



COMMENTARY ON THE

**ABS RULES FOR BUILDING AND CLASSING
MOBILE OFFSHORE DRILLING UNITS, 2001
Part 3 – Hull Construction & Equipment**

JANUARY 2005

**American Bureau of Shipping
Incorporated by Act of Legislature of
the State of New York 1862**

**Copyright © 2005
American Bureau of Shipping
ABS Plaza
16855 Northchase Drive
Houston, TX 77060 USA**

This Page Intentionally Left Blank

Foreword

This document is a Commentary on Part 3 of the ABS *Rules for Building and Classing Mobile Offshore Drilling Units*, 2001, which is referred to herein as the “*MODU Rules*”. This document is referred to herein as the “*Commentary*”. This Commentary is not intended to replace the *MODU Rules*, but serves to supplement them. In case of any conflict between the contents of the Commentary and the *MODU Rules*, the latter will always take precedence. The contents are directed to Self-Elevating Drilling Units and Column-Stabilized Drilling Units, although the “Loadings” section may have application to other types of units. It is expected that this Commentary will be updated periodically to include topics in the *MODU Rules* other than structures, and to reflect significant changes to the *MODU Rules* that warrant a commentary. It is also expected that the scope of this document will broaden in the future to include Surface-type Drilling Units.

The intent of the Commentary is to give guidance and to elaborate on various portions of the *MODU Rules* that have generated questions over the years. The intent is not to provide commentary on every paragraph of the *MODU Rules*; instead commentary is provided for areas that are deemed to merit further discussion.

The style of this document is intended to give guidance as to the origin of the *MODU Rules*, and to elaborate on the information ABS prefers to be submitted at the design appraisal stage of the Classification process.

The arrangement of the text uses the numbering of the 2001 *MODU Rules* with the addition of a prefix “C” to denote that the text is from the “*Commentary*”. Since not all paragraphs of the *MODU Rules* have commentary, the numbering of this Commentary will not be consecutive.

This Page Intentionally Left Blank



COMMENTARY ON THE
**ABS RULES FOR BUILDING AND CLASSING
MOBILE OFFSHORE DRILLING UNITS, 2001**
Part 3 – Hull Construction & Equipment

CONTENTS

SECTION C 3-1-1 Definitions	1
C 3-1-1/1 General	1
C 3-1-1/1.1 Unit	1
C 3-1-1/3 Types of Drilling Unit.....	1
C 3-1-1/3.3 Column-Stabilized Drilling Unit (CSDU)	1
C 3-1-1/7 Water Depth.....	1
C 3-1-1/17 Mode of Operation	2
General.....	2
Self-Elevating Drilling Unit.....	2
Column-Stabilized Drilling Unit (CSDU).....	2
 SECTION C 3-1-2 Environmental Loadings	 3
C 3-1-2/1 Loading Criteria.....	3
C 3-1-2/1.1 General	3
C 3-1-2/1.3 Wind Loadings	3
C 3-1-2/1.5 Wave Loadings	7
C 3-1-2/1.7 Current Loading	20
C 3-1-2/1.9 Loading due to Vortex Shedding.....	22
 TABLE 1 Wind Pressure Height Coefficient Above the Design Water Surface.....	 4
TABLE 2 Shape Coefficients for Wind Force Calculations	7
 FIGURE 1 Plot of Wind Force Height Coefficient vs. Height Above Design Waterline.....	 5
FIGURE 2 Split Force between Pontoons Twisting Pitch Moment about Transverse Horizontal Axis	10
FIGURE 3 Twisting Pitch Moment about Transverse Horizontal Axis Longitudinal Shear Force between Pontoons.....	11
FIGURE 4 Longitudinal Shear Force between Pontoons.....	12
FIGURE 5 Longitudinal and Transverse Accelerations of Deck Mass.....	12
FIGURE 6 Vertical Wave Bending Moment on the Pontoon.....	13

FIGURE 7	Flowchart for Selecting Design Waves by the Stochastic Method	16
FIGURE 8	Flowchart for Selecting Design Waves by the Deterministic Method	18
FIGURE 9	Effect of Wave on Current Velocity	21
APPENDIX C 3-1-A2 Wave Theory for Deep Water.....		23
C 3-1-A2/13	Drag Forces in Deep Water	23
	Drag Coefficients: Cylinders	23
	Drag Coefficients: Inclined Members	23
	Drag Coefficients: Non-Tubulars.....	23
	Drag Coefficients: Appurtenances	26
	Raw Water Tower	26
C 3-1-A2/15	Recommended Mass Factors	26
	Inertia Coefficient C_M	26
FIGURE 1	Reference Angle for Drag Coefficients	24
FIGURE 2	Drag Coefficient of Tubular Chord with Rack: Deterministic Analysis.....	25
FIGURE 3	Drag Coefficient of Triangular Chords: Deterministic Analysis.....	25
SECTION C 3-1-3 Material Selection		27
C 3-1-3/3	Hull Steel Grades.....	27
	Self-Elevating Drilling Unit	27
	Column-Stabilized Drilling Unit	27
C 3-1-3/5	Selection of Grades of Steel	27
	C 3-1-3/5.1 General	27
	C 3-1-3/5.3 Self-Elevating Units	28
	C 3-1-3/5.5 Column-Stabilized Units	28
	C 3-1-3/5.7 Selection Criteria for ABS Grades of Steel.....	29
	C 3-1-3/5.9 Criteria for Other Steels.....	29
SECTION C 3-2-1 Structural Analysis		31
	C 3-2-1/1.1 Analysis of Primary Structure	31
	C 3-2-1/1.15 Analysis and Details of Structural Connections.....	40
	C 3-2-1/1.7 Consideration of Buckling.....	40
	C 3-2-1/1.17 Fatigue Analysis.....	40
TABLE 1	Wave and other Parameters to be used in a Fatigue Analysis.....	43
FIGURE 1	Simplified Load Arrangement on Jack-up Leg.....	32
FIGURE 2	Flow Chart for Overall Analysis Procedure for CSDUs	36
FIGURE 3	Flow Chart for Design Wave Selection and Hydrodynamic Loads and Motion Analysis for CSDUs.....	37

FIGURE 4	Flow Chart for Global Strength and Fatigue Analyses for CSDUs	39
----------	---	----

SECTION C 3-2-2 Common Structures 45

C 3-2-2/5	Structures Supporting the Drilling Derrick.....	45
C 3-2-2/5.1	Substructures.....	45
C 3-2-2/7	Watertight Bulkhead and Watertight Flats	45
C 3-2-2/7.1	General	45

SECTION C 3-2-3 Self-Elevating Drilling Units 47

C 3-2-3/5.1	Legs	47
C 3-2-3/5.7	Wave Clearance	48
C 3-2-3/5.13	Sea Bed Conditions	48

SECTION C 3-2-4 Column-Stabilized Drilling Units (CSDUs)..... 49

C 3-2-4/1.3	Special Considerations Regarding Stress.....	49
C 3-2-4/1.5	Effect of Mooring Forces on Local Structure	49
C 3-2-4/3	Upper Structure.....	49
C 3-2-4/3.17	Deck Houses.....	50
C 3-2-4/5	Columns, Lower Hulls and Footings.....	50
C 3-2-4/5.11	Bracing Members.....	50
C 3-2-4/7	Structures Supporting the Drilling Derrick.....	50
C 3-2-4/9	Wave Clearance	51
C 3-2-4/11	Structural Redundancy	51
C 3-2-4/11.1	Assumed Damage	51

SECTION C 3-5-1 Position Mooring Equipment Systems and Equipment 53

C 3-5-1/1	General	53
C 3-5-1/3	Temporary Mooring Equipment	53
C 3-5-1/5	Position Mooring Equipment.....	53
C 3-5-1/7	Position Mooring Systems	53

This Page Intentionally Left Blank



SECTION **C 3-1-1** **Definitions**

C 3-1-1/1 **General**

Section 3-1-1 of the *MODU Rules* defines the types of units to which the Rules apply, and it contains definitions of depth, bulkhead and freeboard decks, lightweight, weathertight, watertight and Modes of Operation. These items are relatively well-defined in the *MODU Rules*. However, a few of these definitions in the Rules occasionally cause confusions with users. Explanations for some of these definitions are given below.

C 3-1-1/1.1 **Unit**

The Classification Notations for a “Unit” usually contain the word, “Drilling”. This is because drilling-related activities are the most common primary uses of Units. However there is a provision in the *MODU Rules* (1-1-3/3) that permits the Classification of *special purpose* units that are similar in configuration and operation to drilling units. In this case the word “drilling” will be replaced by another word to denote the unit’s primary function. In this Commentary, the term “Drilling Unit” will be used, but the ability to Class units of other types should be borne in mind.

Typically, the bases of Classification for a “unit” entail environmental parameters describing design wave characteristics, current profiles, water depths and other conditions specified by the Owner. When the bases of Classification are site-specific factors (e.g., environmental and geotechnical conditions) that are established and reviewed in accordance with the ABS Rules, the Classification Notation usually contains the word, “Installation” rather than “Unit”. Several ABS Rules and Guides other than the *MODU Rules* apply to Offshore Installations.

C 3-1-1/3 **Types of Drilling Unit**

C 3-1-1/3.3 **Column-Stabilized Drilling Unit (CSDU)**

CSDUs can be placed into two categories: Semi-submersibles and Submersibles. Both depend upon the buoyancy of columns and lower hulls or footings for flotation and stability for all afloat modes of operation, or for ballasting and deballasting of the unit for various modes of operation. A description of the similarities and differences between the two categories is given in C 3-1-1/3.3.1 and C 3-1-1/3.3.2.

C 3-1-1/3.3.1 **Semi-submersible Drilling Unit**

A *Semi-submersible Drilling Unit* (often depicted as a CSDU) is normally designed with an upper hull, stability columns and lower hulls connected by a series of horizontal or horizontal and diagonal bracing members. The upper hull can be constructed either as a single level grillage; or as a multi level “box”, which may have significant reserve buoyancy. The box-shaped, buoyant-type upper hull has become the prevalent design concept in recent years.

In today’s practice, drilling operations are normally carried out in the afloat condition. However, many years ago, some semi-submersible units also had the capability of drilling while supported by the seabed. This type of operation has not been common in recent years.

C 3-1-1/3.3.2 Submersible Drilling Unit

A *Submersible Drilling Unit* is a CSDU designed for drilling operation solely when the unit is supported by the seabed. This type of unit was one of earliest types of offshore drilling unit to be developed, and it became popular during the early days of drilling in the Gulf of Mexico. The early designs often had numerous columns with lower hulls strengthened to resist the bottom-sitting application of the unit. By the early 1980's, some designs entailed three columns with large footings that were strengthened for bottom sitting operation. These units transited to and from location on their lower hulls or footings, and normally drilled while sitting on the seabed in maximum water depths of about 20 meters.

Today, submersible drilling units used for exploration offshore have all but disappeared because self-elevating drilling units are being used in these shallower water depths. Some of the 1980's-built submersible-type units have been converted to semi-submersible drilling units for operation in water depths exceeding 1500 meters.

Another type of submersible unit in current use is the "submersible drill barge" for operation in rivers and inland waterways. This type of unit is normally designed with a barge-type lower hull and a series of columns that support an elevated deck. These units normally operate in fairly shallow water in rivers and other protected waters. Such units may have the Classification designation of "**Posted Drill Barge**", and they usually have a restricted service notation of "**River Bays and Sounds**".

C 3-1-1/7 Water Depth

The ABS definition of *Water Depth* for analysis purposes is the vertical distance from the seabed to the nominal water level plus the height of the astronomical and storm tides.

Other frequently quoted levels include:

- *Mean High Water Springs (MHWS)*. This is the highest average tidal water level that is normally considered to be coincident with a storm and is recommended for use when calculating the air gap.
- *Mean Low Water Springs (MLWS)*. For some self-elevating units operating in relatively shallow water, the worst loads and stresses may be associated with large waves occurring at low tide rather than at high tide. Under these circumstances, it is recommended that the lowest average tidal water level associated with the MLWS is to be considered.
- *Storm Surge* is the change in water level due to wind drag and changes in atmospheric pressure. When calculating the air gap the maximum storm surge for the relevant return period should be used¹.
- *Seiche* is the effect of changes in water level due to "sloshing" in an effectively enclosed body of water. A potential cause of a seiche would be an earthquake affecting, say, Cook Inlet in Alaska. An earthquake-induced seiche is considered unlikely to be coincident with a severe storm, and meteorologically-induced seiche is normally very small, so it is unlikely to be critical to the air gap.

¹ It is usual to use 50 year extreme values when calculating the air gap, even if a lower return period is used for other assessment purposes. The reason is that a slightly conservative air gap is normally inexpensive, added insurance against the vastly increased wave loads caused by waves impacting the hull.

C 3-1-1/17 Mode of Operation

General

As a minimum, MODUs should be analyzed for the Modes of Operation of *Severe Storm, Normal Drilling and Transit Mode*, outlined in 3-1-1/17 of the *MODU Rules*. If the unit's main function is something other than drilling (e.g., an accommodation unit, tender assist, etc.), then the Normal Operating condition should substituted for the Normal Drilling condition.

Self-Elevating Drilling Unit

Normal Drilling is generally taken to be a drilling condition that assumes the unit to be at the maximum water depth, maximum total elevated load, and maximum wind, wave, and current that can be applied so that the unit's structure is within the allowable stresses as specified by the *MODU Rules*. However, self-elevating units are often operated in a variety of water depths, environmental and loading conditions that differ from the Standard Normal Drilling Mode. These conditions are often referred to as *Additional Elevated Operating and Storm Conditions*.

- *Additional Operating Conditions*. For unrestricted service, self-elevating units are normally designed for a maximum water depth, using the 70 knot wind, plus wave and current forces that are compatible with the water depth, together with the maximum or minimum design variable deck load that will keep the global stresses, etc., within the *MODU Rules* limits. Many owners also have a series of elevated drilling and storm conditions in the Operating Manual that show how the unit can be operated in deeper water with lesser environmental load or in shallower water with greater total elevated loads. These conditions need to satisfy the *MODU Rules* allowable stresses and the analyses must be submitted to ABS for review. Similarly, some Owners use an "Envelope of Approved Conditions" to ensure that the unit operates within the *MODU Rules* allowable limits. This "Envelope of Approved Conditions" must also be approved by ABS and is generally referenced in the Operating Manual. The "Envelope of Approved Conditions" is normally compiled in terms of Water Depth, Air Gap, Penetration, Wave Height, Wave Period, Current Profile, Wind Speed and Allowable Total Elevated Load. When the combination of parameters for which the unit is intended to be operated produces results that exceed the "Envelope of Approved Conditions", an appropriate analysis is to be performed to confirm the acceptability of the unit. The "Envelope of Approved Conditions" is not a requirement for Class. However, it should be submitted to ABS for review and included in the Operating Manual.

Column-Stabilized Drilling Unit (CSDU)

Analyses for structural strength and fatigue, as well as intact and damage stability, of a CSDU should be undertaken for three modes of operation using the appropriate wind, wave and current that are established in accordance with 3-1-1/17 of the *MODU Rules*.

The Normal Drilling condition draft is often the same draft as the Severe Storm condition draft, however in older designs the Severe Storm condition draft was often about 2 m lighter than the operating condition draft. This meant that some deballasting had to be done to change from the Normal Drilling to the Severe Storm condition. Modern designs tend to have the same draft for these two conditions. One factor used to determine the operating and transit draft is air gap. It is desirable to design a CSDU such that the crest of the storm and operating waves will not hit the underside of the upper hull. This is normally determined from model testing.

The Transit draft of a semi-submersible is normally near the top of the lower hull. When a CSDU makes an ocean or field transit and the sea states exceed what was used in the structural and stability analyses for the transit condition, the unit will need to be ballasted to the severe storm draft and wait out the weather. This operating instruction together with all other operating modes is to be documented in the Operating Manual of the unit.



SECTION **C 3-1-2 Environmental Loadings**

C 3-1-2/1 Loading Criteria

This section discusses the environmental data requirements outlined in Section 3-1-2 of the *MODU Rules*. Each of the environmental parameters that affect the loads on a unit is discussed.

The method of determining the main environmental loads is set out in the *MODU Rules*. This section of the Commentary will briefly review those loadings, and will go on to discuss other loads that need to be assessed under certain circumstances. It will also discuss implications of the *MODU Rules*, and their interpretation.

One of the most important maxims to follow when calculating the loads on any structure, including self-elevating units and column-stabilized units, is to ensure that the calculation method is compatible with the structural assessment methodology that will be used to determine the influence of those loads. There are many rule sets available to the designer/analyst: the important issue is to ensure that a consistent set is used. The intent here is to give assistance in determining a suitable set of rules and parameters.

C 3-1-2/1.1 General

Requirements for Classification

The *MODU Rules* specify that the Modes of Operation for a drilling unit are to be Severe Storm, Normal Drilling, and Transit Conditions. The only environmental conditions specified in the *MODU Rules* for unrestricted service are 51.5 & 36 m/s (100 & 70 knots) minimum wind velocities for these conditions. See C 3-1-2/1.3.1. There are no specified wave properties, or current velocities stipulated in the Rules. Wave properties and current velocities should be defensible. It is the Owner's responsibility to specify the environmental conditions for which the unit is being designed and for which the plans of the unit are to be approved.

C 3-1-2/1.3 Wind Loadings

C 3-1-2/1.3.1 General

Self-elevating units for unrestricted ocean service are designed with a minimum wind speed of 51.5 m/s (100 knots) in the elevated severe storm condition, and a minimum of 36 m/s (70 knots) in the elevated operating condition. The wave height normally used by a designer is the maximum that causes the unit to be at or within the acceptance criteria.

The global horizontal wind force on a CSDU is considered to be insignificant compared to the wave forces on the unit. Therefore wind forces can normally be neglected in the global structural analysis of a CSDU.

Global wind forces, however, should be included in the afloat stability and mooring analyses of a CSDU. The effects of wind on local structural members and assemblies should be accounted for as warranted.

Restricted Service Classification

In 3-1-2/1.3.1, there is a provision for a *Restricted Classification* designation for MODUs designed for a wind velocity less than 51.5 m/s (100 knots) but with a minimum velocity of 25.7 m/s (50 knots) for Normal Drilling, Severe Storm, and Transit Conditions. Therefore, for MODUs that are to be classed for restricted services, the minimum wind velocity that can be used in design is 25.7 m/s (50 knots).

C 3-1-2/1.3.2 Wind Pressure

The *MODU Rules* specify that for unrestricted offshore service, a self-elevating unit should be designed for a wind speed of at least 36 m/s (70 knots) in the Operating Condition and at least 51.5 m/s (100 knots) for the severe storm condition. The operating manual needs to set out how the unit should change mode from the operating condition to the severe storm condition, and it needs to be demonstrated that the unit will not be overloaded during this change.

**TABLE 1
Wind Pressure Height Coefficient
Above the Design Water Surface**

<i>Height (m)</i>	<i>Height (ft)</i>	<i>C_h</i>
0-15.3	0-50	1.0
15.3-30.5	50-100	1.1
30.5-46.0	100-150	1.2
46.0-61.0	150-200	1.3
61.0-76.0	200-250	1.37
76.0-91.5	250-300	1.43
91.5-106.5	300-350	1.48

The wind speed increases with height above the mean sea level. The *MODU Rules* specify a profile to be applied when calculating the wind pressure, as given in C 3-1-2/Table 1. This is not a complete listing of the table given in the Rules, but should be sufficient for most elevated conditions to be analyzed. (A complete listing is given in 3-1-2/Table 2 of the *MODU Rules*.) It is important to note that this is NOT the same as a wind velocity profile. Velocity profile factors are effectively squared during the calculation of wind force. In order to compare the two it is necessary to either square the velocity profile ordinates, or take the square root of the *MODU Rules* wind pressure height coefficients.

C 3-1-2/Figure 1 gives a plot of the Rule height coefficient, *C_h* compared to those from other standards. The “API 1 min. Force Profile” is the wind force profile as suggested in older versions of API RP 2A ², but modified from a velocity profile, to a force profile. The basic form of these profiles is:

$$V_h = V_{ref} \left(\frac{h}{h_{ref}} \right)^{\frac{1}{n}}$$

where

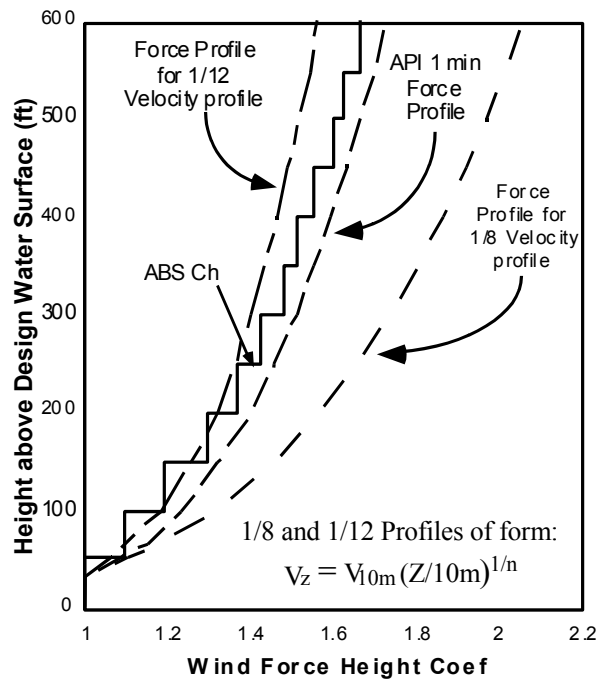
V_h = wind velocity at elevation *h* above the mean sea level

V_{ref} = wind velocity at the reference height

² API RP 2A Section 2.3.2b items 1, 2, and 3

- h_{ref} = reference height (in API it is 10 meters or 33 feet)
- $1/n$ = exponent of the velocity profile ³

FIGURE 1
Plot of Wind Force Height Coefficient vs.
Height Above Design Waterline



Older versions of API RP 2A indicated that the exponent should range between $1/13$ for gusts, and $1/8$ for sustained winds, but there were no definitions for “gusts” or “sustained” winds. The 20th Edition modifies the format and gives an exponent of $1/8$ for a one-hour wind, but then gives a more complex conversion to a height profile for the one-minute mean wind. It is this modified one-minute mean wind speed profile that has been plotted in C 3-1-2/Figure 1.

One of the major causes of difference between different profiles is due to changes in the reference height. C 3-1-2/Figure 1 is not an entirely accurate comparison of the various profiles, because the reference velocities are slightly different. The ABS profile is for a wind measured at a reference height of 50 feet, whereas the API curve is for a wind measured at a reference height of 33 feet. This can be a major cause of differences between different sets of height coefficients. If the API 1-minute wind profile were plotted with respect to the same reference height as the ABS C_h profile, the results would be very similar.

The wind profile in SNAME T&R Bulletin 5-5A “Site Specific Assessment of Mobile Jack-up Units” is similar to API 1-minute wind profile.

³ Note that if the exponent of the velocity profile is $1/n$ the exponent of the force profile will be $2/n$.

C 3-1-2/1.3.3 Wind Force

The wind speeds to be used for the analysis of a self-elevating unit are given in C 3-1-2/1.1. The wind force, in its simplest form, is calculated as the product of the projected area and the wind pressure:

$$F = PA$$

where

- F = Wind Force, in N (kgf, lbf)
- P = Wind Pressure, in N/m² (kgf/m², lbf/ft²)--
- A = Projected Area, in m² (ft²), of exposed surfaces

The wind pressure is a function of the air density; the shape and height coefficient; and the square of the wind speed:

$$P = 0.5\rho V_k^2 C_h C_s$$

where

- V_k = Wind Velocity, in m/s (kn)
- C_h = Height Coefficient (Dimensionless) A limited range is given in C 3-1-2/Table1, with a more complete table in 3-1-2/Table 2 of the *MODU Rules*
- C_s = Shape Coefficient (Dimensionless), as given in C 3-1-2/Table 2
- ρ = air density (1.22 kg/m³ or 0.0024 slugs/ft³)

The form of the equation is slightly different from that given in the *MODU Rules* where the “0.5ρ” is replaced by a dimensional factor that also takes into account the conversion from knots to feet per second. The form given in the Rules is:

$$P = fV_k^2 C_h C_s$$

where

- f = 0.611, 0.0623, 0.00338 for P in N/m² (kgf/m², lbf/ft²), respectively. In the last case, V_k is in knots, in the other two it is in m/s.

It is important when calculating the effects of the height coefficient C_h to break vertical extents of the structure up into sections of approximately 50 feet (15.3 m) height. It is not uncommon to find calculations in which there is a significant vertical exposed structure (e.g., a self-elevating unit with a large leg reserve operating in shallow water) where the height coefficient is taken at the average height of the structure under consideration. In such a case, the value of the height coefficient is not changing with height. The force tends to be overestimated by this approach, and the overturning moment underestimated.

There are two commonly used methods for computing wind forces: projected areas and velocity component.

- *Projected area approach.* The wind force is calculated as the wind pressure multiplied by the structural surface area projected to a plane normal to wind pressure.
- *Velocity component approach.* The wind velocity is first decomposed to a plane normal to the structural surface, wind pressure is then calculated and multiplied by surface area.

Shape coefficients defined in the *MODU Rules* are suitable for “Projected Area” approach only.

The *MODU Rules* specify that no shielding should be considered between the legs of an offshore structure, although there is an implicit allowance for some shielding of deck type and lattice structures.

**TABLE 2
Shape Coefficients for Wind Force Calculations**

(Note: Shapes not given in this table will be subject to special consideration)

<i>Shape of Structure</i>	<i>C_s</i>
Spherical	0.4
Cylindrical Shapes (all sizes) used for crane pedestals, booms, helidecks, etc.	0.5
Hull, based on block projected area	1.0
Deck houses	1.0
Clusters of deck houses and other structures, based on block projected area	1.1
Isolated structural shapes (e.g., cranes, angle channel beams, etc.)	1.5
Under deck areas (smooth)	1.0
Under deck surface (exposed beams and girders)	1.3
Rig derrick, each face, assuming fabricated from angle.	1.25

C 3-1-2/1.3.3(c) Block Projected Area. The simplest method of calculating the wind force on most self-elevating units is to calculate the hull wind loads based on a block projected area above the main deck, and use a shape factor of 1.1. The normal extent of the block area would be to about the top of the jack houses, and then the extra items that are not included in this (the main hull, leg reserve, derrick, and helideck, etc.) would be added later. It may at first appear that this would produce an extremely conservative approach, but with the common use of spreadsheets to calculate wind loads, there is a tendency to include many items that probably would not have been included in the past with hand calculations upon which the Rules were originally based. All of these “isolated” items, with a shape factor of 1.5, can quickly amount to a significant portion of the overall wind load. If there is any doubt, then a comparison can be performed, and the lower value used.

C 3-1-2/1.3.3(e) Wind Loads on Open Trusses. Open truss work, such as is commonly used for derricks, crane booms and certain types of masts, can be approximated by taking 30% of the block projected area of each side/face that is perpendicular to the wind. The relevant shape coefficient from C 3-1-2/Table 2 is then to be applied. For example, take a conventional derrick that is fabricated out of angles. The effective exposed area, excluding the effects of height coefficients, could be approximated as:

$$\begin{aligned}
 \text{Effective Area} &= \text{Block projected area perpendicular to the wind} \times 2 \text{ (for the number of} \\
 &\quad \text{faces)} \times 0.3 \text{ (for truss)} \times 1.25 \text{ (for shape coefficient)} \\
 &= 0.75 \times \text{block projected area perpendicular to the wind}
 \end{aligned}$$

The lattice legs of self-elevating units should not be treated as open trusses, as described above when calculating the wind loads.

C 3-1-2/1.5 Wave Loadings

C 3-1-2/1.5.1 General

The Owner specifies the wave height for Classification purposes, as per the *MODU Rules*, which state that it should be “appropriate to the depth of water in which the unit is to operate”. This still leaves the Owner considerable leeway, as it should, with respect to class.

The Owners best know where they are planning to operate their units, so they should be responsible for defining the design conditions.

For self-elevating units, the chosen maximum wave should be that which is suitable for inclusion in a conventional deterministic wave force analysis using the drag coefficients given in C 3-1-A2/13. 3-1-2/1.5 of the *MODU Rules* also requires that “Consideration is to be given to waves of less than maximum height where, due to their period, the effects on various structural elements may be greater.”

For a twin-hull CSDU, large waves with long periods are not necessarily critical to the design of the primary structural elements.

Wave Periods – Some Variations Commonly Used

Literature refers to a variety of wave periods, each describing a different feature of a series of waves or sea states. The most common ones are:

- *Peak Period (T_p)*. Also known as the “Modal Period”, it is the wave period associated with the “peak” of the wave energy spectrum. It is normally longer than the period associated with the maximum wave.
- *Mean Period (T_m)*. The mean period is a spectrum independent value that equals $T_p/1.296$
- *Mean Zero Crossing Period (T_z)* The mean zero crossing period is the average time between the instances when the instantaneous water surface crosses the mean still water surface, moving in a specific direction (normally the up-crossing period). Normally $0.75T_p < T_z < 0.82T_p$.
- *Associated Period (T_{ass})* The Associated period is the period associated with the highest wave. Most of the other sea state wave periods are based on statistics for that sea state, but there is only one maximum wave in any given storm, so the associated period is the most probable period of the maximum wave. For this reason it is common to give a range of wave periods for T_{ass} that are independent of T_p . One common range is to have $\sqrt{12H_s} < T_{ass} < \sqrt{20H_s}$, where H_s is the significant wave height in meters.

C 3-1-2/1.5.2 Determination of Wave Loads

Determination of Wave Loads for Self-elevating Units

The magnitude of the wave height that should be used in a particular analysis does not only depend on the oceanography of the site, but also on the type of analysis. The intent behind any analysis methodology is that it should be consistent and produce reasonable results when all parts of the methodology are used in unison. Errors are made when parts of different analysis methods are mixed together. The *MODU Rules* have been established based on the use of specific drag coefficients (3-1-2/1.5.3 suggests a C_d of 0.62 for a smooth cylinder at a Reynold’s number exceeding 1×10^6 , and that model test results be used for other sections) and wave models appropriate for the wave height/water depth under consideration.

3-1-2/1.5.1 of the *MODU Rules* states that the design wave criteria “specified by the Owner may be described by means of wave energy spectra or by deterministic waves having shape, size, and period appropriate to the water depth in which the unit is to operate”. Most self-elevating unit analyses submitted for Classification are based on deterministic wave definitions, even when dynamics are being included, although appropriate spectral data can be used. In a static, deterministic analysis, the wave forces on a self-elevating unit are not too sensitive to the choice of wave period, except in the unusual cases of wave force cancellation (see below) and would normally use the “Associated Wave Period”, as previously described. When dynamics are being incorporated into the analysis, then the choice can be more critical, particularly in the case of a single degree of freedom approach. Dynamic analyses based on

spectral wave definitions are usually less sensitive to the choice of period since the spectrum will likely contain significant energy away from the chosen period.

For most reasonable wave period choices the wave surface profile, which can significantly affect the generated loads, is affected by the choice of wave period, but the greater effect is from the choice of wave theory.

Determination of Wave Loads for CSDUs

Waves with critical periods and headings [as characterized in C 3-1-2/1.5.2(a)] that generate significant amounts of hydrodynamic load need to be determined for the design of the primary structural elements. The wave load distribution on columns and bracing members and the submerged hulls of a CSDU are required for the global structural response analysis. Both stochastic and regular wave approaches can be utilized in the response analysis. The stochastic approach usually follows a frequency domain procedure via a spectral analysis.

For each load case, the response analysis determines the critical wave period that produces the maximum wave induced loads. It further permits the establishment of a regular wave, which replicates the hydrodynamic load as determined from the response analysis. The equivalent wave, denoted the “Design Wave”, can then be used for the design of the global strength of a CSDU.

The response analysis can be performed using a stochastic or deterministic approach depending on the wave information available. Details of what ABS expects to be included in a response analysis of a CSDU, using these two approaches, are discussed below.

C 3-1-2/1.5.2(a) Global Hydrodynamic Load Characteristics

General

Generally the following wave induced loads and load effects govern the global strength of a twin-hull CSDU:

- Split force between pontoons,
- Twisting pitch moment about transverse horizontal axis,
- Longitudinal shear force between pontoons,
- Inertia forces induced by longitudinal and transverse accelerations of deck mass,
- Vertical wave bending moment on the pontoon.

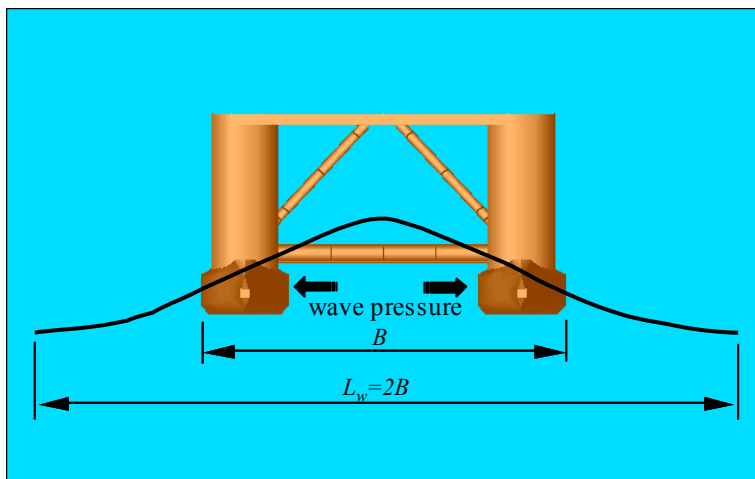
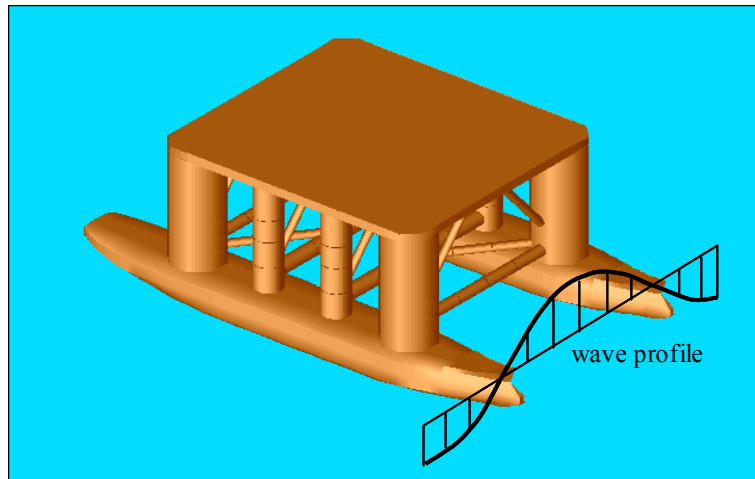
Note: The word “pontoon” is used here in deference to its use in the *MODU Rules* when describing this procedure. Pontoon is synonymous with “lower hull”.

Split Force between Pontoons

A beam wave (90 degrees from the bow, see C3-1-2/Figure 2) with a length of about two times the outer breadth between the pontoons will induce the maximum design split loads that are critical to the following joints or members:

- Horizontal bracings
- Main deck structures if no bracings
- Column connections to upper hulls if no bracings

FIGURE 2
Split Force between Pontoons
Twisting Pitch Moment about Transverse Horizontal Axis

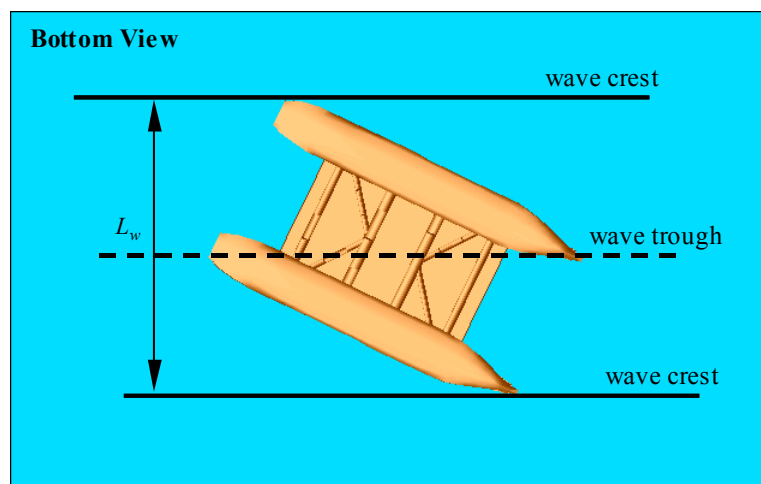
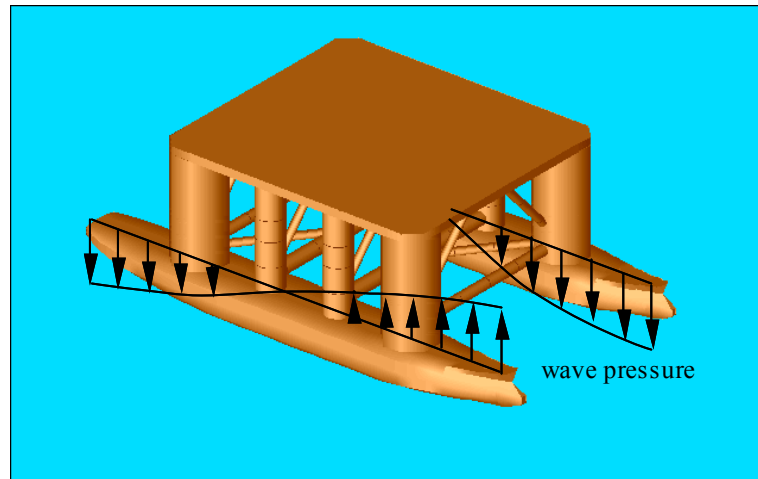


A diagonal wave (30 to 60 degrees from the bow, see C3-1-2/Figure 3) with a length of about the diagonal distance between pontoon ends will induce the maximum design twisting pitch moments that are critical to the following locations or members:

- Diagonal horizontal and vertical bracings
- Main deck structure if no bracings

Split loads occur simultaneously with twisting moments; therefore considering only twisting moments to determine the critical wave direction for the design of these members may be insufficient. The split loads do not contribute to the twisting moments but they will induce a stress component in addition to those induced by the twisting moments. Therefore, more than one wave direction should be considered in the response analysis, in order to ensure that the most critical combined stress effects of these two loads are obtained for the design.

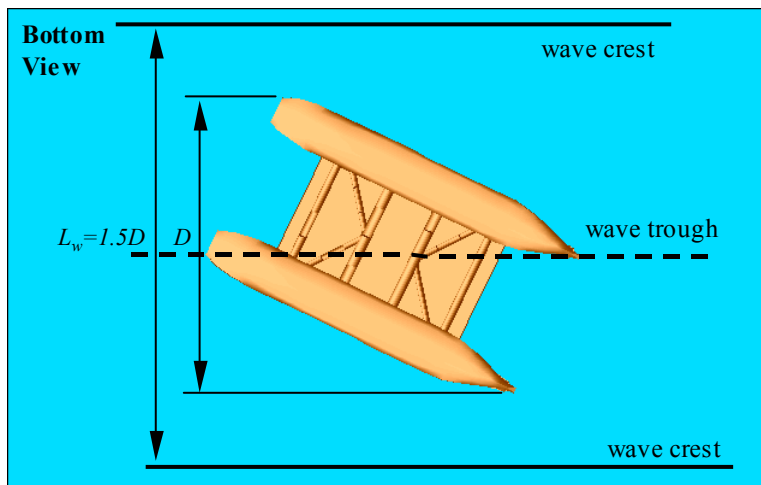
FIGURE 3
Twisting Pitch Moment about Transverse Horizontal Axis
Longitudinal Shear Force between Pontoons



A diagonal wave (30 to 60 degrees from the bow, see C3-1-2/Figure 4) with a length of about one and half times the diagonal distance between pontoon ends will induce the maximum design longitudinal shear force between the pontoons. In this load case, the longitudinal forces on the two pontoons and columns are maximized and acting in the opposite directions. Thus, the horizontal bracings will be subject to the maximum bending moment.

Since split loads occur simultaneously with longitudinal shears, using only longitudinal shear to determine the critical wave direction for the design of these members may be insufficient. For the same reason indicated above, it is necessary to consider more than one wave direction in order to ensure that the most critical combined stress effects of these two loads are obtained for the design.

FIGURE 4
Longitudinal Shear Force between Pontoons

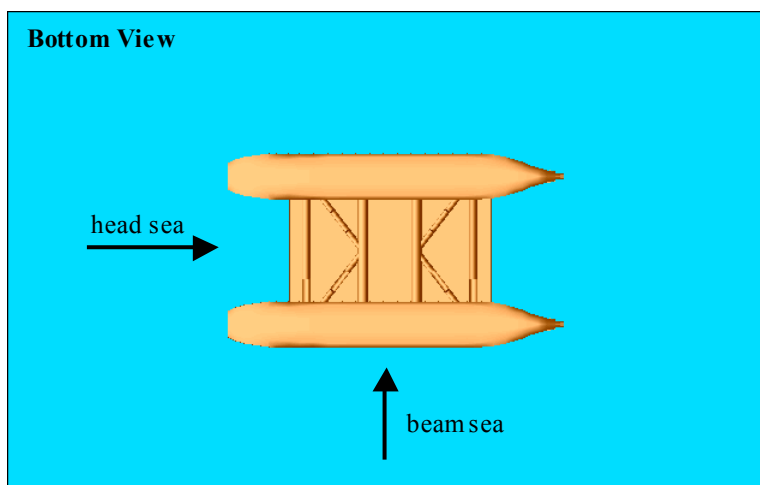


Longitudinal and Transverse Accelerations of Deck Mass

As shown in 3-1-2/Figure 5, the critical wave directions are head and beam seas, respectively, to induce the maximum design longitudinal and transverse accelerations of deck mass. These responses are usually larger at lighter drafts of the unit; therefore this may govern the limiting transit condition. The accelerations of deck mass will introduce shear forces with corresponding bending moments in the column connections to the deck and the pontoons, which may be relatively high if there is no diagonal bracing between columns or columns and the deck.

When diagonal bracing members are fitted, these responses will be developed primarily as axial forces in the bracing members and columns, and bending moments in the columns. The distribution of these loads is dependent on the stiffness properties of these structural members.

FIGURE 5
Longitudinal and Transverse Accelerations of Deck Mass

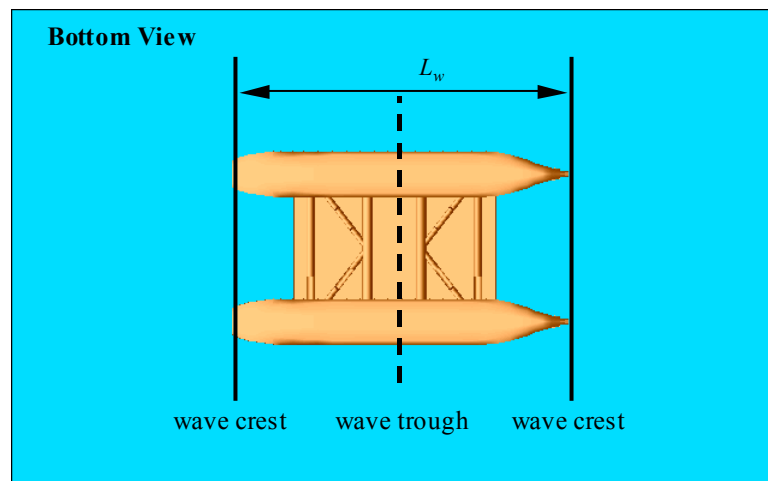
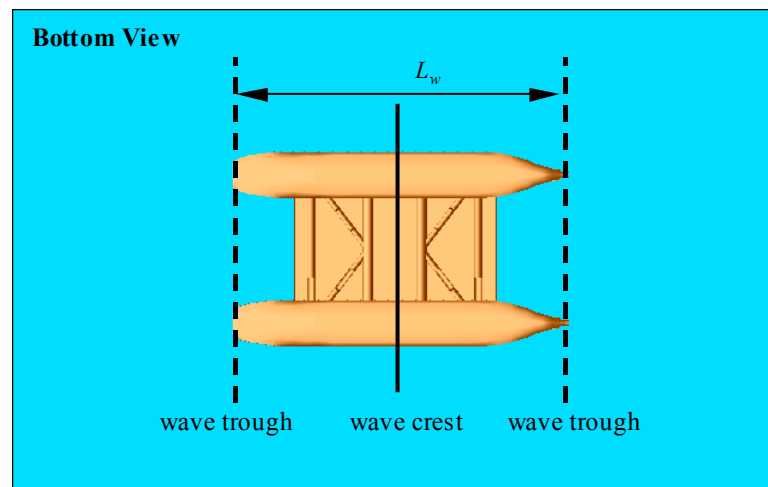


Vertical Wave Bending Moment on the Pontoon

A head or stern wave (0 or 180 degrees from the bow, see 3-1-2/Figure 6) with a length of about that of a pontoon will induce the maximum design vertical bending moments on the pontoon at the following two positions:

- Wave crest at the mid-length of a pontoon, and
- Wave trough at the mid-length of a pontoon.

FIGURE 6
Vertical Wave Bending Moment on the Pontoon



C 3-1-2/1.5.2(b) Selecting Design Waves by the Stochastic Method

General

The stochastic method is used when the wave environment is described in spectral form (irregular waves). This method establishes regular design waves with amplitudes and periods based on the maximum responses of each of the various load characteristics described above. In this approach, only sea states with the extreme steepness of the Owner's selected waves

should be considered for a range of irregular wave periods. The irregular sea steepness is defined in terms of significant wave height (H_s) and average zero-up crossing wave period (T_z) as described below. Alternative methods, including the deterministic approach presented in C 3-1-2/ 1.5.2 (c), below, may also be acceptable.

Analytical Approach

A method to establish regular waves (amplitudes and periods) on a stochastic basis that will replicate the maximum value for each of the critical, wave induced global responses listed previously is given below. A flow chart is also provided in Figure 7 to summarize the analytical approach. These regular waves are used to determine the wave-induced loads that are considered in structural analyses for the CSDUs.

Step 1

Determine the critical wave heading and length, L_C (or approximate critical wave period, T_C) based on the hull geometry of a CSDU and its global hydrodynamic load characteristics as described in C 3-1-2/1.5.2 (a).

The relationship between the critical wave length, L_C and period, T_C is:

$$L_C = g/2\pi * T_C^2$$

where

$$g = \text{gravitational acceleration} = 9.81 \text{ m/sec}^2 \text{ (32.2 ft/sec}^2\text{)}$$

Step 2

Calculate Response Amplitude Operators (RAOs) (per unit wave amplitude) for each load characterized in C 3-1-2/1.5.2(a) and for a range of regular wave periods between 3 to 25 seconds. Finer wave period intervals (say 0.2 to 0.5 second) around T_C should be considered in order to capture the critical peak RAO_C . At the critical peak RAO_C , a more precise critical wave period, T_C , can be determined. For wave periods away from the critical wave period, T_C , larger waver period intervals (say 1.0 to 2.0 seconds) may be used.

Step 3

In the process of deriving the RAO for each regular wave period, the real and imaginary parts are to be calculated separately at two time instances. The real part (R) is corresponding to the time instance when the wave crest is at the mid-ship location. With 90 degrees phase lag, the imaginary part (I) is corresponding to the time instance when the wave zero crossing is at the mid-ship location. The total hydrodynamic load amplitude ($Load$) at any time instance (t) in a regular wave with frequency ω in radians per second can be expressed as the combination of the real and imaginary parts:

$$Load(t) = R * \cos(\omega t) + I * \sin(\omega t)$$

where

$$RAO(\omega) = \sqrt{R^2 + I^2}$$

The determination of RAOs should preferably employ the so-called, “panel based” method to account appropriately for diffraction-radiation forces. Suitable account should also be given to the effects of the mooring lines and other applicable restraints.

Step 4

Calculate design significant wave heights based on the Owner selected sea steepness using the formula described below for the average zero up-crossing wave periods (T_z) ranging from 3 to 18 seconds with one (1.0) second interval.

The irregular sea steepness, S_S is defined as:

$$S_S = 2\pi H_S / g T_Z^2 \quad S_S = 2\pi H_S / g T_Z^2$$

where

$$g = \text{gravitational acceleration} = 9.81 \text{ m/sec}^2 \text{ (32.2 ft/sec}^2\text{)}$$

$$H_S = \text{significant wave height}$$

$$T_Z = \text{zero up-crossing wave period}$$

Step 5

Derive the wave energy spectrum for each irregular sea state found in Step 4 as a function of significant wave height (H_S) and average zero-up crossing wave period (T_Z). Pierson-Moskovitz (P-M), JONSWAP wave spectrum or any other type of wave energy spectrum appropriate for the geographic area under consideration may be used.

Step 6

Combine $RAO(\omega)$ squared from those obtained in Step 3 with wave energy spectral densities, $S_W(\omega)$, from Step 5 to calculate the response spectrum, $S_R(\omega)$, as a function of frequencies in radians per second for each irregular sea state in Step 4.

$$S_R(\omega) = [RAO(\omega)]^2 S_W(\omega)$$

Step 7

Predict the maximum response, R_{\max} for each irregular sea state in Step 4 as follows:

$$R_{\max} = \sqrt{m_0} * \sqrt{2 * [\ln(N)]}$$

where

$$m_0 = \text{area of the response spectrum defined below with } n = 0$$

$$\ln = \text{natural log function}$$

$$N = \text{number of response cycles} = D/T_a$$

$$D = \text{storm duration, usually 3 hours (10800 seconds) is assumed}$$

$$T_a = \text{average response zero up-crossing periods in seconds}$$

$$= 2\pi * \sqrt{m_0 / m_2}$$

$$m_n = \int_0^\infty \omega^n S_R(\omega) d\omega$$

Step 8

Select the maximum response, R_{\max} among the irregular sea states considered.

Step 9

Calculate the design regular wave amplitude, A_D , as follows:

$$A_D = (R_{\max} / RAO_C) * LF$$

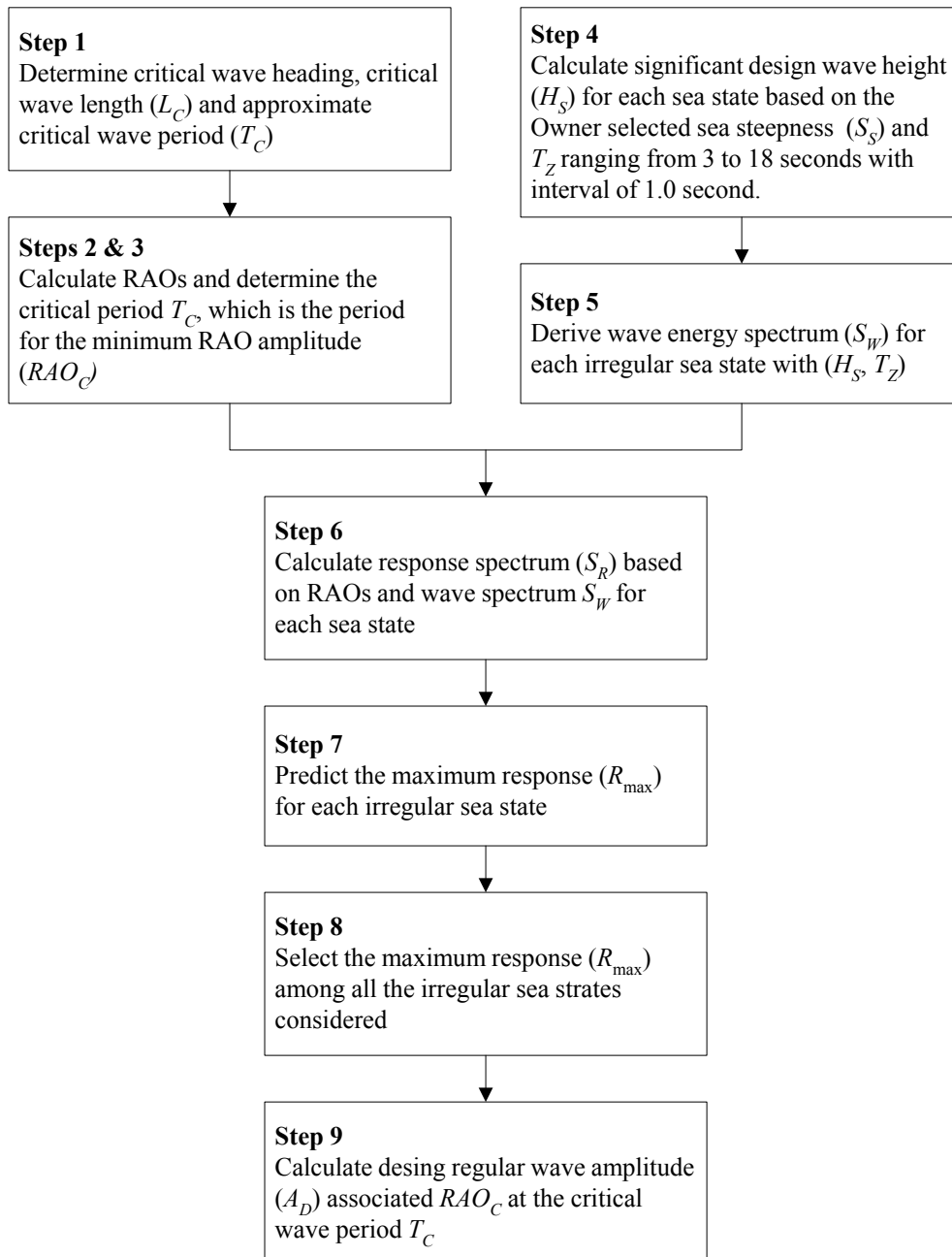
where

$$RAO_C = \text{peak response amplitude operator at the critical wave period } (T_C)$$

LF = Load Factor which is ranging from 1.1 to 1.3, and to be calibrated for various geographic areas

Finally, the selected design regular wave amplitude (A_D) and critical wave period (T_C) will be used in the structural design evaluation.

FIGURE 7
Flowchart for Selecting Design Waves by the Stochastic Method



C 3-1-2/1.5.2(c) Selecting Design Waves by the Deterministic Method

General

The deterministic method will find the design regular wave height based on the maximum regular wave steepness, which is selected by the Owner as described below.

Analytical Approach

The method for deriving the design regular wave height and critical wave period for each characterized hydrodynamic load is described below. A flow chart is also provided in Figure 8 to summarize the analytical approach.

Step 1

Determine the critical wave heading and length (or approximate critical wave period) based on the hull geometry of a semi-submersible and its global hydrodynamic load characteristics as described in C 3-1-2/1.5.2(a).

Step 2

Calculate the Response Amplitude Operators (RAOs) as described in C 3-1-2/1.5.2(b) Analytical Approach Step 2 and 3 above.

Step 3

Using the formula described below for the regular wave steepness and the Owner selected design wave environment (regular wave steepness and the maximum design wave height) to calculate the “limiting regular wave heights” for wave periods ranging from 3 to 15 seconds. The commonly used regular wave sea steepness for the CSDUs classified with ABS is 1/10.

The regular wave steepness, S is defined as:

$$S = 2\pi H / gT^2$$

where

g = gravitational acceleration (= 9.81 m/sec² or 32.2 ft/sec²),

H = regular wave height,

T = regular wave period.

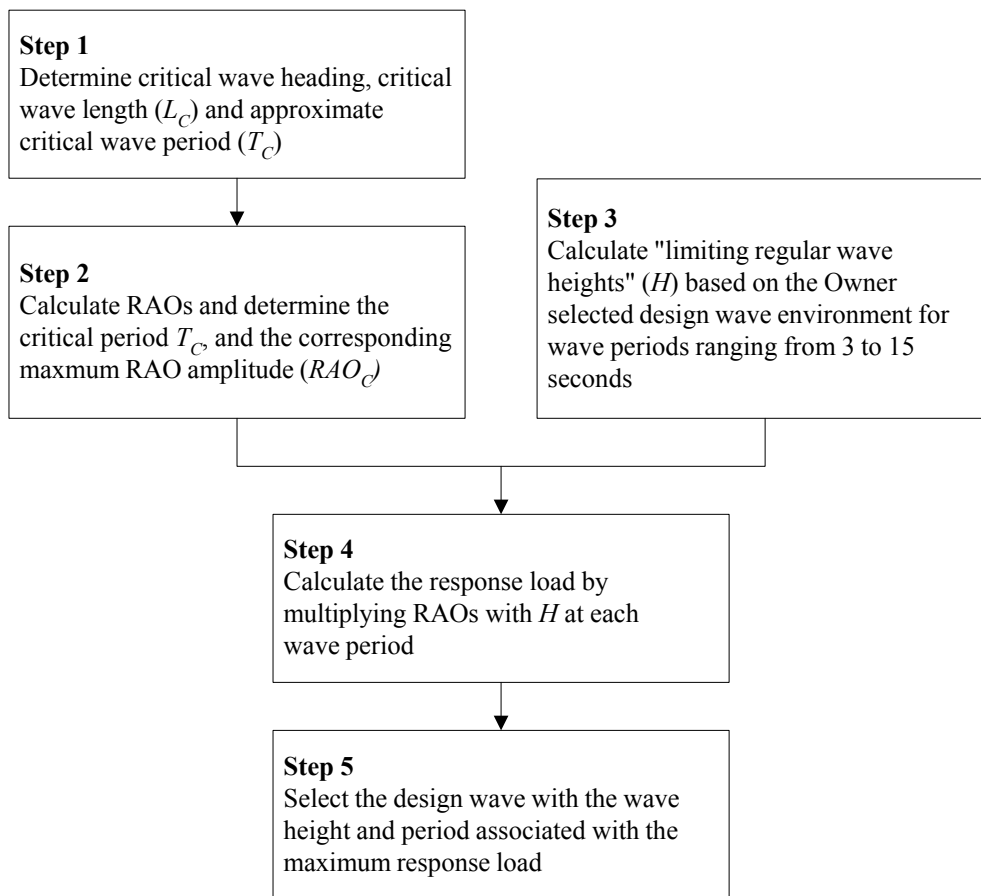
Step 4

Calculate the response load by multiplying the RAO with the “limiting regular wave height” at each wave period.

Step 5

The corresponding wave height and wave period at the maximum response load calculated in Step 4 for all the limiting regular wave heights is the design wave, which will be used in the structural design evaluation.

FIGURE 8
Flowchart for Selecting Design Waves by the Deterministic Method



C 3-1-2/1.5.3 Morison's Equation

Most self-elevating units can be adequately assessed using the Morison equation, which separates the hydrodynamic load into the drag and inertia components. The Morison equation is generally considered applicable in the analysis of members/legs in which the member diameter is no greater than 20% of the wave length. For units with lattice legs, in which there is normally relatively little shielding, virtually all waves can be assessed using Morison. The basic form of Morison's equation is:

$$F_W = F_D + F_I$$

where

F_W = Hydrodynamic force vector per unit length along the member, acting normal to the axis of the member

F_D = Drag force vector per unit length

F_I = Inertia force vector per unit length

The general form of the drag and inertia forces, including the effects of structural motions, are given below. In the case of a rigid structure, the structural velocity and acceleration are set to zero.

$$F_W = 0.5\rho DC_D(u_n - u'_n)|u_n - u'_n| + \rho\left(\frac{\pi D^2}{4}\right)[C_m(a_n - a'_n)] + a_n$$

where

- ρ = water density = 1025 kg/m³ (1.99 slugs/ft³)
- D = projected width of the member in the direction of the cross flow component of velocity. (In the case of a cylinder, D denotes the diameter)
- C_D = drag coefficient
- u_n = component of the wave & current fluid velocity vector normal to the axis of the member
- u'_n = component of the velocity vector of the structural member normal to its axis and in the plane of the wave particle velocity of interest (relative velocity)
- C_m = added mass coefficient, i.e., $C_m = C_M - 1$
- C_M = inertia coefficient based on the displaced mass of fluid per unit length
- a_n = component of the fluid acceleration vector normal to the axis of the member
- a'_n = component of the acceleration vector of the structural member normal to its axis and in the plane of the wave particle acceleration of interest (relative acceleration)

When calculating the hydrodynamic loads it is important to vectorially combine the fluid particle velocities due to both wave and current, but a reputable wave load program will ensure that this is performed properly. The only significant issue is how the current profile changes with the passage of a wave, and this is discussed in C 3-1-2/1.7.1.

Wave Theory

Self-elevating units will generally be operating in relatively shallow water depths where the use of Airy (linear) wave theory to calculate the higher wave loads is not entirely appropriate. As a wave moves from deep water into shallow water, there is an increase in the maximum crest elevation above the still water level and a reduction in the depth of the trough below still water level. With the increase in crest elevation is an increase in the water particle velocities at the crest, and an increase in the steepness of the wave. Since most self-elevating units are drag dominated structures, and the drag force is proportional to the particle velocity squared, it can be seen that there will be a significant increase in the drag force at the crest, and a decrease in the absolute magnitude of the negative drag force at the trough. Clearly, therefore, a wave theory needs to accurately represent the water surface level (so that the point of application of the load is correct) and the particle kinematics in the wave (so the forces) are correct.

The two main wave theories that are used to calculate the wave profile, loads, moments, etc. are Stokes wave theory, and Dean's Stream Function wave theory. In general, using the fifth order of Stokes, or the seventh order of Dean will prove adequate, but when it is critical, it is advantageous to run a comparison using the next higher order. It is of note that neither theory works at the breaking limit, and therefore considerable caution needs to be exercised at anything above 90% of the wave breaking limit. Standard charts can be found in a number of publications (e.g., Shore Protection Manual) that give a series of wave theories, and their range of applicability.

Model Tests

Model test data are not only acceptable, but are to be actively encouraged. The main points to ensure are that the model accurately represents the structure under consideration, and that if Reynolds number is important, it is accurately modeled⁴. The difficulties associated with the latter point cannot be overstated: if the Reynolds number is correct, the forces will be full scale. Given the size in which components should be tested, for example, model tests of a self-elevating unit's leg, the loads that the equipment has to withstand, and accurately measure, are large. There are ways to partially compensate by roughening tubulars, etc. but they need to be used with care. There have been many model tests that have failed proper validation, as it had not been demonstrated that the post critical Reynolds number (>~1 million) had been achieved. There is one helping influence: once post critical flow has been achieved, the drag coefficient becomes relatively independent of Reynolds number, so it may not be necessary to absolutely achieve the correct Reynolds number. It is advisable to undertake some of the tests at a lower Reynolds number to determine the influence, and help establish that post critical flow has been achieved. Without clear documentation, the results may not be acceptable.

If attempting to determine the effects of shielding, it is important to investigate a range of angles, including some small changes from absolutely "in line" flow. In many cases there will be extremely high shielding when there is perfect alignment between components, but even small changes in angle will result in a significant increase in drag (or reduction in shielding). In a real sea state it is rare that alignment will be accurate enough to affect the reductions in drag.

Hull models should include all the relevant components in their relevant locations. As with any testing, it behooves the tester to estimate the expected result prior to conducting the test so that any obvious anomalies can be investigated at the time, rather than having to find out that something was wrong after the tests have been completed, and the testing facility moved on to other contracts.

C 3-1-2/1.7 Current Loading

C 3-1-2/1.7.1 Current Associated with Waves

Current Velocity

The current induced forces on a CSDU are normally neglected when computing the global strength of a unit. Current forces therefore normally need not be included in the global structural analysis.

On a drag dominant structure, such as a self-elevating unit, the force is proportional to the square of the water particle velocity so even a 10% increase in particle velocity due to current will cause a 20% increase in load.

The importance of current velocity on loads can be demonstrated in the following example. Consider the case of a drag dominant self-elevating unit operating in 110 meters (350 feet) water depth under the relatively benign conditions of an 11 meter (36 feet) maximum wave. It would take less than a 1.5 meters per second (3 knot) current to cause a three-fold increase in the wave forces and moments. The reason is that the maximum particle velocity due to waves alone is only just under 3 meters per second (5.6 knots)⁵. Even for a North Sea type wave, say 29 meters (95 feet) in 90 meters (300 feet) water depth, the surface wave particle velocity is only 8 meters per second (15 knots). This will drop to 6.1 meters per second (12 knots) at the mean sea level under the crest.

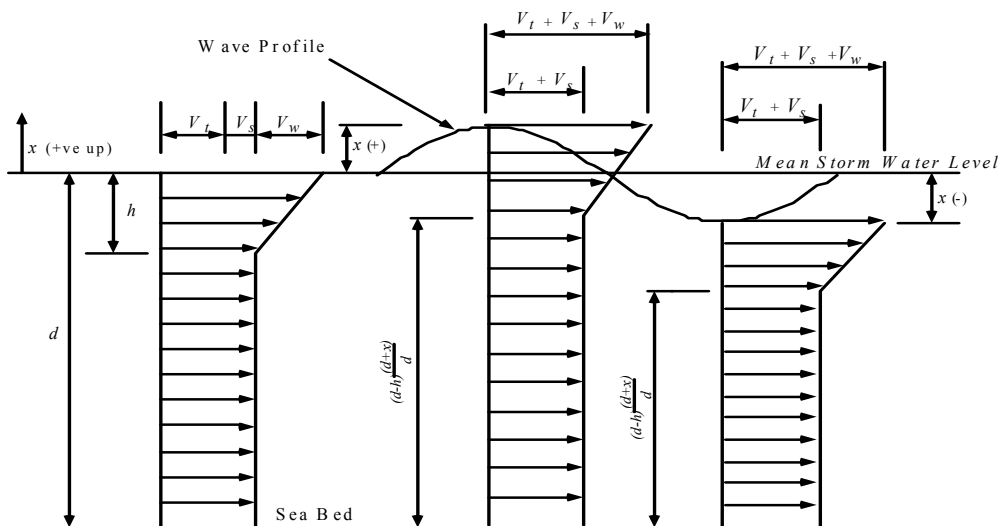
⁴ Reynolds number is very important when testing any structure that contains tubular or spherical objects. It is relatively less important when testing bluff or "hydrodynamically ugly" objects.

⁵ On a drag dominant leg the drag force is proportional to the particle velocity squared, therefore the increase in force at the water surface will be approximately $(3+1.5)^2/3^2 = 2.25$. Given an approximately constant current velocity with depth, and a decreasing wave particle velocity, it can be seen why the force would be increased by a factor about 3.

Components of Current, Profile, and Interaction with Waves

The current velocity at a specific location consists of a tidal component in conjunction with an environmentally generated component (primarily wind driven, but also due to storm surge and, possibly, sieche effects). Given the potential importance of current loads, it is prudent to include some current in the design conditions of a self-elevating unit.

FIGURE 9
Effect of Wave on Current Velocity



where

- V_t = component of tidal current velocity in the direction of the wind
m/s (ft/s)
- V_s = component of storm surge current, m/s (ft/s)
- V_w = wind driven current velocity, m/s (ft/s)

The *MODU Rules* set out a suitable profile for general use. The tidal and storm surge components are constant throughout the water column, while the wind driven component is a maximum at the surface and reduces linearly to zero at some distance (normally taken as 5 meters or 16.4 feet) below the surface (see C 3-1-2/ Figure 9⁶). Other profiles may be suitable at certain locations and may be used if defensible.

In the presence of a wave, the profile should be altered as shown in C 3-1-2/ Figure 9. In effect, the surface current velocity remains constant, regardless of the instantaneous level of the surface, and the wind driven component decreases to zero over a variable distance. (The distance is greater at a wave crest and less in the trough.).

Currents and Fatigue Analysis

Normally current is not considered when performing a general fatigue analysis for Classification. This is a reasonable approach for an exploratory self-elevating unit that does not operate at a specific location for long periods.

⁶ C 3-1-2/ Figure 9 is based on 3-1-2/ Figure 1 in the *MODU Rules*.

This approach may be un-conservative, however, when considering a unit that will be used at one location for an extended period (greater than the Special Survey period cycle, i.e., 5 years). Current affects not only the maximum force on a self-elevating unit, but it also affects the range of the hydrodynamic forces. If the current is random, then the effects will be limited, but if it is either normally in line with the environmental conditions, or is tidal in an area with strongly predominant wind directions, then it is advisable to include the current when undertaking a fatigue analysis.

C 3-1-2/1.9 Loading due to Vortex Shedding

Vortex Induced Vibration

Most of the members in a lattice leg self-elevating unit are sufficiently stiff for wind generated vortex induced vibration (VIV) not to be an issue.

If VIV is found to be an issue, it is important to use the correct level of damping when undertaking a fatigue assessment. Generally, low displacement structural damping is extremely small, say 0.2%, but it is possible that joint flexibility may increase this. Also, at low damping, the maximum excitation takes some time to build up, and any wind gustiness can thereby reduce the magnitude of the VIV.

A particular case where wind generated VIV has been found to be an issue is on units with simple cylindrical legs, particularly when operating with either a large reserve of leg, or when under tow. As a minimum a simple check should always be undertaken on this type of unit to establish VIV likelihood. It is of note that while wrapping a cylinder with strakes can be an effective method of eliminating the problem, the strakes **MUST BE DESIGNED PROPERLY**. Tests have shown that if the strakes are not properly designed, they may have no beneficial effect at all⁷.

⁷ This is particularly true of the “rope wrapping” that is commonly suggested to alleviate the problem on steel jackets.



APPENDIX C 3-1-A2 Wave Theory for Deep Water

C 3-1-A2/13 Drag Forces in Deep Water

Drag Coefficients: Cylinders

The *MODU Rules* specify that a drag coefficient of 0.62 may be used for clean tubular members that are kept free of marine fouling, and in flow with a Reynolds number of more than 1×10^6 .

Drag Coefficients: Inclined Members

If an equivalent leg hydrodynamic model is used when analyzing a lattice leg unit, it will be necessary to determine the drag forces on inclined brace members. This can easily be done by using a wave force program, and analyzing the brace, or even an entire leg bay, in a uniform current. The effective drag coefficient can then be backed out. Alternatively, the effective drag coefficient can be calculated manually.

Consider a brace that is at an angle of α away from being in line with the fluid flow (horizontal angle) and at a vertical angle of β above the horizontal. The factor to multiply the product of the drag coefficient C_D with member diameter D in order to arrive at the effective product is given as:

$$\text{Modifying Factor} = (\sin^2\beta + \cos^2\beta \sin^2\alpha)^{1.5}$$

What is being calculated in the above formula can be broken into three steps:

1. Find the component of fluid velocity that is perpendicular to the member under consideration.
2. Since the drag force is proportional to the velocity squared, square the resolving factor.
3. Resolve the resulting load back into the direction of wave travel

For a horizontal brace that is not in line with the flow, this simplifies to a factor of $\sin^3\alpha$. In order to calculate the equivalent leg coefficient, calculate the sum of all the parts as an effective exposed area per bay, including all the chords and braces, then divide by the bay height. This will result in an effective $C_D D$ for the relevant section of leg.

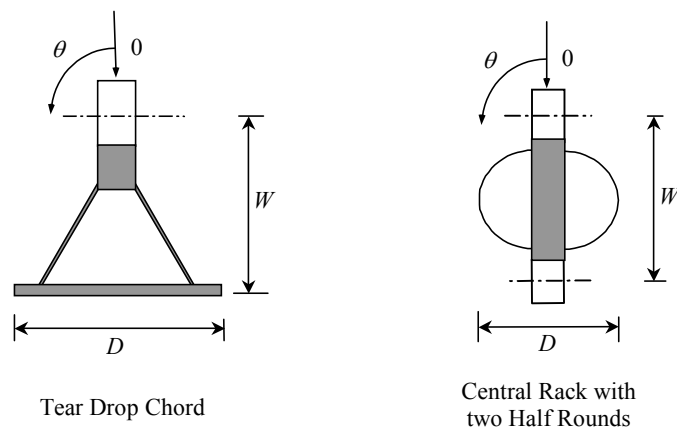
Drag Coefficients: Non-Tubulars

There are four main chord shapes that are used on self-elevating units, apart from tubulars (either leg or chord). These four are:

- Approximately triangular, with a single rack at the apex of the triangle
- Cylindrical with a pair of racks welded to the chord, but offset from the center.
- Double sided rack plate with a half round (or similar) welded on each side of the rack creating a cylindrical chord with a rack through the middle (“split tube” type).
- Cylindrical chord with a box section welded on two opposing faces. The box sections have cut outs for jacking pins

Most of these chords are of the order of 1 meter or less in overall dimensions. In addition to these shapes, there are some units that have relatively large diameter tubular legs (up to 4 meters diameter) with opposing racks welded to the outside close to the centerline. (Two shapes are sketched in C 3-1-2A/Figure 1.) It is not the intent of this Commentary to give detailed values for each of these chord or leg shapes, but to help the analyst decide what is an appropriate value to use in the load determination.

FIGURE 1
Reference Angle for Drag Coefficients



The drag coefficient of the irregular shapes is not dependent on the Reynolds number, and are largely unaffected by surface roughness (although increases in diameter due to marine growth should be included). The tubular based shapes will tend to act similar to tubes when the flow is towards the teeth of the rack (0° flow in C 3-1-A2/Figure 1). When the flow is perpendicular to the teeth (90° in C 3-1-A2/Figure 1) the drag coefficient will be dependent on the size of the rack, but will not be as dependent on whether the tube is smooth or rough. C 3-1-A2/Figure 2 shows the shape of curve that could be used to determine the drag coefficient of such a shaped chord. In effect, the drag coefficient is similar to that used for a cylinder for θ is between 0° and 30° , accounting for surface roughness (i.e., 0.62 if smooth, 0.75 if rough). Between 30° and 80° it linearly increases to a plateau level to be used between 80° and 90° . The value at the plateau would vary between 1.5 if the racks do not appreciably increase the overall size of the member, and 2.0 for very large racks. For large diameter tubular legs (as opposed to chords) with attached racks, the upper plateau level could be reduced to 1.2. All the values suggested incorporate a reduction factor to account for the over-prediction of particle kinematics inherent in a deterministic analysis using Stokes fifth order wave theory, or similar. Larger values would need to be used for a stochastic analysis.

FIGURE 2
Drag Coefficient of Tubular Chord with Rack: Deterministic Analysis

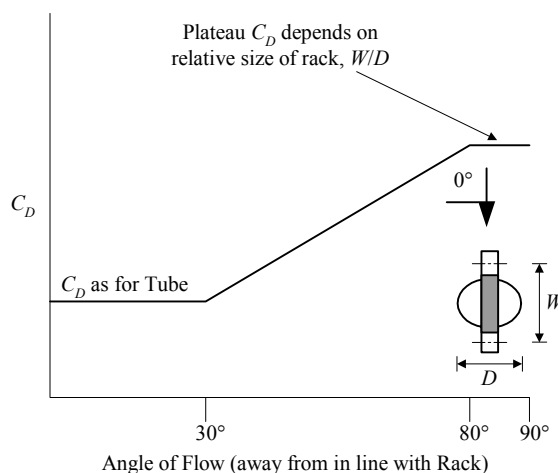
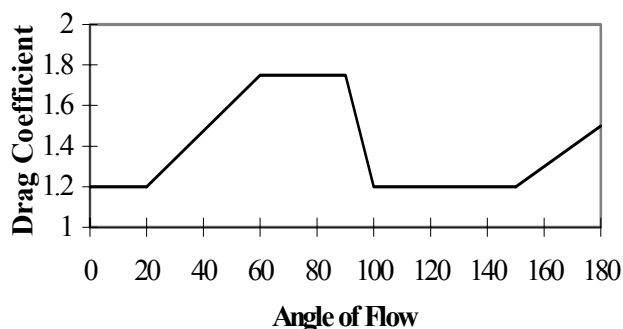


FIGURE 3
Drag Coefficient of Triangular Chords: Deterministic Analysis



The drag coefficient of a simple triangle, excluding the kinematics reduction, is often given as approximately 1.3 for flow towards the apex, and 1.8 for flow towards the base. These can be used as the basis for the basic triangular chord, but some other factors need to be taken into account. Flow towards the apex (0° in 3-1-A2/Figure 1) initially confronts a blunt rack in the actual chord, which will tend to increase the drag coefficient. In addition, the shape at the back plate is not as clean as that of a simple triangle. The net result is that, after the inclusion of the kinematics factor, the drag coefficient for flow towards the apex should be taken as 1.2, based on a diameter equal to the width of the back plate.

As θ increases, initially the coefficient remains flat for approximately 20°, but then it starts to increase. At around 70° (depending on the details of the shape) the maximum projected face is exposed. The shape is also reentrant, so the drag coefficient will increase to a maximum value of approximately 1.75. It will then start to decrease again until the back of the back plate becomes the apex of the triangle. Finally, the coefficient for flow towards the back plate will be 1.5. These values are shown in C 3-1-A2/Figure 3. It must be borne in mind that these are generalized numbers that will not be appropriate for all triangular chord shapes, and the real shape of the graph will be rounded, without abrupt changes of angle at the various change points.

Tubular chords with added box sections will be similar to tubular chords with rack, but will depend on the details of the size and depth of the box sections. Those chords that have eccentric racks need to be considered on a case-by-case basis, as they are not doubly symmetrical. When flow is towards the teeth of the rack, the eccentricity of the rack from the center of the chord will lead to an increased coefficient over that to be expected for “split pipe” type chord. However, flow in the direction perpendicular to the rack will tend to produce a lower coefficient than the split rack type chord.

Drag Coefficients: Appurtenances

There are a number of appurtenances that are often attached to the legs of a self-elevating unit. The most common are anodes, ladders, jetting lines, gusset plates, and the raw water tower. Many of these are small, and can be incorporated through the use of minor conservatism in the calculation, but other items can be of significant size.

Anodes, ladders, and jetting lines, as long as none of them are too large, can normally be incorporated implicitly by using member node-to-node length for members, rather than allowing for the reduction in length due to the joint sizes, when creating the hydrodynamic model of the leg. If there is concern that this will produce too conservative a result, then these items can be incorporated explicitly.

Gusset plates can have a significant impact on the effective drag coefficient of a leg, and should be considered carefully. Unless they are very small, it is advisable to calculate their impact on the hydrodynamic coefficients of the leg. The drag coefficient to use for gusset plates is 2.0, but considerable advantage can normally be taken of shielding. This is particularly true on legs that have high drag chords. These chords severely disrupt the fluid flow, so gusset plates often get heavily shielded. More care needs to be taken when considering the effects of gusset plates on legs with tubular chords, as it is possible for a gusset plate to locally increase the effective drag coefficient of the chord by a factor of three. Rarely would there be such an increase on a triangular chord as the initial drag coefficient is so high.

Raw Water Tower

The item that can cause the largest changes to leg forces is the raw water tower. In the past these were normally independent structures that were cantilevered from the hull down to below the water surface. As such, they attracted some wave load, but in many cases it was not too significant because of the spatial separation from the legs, and because they were relatively small. For various reasons, many modern units incorporate the tower into a leg. There is nothing inherently wrong with this approach, but considerable care needs to be taken in ensuring that the pipes and guides are properly accounted for in calculating the hydrodynamic loads. In many cases it is not the raw water piping itself that attracts the majority of the load, but the guide mechanism, which runs the full extent of the leg.

C 3-1-A2/15 Recommended Mass Factors

Inertia Coefficient C_M

The *MODU Rules* specify that the inertia coefficient, C_M , for a tubular should be taken as 1.8. It is of note that, unlike the drag coefficient, the inertia coefficient for tubes decreases as the roughness increases, but similar to drag, both coefficients decrease with increasing Keulegan Carpenter number.

For other shapes, a C_M of 2.0 should be used, based on an effective diameter of a tubular that creates the same volume per unit length as the member.

The inertia coefficient does not normally have a significant impact on the loads of a braced leg self-elevating unit, particularly in the severe storm condition.



SECTION **C 3-1-3** **Material Selection**

C 3-1-3/3 Hull Steel Grades

Self-Elevating Drilling Unit

The hull structure and tubular leg structure of a self-elevating unit are normally constructed with ABS ordinary steel or higher strength steel or a mixture of these grades.

The lattice leg structure of a self-elevating unit are normally constructed with high strength quenched and tempered steel. Guidance concerning ABS high strength quenched and tempered steel plates is contained in Appendix 3-1-A3 of the *MODU Rules*, however many lattice legs are constructed with non-ABS extra high strength steels. Criteria for non-ABS extra high strength steels are presented in 3-1-3/5.9 of the *MODU Rules*.

Column-Stabilized Drilling Unit

The upper and lower hulls, columns, and bracing structure of a CSDU are normally constructed from ABS Ordinary Strength steel, Higher Strength steel or a mixture of these grades.

The internal structure of the upper and lower hulls, and columns are normally constructed using ABS Ordinary Strength steel. The main supporting members of the structural system, i.e., bracing members, main upper deck or upper hull girders are often constructed from ABS High Strength steel. See the *ABS Rules for Materials and Welding – Part 2*, for properties of the ABS Steel Grades.

The brace to column, brace to deck, and brace to brace connections are often areas prone to fatigue damage; therefore specific consideration should be given to the fatigue strength of these joints. It may be necessary to use “Z” quality steel in these joints to reduce the possibility of lamellar tearing.

Quenched and tempered steel is rarely used in CSDU construction.

C 3-1-3/5 Selection of Grades of Steel

C 3-1-3/5.1 General

For self-elevating or column-stabilized drilling units, it is necessary to take into account the minimum expected service temperature and structural element category when deciding the appropriateness of a structural material. See C 3-1-3/5.7 for commentary on air and water temperature requirements.

The various structural elements of Self-elevating and Column Stabilized units are grouped according to their material application categories. These structural elements fall into Secondary, Primary and Special categories. The main areas of these categories are described, in general, in 3-1-3/5.3 and 3-1-3/5.5 of the *MODU Rules*.

In general the *MODU Rules* are self-explanatory with regard to what is included in each category. However confusion sometime arises, therefore the following provides additional information to aid in the application of 3-1-3/5.3 and 3-1-3/5.5.

C 3-1-3/5.3 Self-Elevating Units

C 3-1-3/5.3.1 Secondary Application Structure (Least Critical)

This is the least critical of the application categories and it mainly includes internal structure that is not considered in the primary or special applications categories. A fairly comprehensive list of secondary application areas is given in the *MODU Rules*.

Areas of secondary application in addition to those listed in the *MODU Rules* can be any structure that is not considered part of the longitudinal or transverse strength of the unit that is considered primary application, e.g., crane pedestals, helideck and its supporting structures, lifeboat platform supporting structure, watertight doors, etc.

Areas where the steel is not required to meet secondary application Charpy V-Notch (CVN) impact (toughness) requirements are outfitting structures such as: walkways, handrails, seating or small supporting platforms for machinery, etc.

C 3-1-3/5.3.2 Primary Application Structure (Intermediate)

This designation is used for the main supporting structures of the unit and areas of high stress except for areas that are specified to be Special Application Structure. The main areas of primary application are outlined in the *MODU Rules*, however in addition to areas mentioned in the Rules the leg to spud can connection is also considered to be primary application.

C 3-1-3/5.3.3 Special Application Structure (Most Critical)

This designation is used for areas predicted to have relatively lower fatigue lives. The main areas of special application are outlined in the Rules.

C 3-1-3/5.5 Column-Stabilized Units

C 3-1-3/5.5.1 Secondary Application Structure (Least Critical)

This is the least critical of the application categories and it mainly includes internal structure that is not considered in the primary or special applications categories. A fairly comprehensive list of secondary application areas is given in the *MODU Rules*. It should be noted that internal structure of brace to a column connection is normally to be included in the special application category.

C 3-1-3/5.5.2 Primary Application Structure (Intermediate)

This designation is used for the main supporting structures of the unit and areas of high stress except for areas that are specified to be Special Application Structure. The main areas of primary application are:

- External shell structure of columns,
- Lower and upper hulls and bracing members except end connection that are categorized as special application,
- Main structural bulkheads and flats forming the major longitudinal and transverse supporting members of the upper hull except in way of major concentrated loads and intersections of main bracing members,
- Supporting structure for the substructure and drilling derrick,
- Various internal bulkheads, flats of decks and framing that provides local reinforcement and continuity of structure in way of major intersections, connections of fairleaders to columns.

C 3-1-3/5.5.3 Special Application Structure (Most Critical)

This designation is used for highly stressed areas and areas predicted to have relatively lower fatigue lives. The main areas of special application are:

- Intersection of vertical columns to lower hulls and decks,
- “Box” or “I” type structure in the upper hull that receive major concentrated loads,
- Major intersections of bracing members to columns and brace to brace connections,
- External brackets and some internal structure at intersections of brace to brace, brace to column, and brace to deck connections.

C 3-1-3/5.7 Selection Criteria for ABS Grades of Steel

The air and water temperatures at a site will affect the types of steel that can be used, and the required material testing. The minimum design temperature, from the standpoint of Classification, is the lowest of the average daily atmospheric temperatures, based on anticipated areas of operation. It is not the minimum temperature that could be expected at the location. The reasoning is that it is the material temperature that is important, so sufficient time must be allowed for it to reach the design temperature.

The design temperature for bulkheads, decks, and flats of internally heated spaces is normally considered 0°C.

The design temperature for internal structure categorized as special application, such as the bracing to column connections of CSDUs, are to be designed using the same temperature as is used for the external structure.

Design temperature is normally considered 0°C for structure underwater even if the minimum air temperature is lower than 0°C. Therefore, structure below the lowest transit draft of a CSDU, may be designed for a service temperature of 0°C. This is normally the lower hull structure.

ABS Ordinary and High Strength Material Grades versus Service Temperature and Application are listed in 3-1-3/Table 1 of the *MODU Rules*.

C 3-1-3/5.9 Criteria for Other Steels

Steels other than ABS grades can be accepted provided that the appropriate supporting information or test data is submitted to indicate that the toughness of the steels will be adequate for their intended application in the unit at the minimum design service temperature. In the absence of supporting data, tests are required to demonstrate that steels would meet the Charpy V-Notch (CVN) impact requirements indicated in 3-1-3/5.9 of the *MODU Rules*.

For secondary applications, at a service temperature of 0°C, ASTM A36 steel can be substituted for ABS Grade A for a thickness up to and including 12.5mm (0.5 in.) for plates and 19 mm (0.75 in.) for sections. ASTM A36 Plates or sections must be produced by an ABS Approved Steel Mill and the steel is to be tested and certified to the satisfaction of ABS.

This Page Intentionally Left Blank



SECTION **C 3-2-1** **Structural Analysis**

C 3-2-1/1.1 Analysis of Primary Structure

C 3-2-1/1.1(a) Analysis of Primary Structure of Self-Elevating Units

General

The *MODU Rules* require that the primary structure of a unit be analyzed using both static and combined loading conditions. Conditions representative of all modes of operations are to be considered, i.e., resting on the sea bed plus the field and ocean transit conditions are to be analyzed and submitted to ABS for review. See 3-2-1 of the *MODU Rules* for details.

ABS approach for the global structural analysis of a self-elevating unit is: use either full or equivalent hydrodynamic model, and as a minimum, analyze the unit for the maximum storm and operating elevated conditions plus the ocean and field transit afloat. As mentioned in C 3-1-1/17 additional elevated conditions over and above the maximum water depth condition are often submitted to ABS for approval.

A Dynamic Analysis is required to be carried out and submitted for review for water depth greater than 100M (328ft).

Section 3-2-1 of the *MODU Rules* gives a general description as to what ABS expects to be considered when carrying out a global structural analysis of a MODU. This section of the Commentary will highlight areas that are not covered in detail in Section 3-2-1 of the *MODU Rules*, but are expected to be included in the global analysis of a self-elevating unit. These are: Wave Stepping, Loading Directions, P- Δ effects, Types of Structural Models, Gravity and Buoyancy Loads and Spudcan/soil interaction as it relates to Classification requirements.

Stepping Wave through the Structure

When analyzing a self-elevating unit, it is normal practice to step the wave through the structure in order to determine the phase of maximum wave force and overturning moment. The length of the phase step will depend on the steepness of the wave. In steep waves it is advantageous to have a final step through in one-degree steps.

Similarly, it is normally reasonable to assume that the maximum leg bending moment and member stresses will occur when the total force on the unit is the maximum. Many structural analysis programs will, by default, perform the structural analysis for the phase with the greatest base shear. The difficulty with this assumption arises when the loads are relatively small, as may be the case in a fatigue analysis, or when assessing the unit near its water depth limits (i.e., in a small wave).

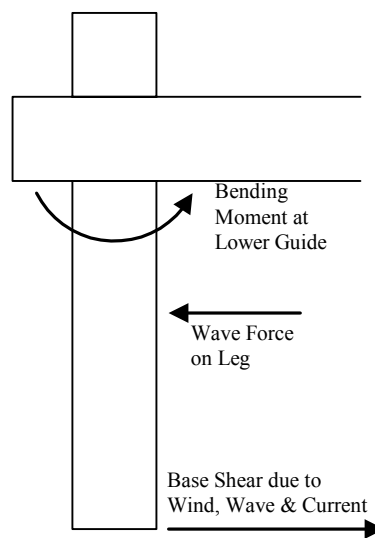
Consider the way the overall structural loads generate leg bending moments. C 3-2-1/Figure 1 gives a very simplified system of loads on the leg of a self-elevating unit. Any increase in base shear will result in an increase in the bending moment at the lower guide. An increase in the direct wave load on the leg in question (incorrectly assuming that it does not increase the base shear on that leg) will tend to reduce the leg bending moment. Clearly any increase in wave load will cause the base shear to increase, but if it is divided between the legs, there are circumstances in which it will be associated with a reduction in leg bending moment. The important issue then becomes where the wave load is acting on the leg. In environments with relatively small waves, but high currents, the point of action of the wave load may be low in the water column.

In steep waves this is not normally an issue on a three legged unit because the overall loads on the unit are maximized by having a wave crest near the two windward legs. This will mean that the single leeward leg is remote from the crest, so the loads will be low: ideal circumstances for maximizing leg bending moments. This will tend to apply even when the current velocity is high.

The main areas where this has been found to be an issue are in benign areas of the world such as in the non-tropical revolving storm (TRS) season in the tropics, and West Africa.

This may be an even greater issue when considering normal operating conditions and fatigue.

FIGURE 1
Simplified Load Arrangement on Jack-up Leg



Steep Waves

As discussed in C3-1-2/1.5.3, as a wave moves into shallow water, the crest becomes higher and narrower. The wave length also decreases, but not to the same extent as the reduction in width of the wave crest. The end result can be that a wave with a total length of 1,000 feet (300 m) may have a crest that is only slightly wider than the width of the self-elevating unit leg.

Take the example of a 70 feet wave (21 m) with a 16 second period. In 300 feet water depth (90 m) the wave length will be 1240 feet (380 m). When close to the breaking limit in 100 feet (30 m) water the wave length will be reduced to 960 feet (300 m). Consider now the forces on the leg of a self-elevating unit that is 45 feet (14 m) between chord centers. The difference in wave load between a detailed leg model and an equivalent leg model is approximately 1% in the deep water case (well within the accuracy of the calculation routines). In the shallow water case, however, the equivalent leg model produces nearly a 30% higher wave force than the detailed leg model. The reason for the increase in load is that the crest is so steep that the wave particle kinematics significantly change within a very small distance from the wave crest. Clearly this is an extreme case, with a wave that is very close to the breaking limit, but situations have arisen where this has been practically significant on a site specific basis.

It is of note that the equivalent leg will always be conservative from the standpoint of overall loads on a leg, and will normally be conservative for total wave load on the structure (assuming the two models are comparable, and the correct coefficients have been used). The equivalent leg idealization can be un-conservative for individual member loads.

Loading Directions

Waves are to be considered as coming from any direction relative to the unit.

In deep water it is normally obvious which storm approach directions will yield the lowest overturning safety factor, and which will lead to the highest preload requirement. The judgment is based on leg position, spacing, and the location of the center of gravity. The same is still generally true in shallow water, although the highly peaked wave can cause some unusual phenomenon. The area in which considerably more care is required is in determining leg member stresses, and jack loads. Many analyses have been undertaken based on the assumption that the analyst “knew” which were the critical directions, only to find out later that they had missed some important cases. A common error occurs in assuming that the single leeward leg case will lead to the highest chord stresses. The argument goes that since the leg axial load is maximized, as (probably) is the bending moment at the lower guide, the leg stresses will be maximized. However, one has to consider how the guides and pinions react the loads to fully appreciate which direction is critical, and it may well vary from water depth to water depth (or even between environmental conditions at a given water depth). As a first pass, all the major directions should be checked. Later it may be acceptable to reduce the number assessed.

P- Δ Effect Modeling

The analysis of a self-elevating unit is to take into account the P- Δ effect (see C 3-2-3/5.1.5). This can be done by using a non-linear structural analysis computer program, or by using a suitably modified linear-elastic structural analysis approach. One commonly employed modification to account for the P- Δ effect is to derive a negative spring that increases the lateral displacement of the unit.

The increased lateral displacement will also affect the overturning moment (OTM) experienced by the unit. Analysis results for OTM that do not account for the P- Δ effect should be appropriately adjusted.

Hydrodynamic Leg Model: Full or Equivalent?

Usually it makes little difference if a full hydrodynamic model of a lattice leg unit is used, or an equivalent leg. In severe storm waves the difference in calculated overall wave loads would be small compared to other errors in calculation methodology. Even in small waves, where the leg is a larger percentage of the total wave length, the difference in overall wave loads will usually be small. The use of an equivalent can be significantly in error when calculating wave loads in very steep waves, such as very large waves in shallow water.

Another major factor that could have an influence on the accuracy of an equivalent leg model is that it is very difficult to include the effects of vertical particle velocities on equivalent legs. Experience has shown, however, for most conventional lattice leg self-elevating units, the effects of vertical kinematics are not significant.

Gravity Loads and Buoyancy

The gravity loads on the unit comprise:

- Structural steel hull lightship, plus
- Owner furnished mechanical equipment, plus
- Legs and spudcans plus
- Solid variable load, plus
- Liquid variable load

The effects of buoyancy to reduce these loads should be accounted for.

In simplest terms, the loads should always be considered conservatively, but realistically. This means that when the unit is being assessed for overturning resistance, a low variable load should be assumed. When footing reaction, or leg stresses are being assessed, a high variable load should be assumed.

Leg Buoyancy

In deep water the buoyancy of the leg can be significant, and should always be incorporated when calculating leg footing reactions and overturning resistance. It is of note that analysts will often correct their structural models to account for non-structural mass/weight (e.g., anodes, rack teeth, ladders, jetting lines, etc.) but rarely correct the leg buoyancy to account for the same items. This can lead to an overestimation of the overturning resistance.

Total Elevated Load

The term “Total Elevated Load” is a common term used in structural analysis, operating manual and design review correspondence. The Total Elevated Load is defined as the total load the unit can sustain in the jacked up operating condition.

For Classification purposes the Total Elevated Load of a Self-Elevating Unit should consist of the following:

- The structural lightweight, including permanent ballast (where fitted), but excluding the weight of the legs and spud cans,
- All shipboard and drilling equipment and associated piping,
- Required spare parts and liquids in machinery and piping to their working levels,
- Liquid variables, and
- Solid variables.

Spudcan

It is easy to omit the spudcan when making a hydrodynamic model of a self-elevating unit leg, particularly in deep water. Usually this is not a critical error, but there are circumstances where it is vital to accurately model the spudcan. Most of the time, even if the hydrodynamic loads on a spudcan are large, the loads are so close to the seabed that they have little effect on leg stresses, preload requirements, or overturning. The time that they are most significant is when the loads may be large, and there is a potential problem with leg sliding (e.g., operations in the harsh environment, hard sea bed conditions off eastern Canada). In order to avoid this problem, and similar ones that may arise, it is advisable to always have a hydrodynamic spudcan model at the base of each independent leg of a self-elevating unit. If the spudcan has completely penetrated the seabed, then the point of fixity, and the parts of the leg below the mud-line can be input to ensure that the loads and reactions generated in the models are correct. While this will rarely be an issue for Classification, it may be significant for site-specific operations. It is therefore better to have the spudcan incorporated into the model rather than discover its significance too late.

The loads on the spudcan may be large due to both drag and inertia. Large gusset plates between the can and the chords can generate large drag loads, and the large volume will tend to generate large inertial loads. Some care needs to be taken to ensure that suitable coefficients are used so as not to over-estimate the loads.

Mat Supported Unit

The wave loads on the mat of a mat supported unit can be very large and, in most cases, the mat is too great a percentage of the wave length to be accurately assessed using the Morison equation. If it is necessary to calculate the loads (e.g., in order to assess the soils for sliding resistance) then a suitable diffraction based analysis should be performed.

C 3-2-1/1.1(b) Analysis of Primary Structures of CSDUs

General

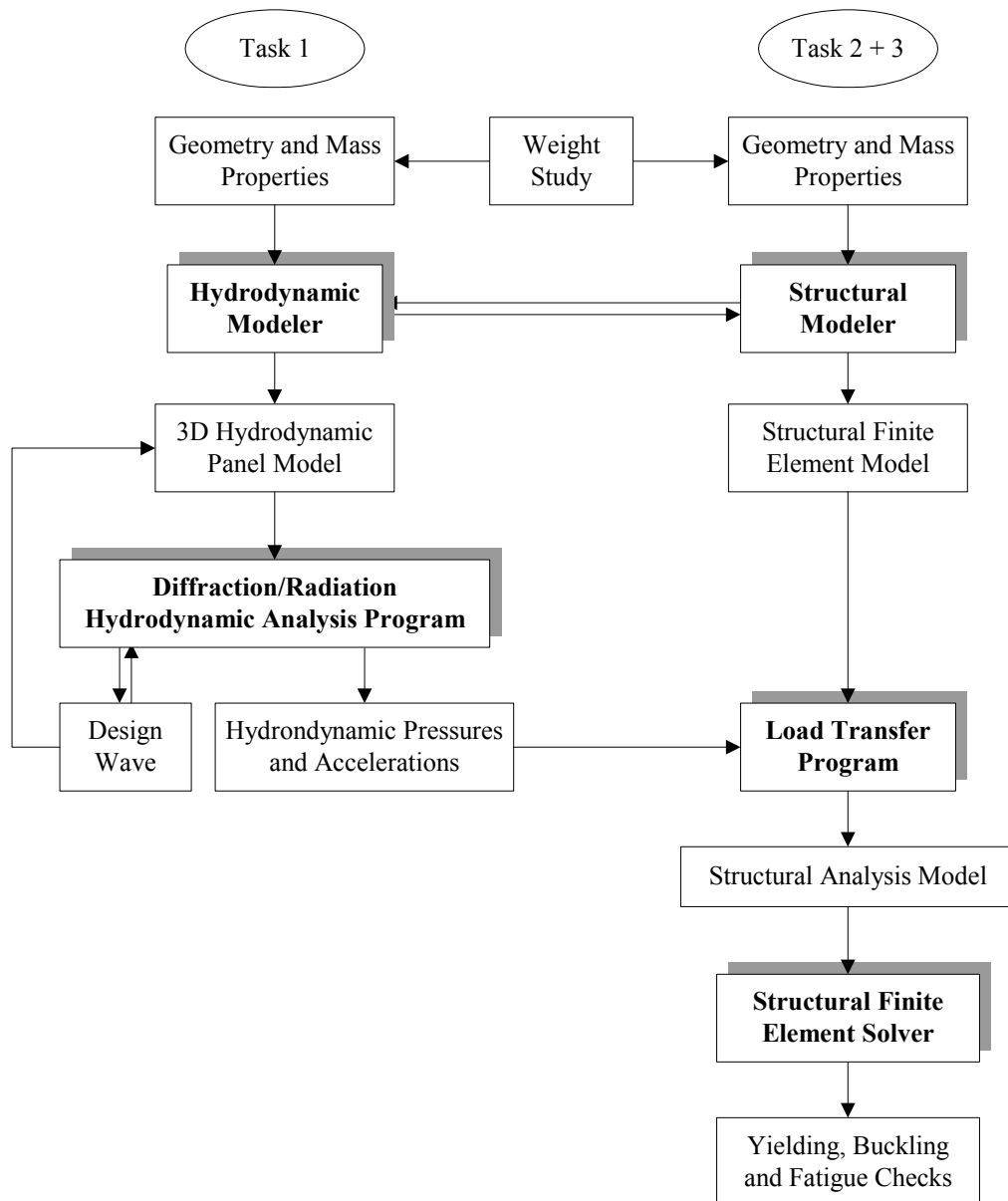
The *MODU Rules* require that the primary structure of a unit be analyzed using both static and combined loading conditions. Conditions representing all modes of operations including normal operating, severe storm, field and ocean transit conditions are to be considered and analyzed and the results are to be submitted to ABS for review. See Section 3-2-1 of the *MODU Rules* for details.

Section 3-2-1 of the *MODU Rules* gives a general description of what ABS expects to be considered when carrying out a global structural analysis of a MODU. Below emphasis is given to the areas that are not covered in detail in Section 3-1-2 of the *MODU Rules*, but are expected to be included in the global structural analysis of a CSDU.

The global strength analysis of a CSDU is normally divided into three main tasks: (1) Hydrodynamic (Response) Analysis, (2) Global Strength Analysis, and (3) Fatigue Analysis.

The following flow chart in C 3-2-1/Figure 2 outlines an overall analysis procedure that is suggested by ABS and may be used for CSDUs.

FIGURE 2
Flow Chart for Overall Analysis Procedure for CSDUs

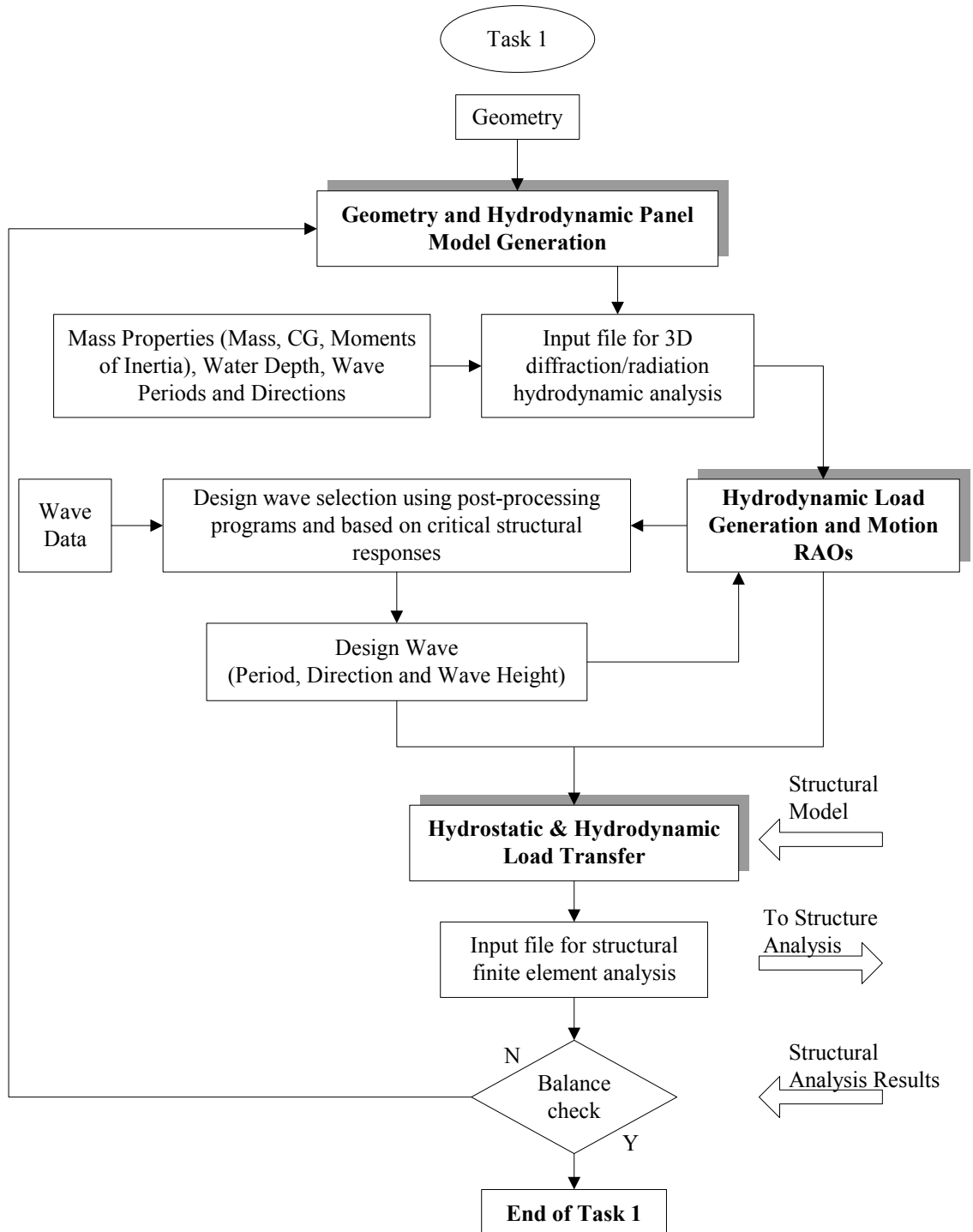


Hydrodynamic (Response) Analysis

This analysis is necessary to derive the design waves for the global strength and fatigue analyses, the slamming analysis to investigate the transit sea states, and the calculations to predict Weibull shape parameters and number of cycles. It should be noted that only the waves with critical periods and headings that generate a considerable amounts of hydrodynamic load are critical to the design of the primary structural elements. In addition, the wave load distributions on the submerged hulls of a CSDU are required in the global structural response analysis. Details of the wave loading and headings ABS expects to be included in the response analysis of a CSDU are detailed in C 3-1-2/1.5.2(a).

The flow chart in C 3-2-1/Figure 3 outlines the procedure that is suggested by ABS and may be used for CSDU hydrodynamic (response) analysis (Task 1).

FIGURE 3
Flow Chart for Design Wave Selection and Hydrodynamic Loads and Motion Analysis for CSDUs

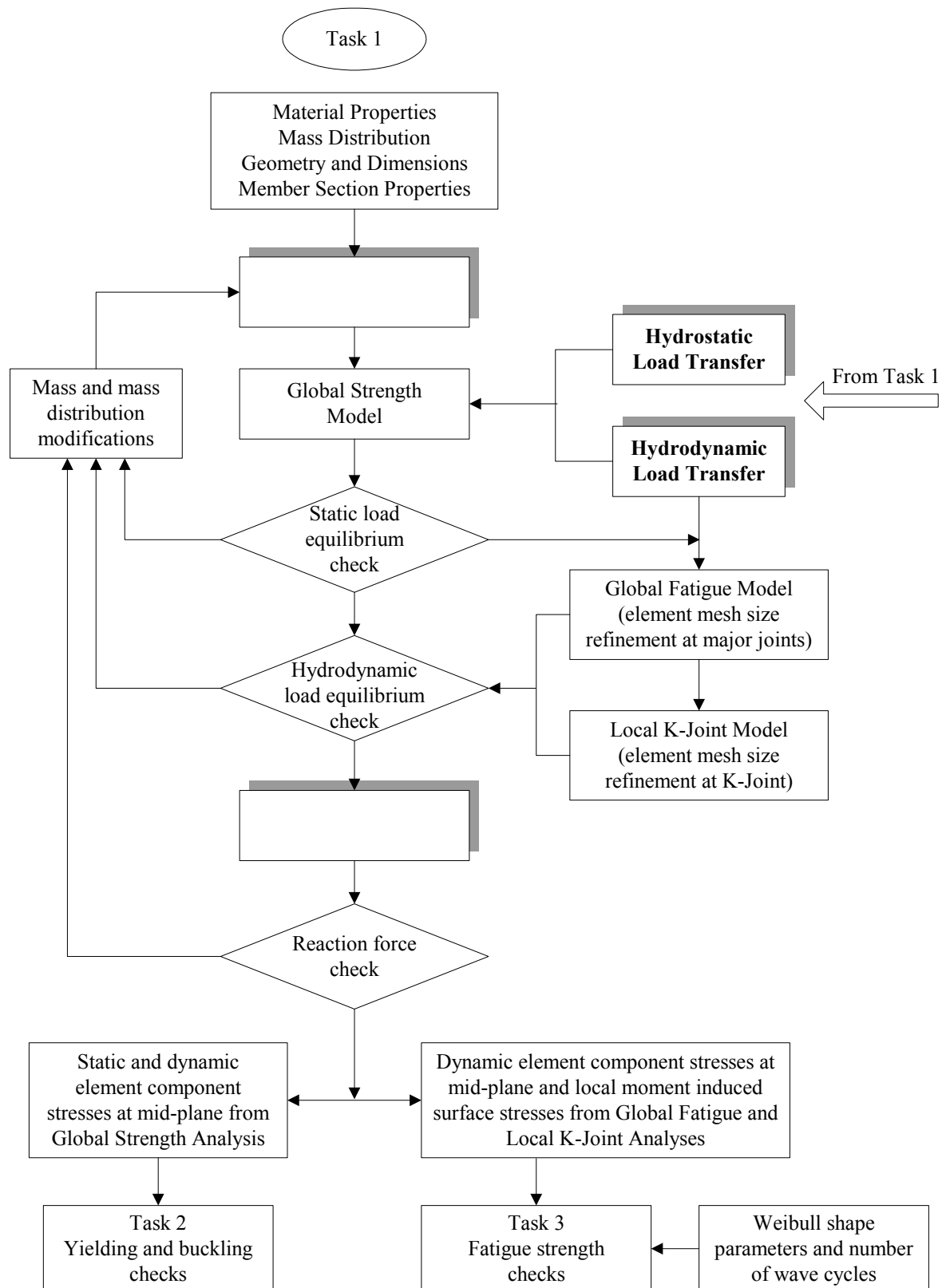


Global Strength Analysis

A global strength analysis of a CSDU is to be carried out to verify the global strength of the unit with respect to material yielding and buckling of the pontoons, columns, bracing members, and upper hull. ABS suggests that the global strength analysis be performed using finite element method (FEM). The global strength analysis model (structural model) is normally constructed using thin shell elements with coarse mesh size for all primary load carrying components, such as shells, decks, and bulkheads. Stress sensitive areas such as the major connections and brackets are also modeled using thin shell elements but with appropriate fine mesh size. All secondary load carrying components such as stiffeners and girders are modeled using beam elements. Hydrodynamic and hydrostatic pressures and accelerations are calculated in the response analysis (Task 1) and transferred to the global strength model. The global strength model is used to calculate global stress in the primary load carrying components of the lower hulls, upper hulls, columns, and bracing members for yielding buckling and fatigue checks.

The flow chart in C 3-2-1/Figure 4 outlines the procedure that is suggested by ABS and may be used for the CSDU global strength and fatigue analysis (Task 2 &3).

FIGURE 4
Flow Chart for Global Strength and Fatigue Analyses for CSDUs



C 3-2-1/1.15 Analysis and Details of Structural Connections

CSDUs have numerous connections that may be highly stressed and prone to fatigue damage; they include brace to column and brace to deck connections, brace to brace connections, and column to lower hull and deck connections. Each of these joints needs to be carefully modeled in the structural analysis.

As can be seen in the description of the response analysis in C 3-1-2/1.5.2, CSDUs are subjected to prying and squeezing forces, torsional moments, longitudinal shear forces between pontoons, inertia forces induced by acceleration of deck mass, and vertical wave bending moments on the pontoons. The combination of these loadings can create high stresses, which are especially important to fatigue sensitive joints and connections. Other important issues such as the effects of high stress gradients near the ends of members and the potential for lamellar tearing through the thickness of a structural element should also be thoroughly considered. It is imperative that each major joint be carefully designed with all these factors in mind. Some examples of viable designs include using “Z” quality material for the brace to column connections where through thickness properties are necessary, allocating generous transition brackets inside the bracing members, and providing adequate back-up structure inside the column. The structural analysis model should be constructed in such a way that the structures inside the column are correctly modeled so as to depict the sufficient details of actual structures.

Special attention should be paid to the column to lower hull and column to deck connections. Although stresses in these areas are usually relatively low the transitions or penetrations through the deck of the lower hull and the bottom of the upper hull need to be carefully designed to avoid fatigue cracking. The column to deck connection can also be further complicated if deck girders and transverses terminate at the column.

C 3-2-1/1.7 Consideration of Buckling

The criteria provided in the *ABS Guide for Buckling and Ultimate Strength Assessment of Offshore Structures* may be used to determine the scantlings and buckling characteristics of structural components.

C 3-2-1/1.17 Fatigue Analysis

3-2-1/1.17 of the *MODU Rules* specifies, “The possibility of fatigue damage due to cyclic loading is to be considered in the design of the major structure...” It then goes on to specify that:

“The type and extent of the fatigue analysis will be dependent on the intended mode and areas of operations to be considered in the unit’s design. An appropriate loading spectrum in accordance with accepted theories is to be used in the fatigue analysis.

The calculated fatigue life of the structure should be at least the design life of the unit, but not less than 20 years.”

The sophistication of fatigue analyses can vary from a simple estimate based on a manipulation of the stresses in the unit under severe storm conditions, to one based on a series of complex, time domain, dynamic analyses. As a general rule, the results of simpler methods tend to be more conservative, and the more complex methods closer to the reality. Whenever one is undertaking a fatigue analysis it is important to remember that the results can be extremely sensitive to the stress ranges used. A 15% error in calculated hot spot stress range may lead to a factor of 2 change in fatigue life. Excessive conservatism in calculating stress ranges may quickly lead to extremely low predicted fatigue lives. Conversely, if dynamic effects are unjustifiably ignored, the calculations could significantly overestimate the fatigue life.

The criteria and procedures described in the *ABS Guide for the Fatigue Assessment of Offshore Structures* and the *ABS Guidance Notes on Fatigue Analysis Procedures of Offshore Structures* may be used for the fatigue analysis of MODU.

Fatigue Analysis – Self-elevating Drilling Units

The vast majority of the leg structure of a self-elevating unit at any given location will normally be highly over-designed for that location: it is only a very small percentage of the leg that is exposed to high storm stresses, and normally those sections are located near the guides.

Members near the waterline are subjected to significant direct wave loads. In most cases these will not produce a problem for those members in a vertical plane, but horizontal members can be subjected to wave slamming loads, and changes in buoyancy as each wave passes. The situation is significantly exacerbated by any marine growth. In addition, these are the members that are least effectively protected against corrosion. If a unit is to be operated at a given location for any significant time, then fatigue of these members may need to be considered.

The other area that needs to be considered from the standpoint of fatigue is the base of the leg, at the leg to spudcan connection. If the spudcan is “pinned” then the load effects due to leg bending will be relatively low, but when assessing the base of the leg it is advisable to use conservatively high spudcan fixity. It may be slightly more difficult to accurately assess the member stresses in this area if an integrated loading/structural model is not used.

Requirements for Classification

ABS does not automatically require that an extremely complex fatigue analysis be undertaken. However the unit must be demonstrated to be suitable for the intended operations. Also, the criticality of the limiting components needs to be considered when deciding upon the detail of analysis required. If it happens that the critical component were to be a brace at the water line, then less justification would be needed than if the critical component were a chord butt weld⁸.

There have been few self-elevating units that have suffered serious fatigue problems in the operating condition and, particularly on independent leg units; generally it is relatively simple to demonstrate that the legs of the unit have sufficient operating fatigue life. Some of the main reasons for this are that exploratory self-elevating drilling units do not operate at one location for extended periods, so typically the most highly stressed area of the leg is continually changing. Also, the stresses in events less than the extreme one tend to be very much reduced. This is not only because of the non-linear nature of the wave forces, but also because in most sea states less than the design event, the base of the legs for independent leg units may have relatively high sea bed fixity. The effect is not only to reduce the dynamic response, but also the bending moments in the leg by redistributing some moment to the base of the leg.

Fatigue analysis submitted to ABS for Classification purposes should include the effects, and be based on the methods, which are listed below. The important point is that the analysis should be suitable to demonstrate satisfaction of the requirements. It may be possible to reduce some of the issues in the following list to a brief technical demonstration using simplified methods, but in the broadest sense, all the issues need to be addressed.

- Dynamic effects of waves on structural response should be included. In lieu of unit specific values, the maximum dynamic amplification factor at, or close to, resonance may be limited to 3 for independent leg units, and 5 for mat supported units.
- The SN curves given in ABS “Guidance on Fatigue Assessment of Offshore Structures” or API Fatigue curves given in “Recommended Practice 2A-WSD” should be used. Other suitable curves will be considered on a case-by-case basis.
- Full account needs to be taken of reduction in allowable fatigue life for thicker materials, when called for by the specific fatigue code or curve in use.
- Cumulative fatigue damage should be calculated using the Palmgren - Miner rule:

⁸ Clearly, when assessing criticality, consideration needs to be given to the components that are found to fail at a marginally longer life if they are significantly more critical.

$$D = \sum \frac{n}{N}$$

where

D = Cumulative fatigue damage ratio

n = Number of cycles applied at a given stress range

N = Number of cycles corresponding to failure at the given stress range, as taken from the design SN curve

- Stress Concentration Factors (SCF) need to be included. The SCF should be calculated through finite element analysis, although appropriate published parametric equations may be used for tubular joints.
- The possibility that the most critical fatigue location is not at a brace/chord node needs to be considered. On units where the hull is supported on chocks, the design of the braces may not be controlled by the maximum operating conditions, and bracing stresses may be low. On some of these units it may happen that the critical component may be the chord at a butt joint, or close to a node. Given the extreme importance of being able to predict chord fatigue failure, considerable care needs to be exercised when assessing this type of unit.
- Current need not be included when calculating the wave loads for use in the fatigue analysis of a self-elevating unit used for exploratory drilling purposes.
- The expected area of operation of the unit should be used to generate realistic combinations of environmental conditions, approach direction, and water depths.
- When assessing the upper sections of leg, the base of the leg should be assumed pinned at a minimum of 10 feet below the mud line.
- The possibility of fatigue in the area of the leg to spudcan connection needs to be considered. This would normally require assuming high spudcan fixity.
- Large deflection, or P- Δ effects need not be incorporated into the analysis, unless the unit is unusually flexible. Most of the fatigue damage is due to the large number of relatively small waves. These are associated with relatively small overall structural deflections.
- The possibility of fatigue failures in and around the jack houses needs to be considered, particularly for ocean wet towing conditions. There have been a number of units that have suffered some deck cracking around the jack houses under tow, and in some cases these cracks have been associated with local compartment flooding. The extent of analysis required will depend on the details of the design, and it is anticipated that in most cases a demonstration of good detailing will prove sufficient, however, ABS reserves the right to ask for more detailed calculations if they are deemed to be necessary.
- Methods of improving the fatigue performance of specific joints will be considered on a case-by-case basis⁹.

⁹ Standard fatigue curves have been developed based on the principle that in welded joints there is no fatigue crack initiation time, and that residual stresses are close to yield. Since fatigue crack propagation rates are comparable for welded structural steels, regardless of yield strength, the same fatigue curve should be used for all grades of structural steel. The reason that there is no initiation time is that the welding process leaves micro cracks at the surface. It is therefore possible to improve the fatigue life of a joint through weld toe grinding (with care). It is of note that crack initiation is affected by the yield strength of the material, so the effectiveness of weld toe grinding is greater in high strength steels, although credit can rarely be taken for this additional improvement. High residual tensile stresses are important since they effectively mean that material that is in general compression throughout the fatigue cycle can still be locally experiencing tensile stress reversal, and hence be subject to fatigue cracking. Residual stresses can be relieved, but most post weld heat treatment has been found to be generally ineffective in improving fatigue lives of joints.

Analysis Methodology – For Classification

The simplest fatigue analysis method that may be suitable for Classification is the “weather box” method. In this deterministic method, the wave conditions that the unit will be exposed to during the course of its life are split into a finite number of regular wave height/period combinations. The minimum acceptable number of combinations would normally be 5, but more would be preferable. The unit is then assessed under these conditions for a number of different headings and water depths. An acceptable set of assessment parameters is given in C3-2-1/Table 1.

TABLE 1
Wave and other Parameters to be used in a Fatigue Analysis

<i>Item</i>	<i>Number of Cases</i>
Number of wave height/period combinations	At least 5 over a realistic range for anticipated areas of operation
Wave steepness (Wave length divided by height)	Should normally be in the range of 12 to 15
Number of water depths	Normally 3 over a realistic range would be acceptable
Number of weather approach directions	Normally 8, but 3 may be possible with symmetry
Leg fixity conditions	2. Pinned for upper leg, high fixity for lower leg

The calculation method can be summarized as:

- Determine the wave/water depth/direction combinations for study.
- Calculate the wave load ranges on the self-elevating unit for each of the chosen combinations. Given the magnitude of most of the waves that inflict significant fatigue damage, it is usually acceptable to use a linear wave theory.
- Determine a suitable Dynamic Amplification Factor (DAF) for each wave/period and water depth combination. It is anticipated that the Single Degree of Freedom approach (SDOF) would be used.
- Apply the wave loads and, suitable inertial loads, to a detailed structural model of the unit and calculate the stress ranges throughout the structure.
- Increase stress ranges by a suitable Stress Concentration Factor (SCF), which is determined from either a finite element analysis, or suitable parametric equations. It is often adequate to use a single SCF for each member end at the joint, and to effectively assume that the most highly stressed material is always the same, regardless of loading details. Alternatively, if a more representative fatigue life is desired, then it is acceptable to keep track of the location of all the stress ranges around each joint.
- Use Palmgren - Miner rule to sum the fatigue damage from each of the individual water depth/wave direction combinations.
- Repeat for changed foundation fixity, if warranted by preliminary estimates using simplified techniques.

Tow Fatigue

Fatigue of the lower sections of a leg due to towage induced variable stresses can be a serious issue. There is no Classification requirement for fatigue in the towage condition to be studied, but it would behoove the designer to undertake some simplified assessment to indicate that the unit does not have an obvious fatigue problem. It is also advisable to consider the potential for fatigue damage before any long duration transportation, be it on the unit's own hull, or by heavy lift vessel. There have been a relatively large number of units that have suffered some cracking while under tow, both in the hull around the legs, and within the legs themselves. For this reason ABS requires that a detailed survey of the leg in way of the upper and lower guides and the jackhouse to deck connection, be carried out after each ocean tow. See Section 5-1-6 of the *MODU Rules*.

Fatigue Analysis – Column-Stabilized Drilling Units

The fatigue analysis procedures described in the *ABS Guidance Notes on Fatigue Analysis Procedures of Offshore Structures* may be used to carry out fatigue analysis for CSDUs.



SECTION **C 3-2-2 Common Structures**

C 3-2-2/5 Structures Supporting the Drilling Derrick

C 3-2-2/5.1 Substructures

The *MODU Rules* state that substructures supporting the drilling derrick, drill floor and associated equipment are to be analyzed using the static and combined loadings as required by 3-2-1/1 of the *MODU Rules* and that the stress are to be within the limits specified in 3-2-1/3.

As stated in the *MODU Rules*, loads to be included in the analysis of the substructure are the following:

C 3-2-2/5.1.1 Individual Loads

The typical Individual Loads include

- Dead load (steel weight, fixed equipment)
- Floor load (personnel, moveable equipment, material)
- Snow or ice load if applicable
- Hook, setback, rotary table and riser tensioner loads (Riser tensioner foundations may be designed based on the designer-specified breaking strength of the riser tensioner wire.

C 3-2-2/5.1.2 Combined Loads

For CSDUs, the wind load resulting from a 70 knot wind, the associated wave induced motions and loads, and the Individual Loads are to be used in the analysis representing the *Operating Condition* loading condition. 100 knot wind with the associated wave induced motions and loads, combined with the Individual Loads should be used to establish the severe storm loading condition. 100 knot and 70 knot winds and associated wave-induced motions and loads on the unit are to be used for the *Ocean and Field Transit Conditions*, respectively. Dead loads are normally the only Individual Load considered in the *Transit Conditions*.

C 3-2-2/7 Watertight Bulkhead and Watertight Flats

C 3-2-2/7.1 General

Watertight (WT) bulkheads and flats are to be designed in accordance with 3-2-2/7 of the *MODU Rules*. The number of watertight bulkheads fitted is to be such that the unit's subdivision meets the damage stability requirements. The formulae in the *MODU Rules* for the strength of WT bulkheads are similar to those used successfully for ships over many years. The main difference arising with the CSDUs is that most modern units have distinct, watertight lower and upper hull regions. The *MODU Rules* state that the design head should be taken to the "bulkhead deck at center". The question then arises on what is the bulkhead deck of the CSDUs. Normally the head for a WT bulkhead calculation

Section C3-2-2 Common Structures

should be taken to the upper deck at center of the upper hull. This applies to the WT bulkhead scantlings of both the lower and upper hull. By using this head the WT bulkheads should meet the structural requirement compatible with damage stability. If the head to the maximum damage waterline is greater than that to the upper deck at center, the head to the maximum damage waterline will control (see 3-2-4/5.3.4 of the *MODU Rules*).



SECTION **C 3-2-3 Self-Elevating Drilling Units**

C 3-2-3/5.1 Legs

C 3-2-3/5.1.2 Legs Without Mats

As specified in 3-2-3/5.1.2 of the *MODU Rules*, legs without mats are to be considered pinned at least 3 m (10 ft) below the seabed. For a leg without mats, but with a significant foundation size, this requirement is not applicable.

C 3-2-3/5.1.5 Unit in Elevated Position, P-Δ Effect

The additional lateral displacement in a structural member due to axial compression is referred to as the P-Δ effect. Linear-elastic analysis of the unit will produce “first-order” displacements, δ_s . When the axial thrust in a leg, P , is a significant portion of its Euler buckling load, P_E , then the displacement is amplified. The following is often used to establish the magnitude of the P-Δ effect.

$$\Delta = \delta_s / (1 - \frac{P}{P_E})$$

where

- Δ = the approximate displacement including P-Δ.
- δ_s = the linear-elastic first order hull displacement.
- P = the average axial load in the leg at the hull (i.e., the total leg load at the hull divided by the number of legs).
- P_E = Euler buckling load of an individual leg.

C 3-2-3/5.1.7 Safety Against Overturning

3-2-3/5.1.7 of the *MODU Rules* specifies that the unit should be assessed with minimum design variable load, and the cantilever in the most unfavorable condition, for overturning safety in the operating condition. From a practical standpoint this means that, in most cases, the cantilever is at its maximum extension with full drilling/set back load, and the hull has approximately one half the maximum variable load on board in a realistically unfavorable arrangement. On larger units, with particularly high variable loads, it may be necessary to use less than half variable, and on smaller unit, it may be acceptable to use more than half. The calculated center of gravity should then be used in overturning assessment.

In the severe storm condition, the unit should be assessed with the minimum design variable load, and the center of gravity in the most onerous design condition. This allows the designer to specify that the cantilever/drill floor be skidded in during preparations for a storm, and that the center of gravity is maintained at a specific location. Given that the unit has to be operated, it is helpful if the designer can give a reasonable range for the center of gravity.

C 3-2-3/5.7 Wave Clearance

3-2-3/5.7 of the *MODU Rules* specifies that:

“A crest clearance of either 1.2 m (4 ft) or 10% of the combined storm tide, astronomical tide, and height of the maximum wave crest above the mean low water level, whichever is less, between the underside of the unit in the elevated position and the crest of the wave is to be maintained. This crest elevation is to be measured above the level of the combined astronomical tide and storm tides.”

There is no requirement in the *MODU Rules* to use specific minimum values for surge and tide when calculating the air gap for Classification purposes, however it should be noted that ABS definition of water depth includes astronomical and storm tides. (See 3-1-1/1.7 of the *MODU Rules*). Therefore, as stated in 3-2-3/5.7 of the *MODU Rules* ABS definition of a minimum air gap for a unit in the elevated condition is the distance from the top of the wave crest to the bottom of the hull. The top of the wave crest elevation is the distance measured above a water depth that includes the combined astronomical and storm tides.

C 3-2-3/5.13 Sea Bed Conditions

When a self-elevating unit is being assessed for Classification, generally there will be no geotechnical data available, therefore sea bed conditions are not considered during the Classification of a MODU. The base of independent jack-up legs are to be considered pinned at least 3 meters (10 feet) below the sea bed (see 3-2-3/5.1.2 of the *MODU Rules*).

3-2-3/5.9 of the *MODU Rules* describes how a mat supported self-elevating unit should be considered. This provision states that for mat supported units resting on the sea bed, 20% of the bottom bearing surface area is to be considered washed away due to scouring. It is also stated that, if effective skirt plates are provided, consideration will be given to their effectiveness in preventing such loss of bottom support due to scouring. However, although skirt plates appear to improve the sliding resistance of mat supported units, it has been ABS experience that the skirt plates normally fitted to mat supported units do not generally assist in reducing scour.

It should be noted that it is the Owner’s responsibility to operate the unit within the limits of the Classification approval, so the Owners are well advised to obtain soil data to ensure that the unit is being operated within its design limits.



SECTION **C 3-2-4 Column-Stabilized Drilling Units (CSDUs)**

C 3-2-4/1.3 Special Considerations Regarding Stress

As mentioned in C 3-1-2/1.5 the highest stresses in some members may be associated with environmental conditions less severe than the maximums specified by the Owner. It is therefore important that the designer investigate the wave-induced loads using the procedure outlined in C 3-1-2/1.5.2 (a).

Brace joints of CSDUs are often subject to relatively high cyclic stresses that could result in premature fatigue damage. Therefore it is necessary that particular attention be given to the structural details of bracing connections and other critical areas in, and on the surface of, bracing members such as hydrophone connections and access coamings and fittings. Careful weld detailing of these areas is needed; and if necessary, appropriate weld profiling or other proven fatigue life enhancement techniques may be pursued to increase the fatigue life of the joint.

C 3-2-4/1.5 Effect of Mooring Forces on Local Structure

Local structure in way of position mooring fairleaders and winches should be designed to be capable of withstanding at least the forces equivalent to the breaking strength of mooring line. Unless noted otherwise, the allowable stresses of local supporting structures are to follow the requirements specified in Section 3-2-1/3 of the *MODU Rules* or the *ABS Rules for Building and Classing Steel Vessels* as applicable. For the buckling consideration, the *ABS Guide for Buckling and Ultimate Strength Assessment of Offshore Structures* may be used alternatively.

The fairleaders are normally fitted into the stability columns of a CSDU therefore care should be taken to ensure that adequate “back-up” structure is incorporated into the columns. The weld profile of the fairleader connection to the columns should be carefully carried out so that hot spots are kept to a minimum.

C 3-2-4/3 Upper Structure

Scantlings of the upper structure are not to be less than those required by local loading requirements outlined in 3-2-4/3 of the *MODU Rules*. The upper structure can be constructed as a flat plate deck with girders, transverses and beams, or a box-shaped hull with top and bottom decks, sides and internal decks and bulkheads. The upper hull may be divided into the following structural categories:

- *Primary bulkheads or girders that should be considered when establishing the global hull strength.* Primary bulkheads and girders will be subjected to stresses induced by global forces and they will also need to resist local deck loads.
- *Secondary bulkheads or girder system.* Secondary upper hull structure is not normally part of the overall strength of a CSDU and their scantlings may be calculated using local loads. However, scantlings of secondary girder systems that are in way of, and act together with, the main girder system, are to be determined using the combined effects of global and local loads.

- *Plating and stiffeners.* Upper hull plating and stiffeners that are not considered part of the global girder system are normally designed using for local loads. Special care is to be taken at cutouts where stress concentrations at corners may be high.

Any major local load should be included in the global analysis.

C 3-2-4/3.17 Deck Houses

CSDUs with box-shaped upper hulls normally have accommodation, control rooms and helideck, etc., which are integral parts of the upper hull. However the accommodation spaces, control rooms and helidecks, etc., on CSDUs with flat plate upper decks are contained in a separate deckhouse structure, often located on the forward part of the upper deck. The strength of such deckhouses is to be calculated using a minimum wind load equivalent to 100 knots in combination with other acting globally and locally applied loads as well as corrosion and fire protection requirements. The strength and structural fire protection characteristics of deckhouse should also meet IMO MODU Code requirements or Section 3-4-1 of the *MODU Rules*, as applicable. Care needs to be exercised with the upper deck structure in way of the deckhouse foundation to ensure that fatigue damage does not occur at the corners of the deckhouse to upper deck connection.

C 3-2-4/5 Columns, Lower Hulls and Footings

Columns and lower hulls of CSDUs are generally large structures that need to be framed with ring stiffeners, girders or flats and bulkheads. *ABS Guide for Buckling and Ultimate Strength Assessment of Offshore Structures* may be used to determine the scantlings and buckling characteristics of these structural components.

Special attention should be paid to the intersection of the columns to the lower hull to ensure that adequate transition material has been included in the design. Although the column to lower hull connection may not be highly stressed or be subject to high cyclic stress, experience has shown that fractures can occur if this joint is not carefully detailed and fabricated.

The periphery of the columns and lower hulls are normally in the damage stability zone. It is therefore necessary to ensure that watertight bulkheads are fitted no closer than 1.5 m (5 ft) from the shell and that compartment sizes are such that they are within the allowable limits of the damage stability criterion.

C 3-2-4/5.11 Bracing Members

3-2-4/5.11 of the *MODU Rules* states that bracing members are to be capable of transmitting load and making the overall structure effective against the design environmental loads. The *MODU Rules* also state that bracing members need to be designed to withstand superimposed local loads due to buoyancy, wave and current forces where applicable. *ABS Guide for Buckling and Ultimate Strength Assessment of Offshore Structures* may be used to determine the scantlings and buckling characteristics of bracing members, however global stress should be investigated as mentioned above and in the *MODU Rules*. Special attention is to be given to the brace to column, brace to deck, and brace to brace connections. See section C 3-2-1/1.15 and C 3-2-4/1.3 for additional commentary on bracing member related connections.

C 3-2-4/7 Structures Supporting the Drilling Derrick

The drilling derrick supports are generally in the substructure area. See C 3-2-2/5 concerning ABS requirements.

C 3-2-4/9 Wave Clearance

3-2-4/9 of the *MODU Rules* states that unless deck structures are satisfactorily designed for wave impact, reasonable clearance between the deck structures and the wave crest is to be ensured for all afloat operations. This may lead to the belief that it is acceptable to have drafts such that the wave crest can impact the underside of the upper hull. In theory this may be possible but experience shows that serious damage to the underside of the hull is the much more likely outcome when the draft is too high. It is therefore suggested that model testing be undertaken to determine the maximum draft and sea state that will avoid a wave crest strike on the underside of the upper hull.

C 3-2-4/11 Structural Redundancy

C 3-2-4/11.1 Assumed Damage

The *MODU Rules* state that the structure of a CSDU is to be able to withstand the loss of a slender bracing member without causing overall collapse of the unit's structure. This poses the question: what is a slender bracing member. ABS interpretation of a "slender bracing member" is that it is a load carrying member with dimensions that can be totally ruptured in the event of an accident; such as a collision from a supply boat, damage from dropped objects, fire and explosion, or other abnormal events.

One method of determining the structural redundancy capacity of a bracing member is to measure the amount of energy that is required to totally rupture the member. The *MODU Rules* do not have a vessel collision requirement nor do they specify the required energy for defining total rupture of a bracing member. However, the most commonly used impact energy is:

- 14 MJ for sideways collisions
- 11 MJ for bow or stern collisions

which corresponds to a vessel of 5000-tonnes displacement with an impact speed of 2 m/sec.

ABS therefore suggests that a calculation be carried out to determine if bracing members of CSDUs can sustain this amount of energy. If a bracing member can sustain this amount of energy, it needs not to be considered completely ineffective in the redundancy analysis; only its damaged portion needs to be considered ineffective by reducing the bracing member's stiffness accordingly. If a bracing member cannot completely absorb this amount energy, it should be considered totally ineffective in the redundancy analysis.

Many modern CSDU designs have very large diameter or rectangular lower bracing members that resemble the lower hulls. Generally, this type of bracing member will not need to be assumed damaged to the extent that it becomes completely ineffective.

This Page Intentionally Left Blank



SECTION **C 3-5-1** **Position Mooring Equipment Systems and Equipment**

C 3-5-1/1 General

Certification and survey of anchors, cables, winches, windlasses, etc., and position mooring systems are not required for Classification. There are, however, three mooring-system-related designations for which an Owner can apply, resulting in the addition of an appropriate symbol that is added to the Classification designations of the unit. These symbols are **Ⓔ**, **Ⓜ** and **Ⓟ**.

A short explanation of each designation is provided below.

C 3-5-1/3 Temporary Mooring Equipment

Ⓔ is a symbol given to a vessel or unit when the temporary mooring equipments (anchors and chain/cable) meet the criteria of 3-5-1 of the *ABS Rules for Building and Classing Steel Vessels* or Section 15 of the *ABS Rules for Building and Classing Steel Barges*. This designation originated for ships and barges moored in a bay or an estuary waiting to be docked. A CSDU is not a trading vessel therefore it does not normally moor at its transit draft. A CSDU also carries much position mooring equipment that is normally in excess of any temporary mooring equipment requirement. It is therefore unusual for a CSDU Owner to request **Ⓔ** for their unit.

C 3-5-1/5 Position Mooring Equipment

Ⓜ is a symbol given to a CSDU when the mooring equipment, anchors, chain or wire rope have been tested in the presence of an ABS Surveyor in accordance with the Owners specification. It should be noted that this designation does not indicate that ABS has approved the mooring equipment, chain or wire rope to be sufficient for the environmental loads and effects that the unit may experience. The symbol attests to the fact that ABS has witnessed the testing of the equipment to the Owners specification.

C 3-5-1/7 Position Mooring Systems

Ⓟ is a symbol that signifies that the position mooring systems meet the requirements outlined in Appendix 3-5-A1 of the *MODU Rules*. Mooring analyses in accordance with the requirements in Appendix 3-5-A1 of the *MODU Rules* are to be submitted to ABS for review. In this approach the minimum factor of safety (FOS) on anchor line tensions are based on quasi-static analysis method. However, for CSDUs operating in water depths in excess of 450 m (1500 feet), the effects of line dynamics due to wave frequency vessel motions are to be considered.

This Page Intentionally Left Blank