



GUIDANCE NOTES ON

AIR GAP ANALYSIS FOR SEMI-SUBMERSIBLES

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Foreword

These Guidance Notes supplement the Rules and Guides that ABS has issued for the classification of semi-submersibles, which refer to column-stabilized drilling units, column-stabilized units and column-stabilized installations. Unless the upper structure and deckhouses are satisfactorily designed for wave impact, ABS classification requirements mandate a reasonable air gap between the deck structures and the wave crests for all afloat modes of operation, taking into account the predicted motion of the semi-submersible relative to the surface of the sea. Calculations, model test results, field measurements or the combinations of these methods may be used to determine the appropriate air gap. These Guidance Notes address the air gap analysis methods and design considerations.

These Guidance Notes provide detailed procedures for the air gap analysis for semi-submersibles. The suggested method is based on direct analysis of vessel motions and wave surface elevations using the linear diffraction-radiation analysis or the second order analysis. Additional considerations may be needed for a particular case, especially when a novel design or application is being assessed. These Guidance Notes should not be considered mandatory, and in no case are these Guidance Notes to be considered a substitute for the professional judgment of the designer or analyst. In case of any doubt about the application of these Guidance Notes, ABS should be consulted.

These Guidance Notes become effective on the first day of the month of publication.

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SECTION 1 Introduction

1 General

The term *Semi-Submersibles* used in these Guidance Notes refers to:

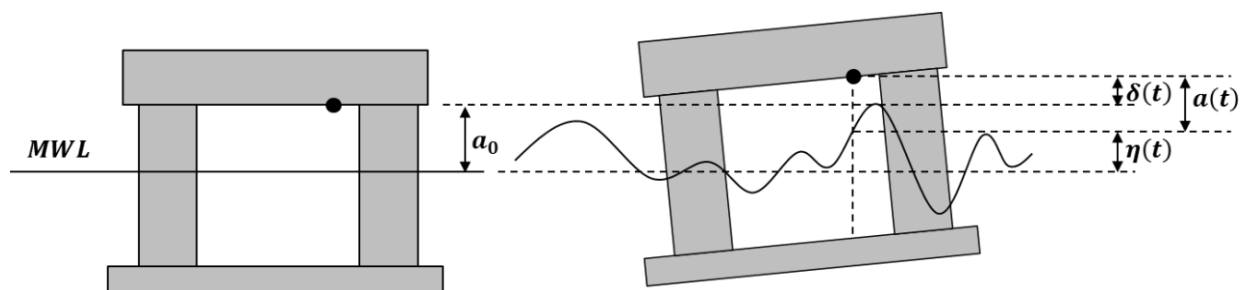
- Column-Stabilized Drilling Units defined in the *ABS Rules for Building and Clasing Mobile Offshore Drilling Units (MODU Rules)*
- Column-Stabilized Units defined in the *ABS Guide for Building and Clasing Mobile Offshore Units (MOU Guide)*
- Column-Stabilized Installations in the *ABS Rules for Building and Clasing Floating Production Installations (FPI Rules)*.

A semi-submersible is a column-stabilized floating offshore structure, which consists of a deck structure with large diameter support columns attached to submerged pontoons. In the design and operation of semi-submersibles, the air gap as defined in Subsection 1/3, also known as the deck clearance, is an important design parameter. A low air gap may lead to wave impact that the structures and equipment of a semi-submersible are not designed for and could potentially cause serious damage. Conversely, an excessive air gap could increase the cost, decrease the stability, reduce payload capacity and impair global performance.

These Guidance Notes provide procedures for the air gap analysis based on either the linear or the second order potential theories, address nonlinear effects on the air gap analysis, and identify industry common design practice. The theories and equations referenced in these Guidance Notes are based on the infinite water depth assumption. However, the procedures described in these Guidance Notes are in general also applicable to finite water depth condition.

3 Definition of Air Gap

FIGURE 1
Air Gap Definition



An air gap or a deck clearance represents the distance between the water surface and the lowest deck of a semi-submersible. Section 1, Figure 1 gives a schematic view of the air gap in the absence of waves and in the presence of waves. In still water, the air gap at a particular location (x, y) on the lowest deck is denoted as $a_0(x, y)$, which is determined by the hydrostatic analysis. In the presence of waves, $\eta(x, y, t)$ denotes the free surface elevation at a particular location on the lowest deck at time instant t , and $\delta(x, y, t)$ is the corresponding vertical motion of the point on the platform at time instant t . In these Guidance Notes, a location on the structure selected for air gap calculation is referred to as a *field point*. The instantaneous air gap at a field point is:

$$a(x,y,t) = a_0(x,y) - [\eta(x,y,t) - \delta(x,y,t)] \dots\dots\dots (1.1)$$

The total change of air gap is a linear combination of two sources: free surface elevation, $\eta(x,y,t)$ and corresponding vertical vessel motion, $\delta(x,y,t)$, at a field point. In this document herein, the total change of air gap is referred to as the *relative wave elevation*, $r(x,y,t)$.

$$r(x,y,t) = \eta(x,y,t) - \delta(x,y,t) \dots\dots\dots (1.2)$$

Deck impact occurs if relative wave elevation, $r(x,y,t)$, exceeds the still water air gap, $a_0(x,y)$. The air gap analysis in these Guidance Notes is to determine the minimum air gap corresponding to the extreme relative wave elevation in storm conditions.

5 Air Gap Design Considerations

The air gap should normally be determined by an appropriate model test. Alternatively, the air gap may also be calculated using numerical approaches that account for relative motions between the semi-submersible and waves. The following items should be considered in the determination of the air gap:

- i) Environmental condition headings relative to the semi-submersible;
- ii) Motions of semi-submersible in six degrees of freedom;
- iii) Wave crest elevation, including wave asymmetry;
- iv) Wave/structure interaction effects (e.g., wave enhancement, run-up);
- v) Effects of interacting systems (e.g., mooring and riser systems);
- vi) Local wave crest effects as described in APR RP 2FPS (2011), where applicable.

For semi-submersibles operated as floating production installations, the *ABS FPI Rules* require a reasonable clearance between the lowest point of the topside deck and the wave crest. A commonly referenced minimum deck clearance is 1.5 m (5 ft), see API RP 2FPS (2011), in the case where the semi-submersible is subject to the 100-year return period environmental conditions. Consideration is also given to performing the robustness check, in which a rarer, but still possible event (e.g., 1,000-year wave crest in the Gulf of Mexico or 10,000-year return period wave crest in the North Sea) is applied and the topside deck elevations should be such that no negative air gap takes place. If the air gap criterion is not satisfied, the anticipated local and global wave forces (including slamming) in both vertical and horizontal directions, where applicable, should be suitably considered in the design of the structural strength.

For semi-submersibles operated as mobile offshore units, the *ABS MODU Rules* require a reasonable clearance between the lowest point of the topside deck and the wave crest, unless the upper structure and deckhouses are satisfactorily designed for wave impact. For mobile offshore units with a DP system, larger vertical motions due to rolling or pitching induced by overturning moment generated by the force from the thrusters, especially at field points near the columns and at the extreme of ends of the unit, may lead to a smaller air gap than what is predicted from numerical analysis. A static trim due to the unfavorable combination of thrust forces may be applied in the absence of a more detailed analysis.

For semi-submersibles used as a mobile offshore unit but which are intended to be deployed at one site for no less than 5 years without dry docking, the air gap analysis should in general follow the requirements for floating production installations.

7 Air Gap Analysis Methods

The following four methods may be used for the air gap analysis. It is possible, however, that other approaches may also exist.

7.1 Linear Air Gap Analysis

Linear air gap analysis relies on the linear three-dimensional diffraction-radiation theory to calculate the first order wave frequency vessel motions and free surface elevations at field points in frequency domain, and then uses a stochastic method to determine the extreme relative wave elevation. Corrections are applied to approximately account for the nonlinear effects of wave surface elevations and vessel motions.

This approach is commonly used in practical application due to its simplicity and ease of use. Empirical corrections are applied through a wave asymmetry factor and a wave run-up factor to consider the nonlinearity of the free surface elevation and the local run-up, respectively. Without these corrections, experimental observations indicate that the linear analysis may significantly under-predict the crest elevation in steep waves and, in particular, at locations very close to columns where local run-up may appear. In addition, the mean and low frequency vessel motions should be considered for the air gap design of semi-submersibles. Current industry practice, however, often ignores the mean and low frequency vessel motions for the air gap design of semi-submersibles operated as mobile offshore units. The mean and low frequency motions can be calculated by the global motion analysis in either frequency domain or time domain.

7.3 Second Order Time-Domain Air Gap Analysis

The second order air gap analysis attempts to model the nonlinear effects of vessel motions in time domain. It usually can improve the prediction accuracy and result in a better agreement with model test results. The free surface elevation can be determined through the linear diffraction-radiation theory and adjusted using empirical corrections as described above in 1/7.1. Alternatively, a second order method based on the second-order diffraction theory may be applied to model the asymmetry in the free surface elevation provided the analysis results of the free surface elevation and the correction to the wave run-up at near-column locations are validated by model tests.

7.5 CFD-Based Air Gap Analysis

Computational Fluid Dynamics (CFD) analysis can solve complex nonlinear flows around an offshore structure. This may be the most promising numerical approach to model the wave run-up effects. However, the computational cost is high and the analysis method should still be validated by the comparison with model tests.

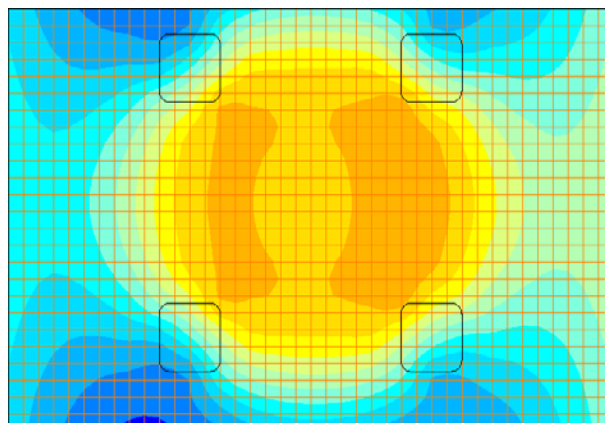
7.7 Model Test

Model test is the most direct method to predict air gap. However, model test results are usually not available in the early design stage. Even in the final design stage, model test is often conducted under limited environmental conditions. In general, model test and numerical analyses are not to replace, but are rather to complement each other. Model test data are good sources to calibrate and validate the numerical model, and in turn, numerical simulations can provide comprehensive analysis results under various environmental conditions.

9 Field Points for Air Gap Analysis

It is suggested that air gap analyses are performed at locations in a grid pattern around a semi-submersible. The extreme relative surface elevations at the grid points are preferably displayed with contour plots, as shown in Section 1, Figure 2 for an example.

FIGURE 2
Field Points in Grid Pattern



If contour plots are not available, the air gap analysis are suggested to be conducted at the following locations, as a minimum:

- Center point
- Extreme center points
- Quartering points
- Locations around column area

Additional locations may also need to be analyzed if the locations are at risk to be exceeded by crest elevation. Special attention should be paid to the up-wave columns, where the minimum air gap most often occurs.

11 Scope and Overview of These Guidance Notes

These Guidance Notes intend to provide the analysis procedures of air gap assessment for semi-submersibles based on either the linear analysis or the second order analysis. The theoretical background of these methods is introduced with critical parameters highlighted.

Section 2 describes the three-dimensional diffraction-radiation analysis used to calculate vessel motions. Both linear frequency domain and nonlinear time domain methods are addressed.

Section 3 discusses the free surface elevation induced by wave-structure interaction and addresses the wave asymmetry and wave run-up phenomenon.

Section 4 presents the linear air gap analysis procedures in frequency domain.

Section 5 demonstrates the second order air gap analysis procedures in time domain.

A diagram outlining the air gap assessment process in accordance with these Guidance Notes is given in Section 1, Figure 3.

13 Symbols

a	instantaneous air gap
a_0	still water air gap
η	free surface elevation
η_I	incident wave elevation
η_D	diffraction wave elevation
η_R	radiation wave elevation
η_{extre}	extreme value of the total free surface elevation
$\eta_{extre}^{(1)}$	extreme value of the first order free surface elevation
δ	vertical vessel motion
r	relative wave elevation
r_{in}, r_{out}	in-phase component and out-of-phase component of relative wave elevation
r_{Amp}, r_{phase}	amplitude and phase angle of relative wave elevation RAO
r_{max}	maximum relative wave elevation
r_{mean}	mean relative wave elevation
r_{WF}, r_{LF}	extreme value of wave frequency and low frequency relative wave elevation
t	time instant

X	vessel motion
$\dot{X}$	vessel velocity
$\ddot{X}$	vessel acceleration
X_{Amp}	amplitude of motion Response Amplitude Operator (RAO)
X_{in}, X_{out}	in-phase component and out-of-phase component of motion RAO
ω	circular wave frequency
F^a	active wave forces
N	the number of discrete regular wave trains of a wave spectrum
ρ	fluid density
M	mass matrix
M_A	added mass matrix
C	radiation damping matrix
K	hydrostatic stiffness matrix
ν	viscous damping matrix
A_{wp}	water-plane area
g	gravity acceleration
∇	displacement volume
GM_T	transverse metacentric height
GM_L	longitudinal metacentric height
(x,y,z)	coordinates of a given point
(x_G, y_G, z_G)	coordinate of center of gravity
ζ	critical damping ratio
T_n	natural period
β	wave heading angle
k	wave number
$H^{(2+)}$	second order sum-frequency Quadratic Transfer Function (QTF) (amplitude)
T_p	peak period
T_z	zero up-crossing period
H_s	significant wave height
ω_c	characteristic frequency of extreme waves
α_{wa}	wave asymmetry factor
α_{run-up}	wave run-up factor
$S_{\eta}(\omega)$	wave spectrum
$S_r(\omega, \beta)$	relative wave surface elevation spectrum
m_n	n -th order spectral moment