

The background of the entire page is a faded, high-angle photograph of an offshore oil field. Several large jack-up rigs are visible, with their lattice structures extending into the sky. One rig on the right has a yellow section with the text 'ENSCO 102'. In the lower-left corner, a red and white supply vessel is partially visible. The ocean surface is a textured blue-grey.

# **JACK UP UNITS**

## **A TECHNICAL PRIMER FOR THE OFFSHORE INDUSTRY PROFESSIONAL**

by

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## 1. INTRODUCTION AND BACKGROUND

### 1.1 SYNOPSIS OF A JACK UP

A Jack Up is an offshore structure composed of a hull, legs and a lifting system that allows it to be towed to a site, lower its legs into the seabed and elevate its hull to provide a stable work deck capable of withstanding the environmental loads. A typical modern drilling Jack Up is capable of working in harsh environments (Wave Heights up to 80 ft, Wind Speeds in excess of 100 knots) in water depths up to 500 feet. Because Jack Ups are supported by the seabed, they are preloaded when they first arrive at a site to simulate the maximum expected leg loads and ensure that, after they are Jacked to full airgap and experience operating and environmental loads, the supporting soil will provide a reliable foundation.

### 1.2 PURPOSE AND DISCLAIMER

Jack Up Units are complex structures used offshore in many modes of operation. When using a particular Unit at a given site, it is important to be aware and understand the basics behind the different designs under different conditions. The focus of this primer is a simplified discussion of the various sensitivities of Jack Ups while in the different modes of operation. It is hoped that by increasing the understanding of how Jack Ups work and behave as well as the sources of the loads acting on them, those making decisions with limited information will be better equipped to respond to incidents and reduce their occurrence and/or consequences. Though there are many variations in design and purposes for Jack Ups, this primer focuses many of these discussions on three-legged Units used for drilling. The primer starts by presenting some background and discussions of the basics of Jack Up components analyses. This is followed by sections on Jack Up Components and Configurations, modes of operation, differences between Class approval and site specific assessment, basic analysis, and a discussion of competing aspects of Jack Up design.

### 1.3 BACKGROUND

Jack Up Units have been a part of the Offshore Oil Industry exploration fleet since the 1950's. They have been used for exploration drilling, tender assisted drilling, production, accommodation, and work/maintenance platforms. As with every innovative technology, Jack Up Units have been used to their operational and design limitations. These limitations include deck load carrying limits when afloat, load carrying capabilities when elevated, environmental limits, drilling limits, and soil (foundation) limits. The reasons for pushing these limits include the desire to explore deeper waters, deeper reservoirs in harsher environments, and in areas where soils and foundations may be challenging or even unstable.

Into this arena of expanding Jack Up Units' capabilities, Industry Groups, Classification Societies, and Flag States have involved themselves in an attempt to Regulate, Codify, and Unify the criteria used to gauge a Jack Up Unit's capabilities. Without a thorough knowledge of the background of these Regulatory efforts and the science that these efforts rely upon, the average Offshore Industry professional is given practically no useful tools when it comes time to assess, understand, and select a Jack Up Unit to fulfill a particular task or Mission Statement. Often times, a thorough understanding of Jack Up Unit capabilities and "sensitivities" prevents or minimizes the consequences of unexpected "incidents." This primer is an attempt to assist such individual in understanding the Regulations, science and engineering principles behind a Jack Up Unit's design and to assist that individual in answering the following questions:

- What are the components of a Jack Up Unit and what are their functions?
- What are the relative pros and cons of different types of Jack Ups and their features?
- How does the arrangement of a Jack Up affect its function and capability?
- What are the loads on a Jack Up, what impact do they have, and how are they evaluated?
- What do I need to look for - what makes a Jack Up "sensitive" to loadings?
- Who are the parties involved in the Jack Up from design through operation, and what are their roles?
- How do I select a suitable Jack Up Unit for my particular application?

This primer does not address commercial issues of Jack Up Rigs. Topics such as Construction Costs, Day Rates, Third Party Equipment, Supply and Crew Boat Costs, etc. are not covered in this primer.



## 2. COMPONENTS OF JACK UP RIGS AND THEIR FUNCTION

### 2.1 INTRODUCTION

There are three main components of a Jack Up Unit: the Hull, the Legs & Footings, and the Equipment. This section of the primer describes each of these components and their functions.

### 2.2 HULL

The Hull of a Jack Up Unit is a watertight structure that supports or houses the equipment, systems, and personnel, thus enabling the Jack Up Unit to perform its tasks. When the Jack Up Unit is afloat, the hull provides buoyancy and supports the weight of the legs and footings (spud cans), equipment, and variable load. Different parameters of the hull affect different modes of operation of the Unit. These are described below.

In general, the larger the length and breadth of the hull, the more variable deck load and equipment the Unit will be able to carry, especially in the Afloat mode (due to increased deck space and increased buoyancy).

Also, larger hulls generally result in roomier machinery spaces and more clear space on the main deck to store pipe, 3<sup>rd</sup> Party Equipment, and provide for clear work areas. The larger hull may have larger preload capacity that may permit increased flexibility in preloading operations.

Larger hulls generally have the negative effects of attracting higher wind, wave and current loads. Since Jack Ups with larger hulls weigh more, they will require more elevating jacks of larger capacity to elevate and hold the Unit. The large weight also affects the natural period of the Jack Up Unit in the elevated mode.

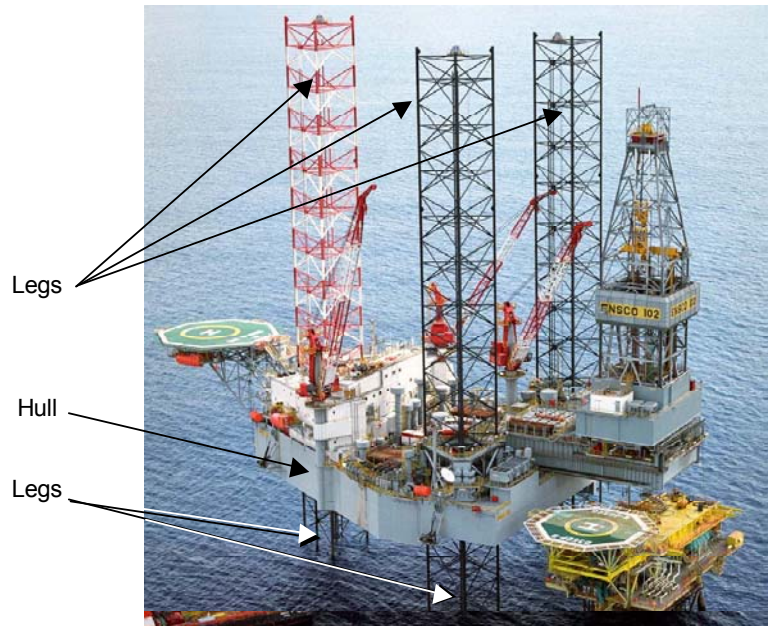
The draft of the hull, or the distance from the afloat waterline to the baseline of the hull, has a direct effect on the amount of variable deck load that can be carried and the stability when afloat. The draft of the hull has an opposing relationship with the hull's freeboard, or the distance from the afloat waterline to the main deck of the hull. Every incremental increase in the draft of a Jack Up decreases the freeboard by the same increment.

For units with identical hulls, the one with the deeper draft weighs more. This increased weight could be in the form of lightship weight or variable deck load. Conversely, for Units with identical hulls, the unit with the deeper draft will have less afloat stability than the unit with shallower draft. Perhaps the most influential parameter in a Jack Up unit's afloat stability is freeboard. For units with identical hulls and leg length, the one with the larger freeboard will have the larger afloat stability margin.

### 2.3 LEGS AND FOOTINGS

The legs and footings of a Jack Up are steel structures that support the hull when the Unit is in the Elevated mode and provide stability to resist lateral loads. Footings are needed to increase the soil bearing area thereby reducing required soil strength. The legs and footings have certain characteristics which affect how the Unit reacts in the Elevated and Afloat Modes, while going on location and in non-design events. Descriptions of various types of legs and footings follow in Section 3 below.

The legs of a Jack Up Unit may extend over 500 ft above the surface of the water when the Unit is being towed with the legs fully retracted. Depending on size and length, the legs usually have the most detrimental impact on the afloat stability of the Unit. The heavy weight at a high center of gravity and the large wind area of the legs combine to dramatically affect the Unit's afloat stability. For Units of the same hull configuration and draft, the Unit with the larger legs will have less afloat stability.



When in the Elevated Mode, the legs of a Jack Up Unit are subjected to wind, wave, and current loadings. In addition to the specifics of the environment, the magnitude and proportion of these loads is a function of the water depth, air gap (distance from the water line to the hull baseline) and the distance the footings penetrate into the seabed. Generally, the larger the legs and footings, the more load wind, wave, and current will exert on them.

Legs of different design and size exhibit different levels of lateral stiffness (amount of load needed to produce a unit deflection). Jack Up stiffness decreases with increases in water depth (or more precisely, with the distance from the support footing to the hull/leg connection). Furthermore, for deeper water depths, flexural stiffness (chord area and spacing) overshadows the effects of shear stiffness (brace). Leg stiffness is directly related to Jack Up stiffness in the elevated mode, thereby affecting the amount of hull sway and the natural period of the Unit (which may result in a magnification of the oscillatory wave loads).

## 2.4 PRELOAD AND SOIL PENETRATION

Jack Ups are preloaded when they first arrive at a site to ensure the soil is capable of withstanding the maximum expected footing reaction (either from the extreme storm condition or from the operating condition) without experiencing additional leg penetration or soil failure. The amount of leg penetration is determined by soil properties, vertical reaction of the legs, and footing area. Generally, the larger the footing area for the same vertical reaction and soil, the lower the penetration. The amount of soil penetration should be checked against the footing structural capabilities and scour characteristics of the site. There are various preload techniques such as single-leg preloading and jacking with minimal air gap that reduce the risk of experiencing adverse effects when rapid penetration (punch-through) occurs. Soil information and predicted penetration curves should be onboard and understood before making the decision to preload at a site. It is recommended that leg penetrations during preloading be recorded (i.e., generate actual penetration vs. footing reaction curves) and compared against the predicted penetration curves, as this information is invaluable in assessing the quality/validity of the soil assessment and will serve to improve future calculations.

## 2.5 EQUIPMENT

The equipment required to satisfy the mission of the Jack Up Unit affects both the hull size and lightship weight of the Unit. There are three main groups of equipment on a Jack Up Unit, the Marine Equipment, Mission Equipment, and Elevating Equipment.

“Marine Equipment” refers to the equipment and systems aboard a Jack Up Unit that are not related to the Mission Equipment. Marine Equipment could be found on any sea-going vessel, regardless of its form or function. Marine Equipment may include items such as main diesel engines, fuel oil piping, electrical power distribution switchboards, lifeboats, radar, communication equipment, galley equipment, etc. Marine Equipment, while not directly involved with the Mission of the Jack up Unit, is necessary for the support of the personnel and equipment necessary to carry out the Mission. All Marine Equipment is classified as part of the Jack Up Lightship Weight.

“Mission Equipment” refers to the equipment and systems aboard a Jack Up Unit, which are necessary for the Jack Up to complete its Mission. Mission Equipment varies by the mission and by the Jack Up. Two Jack Up Units which are involved in Exploration Drilling may not have the same Mission Equipment. Examples of Mission Equipment may include derricks, mud pumps, mud piping, drilling control systems, production equipment, cranes, combustible gas detection and alarms systems, etc. Mission Equipment is not always classified as part of the Jack Up Lightship Weight. Some items, such as cement units, are typically classified as variable deck load as they may not always be located aboard the Jack Up.

“Elevating Equipment” refers to the equipment and systems aboard a Jack Up Unit which are necessary for the Jack Up to raise, lower, and lock-off the legs and hull of the Jack Up. This equipment is described in more detail in Sections 3.7 and 3.8, below.

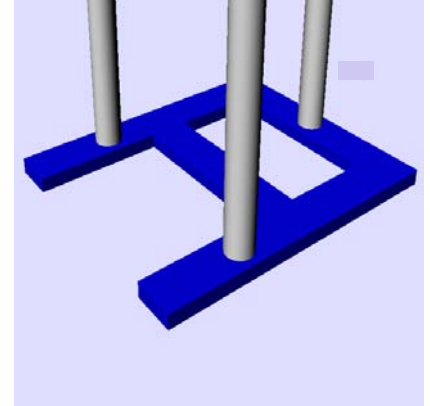
### 3. BASIC JACK UP CONFIGURATIONS

There are many components that are common to all Jack Ups; however, differing design and operational philosophies dictate some of the subtle differences among Jack Up Units. The basic differences between Jack Up Units involve the legs, elevating systems, and load transfer philosophy between the hull and the legs. This section of the primer identifies those basic differences, and elaborates on pros and cons of each.

#### 3.1 MAT FOOTINGS VERSUS INDEPENDENT SPUD CAN FOOTINGS

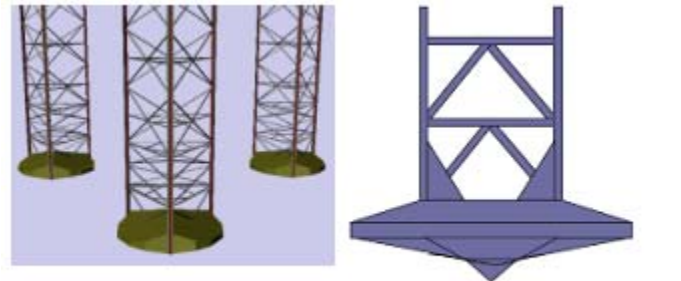
Almost all Jack Up Units have footings. Their purpose is to increase the leg's bearing area, thereby reducing the required capacity of the soil to provide a solid foundation upon which the Jack Up will stand and transfer weight, operational, and environmental loads to the seabed. There are two main footing types: mats and spud cans.

Mat footings connect all the Jack Up Unit's legs to one common footing. Mat footings typically are rectangular structures, flat on the top and bottom, and contain buoyancy chambers which are flooded when the mat is submerged. There are two main advantages of mat footings. First, due to their larger size, mat footings exert a lower bearing pressure on the soil than Units with spud cans. This is beneficial in areas where the soil cannot support high bearing loads. The second advantage is that in the afloat transit mode, mats provide considerable buoyancy, which may translate to increased variable load carrying capability.



There are three main disadvantages of mat footings. Mats cannot be used on uneven seabeds or those with large slopes. Sloping or uneven seabeds induce large bending moments on the mat and legs. A mat structure built to withstand such high bending loads would be comparatively very heavy. Mat units also cannot be used on bottoms where there are obstructions such as pipelines, debris, etc. The final main disadvantage of mats is that during the transition from afloat to on-bottom operations, the mat must be flooded. This flooding sequence must be done carefully so as not to cause large heeling moments or loss of afloat stability of the Unit. When refloating the Unit, the water must be pumped out of the mat, which requires equipment not needed on independent-legged Units.

Units with independent spud can footings have the same number of spud cans as there are legs. Spud cans are typically somewhat conical structures, with sloping tops and bottoms. The sloping top helps in sloughing off mud that may collect on top of the spud can in the event of deep penetration. The sloping bottom helps ensure that there will be some penetration, even in very stiff soils. Spud cans are normally designed to be free flooding when submerged, though they can be pumped dry for internal inspection.



**Typical profile of a Spudcan**

There are many advantages of spud can footings. The biggest advantage is that they can be used on a great variety of seabeds. Units with spud cans have operated on seabeds of hard and soft soils, sloping bottoms (though they may be sensitive to large slopes on hard soils), and in areas where there are pipelines or other structures that must be avoided. In addition, spud cans do not require sensitive ballasting sequences or equipment and some rigs can retract the spud cans flush into the hull to permit easy dry transport of the Unit.

Units with spud cans exhibit larger bottom bearing pressure and result in increased soil penetrations when compared to mat Units. Because of this high bearing pressure, spud cans leave impressions in areas with soft soils. If another Jack Up Unit later works in the same area, these old spud can impressions may induce horizontal forces on one or more legs if the spud cans tend to slide into the old spud can impressions.

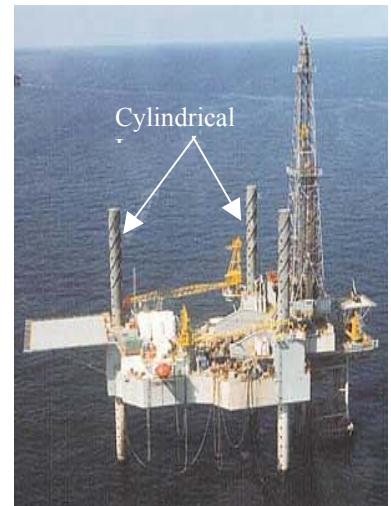
#### 3.2 CYLINDRICAL LEGS VERSUS TRUSSED LEGS

All Jack Up Units have legs. Their purpose is to provide elevation of the hull above the storm wave crest; withstand wave, current, and wind loads; and to transmit operational, environmental, and gravity loads between the hull and footings. There are two main leg types: cylindrical and trussed.

Cylindrical legs are hollow steel tubes. They may or may not have internal stiffening, and may have rack teeth or holes in the shell to permit jacking of the hull up and down the legs. Cylindrical legs are currently found on Units operating in water depths less than 300 feet. The newer Units operating in water depths of 300 feet and greater all have trussed legs. The main reason for this is that cylindrical legs require more steel to provide the same resistance to environmental loads and provide the same elevated response as truss legged Units

The primary advantage of cylindrical legs is for Units that operate in shallow water as these Units are normally smaller and have less deck area. Cylindrical legs take up less deck area and are generally less complicated requiring less experience to construct than trussed legs.

Trussed legs consist of chords and braces. In general, the braces provide the shear capacity of the leg while the chords provide the axial and flexural stiffness. One of the main benefits of the Trussed legs is that they allow for optimal steel utilization and result in lighter stiffer legs with reduced drag loads.

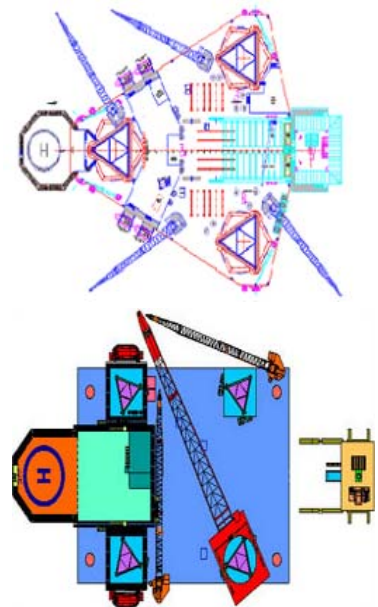


### 3.3 3-LEGGED VERSUS 4-LEGGED JACK UPS

The great majority of Jack Up Units in the world have no more than four legs, with three being the minimum required for stability. There are some Units built with more than four legs, but these will not be addressed in this primer.

Units with 3 legs have the legs arranged in some triangular form. The main advantage of three-legged Units is that they completely eliminate the need to build extra leg(s). Furthermore, for a given hull size, they can carry more deck load in the afloat mode; and usually have a reduced number of elevating units (pinions, cylinders, etc), resulting in reduced power/maintenance requirements, and less weight. Disadvantages of three-legged units include the fact that they require preload tankage and they have no leg redundancy.

Units with 4-legs usually have the legs arranged in some rectangular form. Four-legged Units require little or no preload tanks on board. This is because four-legged Units can preload two legs at a time using the elevated weight as preload weight. This results in a savings of piping and equipment weights, and more usable space within the hull. Because of the fourth leg, these Units are stiffer in the elevated mode than a three-legged Unit. This apparent advantage may be offset by the fact that the additional leg adds wind, wave and current loads. In the afloat transit mode, the fourth leg is a disadvantage as its weight causes a direct reduction in the afloat deck load when compared to an equivalent three-legged unit.



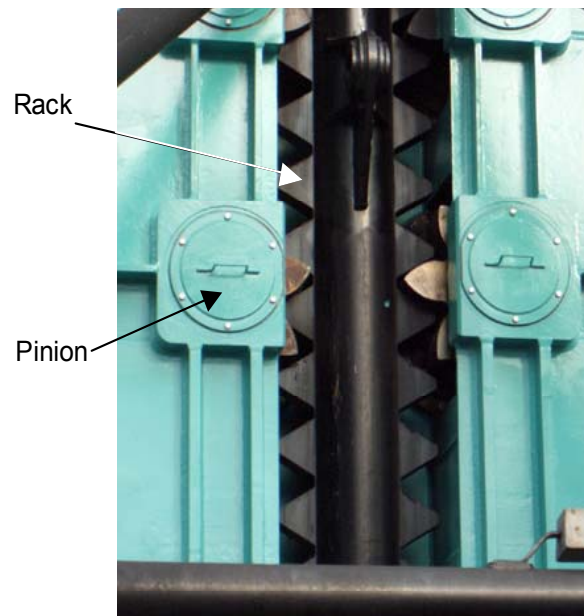
### 3.4 3-CHORDED LEGS VERSUS 4-CHORDED LEGS

Trussed legs have either 3 or 4 main vertical structural members called chords. All trussed-leg Jack Up Units operating today have one of these chord arrangements. In essence, the benefits and disadvantages of three- versus four-chorded legs are comparable in nature to those of three- and four-legged Jack Ups (i.e., overall weight/drag loads and redundancy), except that they do not affect preloading procedures in any way.



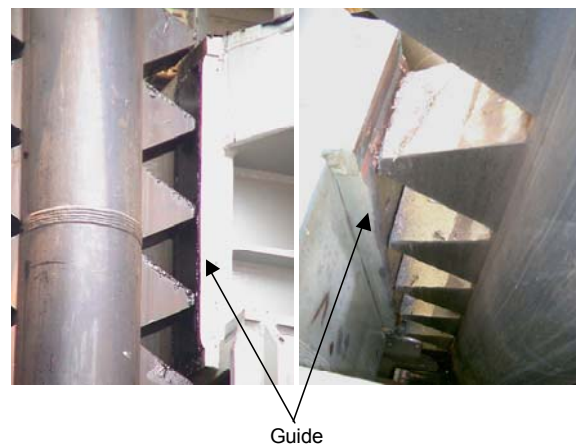
### 3.5 ELEVATING SYSTEM

All Jack Ups have mechanisms for lifting and lowering the hull. The most basic type of elevating system is the pin and hole system, which allows for hull positioning only at discrete leg positions. However, the majority of Jack Ups in use today are equipped with a Rack and Pinion system for continuous jacking operations. There are two basic jacking systems: Floating and Fixed. The Floating system uses relatively soft pads to try to equalize chord loads, whereas the Fixed system allows for unequal chord loading while holding. There are two types of power sources for Fixed Jacking Systems, electric and hydraulic. Both systems have the ability to equalize chord loads within each leg. A hydraulic-powered jacking system achieves this by maintaining the same pressure to each elevating unit within a leg. Care must be taken, however, to ensure that losses due to piping lengths, bends, etc., are either equalized for all pinions or such differences are insignificant in magnitude. For an electric-powered jacking system, the speed/load characteristics of the electric induction motors cause jacking motor speed changes resulting from pinion loads, such that if jacking for a sufficiently long time, the loads on any one leg tend to equalize for all chords of that leg.



### 3.6 UPPER AND LOWER GUIDES

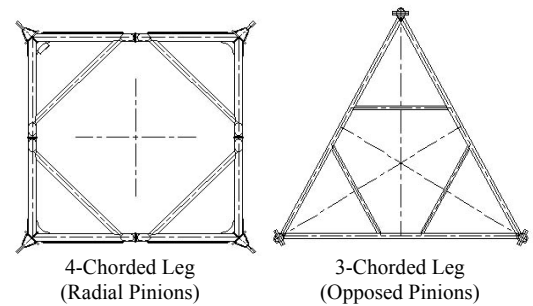
All Jack Ups have mechanisms to guide the legs through the hull. For Units with Pinions, the guides protect the pinions from “bottoming out” on the rack teeth. As such, all Units are fitted with a set of upper and lower guides. Some Jack Up Units, which have exceptionally deep hulls or tall towers of pinions, also have intermediate guides. These guides function only to maintain the rack the correct distance away from the pinions and are not involved in transferring leg bending moment to the hull. Guides usually push against the tip (vertical flat side) of the teeth, but this is not the only form of guides. There are also other forms of guides such as chord guides, etc. Depending on accessibility, some guides are designed to be replaced and are sometimes known as “wear plates.”



In addition to protecting the pinions and hull, all upper and lower guides are capable of transferring leg bending moment to the hull to some degree determined by the design. The amount of moment transferred by the guides to the hull as a horizontal couple is dependant on the relative stiffness of the guides with respect to the stiffness of the pinions and/or fixation system (if any).

### 3.7 OPPOSED PINION CHORDS VERSUS RADIAL PINION CHORDS

Jack Up Units that have rack and pinion elevating systems have the interface between the racks and pinions in one of two configurations: two opposed pinions or a single radial pinion at each chord. All jacking systems exert vertical and horizontal forces on the leg at the pinion/rack interface (as the contact area is not horizontal). Opposed pinion systems balance these loads across the chord introducing zero net additional horizontal load applied to the leg bracing. Radial pinions exert a horizontal load on the leg bracing due to the pinion arrangement.



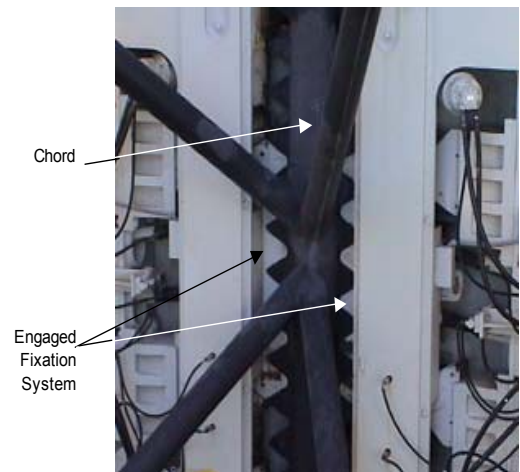
Opposed pinion systems have rack and elevating systems on two opposite sides of the same chord, usually resulting in chord sections with double symmetry. The main advantage of opposed pinion systems is good load sharing between pinions of a chord. If pinions are arranged on both sides of the same chord, the overall height of the jacking tower is reduced when compared to pinions arranged only on one side of the chord. If pinions are arranged two high, load sharing between the two pinions is close to 50/50, though not quite uniform. As more pinions are added to the tower, the difference between the pinion with the largest load and the pinion with the least load increases. The final advantage of opposed pinion systems is the reduced height of the jacking tower. This reduced height results in less wind load on the Jack Up Unit as well as reduced weight.

Radial pinion systems have rack and elevating pinions on one side of the chord only; thereby resulting in chords with only one plane of symmetry and having the net vertical pinion loads inducing bending of the chord due to the eccentricity. Jack Up Units that have radial pinion jacking systems have two main advantages when compared with opposed pinion systems. First, Radial pinion systems have upper guides located farther away from the lower guide than opposed pinion systems. This is due to the fact that radial pinion systems have a greater overall height. The second advantage of the radial system may be a lower drag coefficient on the leg chord. This, in theory, is because one rack will cause less hydrodynamic drag than two racks. This very much depends on the actual design of the particular leg chords being compared, as designs vary.

### 3.8 LEG FIXATION SYSTEMS VERSUS NO LEG FIXATION SYSTEMS

All Jack Up Units must transfer the environmental, gravity, and operational loads between the hull and the legs. Some Units rely on the elevating pinions to transfer these loads in all modes of operation, while others use the pinions primarily for Jacking operations and use a fixation system to transfer the loads the majority of the time other than jacking operations.

Leg bending moment may be transferred from the legs to the hull as a horizontal couple (i.e., opposite forces at the upper and lower guides) or as a vertical couple (i.e., differential chord loading). The proportion of the moment transferred by each of these mechanisms is dependant on their relative stiffness values. Units with leg fixation systems increase the proportion of the moment transferred as a vertical couple.



Jack Up Units without a leg fixation system usually require heavier bracings to react the design operating/survival/tow leg-to-hull loads. Because the jacking units are the only holding/locking mechanism, care must be taken to ensure they are properly maintained. Furthermore, any loss of jacking/holding capacity may have a cascading effect to the other units and eventually become additional load on the leg structure. While larger braces are capable of taking higher loads before buckling, possibly providing reserve capacity for the braces in non-design events, they result in larger wind/wave/current loads; which cause these units to have lower environmental ratings than their counterparts that have a fixation system. For such rigs, balancing the strength of chord and brace is important and the brace and chord connections are critical.

Jack Up Units that have a leg fixation system require fewer pinions, than Units with no leg fixation system. Furthermore, because of the increased stiffness compared with guides, the majority of the leg/hull moment is transferred as a vertical couple, thereby reducing the required brace scantlings. The reduction in bracing scantlings provides the Unit with a leg that weighs less and has less drag than a Unit with no leg fixation system, which directly translates into increased environmental capabilities for the Unit. Because of this, the capacity to tow with large leg lengths fully retracted is also increased. The fixation system can also serve to support the rig in the event service is required for the jacks. For rigs of such design, the leg bracing is typically the component most prone to damage in the event of accident.

#### **4. MODES OF OPERATION OF A JACK UP**

Jack Up Units operate in three main modes: transit from one location to another, elevated on its legs, and jacking up or down between afloat and elevated modes. Each of these modes has specific precautions and requirements to be followed to ensure smooth operations. A brief discussion of these modes of operations along with key issues associated with each follows.

##### **4.1 TRANSIT FROM ONE LOCATION TO ANOTHER**

The Transit Mode occurs when a Jack Up Unit is to be transported from one location to another. Transit can occur either afloat on the Jack Up Unit's own hull (wet tow), or with the Jack Up Unit as cargo on the deck of another vessel (dry tow). These Transit Modes are discussed in more detail below.

Main preparations for each Transit Mode address support of the legs, support of the hull, watertight integrity of the unit, and stowage of cargo and equipment to prevent shifting due to motions.

Though the Unit's legs must be raised to ensure they clear the seabed during tow, it is not required that the legs be fully retracted. Allowing part of the legs to be lower than the hull baseline not only reduces jacking time, but it also reduces leg inertia loads due to tow motions and increases stability due to decreased wind overturning. Lowering the legs a small distance may also improve the hydrodynamic flow around the open leg wells and reduce tow resistance. Whatever the position of the legs during tow, their structure at the leg/hull interface must be checked to ensure the legs can withstand the gravity and inertial loads associated with the tow.

Field Tow corresponds to the condition where a Jack Up Unit is afloat on its own hull with its legs raised, and is moved a relatively short distance to another location. For a short move, the ability to predict the condition of the weather and seastate is relatively good. Therefore, steps to prepare the Unit for Field Tow are not as stringent as for a longer tow. Most Classification Societies define a "Field Tow" as a Tow that does not take longer than 12 hours, and must satisfy certain requirements with regards to motion criteria. This motion criterion, expressed as a roll/pitch magnitude at a certain period, limits the inertial loads on the legs and leg support mechanism.

For certain moves lasting more than 12 hours, a Unit may undertake an Extended Field Tow. An Extended Field Tow is defined as a Tow where the Unit is always within a 12-hour Tow of a safe haven, should weather deteriorate. In this condition, the Jack Up Unit is afloat on its own hull with its legs raised, similar to a Field Tow. The duration of an Extended Field Tow may be many days. The motion criteria for an Extended Field Tow is the same as for a Field Tow. The main preparations for a Unit to undertake an Extended Field Tow are the same as those for a Field Tow with the additional criteria that the weather is to be carefully monitored throughout the duration of the tow.

A Wet Ocean Tow is defined as an afloat move lasting more than 12-hours which does not satisfy the requirements of an Extended Field Tow. In this condition, the Jack Up Unit is afloat on its own hull with its legs raised as with a Field Tow, but, for many Units, additional precautions must be made. This is because the motion criteria for a Wet Ocean Tow are more stringent than for a Field Tow. The additional preparations may include installing additional leg supports, shortening the leg by cutting or lowering, and securing more equipment and cargo in and on the hull.

A Dry Ocean Tow is defined as the transportation of a Jack Up Unit on the deck of another vessel. In this condition, the Jack Up Unit is not afloat, but is secured as deck cargo. The motion criteria for the Unit is dictated by the motions of the transportation vessel with the Unit on board. Therefore, the precautions to be taken with regard to support of the legs must be investigated on a case-by-case basis. Generally, though, the legs are to be retracted as far as possible into the hull so the Jack Up hull can be kept as low as practicable to the deck of the transport vessel and to reduce the amount of cribbing support. The other critical precaution unique to Dry Ocean Tow is the support of the Jack Up hull. The hull must be supported by cribbing on strong points (bulkheads) within the hull and in many cases, portions of the hull overhang the side of the transportation vessel. These overhanging sections may be exposed to wave impact, putting additional stress on the hull, and if the overhanging sections include the legs, the resultant bending moment applied to the hull (and amplified by vessel motions) can be significant. Calculations should be made to ensure that the hull will not lift off the cribbing with the expected tow motions.

## 4.2 ARRIVING ON LOCATION

Upon completion of the Transit Mode, the Jack Up Unit is said to be in the Arriving On Location Mode. In this Mode, the Unit is secured from Transit Mode and begins preparations to Jack Up to the Elevated Mode. Preparations include removing any wedges in the leg guides, energizing the jacking system, and removing any leg securing mechanisms installed for the Transit thereby transferring the weight of the legs to the pinions.

## 4.3 SOFT PINNING THE LEGS

If an independent leg Jack Up Unit is going to be operated next to a Fixed Structure, or in a difficult area with bottom restrictions, the Jack Up Unit will often be temporarily positioned just away from its final working location. This is called “Soft Pinning” the legs or “Standing Off” location. This procedure involves lowering one or more legs until the bottom of the spud can(s) just touches the soil. The purpose of this is to provide a “Stop” point in the Arriving On Location process. Here, all preparations can be checked and made for the final approach to the working location. This includes coordinating with the assisting tugs, running anchor lines to be able to “winch in” to final location, powering up of positioning thrusters on the Unit (if fitted), checking the weather forecast for the period of preloading and jacking up, etc.

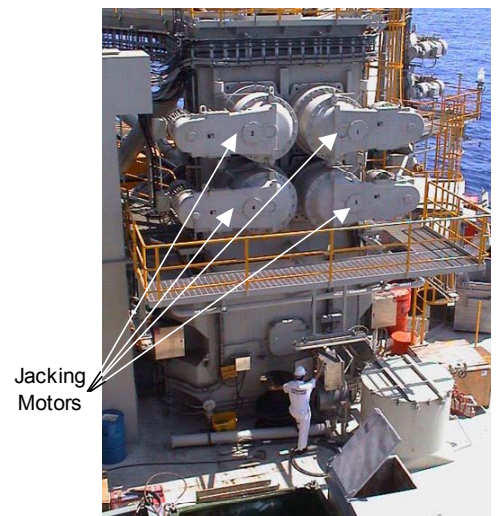
## 4.4 FINAL GOING ON LOCATION

Whether a Unit stops at a Soft Pin location, or proceeds directly to the final jacking up location, they will have some means of positioning the Unit so that ballasting or preloading operations prior to jacking up can commence. For an independent leg Jack Up Unit, holding position is accomplished by going on location with all three legs lowered so the bottom of the spud can is just above the seabed. When the Unit is positioned at its final location, the legs are lowered until they can hold the rig on location without the assistance of tugs.

Mat type Jack Up Units are either held on location by tugs, or they drop spud piles into the soil. These spud piles, usually cylindrical piles with concrete fill, hold the Unit on location until the mat can be ballasted and lowered.

## 4.5 JACKING

A mat Unit will jack the mat to the seabed in accordance with the ballasting procedure. Once the mat has been lowered to the seabed, the hull will be jacked out of the water. The Unit then proceeds to Preload Operations (see Section 4.6 below). All Independent leg Units must perform Preload Operations (see Section 4.6 below) before they can jack to the design air gap. Most independent leg Units do not have the capacity to elevate the Unit while the preload weight is on board. For these Units, the next step is to jack the hull out of the water to a small air gap that just clears the wave crest height. This air gap should be no more than five (5) feet. Once they reach this position, the Unit may proceed with Preload Operations.





Some of the newer Independent Leg Units do have elevating systems capable of lifting the entire weight of the hull with full preload weight. For these Units, preload is loaded on board while the hull is still in the water. Once full preload is on board, the Unit is slowly jacked out of the water until the preload air gap is reached, no more than 5 feet.

#### 4.6 PRELOAD OPERATIONS

All Jack Up Units must load the soil that supports them to the full load expected to be exerted on the soil during the most severe condition, usually Storm Survival Mode. This preloading reduces the likelihood of a foundation shift or failure during a Storm. The possibility does exist that a soil failure or leg shift may occur during Preload Operations. To alleviate the potentially catastrophic results of such an occurrence, the hull is kept as close to the waterline as possible, without incurring wave impact.

Should a soil failure or leg shift occur, the leg that experiences the failure loses load-carrying capability and rapidly moves downward, bringing the hull into the water. Some of the load previously carried by the leg experiencing the failure is transferred to the other legs potentially overloading them. The leg experiencing the failure will continue to penetrate until either the soil is able to support the leg, or the hull enters the water to a point where the hull buoyancy will provide enough support to stop the penetration. As the hull becomes out-of-level, the legs will experience increased transverse load and bending moment transferred to the hull mostly by the guide. With the increased guide loads, some braces will experience large compressive loads. There are detailed procedures to be followed during such a failure to minimize the structural damage, but these are beyond the scope of this primer.

During normal preload operations it is important to keep the weight of the hull, deck load, and preload as close to the geometric center of the legs as possible, as this will assure equal loading on all legs. Sometimes, however, single-leg preloading is desired to increase the maximum footing reaction of any one leg. This is achieved by selective filling/emptying of preload tanks based on their relative position to the leg being preloaded.

Preload is water taken from the sea and pumped into tanks within the hull. After the preload is pumped on board, it is held for a period of time. The Preload Operation is not completed until no settling of the legs into the soil occurs during the holding period while achieving the target footing reaction. The amount of preload required depends on the required environmental reaction and the type of Jack Up Unit. Mat Units normally require little preload.

Four-legged independent Units usually require little or no preload water. This is because four-legged Units preload two diagonally opposite legs at a time using the weight of the hull. These Units jack to their preload air gap, then lift two legs slightly off the seabed. This causes the Unit to settle on the other two legs. The hull is jacked back up to preload air gap, and the procedure is completed when all four legs have been preloaded to the target footing reaction and no additional penetration takes place.

Three-legged independent Units require the most preload water. For Units that cannot jack with preload, preload water is pumped on board after the hull reaches the preload air gap. If significant settling occurs, the preload must be dumped before the hull is jacked to its preload air gap again, and the procedure repeated until no settling occurs.



For Units that can jack with full preload, preload is pumped into the hull while the hull is still in the water. The hull is then jacked up, usually stopping for a short time at certain pre-arranged drafts. This continues until the hull is at the preload air gap and holds the preload for the holding period.

Once the preload is held for the specified time, the preload water is dumped and the Jack Up is ready to be elevated to the operating air gap.

#### 4.7 JACKING TO FULL AIR GAP OPERATIONS

Once Preload Operations are completed, the Unit may be jacked up to its operational air gap. During these operations it is important to monitor the level of the hull, elevating system load and characteristics, and for trussed-leg Units, Rack Phase Differential (RPD) which is described in section 7.7. All of these must be maintained within design limits. Once the Unit reaches its operational air gap, the jacking system is stopped, the brakes set, and leg locking systems engaged (if installed). The Unit is now ready to begin operations.

#### 4.8 ELEVATED OPERATING CONDITION

When the Unit is performing operations, no particular differences exist between the various types of Units. Likewise, there are no particular cautionary measures to take other than to operate the Unit and its equipment within design limits. For Units with large cantilever reach and high cantilever loads, extra care must be taken to ensure that the maximum footing reaction does not exceed a specified percentage of the reaction achieved during preload.

#### 4.9 ELEVATED STORM SURVIVAL CONDITION

When the Unit is performing operations, the weather is to be monitored. If non-cyclonic storms which exceed design operating condition environment are predicted, Operations should be stopped and the Unit placed in Storm Survival mode. In this mode, Operations are stopped, equipment and stores secured, and the weather and watertight enclosures closed. If cyclonic storms are predicted, the same precautions are taken and personnel evacuated from the Unit.

### 5. CLASS APPROVAL VS. SITE SPECIFIC ASSESSMENT

There are many parties involved in the safety regime for jack ups. These include Shelf States (national legislation), Flag States (national maritime legislation), Class Societies (class rules), and International Bodies (international codes, e.g. MODU code, etc.).

Jack ups may not require a flag but are free to move in international waters when carrying flag. In such case a jack up has to comply with safety regulations of the Maritime Authority in the country whose flag the unit is flying (the Flag State).

Jack up drilling units are normally registered with a Flag State Governmental Administration. The role of the Flag Administration, is to implement statutory requirements of the government for registering the unit. Normally, these statutory requirements are derived from internationally agreed regulations developed by the International Maritime Organization (IMO). Today, Flag Administrations largely delegate the tasks of verification of compliance with IMO Conventions to classification societies. Classification societies also issue Loadline, Tonnage and Marpol certificates on behalf of Flag Administrations.

Besides classification and statutory requirements, some governments require drilling units, regardless of flag, operating in their territorial waters to comply with their own safety and pollution requirements. A typical example is in the UK. The UK Health and Safety Executive's Offshore Division enforces health and safety laws on offshore installations, including jack up drilling units.

Classification societies are independent, third party organizations that serve as a verification system for a number of parties who have special interest in the safety and quality of jack ups. These may include regulatory authorities, insurance underwriters, owners, building yards and sub-contractors, finance institutions, and charterers.

#### 5.1 CLASSIFICATION SOCIETIES

Classification is a comprehensive verification service providing assurance that a set of requirements laid down in rules and standards established by the classification society are met during design and construction and maintained during operation of the jack up. The rules and standards ensure safety against hazards to the unit, personnel and the environment. Each classification society, such as the American Bureau of Shipping (ABS), Det Norske Veritas (DNV), Lloyds Register (LR), etc., has its own rules for classification of jack ups. However, many aspects of classification rules of different classification societies are harmonized through the International Association of Classification Societies (IACS).

Like ships and other marine structures, jack up drilling units are designed and constructed to satisfy the rules of classification societies. While classification certificates issued by a classification society attest to compliance with such Rules, they also indicate that the unit meets a minimum industry standard for structural and mechanical fitness. To maintain the unit in class, classification societies require periodical surveys to check that the unit is adequately maintained.

The class structural scope includes structural strength, materials, welding, fabrication and corrosion protection for jack up hull, superstructures, legs, spudcans, etc. The rig's ultimate strength in different operation modes, like storm survival, elevated operations, transit, preloading and jacking, etc. are considered. Possible accidental conditions and fatigue are also examined. Design conditions used as bases for the strength approval, such as hull weights, water depths, environmental conditions, etc., are presented in the rig's operation manual. Assumed foundation fixities may be considered and in such cases included in the operation manual. However, foundation capacity and safety is not part of class structural approval for a jack up rig.

It is the owner's responsibility to operate the jack up within the conditions used as basis for class approval, and to confirm that the unit can safely operate at a particular site.

Classification rules (e.g. ABS Rules for Building and Classing Mobile Offshore Drilling Units) typically address the following areas:

- Materials of construction and fabrication
- Structural integrity
- Afloat stability
- Safety issue such as structural fire protection and means of escape
- Machinery and systems
- Periodical survey

Since jack up units are mobile in nature and can be expected to operate in any part of the world, the rules for structures are not associated with the environmental, geotechnical and operational conditions of any specific area. The owner and designer define the environmental and operational conditions to which the unit has been designed; these are the design criteria and theoretical operating envelope of the unit. Designers and owners must assess the desired operating modes and site conditions to ensure they are within the approved envelope.

Classification rules require global analyses of the primary structure of the unit in the jacked up and afloat modes of operation. In the transit (afloat) condition leg structures are assumed subjected to defined roll characteristics and gravity bending moment, with correspondingly more demanding criteria in severe storm condition. In addition to the global structural analysis, fatigue analyses are required for classification of all new construction jack ups. Machinery and systems classification requirements are derived mainly from rules for ships, except for specific equipment, such as jacking gears, and safety requirements related to hazards of drilling operations, such as definition of hazardous areas and the installation of electrical equipment in such areas, high pressure piping systems related to drilling, fire safety systems, emergency shutdown systems, and others.

Classification rules impose stability criteria for jack up units in all afloat conditions, including temporary conditions, such as lowering leg structures. Two sets of criteria are specified: intact stability and damage stability criteria. While classification of a jack up unit signifies its compliance with a set of minimum standards (Classification Rules), it does not imply that the jack up is adequate to operate in any specific area. In fact, in each case, the owner/operator of the unit should assess the adequacy of the jack up taking into consideration the water depth, environmental, geotechnical, seismic and climatic conditions of the area of operation. For this purpose, industry has developed a standard: SNAME T&R Bulletin 5-5A Guidelines for Site Specific Assessment of Mobile Drilling Units, which can be used as a guide for performing such assessments (See 5.2 Site Specific Assessment below).

## 5.2 SITE SPECIFIC ASSESSMENTS

When a jack up is to operate at a particular location, the Shelf State Legislation of the country in which it is to operate will regulate the activity. Industrialized countries are normally well regulated and have comprehensive rules for activities on the continental shelf, while other countries may have less developed regulations and it will be the oil company / owner's responsibility to define the documentation basis for the site assessment. Both shelf state legislation and oil company / owner's specification may refer to their own regulations or international guidelines like "Recommended Practice" (RP) for the Site Specific Assessment of Mobile Jack Up Units (SNAME Technical and Research Bulletin 5-5A) issued by The Society of Naval Architects and Marine Engineers (SNAME) for site assessment of jack ups. In some cases Class Rules and other standards are also considered.

As the name indicates, a Site Specific Assessment is an evaluation of the capability of a jack up in the elevated condition to meet a set of standards for structural strength of the jack up and foundation (soil strength of the site) supporting the jack up at a particular site. In general, the rig owner will be given the environmental conditions that must be met, along with the soil information needed to perform the assessment.

It is not uncommon for oil companies to have in-house criteria modifying the SNAME RP to better reflect their risk philosophy. The main objective of the SNAME RP is to document foundation capacities and global structural strength for jack up site operations. In cases where the rigs loads, actual environmental condition and soil conditions fall clearly within the basis for class approval of the structure, it may be that only foundation capacities need to be considered.

### 5.3 FIELD MOVES

Classification rules require that jack up drilling units meet the intact and damage stability criteria outlined in the rules. To meet typical intact stability requirements, jack up units must be capable of withstanding a wind velocity of not less than 36 m/s (70 kn) for field transit and 51.5 m/s (100 kn) in severe storm (ocean tow) conditions. Typically leg strength for transit conditions must meet the following:

- Field Transit – Leg strength is to be developed to withstand a bending moment caused by a 6-degree single amplitude roll or pitch at the natural period of the unit plus 120% of the gravity moment at that angle of inclination of the legs.
- Severe Storm (Ocean Transit) – Legs are to withstand acceleration and gravity bending moments resulting from the motions in the most severe anticipated environmental transit conditions, together with wind moments corresponding to a velocity of not less than 51.5 m/s (100 kn).

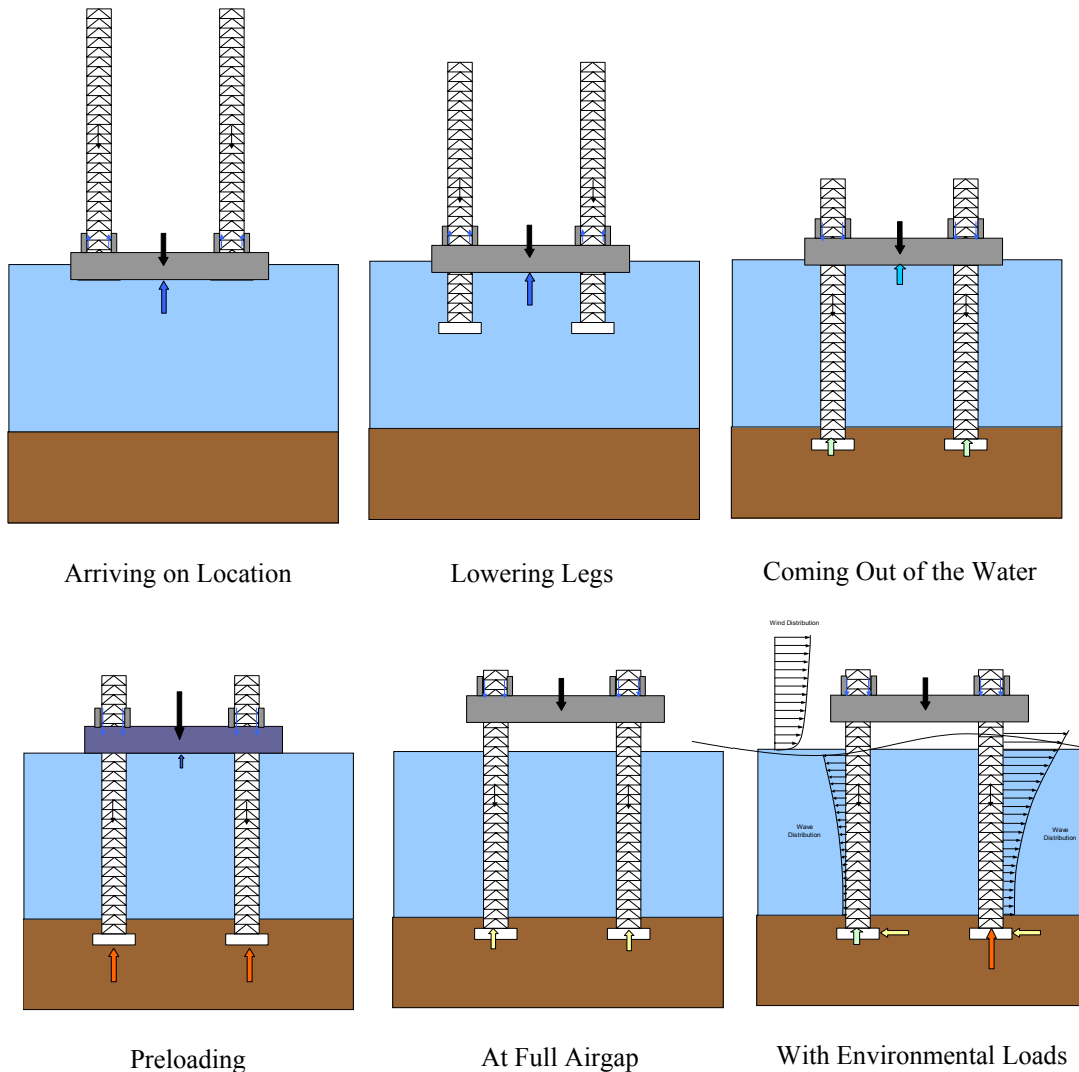
During dry tows, classification societies consider the jack up as cargo on the transport vessel and are not normally requested to review field or ocean transit arrangements. This is normally carried out by Warranty Surveyors. However at the completion of an ocean tow, classification societies usually require a comprehensive survey of the legs, leg to hull connections, the jack house to hull connections, and any other areas deemed to be highly stressed during the tow.

Warranty survey companies are often requested to approve wet and dry tow arrangement and weather predictions of transit routes. Areas that warranty surveyors normally review and approve for wet tow are: hold down arrangements of cantilevers and any cargo on the deck. The warranty surveyor also ensures that the jack up meets the classification rule requirements for intact and damage stability. For dry tows warranty survey companies review and approve such things as the motions of the transportation vessel, cribbing, size of towing tug and towlines, and weather en route. The weather en route and motions of the jack up and/or towing vessel are carefully monitored throughout the duration of the tow.



## 6. JACK UP DESIGN--THE ULTIMATE COMPROMISE

In addition to all the drilling equipment and layout requirements, and given the fact that a Jack Up operates in different modes, there are two main opposing disciplines that govern the design of a Jack Up: Naval Architecture and Structural Capabilities. These two disciplines often benefit at the expense of each other.



### 6.1 ENVIRONMENTAL LOAD BASICS

Environmental Loads are the loads on the Jack Up that result from wind, wave, current, snow, and ice. Seismic loads (earthquakes) may also be classified as Environmental Loads, but these are addressed in Section 7.5, below.

Wind loads result from the effect of wind on an exposed structure above the waterline. Wind loads are affected by the wind speed, amount of surface area the wind impacts, the drag coefficient of the surface the wind impacts, and the height of the surface area above the waterline. As the above factors increase, the resultant wind load gets larger, though not to the same degree. Surface area and drag coefficients have a direct linear relationship to the resultant wind load; for example, if either of these values increase by 25%, the resultant wind load increases 25%. The load resulting from an increase in wind speed increases as the square of the wind speed; if the wind speed doubles, the resultant wind load increases fourfold. The relationship between height above waterline and wind load is less than linear; doubling the height above waterline results in less than doubling of the wind load. These relationships are available in published Classification Society or Industry documents.

Wave and current loads result from the effect of wave and current on structure below the waterline or in the splash zone. In the elevated mode, wave and current loads are affected by the wave height, wave period, current velocity, drag and the inertia coefficients, and the amount of surface area the water impacts. The resultant wave and current loads get larger, though not to the same degree, as four of the above five factors increase; the sole exception being wave period. It must be noted that the effect of current is not independent of waves (i.e., the maximum loads from a given wave with current is larger than the sum of the loads due to waves without current plus the current-induced loads in the absence of waves).

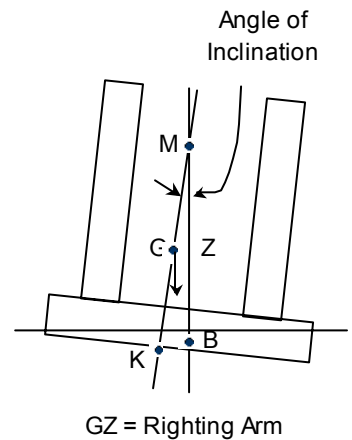
Snow and Ice loads result from the effect of snow and ice on structure above the waterline or in the splash zone. There are two types of ice loads, ice from wind/wave driven spray, and pack/floe ice. This document will only address the former.

Snow and Ice loads are affected by the thickness and density of the accumulated snow and ice. The primary effects of snow and ice are increased weight on the Jack Up, increased wind area, and increased area exposed to wave and current loads (in the splash zone only). It should be noted that if the Jack Up is exposed to snow and ice loads, it follows that the Jack Up is being exposed to sub-freezing temperatures. The steel structure of the Jack Up is to be of appropriate material grade for operations in such service temperatures. Snow and ice loads are the only environmental loads that can be reduced by active mitigating efforts, such as continual removal of the accumulated snow and ice from the Jack Up.

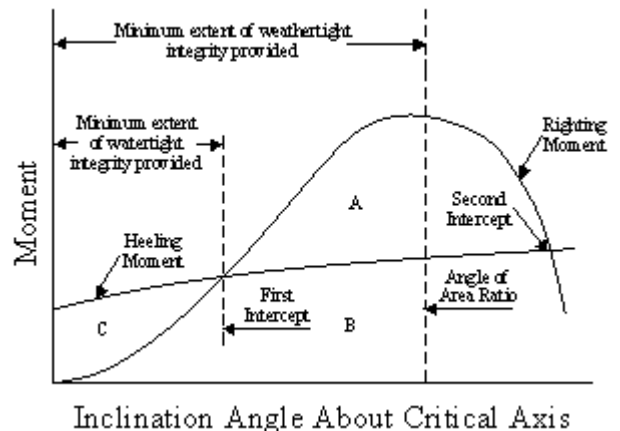
## 6.2 BASICS OF A STABILITY ANALYSIS

When a Jack Up is being designed, a stability analysis is used to verify that the hull is capable of carrying the desired amount of leg. A Stability Analysis is performed at a series of afloat drafts to determine the value of the Allowable Vertical Center of Gravity (VCG) for the Jack Up at each of the drafts. Each time the Jack Up undergoes an afloat transit, the Jack Up Owner prepares his afloat loading condition to verify that the combined VCG of all the weights is less than or equal to the Allowable VCG.

Two types of Stability Analyses are performed; one with the Jack Up hull intact, and one with the hull damaged. Each of these analyses results in an Allowable Maximum VCG at each draft. For each draft the lowest of these values is the Final Allowable VCG.



The main input parameters used to perform a Stability Analysis are hull shape, draft, wind area, hull compartment size (for Damaged Stability Analysis), downflood point location, and Classification/Flag State Rule requirements. A complete Stability Analysis is performed early in the design process, and must be repeated if any of the above-listed input parameters are changed during the life of the Jack Up. The only exception is for new Rules implemented by Classification Societies after the Jack Up's keel is laid. If a Classification Society changes its Rules after this point, and the Jack Up does not change Classification Society, it need not comply with the new Rules, but remains instead subject to the rules in place at the time the keel was laid.



## 6.3 BASICS OF A TOW ANALYSIS

After it has been established that the hull has sufficient buoyancy and stability to withstand the target motions, a tow analysis is conducted to verify the structural capacity of the legs and jacking system to withstand the inertia loads associated with motions during tow. Typically, a target motion is defined as a maximum pitch/roll angle at a given oscillating period, acting in conjunction with heave accelerations. The inertia loads increase for larger oscillating angles and lower periods. Though this is a dynamic situation, a tow analysis usually consists of a static analysis representing the maximum inertia loads, using a structural model of the leg and jacking system at its mean (vertical) position. Furthermore, the analyses are typically conducted solely for inertia loads, and do not directly account for wind/wave loads acting on the legs, as these environmental loads were used to determine the maximum roll/pitch angles.

Given the noticeable benefits of lowering the legs, tow analyses are usually conducted for various positions of the leg (or Tip of Spud Can), with respect to the hull base line (TOC). For Jack Ups having fixation systems, it is common to have curves of allowable oscillation angles vs. period for the unit with and without the fixation system engaged, for a series of TOC positions.

## 6.4 BASICS OF AN ELEVATED ANALYSIS

A typical Jack Up elevated analysis is a structural analysis on a representative model of the Jack Up at its mean position for a particular water depth, air gap and penetration, for a given environment (wind, wave and current) and elevated weight (i.e., VDL, LCG and TCG). It is usual to assume that all loads from wind/waves/current are horizontal and that they all act in the same direction. While the effects of wind and current are fairly steady, wave loads are oscillatory in nature. Though it is becoming more and more common to perform dynamic analyses, it is standard practice to treat wave loads as quasi-static loads, by using a single critical wave load associated with the crest position that induces the largest overall load (base shear, overturning moment, or some other criteria), and possibly magnifying the load to account for possible dynamic effects (see next section on Dynamic Amplification Factors). Environmental loads are applied in a series of discrete directions and may take advantage of symmetry. Environmental loads arising from wind, wave and current are computed based on the projected area of the components and calibrated coefficients.

Application of horizontal forces to an elevated Jack Up can cause relatively small horizontal displacements of the hull (hull sway). Due to the magnitude of vertical loads on the unit, these displacements can have a significant effect on the leg loads. This effect, known as the P-delta effect, is often accounted for in the elevated analysis of a Jack Up.

A typical model for an elevated analysis consists of detailed legs with line (beam/frame) elements for chords and braces, a grillage representing the major structural components of the hull, equivalent members for the spud cans, and jack case/support structures connecting the legs to the hull via pinions/fixation system and upper/lower guides at the proper locations. The connecting elements are usually released in key directions to ensure that the calculated loads act in the appropriate directions. The results of an elevated analysis are stress/load levels for the critical structural elements and are usually compared to allowable values and expressed as utilization ratios (often referred to as unity checks, since a value of 1.0 or lower indicates acceptable levels of loading). It is noted that separate detailed hull and spud can analyses using plate elements are usually conducted for the critical loadings.

## 6.5 NATURAL PERIOD AND DYNAMICS BASICS

As with all structures, Jack Ups have natural response periods. For the elevated mode, the relevant natural periods (i.e., those in the vicinity of the excitation periods) are surge/sway (and possibly yaw), as the heave/pitch/roll periods are quite low. For the afloat mode, the relevant natural periods are heave/pitch/roll, as the surge/sway/yaw periods are extremely large.

Typically, surge/sway natural periods in the elevated mode are almost identical. The following factors affect the natural period in the elevated mode:

- The larger the water depth/airgap/penetration, the larger the natural period.
- The larger the elevated weight, the larger the natural period.
- The larger the rotational soil resistance (fixity), the lower the natural period.
- The larger the legs (chord cross-sectional area and spacing), the lower the natural period.

Pitch and Roll natural periods in the afloat mode are slightly different from each other due to the geometry of the hull. Though hand-calculations can be used to estimate the afloat natural periods, a more effective way that automatically accounts for added-mass effects using diffraction analysis is often used, once the Unit's mass characteristics (displacement, VCG and radii of gyration) are known. Pitch/Roll natural periods are sensitive to VCG as well as displacement, but the Heave natural period is only sensitive to displacement.

When the excitation loads are periodic in nature, the magnitude of the response in the different modes is dependent on the relative values of the excitation and natural periods. As such, a Dynamic Amplification Factor (DAF) is defined as the ratio of the response to the oscillatory load to the corresponding response to a static load having the same amplitude as the peak oscillatory load. Furthermore, the DAF is dependant on the amount of damping in the system. Damping is usually referenced as a percentage of critical damping (which is a function of mass and natural period).

Though Jack Up Units are complex structures, for dynamic purposes they can be approximated reasonably well as simple mass-spring-damper systems having a single lumped mass. As such, DAFs are usually approximated using the standard harmonic loading solutions for Single-Degree-Of-Freedom (S-DOF) systems. Typical damping values for Jack Up Units are in the range of 5-10% of critical damping.

Typically, storm survival waves have periods of 13-18 seconds while operating waves have periods of 8-12 seconds. Jack Ups in large water depths have natural periods of 6-11 seconds in the elevated mode. That means that it is possible to get larger wave-induced responses from smaller, operating condition waves than from larger waves due to the dynamics of the system.

## 6.6 TRADING BENEFITS

As is the case with any design, optimization means elimination of excess, resulting in reduced redundancy for non-design conditions. This section shows how several of the main components of a Jack Up benefit/improve or hurt/diminish the overall capabilities of the Unit.

**Hull** - The bigger the better as far as stability, strength, and operability, but larger hulls have more wind load, are heavier, and require more effort during tow. For three-legged Jack Ups, the larger the wind loads the larger preload (tanks) requirements.

**Legs** - Large cylindrical legs or trussed legs with large chord spacing are stiffer, but also weigh more and end up reducing hull buoyancy. Trussed legs with large chord spacing require longer braces that, in turn, are less capable in buckling and have more wind/wave/current loading. Furthermore, these legs are heavier and act as huge sails when the Unit is afloat, requiring even more hull buoyancy to meet stability requirements.

**Leg Spacing** - Larger spacing between legs decreases the footing reactions during a storm. This also helps in the event of a given leg slide or rapid penetration during preload; the larger leg spacing results in a smaller out-of-horizontal angle before the hull picks up buoyancy and relieves leg load. The greater leg spacing, however, requires a larger, heavier hull.

**Leg Length** - Longer legs permit larger water depth/penetration/airgap and are more flexible, but they also result in larger wind loads, reduced stability and larger inertia loads in the tow condition.

**Steel** - Higher steel grades result in a lighter structure, but they also produce less stiff components and have a lower level of redundancy. This is of particular importance for fatigue-sensitive areas, as the fatigue life of steel does not increase with its yield strength, but it reduces rapidly with increased stress range levels.

**Spud Can** - As the spud can size increases, the bearing pressure decreases, resulting in lower soil penetration. Larger spud can size, however may require larger leg well openings on the hull, reducing its afloat stability and its capacity to pick up buoyancy forces in the event of rapid penetration.

**Cantilever Beam** - Larger cantilever beams allow the Jack Up to be positioned farther from a fixed structure, but they also result in increased wind loads and large offsets of weight producing large reactions on the aft legs.

**Brace Size** - Increasing the brace diameter of truss legs improves the leg's capacity to withstand transverse loads, but larger braces have more wind/wave/current load due to higher drag loads.

**Chord Size** - Larger chords with thin members are better for carrying large compressive loads and local bending moment on the legs, but they are more susceptible to localized problems when the brace loads reach high levels. These chords are less compact and stout. Furthermore, these chords have a lower margin of load increase between the elastic and ultimate limits.

## 7. SELECTED TOPICS ON SENSITIVITIES OF JACK UPS

Depending on the general philosophy of the designer, different Jack Ups have their strengths and sensitive areas. Poor understanding of the situation and lack of preparation are often the main cause of otherwise avoidable damage. The sections below present a few of the known sensitivities of various Jack Ups focusing primarily on three-legged units used for drilling.



## 7.1 TOW

More Jack Ups have been lost at sea during tow than in any other condition. There are many factors that contribute to this, but the main ones are low freeboard, high center of gravity, large wind area, poor hydrodynamic response, and poor speed performance. These topics are addressed in more detail in the following paragraphs.

The tendency of any Owner or Operator when moving a Jack Up is to carry as much on board as possible, at as deep a draft as possible. The hull of a Jack Up is essentially a barge or box-shaped hull. This normally results in low freeboard, such that green water on deck is not an uncommon occurrence, even during a storm that is not severe. If there is any loose cargo on deck, it may break free and damage structures such as hatches, ventilation trunks, etc. If a watertight enclosure gets damaged, green water may flood spaces below deck, putting the Jack Up in imminent danger of capsizing. Additionally, since the Jack Up has a barge-shaped hull, it cannot sustain transit at a high speed, even if it had its own propulsion system. This eliminates a Jack Up's ability to out-run or out-maneuvre a storm. In some cases where the towing vessel(s) or towing gear were undersized, Jack Ups have broken free from their towing vessels and wallowed in the storm posing an extremely dangerous situation to personnel on board. Finally, as Jack Up hulls are not ship-shaped, the benefit gained from "heading into" waves may be minimal at best, and does not significantly reduce severe motions, or green water on deck. One benefit Jack Ups have over other floating vessels is the capability of lowering the legs, thereby easily lowering the VCG, and even reaching a stable foundation to weather storms, if the water depth/seabed permit it.

The tall legs of a Jack Up Unit in tow have the doubly negative effect of raising the vertical center of gravity, making the Jack Up less stable afloat, and acting as large sails which, in high winds, increase the heeling effect significantly. The center of gravity of the legs can be hundreds of feet above the waterline, so even slight motions of the hull in waves cause the legs to move like pendulums. Unless the legs are tightly secured at the jack case of leg fixation system, damage can occur to the leg structure, jacking machinery, jack case structure, or even the hull structure itself.

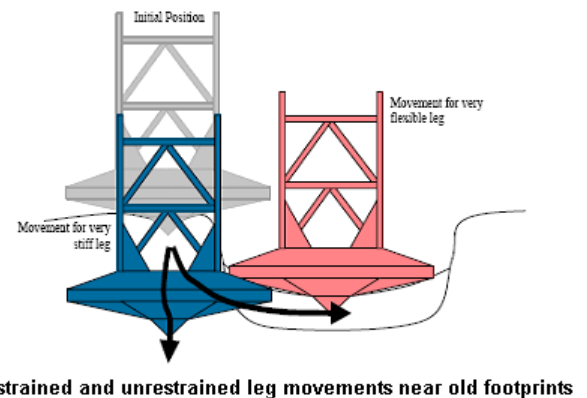
## 7.2 GOING ON LOCATION

In addition to the obvious issues related to debris and the existence of pipelines, when lowering the legs at a target site, it is important to note that different leg/jacking designs have different limiting seastates under which the legs may be lowered. In general, the degree of leg loading as impact takes place can be thought of as a transfer from kinetic energy (proportional to velocity square) to potential energy (proportional to the combined stiffness of the leg, jacking/holding system and soil). Furthermore, it is not only pitch/roll oscillations that affect the intensity of these loads, but heave oscillations are also important. As such, the following factors affect the degree of loading on the leg as first contact is made with the sea bed:

- **Period of oscillation** - Though small period waves may induce relatively small oscillating amplitudes, the low periods may induce high velocities and accelerations. Furthermore, swells (long-period waves) are likely to induce one-to-one heave responses.
- **Soil stiffness** - Harder (stiffer) soils result in a larger impact load on the leg.
- **Water depth** - Lower water depth (and therefore higher leg axial stiffness) increases the impact load on the leg. Furthermore, the afloat response of the Unit to waves is dependant on the VCG, which in turn is dependant on the relative position of the spud cans with respect to the hull (TOC).
- **Hull shape and draft** - Hull shape and draft affect the response of the Unit to waves of different periods and in different directions.

## 7.3 JACKING ON EXISTING FOOTPRINTS

Care must be taken when positioning a new jack up rig at a site previously occupied by another jack up because of the tendency of the spud cans of the new rig to slip into the spud can holes or "foot prints" left on the sea floor by the previous rig. If there is an overlap of a spud can over an old spud can hole, there is a tendency for the spud can not to penetrate straight into the soil, but instead to slip into the old spud can hole. This movement of a spud can, without a corresponding movement of all the other spud cans in the same direction, will impose a bending moment on the legs. This bending moment can be quite severe and may damage the leg in the preloading or jacking up process or it may reduce the allowable storm environmental load of the rig due to the resulting bend of the leg.



When selecting a rig for a platform, it is always best to choose a rig with the same leg spacing as a rig that previously drilled at the platform. However, the effect of previous spud can holes can be mitigated if the new rig is positioned so that the centers of its spud cans are positioned either at the center of the holes left by the previous rig or about 1.5 spud can diameters away for the edge of the holes left by the previous rig.

If the rig selected for the platform does not have the same leg spacing as a rig previously at the platform and it is not possible to position the new rig so that its legs either are centered over old holes or 1.5 diameters away from old holes while still reaching all of the required drilling positions, there are two techniques which can be used to minimize the effects of old holes. These techniques are “Reaming” and “Swiss Cheesing”.

“Reaming” is a technique by which the leg or legs are sequentially raising and lowering the spud can in the hole left by the previous rig in an attempt to wear away the side of the hole, thereby elongating the hole and creating a new hole center location at the spacing of the legs of the new rig.

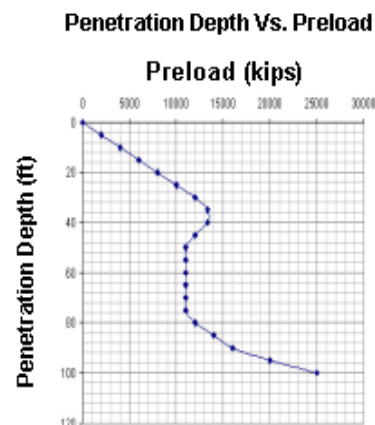
“Swiss Cheesing” is a method in which a number of large diameter holes (24 to 30 inch diameter) are drilled at the side of an existing can hole in order to degrade the strength of soil at the side of the can hole, effectively enlarging the hole.

After all precautions have been taken to minimize the effect of previous can holes, care should be taken in preloading and elevating the new jack up. The following should be observed:

- The relative position of the rig to the platform should be monitored as a movement of a leg into a previous can hole may cause an associated movement of the hull.
- If the rig is of the type that exhibits visible deformation before failure, the Rack Phase Differential (RPD) of the legs should be monitored, as this is a good indication of an external bending moment applied to a leg.
- The noises made by the legs rubbing on the leg guides should be monitored, as an increase in guide noise can be an indication of increased guide forces caused by an external bending moment applied to a leg.

#### 7.4 LEG PUNCH THROUGHS

When a Jack Up is being preloaded, it is important to be prepared to act in the event of rapid penetration of one or multiple legs. Because of the increased demands on Jack Ups (i.e., larger water depths and higher environmental loads) resulting in higher elevated weights during preload, the consequences of a punch through are increasingly more pronounced. A typical soil's bearing capacity increases with depth. When a soil layer is underlain by a weaker soil layer, there is a rapid reduction of soil strength. When the spud can reaches this interface, the weaker soil gives way and the support of the leg moves downward at a faster rate than the jacking system is capable of lowering the leg to maintain the hull level. As such, the hull rotates, the legs tilt and bend, causing the hull to sway. This results in a weight shift relative to the supports, thereby increasing the required footing reaction needed to maintain equilibrium. This process continues until either the soil's bearing capacity or any hull buoyancy arising from the hull entering the water increase sufficiently to reach equilibrium.



Jack Ups of all design types experience punch throughs and their resulting damages to braces, chords and jacking units. The accidental loading resulting from a punch through can lead to several types of leg damage including buckling of the braces, buckling or shearing of the chord, punching shear and joint damage. The extent of possible damage is dependent on the magnitude of the punch through and, more importantly, on the actions taken before, during, and immediately after the punch through.

Punch through is an extreme event; therefore, proper management of this event is necessary. Modern rigs with a better guide design along with a proper punch through management system, can minimize some of the risks.



The following factors affect the consequences of a punch through, for a given amount of “leg run” (with increased leg bending being an indication of the severity of the event):

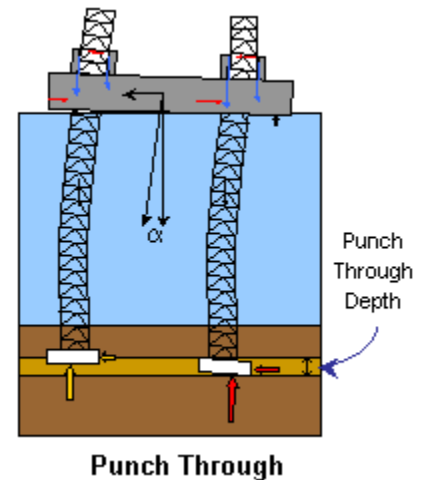
**Elevated Weight** - Higher elevated weight (i.e., amount of preload on board) results in an increased amount of leg bending.

**Water depth** - Greater water depth increases the amount of leg bending.

**Airgap** - A larger airgap means that it takes longer for buoyancy to start helping and therefore, the amount of leg bending increases.

**Leg spacing** - Greater leg spacing decreases the amount of leg bending.

It is noted that when the soil strength versus depth (penetration) curve shows regression in strength over a large enough span, especially if this regression occurs near the maximum footing reaction of the Jack Up, a procedure known as “Swiss Cheesing” can be used to lessen the effects of a punch-through. The procedure consists of drilling a number of holes through the critical soil layer(s) to reduce the soil strength so that the legs reach past the critical depth at a reduced load level in a more controlled manner.



## 7.5 OTHER SOIL ISSUES (SCOUR, EARTHQUAKE)

There are soil issues other than poor bearing capacity to consider when reviewing a Jack Up's suitability for a given location. This section presents just a few of the main issues.

The first is the case where the soil is extremely hard or calcareous. In these cases, the penetration of the spud can will be minimal allowing only a portion of the spud can bottom plate to be in contact with the seabed. In this condition, only that part of the spud can structure in contact with the soil will be supporting the environmental loads, deadweight, and operational weight of the Jack Up. It is extremely important to verify that such partial bearing will not cause damage to the spud can structure. In cases like these, an adequately reinforced tip on the spud can may be advantageous compared to flat-bottomed footings.

Scour is another problem that occurs in certain locations such as areas with sandy bottoms and high bottom current. In this case, the footing is originally supported over a certain portion of its bottom area during the initial preload operation. Over time, however, high currents may cause erosion under a portion of the footing. When this happens, the bearing pressure increases over the preload value due to loss of support area. Depending on the bearing capacity of the soil, additional penetration or spud can rotation may occur. Additionally, if the footing is not structurally adequate, structural damage may occur. Finally, if scour is severe and over a large enough area, the footing may slide into the depression created. Any of these scenarios can be extremely severe, especially since they occur with the hull at full air gap.

Seismic activity (earthquakes, tremors) and its effect on soils must also be considered in certain parts of the world. In extreme situations, seismic activity may induce liquefaction of sandy soils. There is no preparation that can be made to lessen the consequences of this situation. If seismic activity is predicted in a given area, structural analyses should be performed on the Jack Up, based on historical measured events in the area, to determine if it is structurally capable of withstanding the seismic loads and corresponding dynamic effects in combination with other operating and environmental loads.

The last soil issue addressed herein is that of bottom obstructions. Part of the process of determining if a Jack Up is suitable for a particular location is to identify bottom obstructions and determine if they will affect the location of the Jack Up's footings. Bottom obstructions include pipelines, wellheads, fixed platform piles, debris, etc. Prior to a Jack Up's arrival on site, such obstructions should be surveyed and marked with transponders. Likewise, transponders are typically placed on a Jack Up's lower legs, so their location can be monitored throughout the Soft Pinning (Section 4.3) and Final Coming On Location (Section 4.4) operations. This will reduce the risk of the Jack Up leg accidentally contacting a bottom obstruction and causing damage.

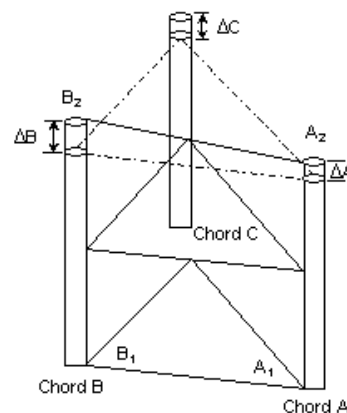
## 7.6 GUIDE/RACK TEETH WEAR

The legs are restrained in horizontal movement and in rotation by the leg guides. Leg guides may also maintain the allowable position of the elevating pinions with respect to the leg rack. Over time, it is normal to experience wear in both the guides and in the part of the leg that is in direct contact with the guides. This wear in both the leg guides and the leg should be monitored. When the leg guides are excessively worn, they should be replaced. If leg wear should become excessive, the leg should be repaired.

## 7.7 RACK PHASE DIFFERENTIAL

When reacted by the upper and lower guides, a high bending moment acting on a truss leg can cause the leg braces within the guides to buckle. Certain truss leg Jack Up designs are capable of considerable (i.e., visible and measurable) leg distortion before brace buckling occurs. This distortion, manifested in the form of differential vertical displacement of the leg chords with respect to a reference horizontal plane, is termed Rack Phase Differential (RPD). On units with measurable leg distortion before brace buckling, RPD is a good indicator of brace loading. As such, monitoring of RPD may be used as a means for reducing risk.

When measuring RPD, it is important to have a standard method of reporting (i.e., measuring up or down from the reference point). RPD values can be used to establish “leg attitudes” (i.e., inclination of the legs), which in turn can be a good indicator as to the source of the leg bending moment. For instance, when legs are leaning towards each other, the source of the leg bending moment is likely to be a leg slide.



**Schematic View of RPD Effect**

## 7.8 PINION OVERLOAD

The elevating pinions and the major gears in the elevating system may be duty cycle rated gears that are designed for a fixed life. The life cycle rating is composed of an assumed period of operation at various loads (i.e., lifting leg weight, lowering leg weight, lifting hull, lowering hull, preload lifting, etc.) An older Jack Up rig, or a Jack Up rig that has moved frequently, may exhibit signs of wear in the jacking system gears. These could be metal flow to the tooth edge, wear on the tooth surface, or spalling (flaking from tooth surfaces). If wear in the elevating gears are observed, the jacking system manufacturer should be consulted to determine the allowable amount of wear.

## 7.9 PULL-OUT OF LEGS

The first step in demobilization of the Jack Up after completion of the drilling assignment is the transition of the rig from the elevated mode to the afloat mode. In clay soils and in situations with deep spud can penetrations, the leg cans may be “stuck” or have considerable overburden soil weight on the top of the spud cans. In these situations considerable effort may be required to retrieve the legs.

If the legs are “stuck”, they may be retrieved by a combined use of the leg jetting system and utilization of hull buoyancy. The leg jetting system is a water system with a series of intakes connections along the length of the leg and discharge nozzles on the spud can. Water is pumped from the rig down the leg to the nozzles that are used to break the adhesion of the spud can bottom to the soil. The leg jetting system may have the additional benefits of filling the cavity below the spud can with water so that the soil does not have to fill the cavity and it may provide some slight positive upward pressure to the bottom surface of the spud can.

To provide an upward force tending to pull the legs out of the soil, the hull is jacked to a draft greater than the calculated afloat draft. The amount that the hull can be pulled down below the calculated afloat draft is determined by the rig designer and can usually be found in the Marine Operating Manual of the rig.

Care must be taken when retrieving the legs to maintain the hull in a level condition as an out-of-level condition can impose high bending moments on the legs. It is desirable that the retrieval process is simultaneous on all legs; it may be helpful to suspend jetting on one leg to allow the other legs to “catch up”. It should be noted that when the rig is in the water and the legs are in contact with the seabed, the unit might experience large sway motions even in relatively calm seas. When only one leg is in contact with the seabed, horizontal motions of the hull must be limited by anchors or tugs in order to prevent high bending moments on the leg.