Environmental Load Effects at Offshore Jack up Unit

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Abstract—The aim of this paper is to investigate the challenges and possible limitation associated with purpose-built jack-up units for weathering the ultra-harsh environment of the red sea and as per designated operation manual

A review of analysis methodologies and procedures applicable to a Site-Specific Assessment of a jack-up unit will be presented.

One Site-Specific Assessments (SSAs) of a jack-up unit for all-year operations at the RAS GHARIB field will be performed in accordance with the ISO 19905-1 standard.

The jack-up unit studied is a “similar” design as the AD MARINE 6 unit, with all its characteristics.

Finally, a parametric study will be addressed using the software SACS to investigate and quantify the sensitivities related to the assessment.

Index Terms—Dynamic analysis, Environmental load, ISO 19905-1, Jack up, SACS, Stiffness, SNAME, SSA, Wave

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1 Introduction

In addition to the Site-Specific Assessments

(SSAs), a parameter study has been performed to investigate and quantify the sensitivities related to water depth, air gap, lightship weight, soil conditions and other effects related to uncertainties in stiffness, hydrodynamic loading, soil structure interaction, nonlinearities and statistical parameters.

Analysis methodology and procedures for assessing jack-up units have been much debated over the last 30 years. This is mainly caused by the large extent of nonlinearities associated with estimating the jack-up responses, due to a wide number of significant uncertainties.

Nonlinearities arise because these units are drag dominated marine structures with nonlinear hydrodynamic loading, nonlinear stiffness characteristics due to the soil structure interaction and to P-δ effects in addition to be dynamic sensitive structure. The responses are therefore non-Gaussian implying assessment of various statistical methods to determine the extreme maximum responses in a sea state. The nonlinear soil-structure interaction is one of the main uncertainties to overcome because of the complicated stiffness characteristics of the foundation, which is strongly nonlinear.

The effects of foundation stiffness are significant when assessing a jack-up unit.

In this study, a two-stage deterministic procedure will be used to perform the analyses. This analysis procedure is considered acceptable by the industry because it produces satisfactory results and treats associated nonlinearities in an adequate manner. This analysis method together with the more stringent requirements in the Norwegian Annex in the ISO 19905-1 standard have been the basis for the assessment.

We will try to find the Results related to the Site-Specific Assessments for the Red Sea field at 85 ft water depth show the purpose-built jack-up unit satisfies the regulatory requirements with respect to overturning stability, leg sliding, preload capacity, leg strength, leg holding system strength and foundation bearing capacity.

The parametric studies show that some parameters have significant effect on the extreme responses due to increasing water depth, foundation fixity and leg length. Several other parameters investigated did have only minor effects on the extreme responses.

Moving into much deeper water than 250 ft. in the harsh environment of the Red Sea is questionable due to the uncertainties inherent in the applied methods, the damping characteristics, and non-linear dynamic response estimations, the structural high yield strength capacities of the legs and the soil resistance capacities of the spud cans.

A jack up model will be designed in Sacs Software, with the same characteristics of ADMARINE VI, it will be helpful to use this soft to get our results, knowing that Bentley Sacs software can achieve offshore structure compliance more quickly with the most comprehensive and up-to-date international design code coverage available. Improve design quality and predict offshore structural performance using a unified analysis environment that enables the efficient exploration of alternatives.

Analysis that can handle with SACS, including:

• Nonlinear structural analysis

• Dynamic response analysis due to environmental loads

• Impact effects analysis

• Severe accidental loadings analysis

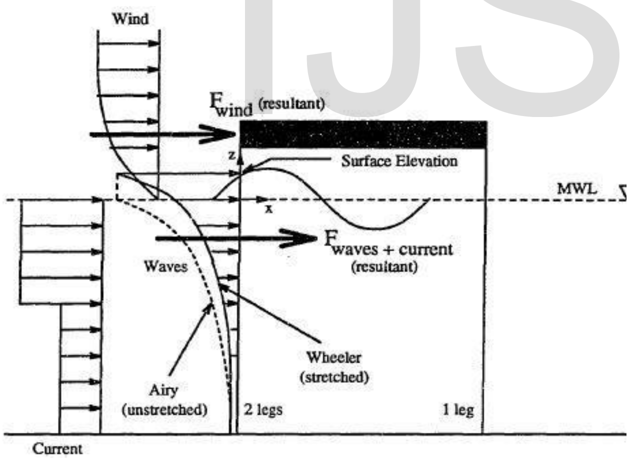


Figure Representation of wave, current and wind loads

2 Modelling of the environmental loads (1):

The suitability of a jack-up platform for a given location is normally governed by the environmental conditions on that location.
A jack-up platform may be designed for the specific environmental conditions of one location, or for one or more environmental conditions not necessarily related to any specific location.
The environmental conditions are described by a set of parameters for definition of:
Waves
Current
Wind
Temperature
Water depth
Bottom condition
Snow and ice

3 Dynamic Analysis Modeling (2)

Introduction to dynamic analysis modeling:
To determine a DAF, a simplified Dynamic Analysis model, as indicated below, may be used. The usual level of modeling employed in this case is designated as an "equivalent model". Inaccurate or inappropriate modeling can have a major effect on the calculated structural responses, therefore, special care should be exercised to assure that the modeling and application of the dynamic loading is done appropriately. The stiffness of the Dynamic

(1)RECOMMENDED PRACTICE DNV-RP-C104 SELF-ELEVATING UNITS

(2)GUIDANCE NOTES ON DYNAMIC ANALYSIS PROCEDURE FOR SELF-ELEVATING UNITS

Analysis model should also be consistent with that of the "detailed" model used for the Quasi-Static structural analysis to check the adequacy of the structure by the permissible stress unity check criteria of the MODU Rules.
The level of stiffness modeling of the "equivalent model" for dynamic analysis that should be discussed includes
Leg stiffness
Hull stiffness
Leg-to-hull connection stiffness (stiffness of jacking system, proper load transfer direction of guides, pinions and clamps, etc.)
P-Delta effect
Foundation stiffness (leg-to-seabed interactions)
Modeling the Mass
Hydrodynamic Loading
Damping modeling

4 JACK-UP ANALYSES STUDY

In this study, two Site-Specific Assessment (SSAs) have been performed of a jack-up unit for all-year operations at the Red Sea area, to address the Ultimate Limit State (ULS) condition. The jack-up unit is a Marathon LeTourneau hull no90 design.
This study has assessed the unit in its elevated mode under all-year survival conditions using Omni-directional 100-year wind and wave and 10-year current data extracted from regular survey reports. The Site-Specific Assessment has been carried out in accordance with the requirements of the ISO 19905-1 with specific reference to the Norwegian Annex criteria.
Spudcan penetrations are assumed to be of approximately 7 feet from tip of can for each leg. Foundation fixity parameters have been calculated and incorporated based on this basis.
The SSAs has been carried out using the software SACS.
This study has assessed the overturning stability, preload capacity, foundation bearing capacity, leg sliding, leg strength and the leg holding system strength. Finally, the unit's hull displacements have been addressed. No assessment of hull strength or fatigue has been made.

(3)SNAME-Jack Up Site Assessment Recommended Practices

(4)ADMARINE VI operation manual

Upon SNAME (3), It has been decided that the most suitable models for application are the equivalent 3 stick leg model in conjunction with the single detailed leg. It is appropriate to calibrate the leg properties in the 3-leg model against the characteristics of the detailed single leg model.

Principal dimensions characteristics (4):

Characteristics
Length overall
Width overall
Depth of hull
Longitudinal Leg Spacing
Transverse Leg Spacing
Leg Chord Spacing
Leg Length
Load Line Draft (Maximum Allowed Draft)
Load Line Displacement
Maximum Draft prior to elevating
Maximum Displacement prior to Elevating (with 362' legs)
Longitudinal Leg Centers
Transverse Leg Centers
Diameter of Spud Can (across the flats)
Height of Spud Can
Volume of Spud Can
Tip of Can below Hull with Legs in Raised Position
Heliport Diameter

Weights and Centers of Gravity

Hull weights and centers of gravity (CofG) used in this study are summarized in Table 5-2. The LCG and TCG are measured from the legs centroid with LCG +ve forward and TCG +ve to port side.4

Hull and leg weights4

Hull Lightship Weight (Kips) 12578.45

Storm Survival Variables (Kips) 2,296.0

(4)ADMARINE VI operation manual

Total Hull Weight (Kips) 14874.45 368.45

Centre of Gravity from Leg Centroid

LCG (m) 0.0 and -3.5

TCG (m) 0.0 and 0.0

LCG	TCG	VCG
123.23	0.69	62.79

All Legs, Footing (Kips) 3523.10

LCG	TCG	VCG
137.48	119.66	0.00

LCG (measured from Frame 0; - = Forward, + = aft)

TCG (measured from hull centerline; + = Stbd., - = Port)

VCG (measured from hull baseline; + = Upward, - = Downward)

5 Leg Hydrodynamic Model (5):

Three types of structural modelling, Barstool, Equivalent and detailed,

We will work with detailed structural modelling and barstool model

The hydrodynamic modeling of the jack-up leg may be carried out by utilizing 'detailed' or 'equivalent' techniques. In both cases the geometric modeling procedure corresponds to the respective modeling techniques the hydrodynamic properties are then found as described below:

Preloading Maximum Weight (Kips), 15,851.00	Variable Load (Kips) 6,796.00	Max. Drilling Load (Kips) 0

Detailed model5

All relevant members are modeled with their own unique descriptions for the Moris on term values with the correct orientation to determine V_n and U_n and the corresponding $C_dD=C_{di}D_i$ and $C_MA=C_{mi}\pi D_i^2/4$

Sacs Modelling steps5:

The main parts that we are going to model are:

Main Parts:

- Hull
- Leg
- Hull-Leg Connection
- Support (spud can)

Hull modeled using plates, shells & beams

Spud can & jack house modeled using beams with equivalent stiffness

Hull, Jack case, Spudcan modeled using beams as dummy with equivalent stiffness

Hull-leg connection can be modeled as cross of beams

Foundation parameters6

Initial foundation small strain stiffness and ultimate capacities have been estimated using formulas given in ISO 19905-16 and in Section 3.6.1. For simplicity, stiffness and capacities are equal for all the three legs. The resulting foundation parameters are tabulated in below Table.

By applying foundation stiffness equation

As the ISO 19905-1 standard states that the vertical load bearing capacity shall not exceed the preload capacity

Vertical small strain stiffness, K1 (MN/m)	(5,786)
Horizontal small strain stiffness, K2 (MN/m)	(5,208)
Rotational small strain stiffness, K3 (MNm/rad)	(18,903.1)
Ultimate vertical capacity, Qv (MN)/kips	100.7 /22647

(5) SACS Capabilities for Jack up Analysis
(6) ISO 19905-1

Ultimate horizontal capacity, Qh (MN)	49.0
Ultimate moment capacity, Qm (MNm)	500.0

(Table 1-1) Foundation parameters

- In the dynamic analysis, the linearized rotational small strain stiffness is calculated by, Krot= 80%K3 (MNm/rad).
- Usually a lower and upper bound of foundation stiffness and capacities are calculated and assessed. This is not performed in this study, due to lack of geotechnical data.

6 SITE ASSESSMENT ANALYSIS METHODOLOGY 6

The assessment of the jack-up unit adopts the two-stage deterministic procedure described in ISO 19905-1.
The first stage of this procedure is to perform a random wave time domain analysis to establish the dynamic response and determine the DAFs. An inertial load set is calculated by these DAFs.
During the second stage, a quasi-static deterministic extreme wave analysis is carried out which includes the inertia forces calculated during the first stage within the overall load set.
The load set within the first stage comprises a random wave train and current only, plus the inertia forces. The load set within the second stage comprises a maximum extreme deterministic wave, current, wind and a series of point forces to represent the effective dynamic amplification as derived in the first stage6

7 STRUCTURAL MODELLING

General
Equivalent 3-stick-leg mode (Barstool model) The model consists of 'equivalent legs' model, hull structure modeled using beam elements, leg to hull connections model and spud cans modeled as a stiff or rigid extension to the equivalent leg. The results from this model can be used to examine the preload requirements and overturning resistance. This model may also be used to obtain the reactions at the spudcan or internal forces and moments in the leg at the vicinity of lower guide for application to the 'detailed leg' and hull/leg model (d) which should be used to assess the strength of the leg in the area between lower and upper guides.

Modeling the Leg

It is recommended that the leg model(s) be generated in accordance with the following: The leg can be modeled as a 'detailed leg', an 'equivalent leg' or a combination of the two. The 'detailed leg' model consists of all structural members such as chords, horizontal, diagonal and internal braces of the leg structure and the spudcan (if required). The 'equivalent leg' model consists of a series of collinear beam elements (stick model) simulating the complete leg structure.

Leg modeling 'Equivalent Leg' Model The leg structure can be simulated by a series of collinear beams with the equivalent cross-sectional properties calculated using the formulas indicated in Figure 5.1 or derived from the application of suitable 'unit' load cases to the 'Detailed Leg' model. Where such a model is used, detailed stresses, pinion loads, etc. will be derived either directly or indirectly from a 'detailed model'.

Modeling the Hull

Equivalent Hull Model Alternatively, the hull can be modeled by using a grillage of beams. Deck, bottom, side shell and bulkheads can be used to construct the grillage. The properties of the beam can be calculated based on the depth of the bulkheads, side-shell and the 'effective width' of the deck and bottom plating. Attention should be paid to the in- plane and torsional properties due to the continuity of the deck and bottom structures.

Modeling the Hull/Leg Connection

(6) ISO 19905-1

The hull/leg connection modeling is of extreme importance to the analysis since it controls the distribution of leg bending moments and shears carried between the upper and lower guide structures and the jacking or fixation system. It is therefore necessary that these systems are properly modeled in terms of stiffness, orientation and clearance. For the 'Equivalent 3-stick-Ieg model'

A simplified derivation of the equivalent leg-hull connection stiffness may be applicable.

For jack-ups with a fixation system, the leg bending moment will be shared by the upper and lower guides, the jacking and the fixation systems. Normally the leg bending moment and axial force due to environmental loading are resisted largely by the fixation system because of its high rigidity. Depending on the specified method of operation, the stiffness, the initial clearances and the magnitude of the applied loading a portion of the environmental leg loading may be resisted by the jacking system and the guide structures. Typical shear force and bending moment diagrams for this configuration.

For jack-ups without a fixation system, the leg bending moment will be shared by the jacking system and guide structure. For a fixed jacking system, the distribution of leg moment carried between the jacking system and guide structure mainly depends on the stiffness of the jacking pinions.

For a floating jacking system, the distribution of leg bending moment carried between the jacking system and guide structure depends on the combined stiffness of the shock pads and pinions.

The hull/leg connection should be modeled considering the effects of guide and support system clearances, wear, construction tolerances and backlash (within the gear-train and between the drive pinion and the rack).

The following techniques are recommended for modeling hull leg connections (specific data for the various parts of the structure may be available from the designers' data package):

Simple modeling

Equivalent 3-stick-Ieg model is a simplified representation of the hull to leg connection is required. In this instance, the rotational stiffness may be represented by rotational springs and, where applicable, horizontal and vertical stiffness by linear springs. Where these are derived from a more detailed modeling, as described above, it is important that suitable loading levels (typical of the cases to be analyzed) are selected so that the effects of clearances, etc. do not dominate the result. Hand calculations may also be applicable.

We will work with detailed structural modelling

The hydrodynamic modeling of the jack-up leg may be carried out by utilizing 'detailed' or 'equivalent' techniques. In both cases the geometric modeling procedure corresponds to the respective modeling techniques. The hydrodynamic properties are then found as described below:

Detailed model

All relevant members are modeled with their own unique descriptions for the Moris on term values with the correct orientation to determine Vn and Un and the corresponding CdD=CdiDi and CMA=CmiπDi2/4

Sacs Modelling steps5:

The main parts that we are going to model are:

Main Parts:

-Hull

-Leg

-Hull-Leg Connection

-Support (spud can)

-Hull modeled using plates, shells & beams

-Spud can & jack house modeled using beams with equivalent stiffness

(5) SACS Capabilities for Jack up Analysis

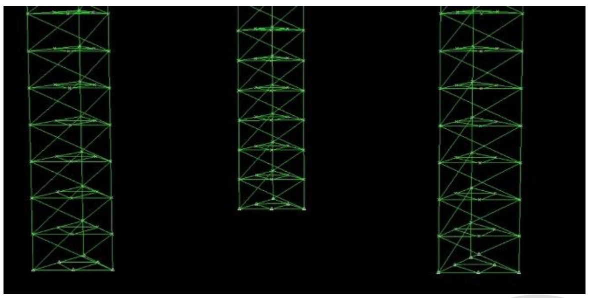
- Hull, Jack case, Spudcan modeled using beams as dummy with equivalent stiffness
- Hull-leg connection can be modeled as cross of beams

Sacs steps for building the detailed model:

Legs:

For one leg:

Using modeler



Leg modelling

Hull:
By hull mesher,

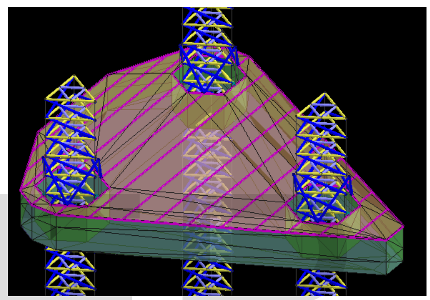
- Save the model from modeler and open it by mesher,
- Use joint tab to add joints of highest and lowest points,
- Use panel tab to add N-sided panel by draw the panel by attaching joints
- Make joints of leg opening
- Use panel tab to add N-sided opening by draw the opening by attaching joints

Hull-Leg Connection

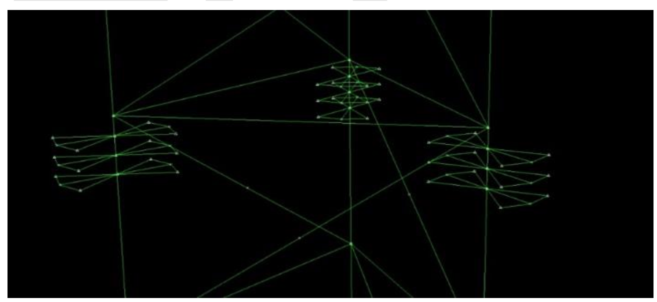
- Hull-leg connection can be modeled as cross of beams

First, calculate all dimensions from your model to help you in getting the most accurate model

- Use joint tab to add joints of highest and lowest points,
- Use member tab to add three leg chords between joints,
- Then divide them by equal parts
- Complete the structure for horizontal braces and diagonal braces by connect the required joints to make the right designed braces
-
- Complete all unpaneled sided



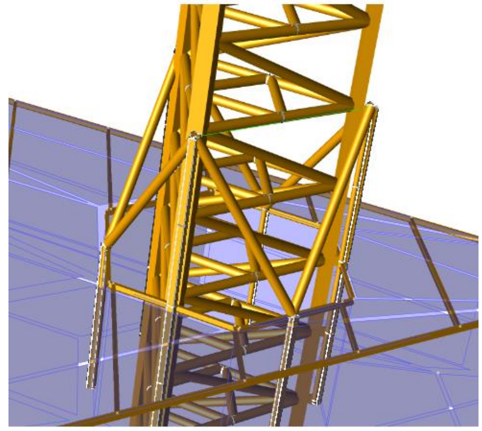
Hull modelling



Hull-Leg connection

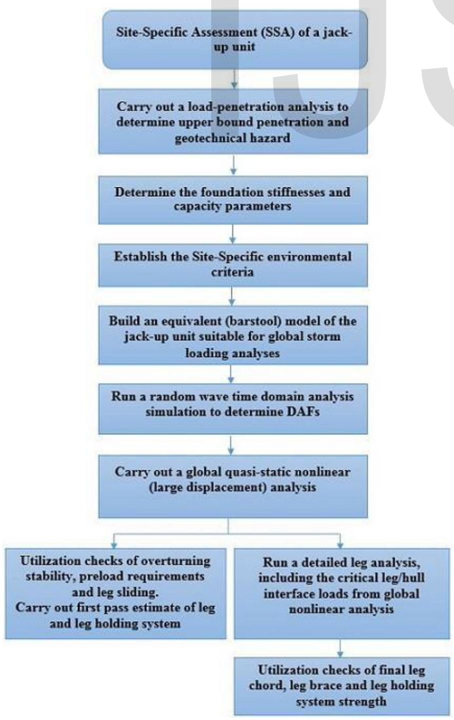
Leg jack-house:

- Spud can & jack house modeled using beams resulting in equivalent stiffness
- Site assessment analysis methodology:
- The assessment of the jack-up unit adopts the two-stage deterministic procedure described in ISO 19905-1. The first stage of this procedure is to perform a random wave time domain analysis to establish the dynamic response and determine the DAFs. An inertial load set is calculated by these DAFs. During the second stage, a quasi-static deterministic extreme wave analysis is carried out which includes the inertia forces calculated during the first stage within the overall load set. The load set within the first stage comprises a random wave train and current only, plus the inertia forces. The load set within the second stage comprises a maximum extreme deterministic wave, current, wind and a series of point forces to represent the effective dynamic amplification as derived in the first stage



Leg jack house

A flow chart summarizing the main areas covered in a SSA.



Main areas covered in SSA

8 Details on dynamic analysis[7]

The dynamic random wave analysis was carried out using a qualified wave surface history and the DAFs were calculated using the 'drag-inertia parameter' method.

The qualified wave surface history was established by a random wave train of one-hour simulation time, generated using 400 Airy wave components, and then stepped through the in

0.5 Second intervals.

The analysis accounted for P-δ effects by including negative springs to reduce leg stiffness due to axial load.

The damping was specific as 7% of critical, as recommended in the ISO standard.

A JONSWAP spectrum, with a gamma factor of 3.3, was used to define the sea state energy. Added mass on the submerged part of the legs was accounted for and linear (Wheeler) stretching was used to define the current profile in the vicinity of the wave action.

9 Details on global quasi-static nonlinear analysis[7]

The loading in the final quasi-static analysis comprised:

Gravity loads applied partly at hull grillage, and partly by applying point loads at leg centers

Wave-current loading using Stokes 5th order wave theory. The wave-current loading comprises a deterministic extreme wave plus current

Wind loads applied at hull and legs. Inertia loads applied as point forces to the hull grillage at the leg centers to represent the inertia base shear and overturning moment

An environmental load factor of 1.25 was applied in accordance with the ISO standard 19905-1.

(7) University of Stavanger master thesis at Evaluation of Jack-up units in deeper water in the North Sea

The final quasi-static extreme global response analysis was carried out using the nonlinear fixity (rotational stiffness reduction) procedure of the ISO standard 19905-1.

Using this procedure, the level of rotational restraint (fixity) at the foundations is taken as a function of the vertical, horizontal and moment loads at each footing under all applicable loadings

Since the response (and therefore the footing loads) is a function of the foundation stiffness, an iterative procedure is required to determine the correct fixity.

This is achieved by using a nonlinear large displacement analysis in SACS.

10 Large displacement analysis procedure[6]

A large displacement analysis is performed for each necessary iteration in the nonlinear fixity analysis. The procedure of the large displacement analysis is as follows: Loads are applied in increments (10 load increments is used in this analysis). The structural stiffness is progressively updated to allow for the displaced shape, using a secant method. The response is the sum of all applied load increments.

The nonlinear large displacement analysis directly accounts for P-δ effects

Nonlinear fixity procedure in ISO 19905-1

The analysis procedure is as follows:

The initial small strain foundation stiffnesses is applied to the barstool model and the nonlinear large displacement analysis run.

Then, the value of the yield interaction formula is calculated using the resulting forces and moment on each footing. Depending the soil condition, the appropriate formulation is applied to calculate the failure ratio, rf.

If rf is more than unity, the force combination lies without the yield surface. If rf is less than unity,

(6) ISO 19905-1

that means that the force combination is within the yield surface and that the load combination is acceptable.

If, on the first iteration and with the small strain stiffness, the load combination is acceptable, the initial small strain stiffness is reduced by a factor fr in stages. The analysis is re-run several times, until the change in the rotation stiffness at the footing is within a pre-set tolerance (2%). The maximum permitted change in the rotational stiffness throughout any one iteration is 1/50th of the small strain stiffness.

If, on the first iteration and with the small strain stiffness, the load combination is not acceptable, the initial small strain stiffness is arbitrary reduced in a graded fashion, depending on the value of rf, until the value of rf implies that the load combination is now within the Yield surface. If the rotational stiffness must be reduced to less than 1/100th of the small strain stiffness, this implies a bearing failure, and the stiffness is reduced to a very small

Stiffness, equivalent to a pinned condition. That footing is then left at that stiffness until all the other legs converge or indeed also reduce to a pinned condition.

The vertical and horizontal foundation stiffness are maintained at their small strain value throughout the analysis.

The peak wave period (in seconds) is defined as the wave period associated with the most energetic waves in the total wave spectrum at a specific point. Wave regimes that are dominated by wind waves tend to have smaller peak wave periods, and regimes that are dominated by swell tend to have larger peak wave period

In the dynamic analysis, the linearized rotational small strain stiffness is calculated by, Krot= 80%K3 (MNm/rad).

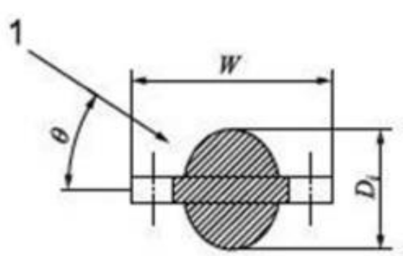
Load condition 1: preloading condition

One direction will be considered 0 degree

Vertical small strain stiffness, K1 (MN/m)	(5,786)
Horizontal small strain stiffness, K2 (MN/m)	(5,208)
Rotational small strain stiffness, K3 (MNm/rad)	(18,903.1)

(Table 1-2) Strain stiffness in preload condition

Relation between drag coefficient and angle between flow direction and plane of rack, taken from the ISO standard 19905-1



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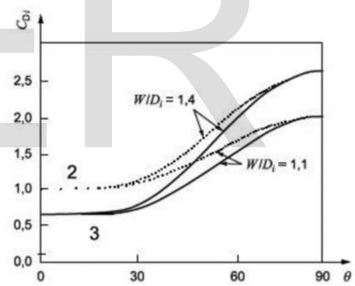
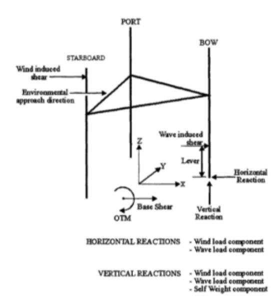


Relation between drag coefficient and angle between flow direction and plane of rack



Horizontal and vertical reaction at legs

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11 Structure calculation

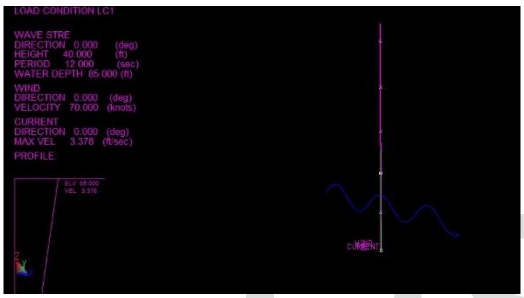
First case one leg model:

One leg stiffened at spud can with fully stiffened axial and rotational

Basic static analysis will be applied, consider linear elastic behavior and both structural material and geometry,

Extreme wave analysis:

Linear elastic dynamic analysis will be performed for a given regular wave, use to determine the steady state response for the structure and dynamic amplification factor



One leg model with applied load at certain joint

Applied loads:

Environmental loads, Loading due to extreme wave and current on legs and other submerged structure, plus

Joint load express the hull weight as 3018 kips in z direction at joint no. 12

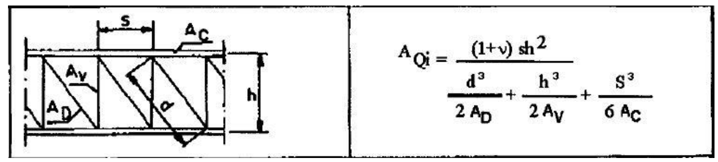
Leg self-weight about 1000 kips (distributed load).

Variable load: 2220 kips in z direction at joint no. 12

We will use a barstool leg model with equivalent properties for the original leg structure:

Effective shear area3:

For leg z design:



Equation for determining the effective shear area for two-dimensional structure

V = 0.3 for steel (Poisson ratio)

H = 12 m = 39.34 feet

S = 4.6m = 15 feet

d = 12.85m = 42.15 feet

ht = dt = 0.4 m = 1.34 feet

Ct = .8m = 2.613 feet

Ah = Ad = $^{\pi}/_{4}$d2 = 0.12 m2

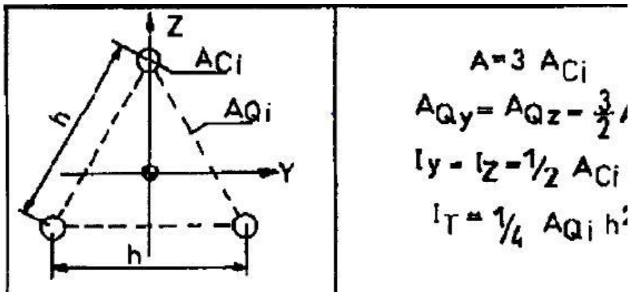
Ac = $^{\pi}/_{4}$d2 = 0.5 m2

Shear area:

As = $\frac{(1+v)sh^2}{\frac{d^3}{2A_h}+\frac{h^3}{2A_d}+\frac{s^3}{2A_c}}$ = 0.05 m2

(3) SNAME-Jack Up Site Assessment Recommended Practices

Equivalent properties[3]:



Equation for determining the equivalent section properties of three-dimensional lattice legs

A = 3 Ac

Asl = As

Iy = Iz = ½ Aclh2

It = ¼ Aslh2

A = 1.5 m2

Asl = 0.18 m2

Iy = Iz = 36 m4

It = 4.32 m4

Storm No.	1
Depth (ft)	85

Wave height (ft)	40
Wave period (sec)	12
Wind vel. (Knots)	70
Surface Current vel.(Knots)	0
Air gap (feet)	25
Leg penetration below mud line (ft.)	7

Case Condition

Distance (ft)	Velocity (ft/sec)
0.	1.689
85.	3.378

Current

Results:

Static analysis

RESULTS FOR LOAD CASE LC1

6.9 FT WAVE AT 0.0 DEG + CURRENT + WIND + USER GENERATED LOADS

SUMMATION OF FORCES AND MOMENTS FOR LOAD CASE LC1

	SUM FX KIPS	SUM FY KIPS	SUM FZ KIPS	SUM MX FT-K	SUM MY FT-K	SUM MZ FT-K
TOTAL	58.025	0	-7681.124	0	12647.687	0.0

MOMENTS ABOUT MUDLINE AT ELEVATION 0.00 FT.

(3) SNAME-Jack Up Site Assessment Recommended Practices

	X direction			Y direction			Z direction	
	JOINT	DEF. IN		JOINT	DEF. IN		JOINT	DEF. IN
LC3	0031	1.8486	LCOM	0000	0.00	LCOM	0031	-2.99

MAXIMUM JOINT DEFLECTION REPORT

JOINT	FORCES			MOMENTS		
	X (kips)	Y(kips)	Z(kips)	X (in kips)	Y(in kips)	Z(in kips)
0000	18.8	0.00	61.5	0.00	25.89	0.00
0012	128	0.00	-7842	0.00	16454	0.00
Load case	LCOM	LCOM	LCOM	LC2	LC2	LC2

SACS-IV SYSTEM SPRING FORCES AND MOMENTS

CRITICAL member	Load con.	Max unity check
0012-0013 LEG	LCOM	0.82

MAXIMUM MEMBER UNITY CHECK RANGE

12 Extreme wave analysis:

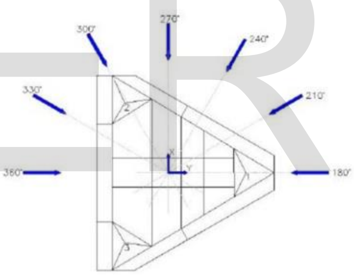
We will simple the analysis due to case simplicity

The dynamic extreme wave analysis was carried out using a qualified wave surface history and the DAFs were calculated using the 'drag-inertia parameter' method. The qualified wave surface history was established by an extreme wave train of one-hour simulation time, generated using stream wave components, and then stepped through the in 0.5 second intervals.

The analysis accounted for P-δ effects by including negative springs to reduce leg stiffness due to axial load. The damping was specific as 7%, as recommended in the ISO standard.

Loading directions

The storm loading directions and leg numbering system used in the assessment are illustrated in Figure the loading direction is such that 180° is bow-on, 270° port-on, etc. Leg number 1 refer to the bow leg, while leg number 2 and 3 refer to port- and starboard leg respectively. In total seven storm directions, have been analyzed for the ULS condition: 0° (or 360°), 180°, 210°, 240°, 270°, 300°, 340°. The rotational stiffness is reduced to 80 %.



Storm loading directions

13 Foundation evaluation

- Foundation stiffness
- Bearing capacity
- SSA
- Over turning stability
- Foundation bearing capacity
- Leg sliding
- Preload check
- First pass leg and holding system strength
- Jack up lateral hull displacement

The foundation capacities are evaluated in two steps.

i) A preload check, requiring that the foundation reaction during preloading on any leg should be equal to, or greater than, the maximum vertical reaction arising from gravity loads and 100% of environmental loads. The preload defines the static foundation capacity under pure vertical loading immediately after installation.

ii) A foundation capacity and sliding checks. The checks are based on resultant loading on the footing under the design storm.

Vertical small strain stiffness, K1 (MN/m)	(5,786)
Horizontal small strain stiffness, K2 (MN/m)	(5,208)
Rotational small strain stiffness, K3 (MNm/rad)	(18,903.1)
Ultimate vertical capacity, Qv (MN)/kips	69,000
Ultimate horizontal capacity, Qh (MN)/kips	33,534
Ultimate moment capacity, Qm (MNm)	4,968,000

Foundation parameters at storm design

Dynamic amplification factor

For lower bound 0 degree (for simplicity just one pound)

Storm heading	DAF bs	DAF otm
0	1.2	1.230916031

Dynamic amplification factors

Environmental loads:

The inertia base shear (BS) and overturning moment (OTM) are calculated by multiplying the wave/current force BS/OTM by (DAFBS/OTM-1). The total environmental loading is the sum of wave/current, wind and inertia contributions. The values include an environmental load factor of 1.25 as per ISO 19905-1 requirements.

Total forces for load case selected

Storm heading	Otm (ft-k)	Bs (kips)
0	131	0.62

Environmental overturning moment

Still water reactions

The vertical footing reactions for the still water condition are based on the total hull weight, a single buoyant leg plus the footing weight and a hull center of gravities

	Forces (kips)
One leg	6375.934

Reactions for joint 0000 (footing)

The vertical footing reactions for the still water condition are based on the total hull weight, a single buoyant leg plus the footing weight and a hull center of gravities

Resistance factors	
Righting moment	1.05
Foundation bearing capacity	1.1
Leg sliding	1.56
Preload capacity	1.1
Chord capacity	1.1
Rack-chock capacity	1.15

Resistance factors in accordance with the ISO19905-1

Maximum footing reactions and leg loads at rack-chock level

The maximum footing reactions and leg loads at rack-chock level occurs in a loading direction of 0°.

Storm heading	Footing reactions			Rack chord		
	Bs (kips)	Vertical (kips)	Moment y (ft-kips)	Bs (kips)	Vertical (kips)	moment (ft-kips)
00	98 kips	7315	131	169	1605	401

Maximum footing reaction and rack chord level

Site specific assessment criteria:

Overturning stability

The critical load case was the 0° (one leg) storm heading.

The righting moment includes a safety factor of 1.05 in accordance with the ISO 19905-1.

Otm/ Ms ≤ 1.0

MS: stabilizing moment, i.e. caused by functional loads.

OTM: overturning moment, i.e. caused by environmental loads.

Storm heading			
	OTM (ft.kips)	MS (ft.kips)	Ot uc
0	1575.75	4130	0.37

Overturning stability check

The unit passes the overturning stability assessment.

Foundation bearing capacity (horizontal capacity)

	Maximum reaction (kips)	Foundation horizontal capacity (kips)	
One leg	18.8	336.5 (1500 kn)	0.058

Horizontal bearing capacity check

Foundation bearing capacity (vertical capacity)

	Maximum reaction (kips)	Foundation vertical capacity (kips)	
One leg	61	674 (3000 Kn)	0.09

Vertical Bearing capacity check

The unit passes the Foundation bearing assessment.

Leg sliding

The leg sliding utilization checks are based on a ratio of the horizontal footing reaction (base shear) to the factored horizontal foundation capacity, the maximum horizontal footing reaction is situated in the leg for a 240° storm direction. The horizontal capacity includes a sliding resistance factor of 1.56.

Ultimate horizontal capacity, Qh (MN) 11000 kips

Maximum horizontal footing reaction 1399 kips (due to lack of applied loads)

	Maximum base shear (kips)	Foundation horizontal capacity	
One leg	140.7	336.5 (1500 kn)	0.418

Leg sliding assessment check

The unit passes the Leg sliding assessment.

(Preload check) Ultimate bearing capacity for vertical loading

The preload check was based on a factored preload capacity at the level of the footing, a resistance factor of 1.1 is included in the preload capacity. The preload utilization checks are for the most onerous leg of each storm direction. The critical preload was on the barstool leg for a 0° storm heading

Maximum vertical reaction arising from gravity loads and 100% of environmental loads	foundation reaction during preloading 61 * 0.9	UC
49.1	54.9	0.89

Bearing capacity assessment check

The unit passes the bearing capacity assessment.

First pass leg and holding system strength

The leg and leg holding system strength is based on calculated leg loads and loads at the hull interface. The chord capacity of 161 400kN is calculated after the ISO standard 19905-1, while the rack-chock capacity is an assumed value of 145 000kN.

Assuming member 11-12 represent Rack-chock strength.

Assuming member 12-13 represent chord strength.

Leg chord strength UC	0.78
Rack-chock strength UC	0.82

Leg chord strength and rack chock strength utilization check

Jack-up lateral hull displacement

Max unity check 0.55 at member 0002-0001

The unit passes the structural strength assessment.

	Lateral hull displacement
joint 0000	1.84 INCH

Structural strength assessment.

Summary

The results from this assessment show that the jack-up unit satisfies the ISO standard requirements with respect to overturning stability, leg sliding, preload capacity, leg strength, leg holding system strength and foundation bearing capacity

.

Overturning stability (UC)	0.36
Bearing capacity (UC) hor barstool leg	0.06
Bearing capacity (UC) Ver barstool leg	0.09
Leg sliding (UC) Port leg	0.41
Preload capacity (UC) ver	0.89
Leg chord strength (UC)	0.78
Rack-chock strength (UC)	0.82
Lateral hull displacements (inch) JOINT 0000	1.84

UC summery

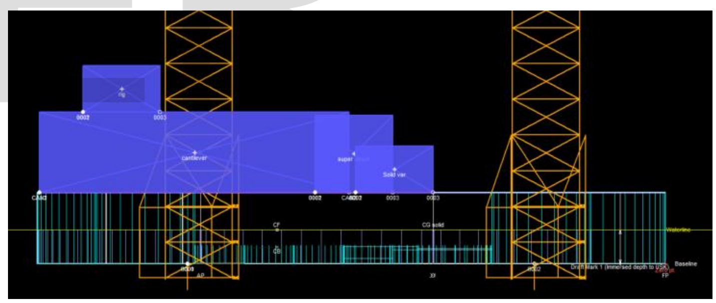
13 Intact and damage Stability Analysis calculations:

Intact stability analysis calculation

The most simple and failsafe approach is where the axis is fixed and rig is heeled around this axis with zero trim.
Various axis directions are to be investigated to arrive at the most critical one.
Top of the Red Sea environmental loads
Wave length = 20 m
(Applied stability criteria on 300 ft.)
Significant wave height 0.5 – 1 m
(Applied stability criteria on 20 ft.)
Maximum wind speed is about 12.5 ms−1
(Applied stability criteria on 100 knots, 50 knot on flooding stability)

Most dominant wind speed 6 – 6 ms−1
We will use SACS stability to define calculations

Hull Hydrostatics:



Full rig model analysis

	Draft 11 ft	
Displacement kip	15033	kip
Heel deg	0.0	ft^3
Draft at FP ft	11ft	ft
Draft at AP ft	11ft	ft
Draft at LCF ft	11ft	ft
Trim (+ve by stern) ft	0in	ft

WL Length ft	202ft 9.07in	ft^2
Beam max extents on WL ft	170ft	ft^2
Wetted Area ft^2	26910.02	ft^2
Waterpl. Area ft^2	21357.07	
Prismatic coeff. (Cp)	0.620	
Block coeff. (Cb)	0.620	
Max Sect. area coeff. (Cm)	1.000	
Waterpl. area coeff. (Cwp)	0.620	from zero pt. (+ve fwd) ft
LCB from zero pt. (+ve aft) ft	125ft 3.83in	from zero pt. (+ve fwd) ft
LCF from zero pt. (+ve aft) ft	125ft 3.83in	from zero pt. (+ve fwd) % Lwl
KB ft	5ft 6in	from zero pt. (+ve fwd) % Lwl
KG ft	11ft	ft
BMt ft	134ft 11.45in	ft
BML ft	218ft 5.26in	ft
GMt ft	129ft 5.45in	ft
GML ft	212ft 11.26in	ft
KMt ft	140ft 5.45in	ft
KML ft	223ft 11.26in	ft
Immersion (TPi) Long Ton/in	50.841	ft
MTi Long Ton.ft	793.910	Long Ton/in
RM at 1deg = GMt.Disp.sin(1) kip.ft	33963.15	Long Ton.ft
Max deck inclination deg	0.0000	kip.ft
Trim angle (+ve by stern) deg	0.0000	

Rig stability analysis at different drafts

We will make stability analysis on Wind velocity (knots) 100

On large angle stability, wave height will be max 20 ft

On Equilibrium analysis, wave height will be max 20 ft max

By applying below equation to get wind force

Wind Load acting on a Surface

$F_w = 1/2\ \rho\ v^2\ A$

ρ (Air density) = 1.2 kg/m3 = 0.0000749088 kips/ft3

v = 70 knot = 118 ft. /s

Area exposed to Wind

Heeling moment calculations:

$F_w = 0.52\ A$

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For hull:

Draft at LCF = 3.65 m

Center of gravity G = 5.4 m

Wind arm = 1.75 m = 4.75 ft

Area exposed = 2200 ft2

Cs = 1

Ch = 1

Fw = 1.06581 A

Wind force = 2344 kips ft.

ARM = 5.5 ft.

Moment = F*ARM = 6300 kips. Ft.

For legs:

Draft at LCF = 3.35 m

Center of gravity G = 137 ft

Wind arm = 126 ft

Area exposed = 678 ft2

C_s = 0.5

C_h = 1.2

Wind speed = 100 knots = 51.4 m/s (storm) = = 168.7 ft/s

Wind force = 1652 = kips

Wind arm = 126 ft

Moment = F*ARM = 45490 kips.ft

Total moment = 51790 kips.ft

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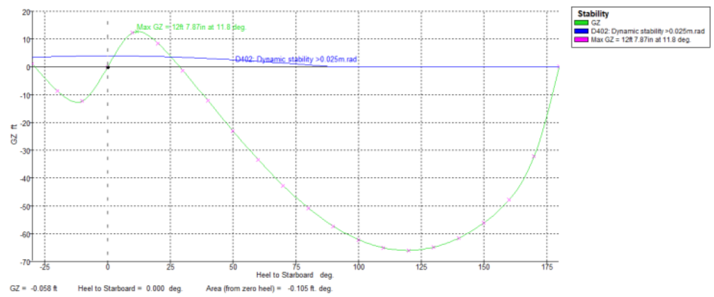

Righting moment and heeling moment curves

Ratio of areas type 3

General heeling arm the ratio of the area under the GZ curve to the area under the heel arm curve is computed. This criterion is based on the area ratio required by BS6349-6:1989. The criterion is passed if the ratio is greater than the required value. Areas under the GZ=0 axis are counted as negative.

Area GZ = $\int_{\phi_1}^{\phi_2} GZ(\phi)d\phi$; ;

Area HA = $\int_{\phi_1}^{\phi_2} \text{heel arm}(\phi)d\phi$; ;

Ratio = HA Area /GZ Area

Criteria	Value	units	Actual	Status	Margin
Ratio of areas type 3				Pass	
General heeling moment					
Areas integrated from the greater of					
spec. heel angle	0.0	deg	0.0		
to the lesser of					
first downflooding angle	n/a	deg			
angle of vanishing stability (with heel arm)	24.7	deg	24.7		
AreaGZ / AreaHA shall be greater than (>)	140.00	%	216.73	Pass	+54.81
Intermediate values					
Area under GZ, from 0.0 to 24.7 deg.		ft.deg	181.905		
Area under HA, from 0.0 to 24.7 deg.		ft.deg	83.932		

Righting moment check

Range of positive stability:

Computes the range of positive stability with the heeling arm. [Range of stability] = [Angle of vanishing stability] – [Angle of equilibrium] The criterion is passed if the value of range of stability is greater than the required value.

Criteria	value	unit	Actual	status	Margin
Range of positive stability				Pass	
General heeling moment					
from the greater of					
spec. heel angle	0.0	deg			
angle of equilibrium	2.6	deg	2.6		
to the lesser of					
first down flooding angle	n/a	deg			
angle of vanishing stability	24.7	deg	24.7		
shall be greater than (>)	0.0	deg	22.0	Pass	infinite

Positive stability check

Down flooding analysis:

Criteria	value	unit	Actual	status	Margin
Margin line immersion				Fail	
the min. freeboard of the	Marginline				
shall be greater than (>)	0in	ft	-1.89in	Fail	infinite
Deck edge immersion				Pass	
the min. freeboard of the	DeckEdge				
shall be greater than (>)	0in	ft	1.06in	Pass	infinite
Maximum trim				Pass	
the angle of	Trim				
shall be less than (<)	10.0	deg	-5.2	Pass	+152.33
Minimum GMt				Pass	
the value of	GMtransverse				
shall be greater than (>)	7.87in	ft	75ft 1.77in	Pass	+11352.50

Down flooding analysis check

Damage stability analysis:

Apply Bow damage:

For single compartment damage stability for wind speeds up to 50 knots.

Wind velocity (knots) 50

Criteria	value	unit	Actual	status	Margin
D402: Dynamic stability >0.025m.rad				Pass	
Heeling arm = A cos^n(phi)					
A =	3ft 11.24in	ft			
n =	1				
Area integrated from the greater of					
angle of equilibrium (with heel arm)	2.5	deg	2.5		

to the lesser of					
spec. heel angle	45.0	deg			
first downflooding angle	n/a	deg			
angle of vanishing stability (with heel arm)	25.3	deg	25.3		
shall be greater than (>)	4.698	ft.deg	125.467	Pass	+2570.56
Intermediate values					
Area under GZ curve.		ft.deg	211.995		
Area under heeling arm curve.		ft.deg	86.528		

Damage stability analysis check

ROS equation For Damage Stability:

Max Deck inclination (θs)= 5.2 degree

Maximum angle of positive stability = 24.2 degree

By Appling ROS equation:

ROS > 7 + 1.5 θs

ROS = 24.2 – 5.2 = 19 degree

7 + 1.5 θs = 14.8 degree

So ROS satisfy deck inclination,

The damage stability criteria is PASS

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