

[54] SPUD TANK FOR OFFSHORE DRILLING UNIT

Primary Examiner—Jacob Shapiro  
Attorney, Agent, or Firm—Torres & Berryhill

[75] Inventor: Peter M. Lovle, Houston, Tex.

[73] Assignee: Engineering Technology Analysts, Inc., Houston, Tex.

[22] Filed: Sept. 5, 1972

[21] Appl. No.: 286,162

[57] ABSTRACT

A spud tank for attachment to at least one of the legs of an offshore drilling unit having a work platform and a plurality of legs depending therefrom for supporting the drilling unit on the floor of a body of water. The spud tank may comprise an elongated body section and a tip section depending downwardly from the body section. The uppermost portion of the body section may be provided with a polygonal cross section, the lowermost portion having a substantially star-shaped cross section of a relatively smaller area. The sides of the polygonal cross section may be connected to the sides of the star-shaped cross section by nonplanar walls. The tip section may comprise a plurality of radial blade members, the outer edges of which are tapered downwardly and inwardly from the points of the star-shaped body cross section, converging together in a pointed tip.

- [52] U.S. Cl. .... 61/46.5, 61/53, 37/73
- [51] Int. Cl. .... E02b 17/00, E02d 5/72
- [58] Field of Search ..... 61/46.5, 46, 53; 37/73; 52/170

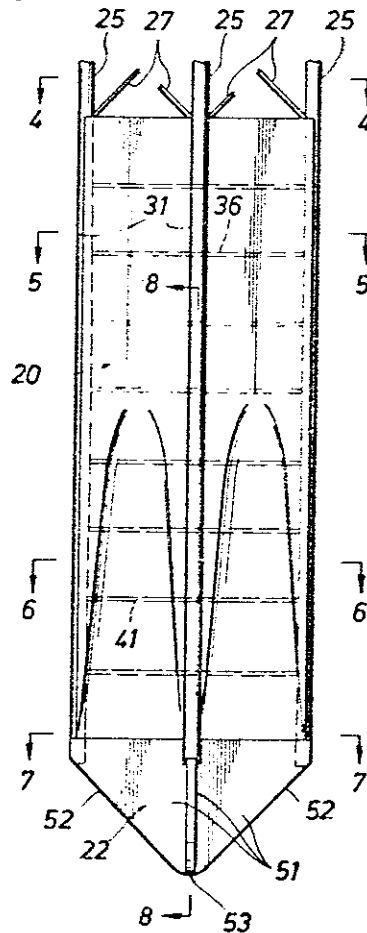
[56] References Cited  
UNITED STATES PATENTS

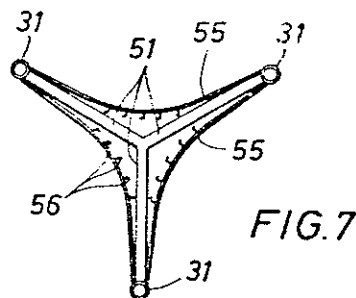
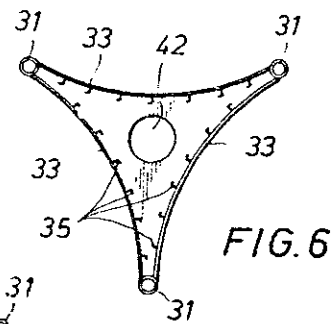
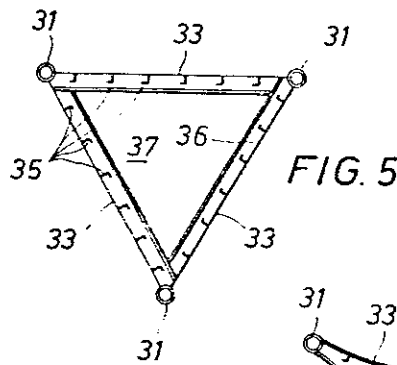
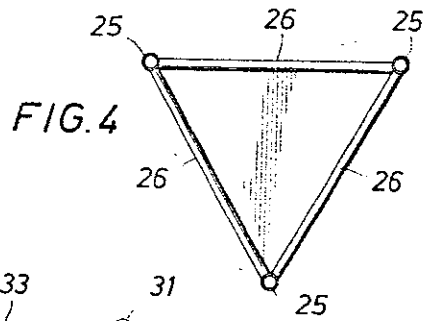
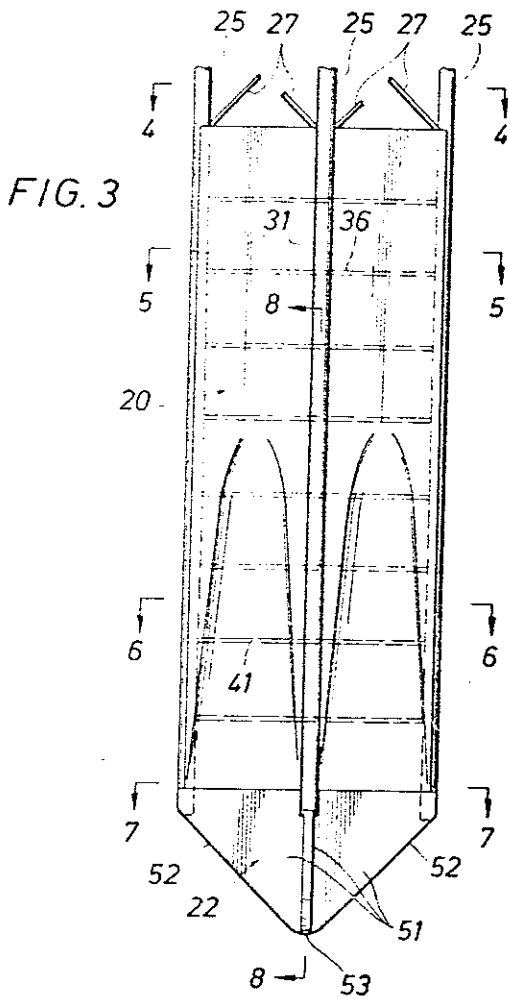
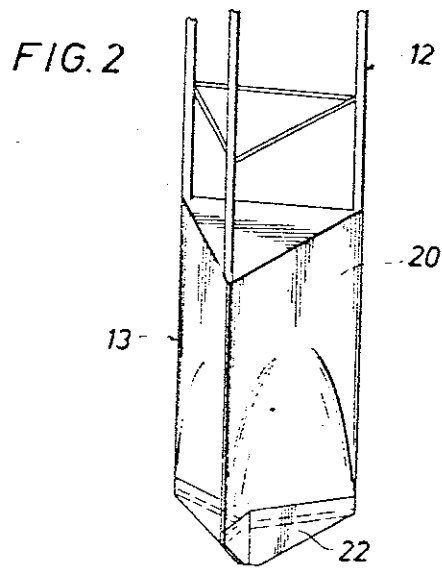
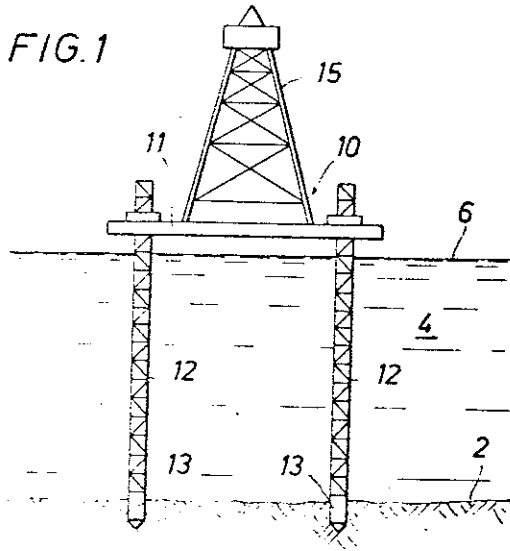
2,049,605	8/1936	Driemeyer	37/73
3,479,828	11/1969	Luque	61/46.5

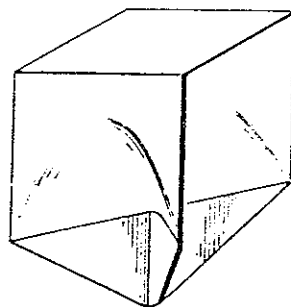
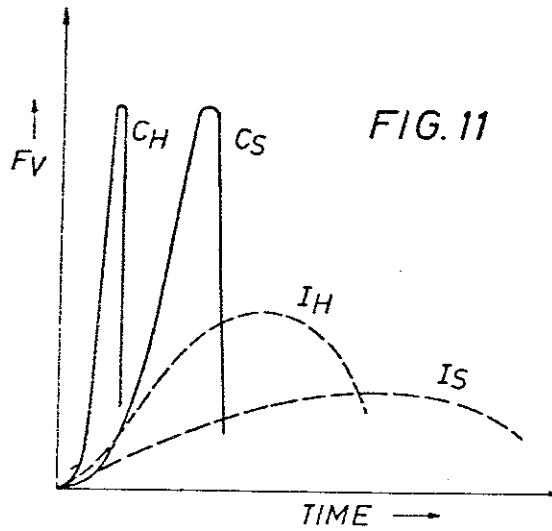
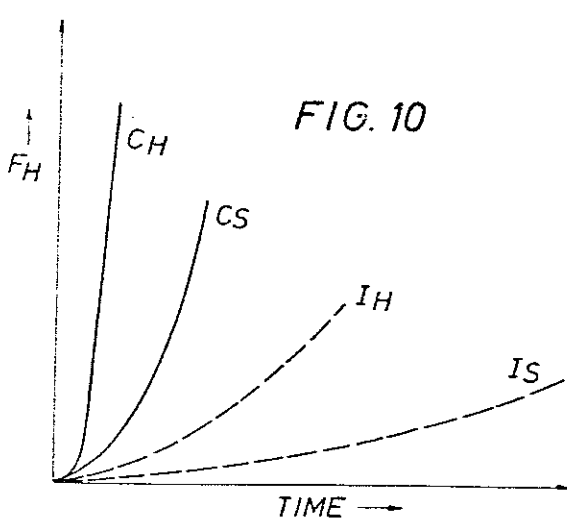
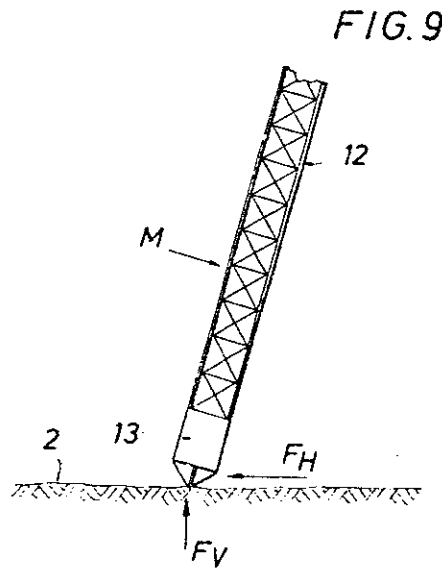
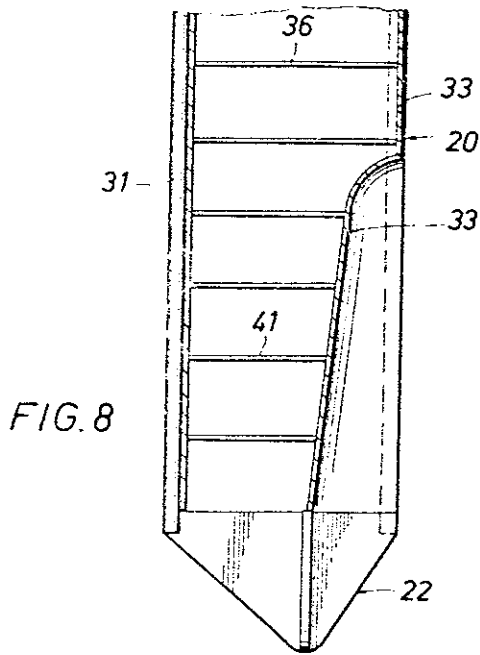
FOREIGN PATENTS OR APPLICATIONS

536,165	9/1930	Germany	61/53
---------	--------	---------	-------

20 Claims, 12 Drawing Figures







## SPUD TANK FOR OFFSHORE DRILLING UNIT

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention pertains to offshore drilling units. In particular, it relates to units having a work platform and a plurality of legs depending therefrom for supporting the unit on the floor of a body of water. More specifically, the present invention pertains to spud tanks or feet for attachment to the lower end of the legs of such a unit.

#### 2. Description of the Prior Art

With the increasing scarcity of petroleum deposits which are accessible by drilling on land, there has been a corresponding increase in the search for petroleum deposits at offshore locations. In the shallower water depths up to 300 feet, drilling operations are usually conducted from semi-submersible and jack-up drilling units. Until very recently, drilling operations in water depths exceeding 300 feet have been exclusively performed from semi-submersible and floater type drilling units. In the past four or five years a few jack-up drilling units have been built which are capable of use in water depths of up to 350 feet.

But offshore drilling for oil and gas deposits is proceeding in deeper and deeper water. Furthermore, the trend has also been towards exploration drilling in more hostile environments. Currently semi-submersible and floater type drilling units are being used on the outer reaches of the Continental Shelf (300 to 600 feet).

Thus far, design technology has limited the jack-up units to water depths of 300 feet and less. It can be demonstrated that a jack-up drilling unit, if design technology so permits, would be more practical for drilling in depths of 300-500 feet than semi-submersible and floater type units. This is due to the decrease in construction costs and increase in operating efficiencies.

Some of the problems encountered in the design of a jack-up drilling unit for water depths of 300 to 500 feet are:

1. Greater difficulty in getting on and off location
2. More severe wind and wave conditions
3. Size and costs for current types of designs increase almost exponentially with operating water depth.

The difficulty of getting a jack-up drilling unit on and off location increases with increasing water depths and the consequent increases in leg lengths. Motion of the hull causes the spud tank or foot to move at a velocity proportional to the leg length. Thus the impact on the leg, as it first hits bottom, increases dramatically with longer legs. This problem is further compounded by the rough sea conditions which prevail in areas where such a large unit may be used. When such a jack-up drilling unit lowers its legs in the rough water, the sea conditions may cause the spud feet, attached to the lower end of the legs, to strike the ocean floor with considerable force. Such impacts can damage the leg structure and the barge or platform structure itself, if excessive. The spud tank or foot design of the prior art is not suitable for sufficiently reducing the impact on the unit legs as they first hit bottom in deep water, particularly in rough sea conditions.

Another problem encountered in such units is a lack of sufficient penetration of the spud foot into the ocean bottom when firm soil conditions are encountered. Although some of the prior art designs may allow good

penetration, many do not have good directional restraint. Furthermore, the prior art spud feet which have good penetration characteristics do not exhibit good impact characteristics.

### SUMMARY OF THE INVENTION

The present invention concerns a new and improved spud foot for attachment to the legs of a jack-up drilling unit. The spud foot of the present invention is designed to reduce the impact on the unit legs as the jack-up unit is getting on and off location. In addition, the spud foot is designed to provide good penetration and directional restraint characteristics.

The spud tank or foot of the present invention comprises an elongated body section affixed to the lower end of the drilling unit legs and a tip section depending downwardly from the body section. The uppermost portion of the body section has a relatively large transverse cross-sectional area, the boundaries of which may define a polygon. The lowermost portion of the elongated body section has a star-shaped transverse cross section, the area of which is substantially smaller than the uppermost cross section. The lowermost cross-sectional area is connected to the uppermost cross-sectional area by a nonplanar wall so that the cross-sectional area of the elongated body increases from the lowermost portion to the uppermost portion.

The tip section may comprise a plurality of radial blade members whose outer edges are tapered downwardly and inwardly from the points of the star-shaped cross section, converging together in a pointed tip. In preferred embodiments there are the same number of blade members as there are points in the lowermost star shaped cross section of the body.

In a preferred embodiment of the invention the uppermost cross section of the body is triangular in shape and the lowermost cross section is a three pointed star. The intersection of the sides of the triangle are connected to the points of the star by longitudinally disposed chord members which transmit forces encountered by the spud feet to the drilling unit legs. One side of the triangular cross section may be connected to a pair of adjacent sides of the lowermost star-shaped cross section by a concave curvilinear surface. A three bladed tip, the radial blade members of which are aligned with the star-shaped lowermost cross section may be provided.

With such a spud foot design good penetration of the ocean bottom and good directional restraint is accomplished as the unit leg first reaches the ocean floor. Impact on the leg is minimal since the soil bearing area of the spud foot is relatively small when the leg first touches bottom. As the spud foot digs in, the bearing area gradually increases until it is sufficient to support the load of the unit.

With the spud foot design of the present invention and other improvements a jack-up unit can be built which is suitable for operation in depths of 300 to 500 feet. Further objects and advantages of the present invention will become apparent from the description which follows when read in conjunction with the accompanying drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

In the description which follows reference will be made to the accompanying drawings in which:

FIG. 1 is a schematic representation of a jack-up drilling unit at an offshore location in position for drilling operations;

FIG. 2 is a perspective view of the lower end of a jack-up unit drilling leg at the end of which is attached a spud foot according to a preferred embodiment of the invention;

FIG. 3 is a side elevation view of the spud foot and the lower end of the drilling unit leg illustrated in FIG. 2;

FIG. 4, taken along line 4—4 of FIG. 3, is a transverse cross-sectional view of the jack-up drilling unit leg;

FIG. 5, taken along line 5—5 of FIG. 3, is a transverse cross-sectional view of the uppermost portion of the elongated body which makes up a part of a spud foot constructed according to a preferred embodiment of the invention;

FIG. 6, taken along line 6—6 of FIG. 3, is a transverse cross-sectional view of the lowermost portion of the elongated body which makes up a part of the spud foot;

FIG. 7, taken along line 7—7 of FIG. 3, is a transverse cross-sectional view of the tip section which makes up a part of the spud foot of the present invention, according to a preferred embodiment;

FIG. 8, taken along line 8—8 of FIG. 3, is a longitudinal cross-sectional view of the spud tank illustrated in FIGS. 2-7;

FIG. 9 is a force diagram illustrating the forces which may be encountered by the leg and spud foot of a jack-up drilling unit as it is being placed on location;

FIG. 10 is a series of curves representing horizontal force versus time relationships for both conventional spud foot designs and the design of the present invention and for both hard and soft ocean bottom materials;

FIG. 11 is a series of curves illustrating vertical force versus time relationships for both hard and soft bottom material, showing conventional spud tank designs in comparison with the design of the present invention; and

FIG. 12 is a perspective view of the lower end of a jack-up unit drilling leg and an alternate embodiment of the spud foot.

#### DESCRIPTION OF A PREFERRED EMBODIMENT

Referring first to FIG. 1 there is shown a jack-up drilling rig 10 on location and supported on the floor of a body of water 4. The drilling unit 10 may comprise a work platform 11 supported above the water surface 6 by a plurality of legs 12. Attached to the lower end of each of the legs 12 is foot support apparatus 13, sometimes commonly referred to as "spud cans" or "spud tanks." The derrick 15 and other equipment may be supported on the work platform 11 from which the drilling operations will be performed.

In moving to and from locations the unit legs 12 are in a raised position and are carried by the work platform 11. The platform 11 is designed to float, as a barge, so that with the drilling unit 10 it may be towed to and from locations by a suitable ocean going vessel. When jack-up units are brought onto location the legs 12 are lowered through the body of water 4 until they contact the floor 2. The spud cans or tanks 13 provide the bearing surfaces by which the unit is supported. As

the legs 12 are moved downwardly through the body of water 4, motion of the barge or platform 11 causes the spud tanks 13 to move at a transverse velocity proportional to the leg length. Thus the impact on the legs 12 as they first hit bottom increases at a rapid rate for longer legs. This problem may be further compounded if the unit is on location where rough sea conditions prevail.

A floating body may be subjected to three translational motions and three rotational motions. The translational movements are heave (up and down), longitudinal surge (backward and forward motion in a longitudinal direction) and transverse surge (backward and forward motion in a transverse direction). The three rotational movements are pitch (rotation about the transverse axis), roll (rotation about the longitudinal axis), and yaw (rotation about the vertical axis). The combination of these six motions affect the impact on the unit legs as they first hit bottom.

To reduce the impact on long legs required in jack-up units designed for water depths of 300 to 500 feet, spud tanks, according to the present invention, may be attached to the legs as shown in FIG. 2. Details of the spud tank of FIG. 2 are also shown in FIGS. 3-8 and reference will be made to all of these drawing figures in describing a preferred embodiment of the invention.

The spud tank 13 may comprise elongated body section 20, which may be welded to the lower end of leg 12, and a tip section 22 which depends downwardly from the body section. Leg 12 may be of any suitable construction. The construction shown is of triangular cross section, as shown in FIG. 4, having three longitudinal chord members 25 joined by horizontal supports 26 and suitable cross-bracing 27. The chord members 25 are illustrated as being circular, such as pipe. However, they may be of any structural shape desired. The leg itself may be of any cross section desired. In fact it may be a solid section such as a circular or noncircular caisson.

The uppermost portion of the elongated body section 20 may be triangular in cross section as shown in FIG. 5. It is not necessary that the cross section be triangular. It can be square, rectangular, circular or any other shape. However, in preferred embodiments it will usually be an equilateral polygon. At this point, the spud tank body 20 may comprise longitudinal chord members 31 joined together in conventional ship construction by outer plates 33 reinforced by longitudinal stiffeners 35. These stiffeners 35 may be structural angles or any other suitable structural members. Near the uppermost cross section the body 20 may be provided with a triangular bulkhead 36 having a triangular opening 37 therethrough. Chord members 31 may actually be a continuation of leg chord members 25.

The lowermost portion of the elongated body 20 is star-shaped in cross section, as shown in FIG. 6, and may be provided with a star-shaped bulkhead member 41 having an opening 42 therethrough. In preferred embodiments there are the same number of points in the lowermost star-shaped cross section as there are number of sides in the uppermost polygonal cross section and the points of the star in the lowermost cross sections are connected to the intersection of polygon sides in the uppermost cross sections by the longitudinal chord members 31. The outer plates 33 which form the enclosure walls of the elongated body 20 extend

from the upper end of the body to the lower end and are necessarily bent inwardly in a nonplanar or concave curvilinear surface to provide transition from the star-shaped cross sections to the uppermost triangular cross sections. As in the uppermost cross section the outer plates 33 may be reinforced by longitudinal stiffeners 35.

Looking also at FIG. 8, a better understanding of the curvature of outer plates 33 may be had. As seen in FIG. 8, a perpendicular plane intersecting one side of the uppermost triangular cross section at its mid-point will intersect the outer plate 33 in a parabolic or similar type of curve substantially asymptotic to the longitudinal axis of the body 20.

As stated before the spud tank 13 also comprises a tip section 22 depending downwardly from the body section 20. As best seen in FIGS. 3 and 7 the tip section 22 may comprise a plurality of radial blade members 51, the outer edges 52 of which are tapered downwardly and inwardly from the points of the star-shaped cross section, converging together in a pointed tip 53. In preferred embodiments of the invention there are the same number of radial blade members 51 as there are points in the lowermost star-shaped cross section of body 20. Reinforced plate members 55 may be utilized to provide transitions from the blades 51 to the outer plates 33 of the body section and may in fact be a continuation of the same plates. These plates 55 may also be reinforced by longitudinal stiffeners 56.

As can be seen from the details of construction of the spud tank, the sharp tip section 22 is provided for making initial contact with the ocean floor as the legs of the drilling unit are lowered into place. The relatively small cross-sectional area of the tip section 22 prevents excessive shock loading parallel to the floor 2, thus allowing a smooth stopping action as the spud tank brushes the floor and progressively digs in. The relatively small cross-sectional area of the tip section 22 also prevents excessive shock loading in the direction of the leg 12. In addition, the tip section allows good penetration of the bottom material which then provides good directional restraint as well as good resistance to scouring. As the spud tank digs further in, the cross-sectional area providing bearing load is increased from the lowermost sections toward the uppermost sections of the body until a sufficient bearing area is provided to support the unit. The transition from a small bearing area to a larger bearing area is smooth and gradual, minimizing the shock forces and distributing them over a longer period of time.

To illustrate the improved force versus time relationships of the spud tanks of the present invention, reference is made to FIGS. 9-11. As seen in the force diagram of FIG. 9 the leg 12 may be said to move in a direction M as the unit legs are lowered into place for contact with the ocean floor 2. As previously stated, the movement of leg 12 may be affected by roll, pitch, yaw and surge movements in the barge or platform from which the legs depend. The resultant horizontal force  $F_H$  acting on the spud tank 13 as the leg hits bottom can be caused by a combination of roll, pitch, yaw and surge. However, it would usually be caused with pitch or roll dominating. The resulting vertical force  $F_V$  acting on the spud tank 13 may be predominantly caused by heave, but pitch and/or roll may contribute. Referring to FIGS. 10 and 11 resultant horizontal force  $F_H$  and vertical force  $F_V$ , respectively, are shown plot-

ted against time for a conventional spud tank and a spud tank according to the present invention, for both hard and soft soil conditions. Curves  $C_H$  are for conventional spud tanks with a hard bottom while Curves  $C_S$  are for conventional spud tanks with a soft bottom. Curves  $I_H$  are for the improved design of the present invention with hard bottoms while curves  $I_S$  are for the improved design with soft bottoms. It can therefore be seen that the resultant horizontal forces  $F_H$  and vertical forces  $F_V$  are substantially reduced with a spud tank constructed according to the present invention and in addition these forces are distributed over a longer period of time. Thus, the high impact loads that substantially limit the rough sea conditions and water depths in which a jack-up drilling unit may be used are greatly reduced.

As previously pointed out, in addition to minimizing the impact on the jack-up unit legs when getting on location, the spud tank design of the present invention also provides better penetration of the bottom material which provides good directional restraint. It may also reduce scouring while the rig is in place and allow easier removal of the legs when it is desired to move to a new location.

Although the present invention has been primarily described for the purpose of increasing the depth in which a jack-up drilling unit may be operated, it is not so limited. For example, the performance of existing or proposed units for less than 300 foot water depths can also be improved by the use of the invention.

Although only one embodiment of the invention has been described in detail, there are, of course, many variations that may be made by those skilled in the art. For example, the spud tank may be square shaped at its uppermost portion and provided with a four pointed star-shaped cross section as its lowermost portions, as shown in FIG. 12. As suggested throughout the description many other variations may be made. For example, fins or blade extensions may be attached to the spud tank body depending upon the condition of the bottom and drag requirements. Still other variations of the invention may be made without departing from the spirit of the invention and it is intended that the scope of the invention be limited only by the claims which follows.

I claim:

1. In an offshore drilling unit having a work platform and a plurality of legs depending therefrom for supporting said unit on the floor of a body of water, spud means comprising: an elongated body affixed to and depending downwardly from the lower end of at least one of said legs, the uppermost portion of said body having a relatively large transverse cross-sectional area, the lowermost portion of said body having a substantially smaller star-shaped transverse cross-sectional area, the distance between adjacent points of said star-shaped transverse cross-sectional area being substantially the same as the distance between corresponding points in said uppermost cross-sectional area, said lowermost cross-sectional area being connected to said uppermost cross-sectional area by nonplanar wall means so that the cross-sectional area of said body increases from said lowermost area to said uppermost area.
2. Spud means as set forth in claim 1 in which said nonplanar wall means is curvilinear, said cross-sectional area of said body increasing as an exponential

function of the distance from said lowermost cross-sectional area.

3. Spud means as set forth in claim 1 in which said uppermost cross section is polygonal having the same number of sides as the number of points in said star-shaped lowermost cross-sectional area, the length of said sides being substantially the same as the distance between corresponding adjacent points in said star-shaped lowermost cross-sectional area.

4. Spud means as set forth in claim 3 in which said wall means comprises a plurality of curvilinear wall sections connecting one side of said polygonal cross section to two sides of said lowermost star-shaped cross section.

5. Spud means as set forth in claim 4 in which said spud means comprises a plurality of radial blade members depending downwardly from the lowermost portion of said elongated body, said blade members being symmetrically disposed relative to said star-shaped cross section.

6. Spud means as set forth in claim 5 in which the outer edges of said blade members are tapered downwardly and inwardly from said star-shaped cross section converging together in a pointed tip.

7. Spud means as set forth in claim 6 in which the number of said blade members is equal to the number of points in said star-shaped cross section, each of said blade members being radially aligned with one of said star points.

8. Spud means as set forth in claim 1 in which each of the points of said star-shaped lowermost portion is connected to said uppermost portion by longitudinal chord members through which forces applied to said elongated body are transmitted to said leg.

9. Spud means as set forth in claim 8 in which said chord members are vertically disposed in a parallel relationship with each other.

10. In an offshore drilling unit having a work platform and a plurality of legs depending downwardly therefrom for supporting said unit on the floor of a body of water, foot apparatus affixed to the lower end of at least one of said legs comprising:

- a. a body section;
- b. a tip section depending downwardly from said body section;
- c. the uppermost portion of said body section having a polygonal cross section, the lowermost portion having a substantially star-shaped cross section, the sides of said polygonal cross section being connected to the sides of said star-shaped cross section

by nonplanar walls and the distance between adjacent points of said star-shaped cross section being substantially the same as the length of a corresponding side of said polygonal cross section.

11. Foot apparatus as set forth in claim 10 in which the number of points in said star-shaped cross section are equal to the number of sides in said polygonal cross section, each of the intersections between the sides of said polygonal cross section being connected to one of said star points by a chord member.

12. Foot apparatus as set forth in claim 10 in which each side of said polygonal cross section is connected to two sides of said star shaped cross section by one of said nonplanar walls.

13. Foot apparatus as set forth in claim 12 in which said cross sections are symmetrical, a plane perpendicular to one side of said polygonal cross section at its midpoint intersecting one of said nonplanar walls in a parabolic curve substantially asymptotic to the longitudinal axis of said body section.

14. Foot apparatus as set forth in claim 12 in which said polygonal cross-section is triangular in shape, said star-shaped cross section being a three pointed star.

15. Foot apparatus as set forth in claim 10 in which said tip section comprises a plurality of radial blade members depending downwardly from said body section.

16. Foot apparatus as set forth in claim 15 in which there are the same number of radial blade members as there are points in said star-shaped cross section.

17. Foot apparatus as set forth in claim 16 in which the outer edges of said blade members are tapered downwardly and inwardly from the points of said star-shaped cross section, converging together in a pointed tip.

18. Foot apparatus as set forth in claim 15 in which said tip section is provided with downwardly tapered walls providing a transition from the lowermost portion of said body section to said radial blade members.

19. Foot apparatus as set forth in claim 10 in which the cross-sectional area of said body section gradually increases from said star-shaped cross section toward said polygonal cross section.

20. Foot apparatus as set forth in claim 19 in which the lateral dimension from one point of said star-shaped cross section to an adjacent point is substantially the same as the length of one side of said polygonal cross-section.

\* \* \* \* \*

55

60

65