said pinions being mounted on said frame for rotation about parallel horizontal axes with the pinions of each pair spaced apart horizontally and with the pairs of pinions arranged one above another, one pinion of each pair being operatively meshed with the teeth of one of said rack bars of the corresponding one of said rack means and the other pinion of each pair being operatively meshed with the teeth of the other of said rack bars, and

power means carried by said frame and operatively connected to said pinions to drive the same; and

means mounting each of said jacking units on said platform structure with freedom of horizontal movement, relative to said platform structure, in directions parallel to the plane of said rack bars.

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