

GUIDE FOR

SPECTRAL-BASED FATIGUE ANALYSIS FOR FLOATING PRODUCTION, STORAGE AND OFFLOADING (FPSO) INSTALLATIONS MAY 2010

Guide to Color Coding Used in Online Version of the Guide

The following summarizes the colors corresponding to Rule Changes, Corrigenda items and editorial changes in the Guide files which are available for download.

Rule Changes:

NOTICE NO. 1 – February 2013 (effective 1 February 2013)

NOTICE NO. 2 – January 2018 (effective 1 January 2018)

Corrigenda:

CORRIGENDA/EDITORIALS – 1 February 2013

CORRIGENDA/EDITORIALS – 1 February 2014

Editorials:

Editorial Changes



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MAY 2010 (Updated January 2018 – see next page)

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Updates

January 2018 consolidation includes:

- February 2014 version plus Notice No. 2

February 2014 consolidation includes:

- February 2013 version plus Corrigenda/Editorials

February 2013 consolidation includes:

- May 2010 version plus Notice No. 1 and Corrigenda/Editorials

Foreword

This *Guide for Spectral-Based Fatigue Analysis for Floating Storage and Offloading (FPSO) Installations*, herein referred to as the “Guide”, provides information on the method to perform spectral fatigue analysis for ship-type “Floating Production Installations”. This type of offshore installation is usually referred to as a “Floating Storage and Offloading (FSO) System”; or “Floating Production, Storage and Offloading (FPSO) System”. FPSO is the term that will be used in this Guide to denote these ship-type Floating Production Installations. Spectral fatigue analysis performed for FPSOs in accordance with the procedures and criteria in this Guide will be identified in the *Record* by the notation **SFA**.

The Rules and Guides for Classification for which this Guide is considered to be most relevant are:

- ABS *Rules for Building and Classing Mobile Offshore Drilling Units*
- ABS *Rules for Building and Classing Offshore Installations*
- ABS *Rules for Building and Classing Floating Production Installations*

Additionally, the use of the Guide relies on reference to:

- ABS *Guide for the Fatigue Assessment of Offshore Structures*

This Guide specifically relates to the latest editions of the above-mentioned Rules and Guides. The use and relevancy of the Guide to other editions of these references, or with other ABS criteria, should be established in consultation with ABS.

This Guide is based on an earlier publication entitled *ABS Guidance Notes on Spectral-Based Fatigue Analysis for Floating Offshore Structures* (March 2005). The present document supersedes the earlier one.

ABS welcomes comments and suggestions for the improvement of the Guide. Comments or suggestions can be sent electronically to rsd@eagle.org.



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SECTION 1 Introduction

1 Background and Applicability

This Guide provides a detailed description of the method to perform spectral fatigue analysis for ship-type offshore installations in order to obtain the optional classification notation **SFA**. Spectral fatigue analysis relies on the presumed linearity of wave-induced loads with respect to waves. This condition is sufficiently satisfied for ship-type offshore installations; such as Floating Production, Storage and Offloading (FPSO) and Floating Storage and Offloading (FSO) systems. For a ship-type hull, linear diffraction forces are the dominant component of wave load. The application of the spectral fatigue analysis method to a ship-type hull is presented in this Guide. For other hull configurations composed of members with relatively large cross sectional dimensions; such as a Tension Leg Platform, Spar, or Column Stabilized units, a spectral approach is often employed; but with appropriate modifications to account for the influence of nonlinear drag forces that tend to become more important as cross sectional member dimensions decrease. This Guide assumes that any required modification to linearize the wave-induced load effects has been satisfactorily accomplished.

This Guide employs basic concepts and terminology that were defined in the *ABS Guide for the Fatigue Assessment of Offshore Structures* (2003). In that reference it is stated that:

*“Fatigue assessment denotes a process where the fatigue demand on a structural element (e.g., a connection detail) is established and compared to the predicted fatigue strength of that element. One way to categorize a fatigue assessment technique is to say that it is based on a direct calculation of fatigue damage or expected fatigue life. Three important methods of assessment are called the *Simplified Method*, the *Spectral Method* and the *Deterministic Method*. Alternatively, an indirect fatigue assessment may be performed by the *Simplified Method*, based on limiting a predicted (probabilistically defined) stress range to be at or below a permissible stress range. There are also assessment techniques that are based on *Time Domain* analysis methods that are especially useful for structural systems that are subjected to nonlinear structural response or nonlinear loading.”*

In this Guide, the fatigue assessment technique that is presented is a direct calculation method based on the spectral analysis method, which can produce a fatigue assessment result in terms of either expected damage or life. The fatigue strength of structural details is established using the S-N curve approach that is specified in the referenced Guide.

It should be borne in mind that for the hull structure of an Offshore Installation, wave-induced loading is usually the dominant source of fatigue damage. However some types of floating offshore structures may also be subjected to significant fatigue loading from other loading sources. This can be true for hull types that undergo frequent loading and discharge of produced fluids. For example, in FPSO and FSO systems, such load changes can induce large ranges of hull girder stress and secondary stress (albeit at lower cycles than direct wave loads). Such load cycle fatigue is also addressed in this Guide. In addition, fatigue loading may also be induced by the operation of equipment associated with the function of the Offshore Installation. The extent to which the spectral-based fatigue method can or will be adapted to take into account these “non-wave” sources of fatigue damage must be further considered by the designer.

3 FPSO Areas for Fatigue Assessment

There are two general categories of FPSO structural details for which fatigue assessments are required. The first type relates to conventional tanker hull details and is indicated in 1/3.1. For some of these details, in addition to wave loads, low cycle produced fluid (cargo) loading and offloading induced loads should be considered in the fatigue assessment. The second type of details is specific to an FPSO as indicated in 1/3.3. For some of the latter type, other kinds of loads, (e.g., low-frequency loads or operational dynamic loads) should be included in the fatigue assessments.

3.1 Hull Structure

General guidance on areas of the hull where fatigue assessment should be performed is as follows:

3.1.1 Connections of Longitudinal Stiffeners to Transverse Web/Floor and to Transverse Bulkhead

3.1.1(a) 2 to 3 selected side longitudinal stiffeners in the region from 1.1 maximum draft to about 0.33 maximum draft in the midship region and also in the region between $0.15L$ and $0.25L$ from F.P., respectively.

3.1.1(b) 1 to 2 stiffeners selected from each of the following groups:

- Deck longitudinals, bottom longitudinals, inner bottom longitudinals and longitudinals on side longitudinal bulkheads.
- One longitudinal on the longitudinal bulkheads within $0.1D$ from the deck is to be included.

For these structural details, the fatigue assessment is to be first focused on the flange of the longitudinal stiffener at the rounded toe welds of attached flat bar stiffeners and brackets.

Then, the critical spots on the web plate cut-out, on the lower end of the stiffener, as well as the weld throat, are also to be checked for the selected structural detail.

Where the stiffener end bracket arrangements on two sides of a transverse web are different, both configurations are to be checked.

3.1.2 Shell, Bottom, Inner Bottom or Bulkhead Plating at Connections to Webs or Floors (for Fatigue Assessment of Plating)

3.1.2(a) 1 to 2 selected locations of side shell plating near the summer LWL amidships and between $0.15L$ and $0.25L$ from F.P. respectively.

3.1.2(b) 1 to 2 selected locations in way of bottom and inner bottom amidships.

3.1.2(c) 1 to 2 selected locations of lower strakes of side longitudinal bulkhead amidships.

3.1.3 Connections of the Slope Plate to Inner Bottom and Side Longitudinal Bulkhead Plating at the Lower Cargo Tank Corners

One selected location amidships at transverse web and between webs, respectively.

3.1.4 End Bracket Connections for Transverses and Girders

1 to 2 selected locations in the midship region for each type of bracket configuration

3.1.5 Other Regions and Locations

Other regions and locations, highly stressed by fluctuating loads, as identified from structural analysis

3.3 FPSO-Specific Structural Areas

The adequacy of the following FPSO-specific areas for fatigue should be suitably demonstrated:

- Position mooring/hull interface, if spread moored (5A-1-4/3 of the ABS [Rules for Building and Classing Floating Production Installations \(FPI Rules\)](#))
- Turret and its interface with hull, if turret moored (6-2-1/13 and 6-2-1/15 of the [FPI Rules](#))
- Riser porches

- The details, below and on the deck of the hull, comprising the supports of the topside structures. (The interface details between the hull structure and equipment skids and support frames deserve particular attention.)
- Additional areas, as applicable, including: flare tower foundation, crane pedestals, helideck to deck connections and deck penetrations.

5 Tanker Conversion

When an FPSO is converted from a trading tanker, the fatigue damage accumulated during the “trading tanker” phase is to be deducted when establishing the remaining fatigue life for future service as an FPSO.

When calculating the fatigue damage for past services, the wave conditions of specific routes the vessel has experienced in past service can be employed, instead of using the wave condition representing unrestricted service as may have been done for classification as a tanker.

When calculating the fatigue damage accumulated during the “trading tanker” phase, the effects of vessel speed (encounter frequency) should be included (i.e., in the evaluation of stress RAOs and the number of stress cycles).

7 General Comments about the Spectral-based Method

Spectral-based Fatigue Analysis is a complex and numerically intensive technique. As such, there is more than one variant of the method that can be validly applied in a particular case. This Guide is not intended to preclude the use of any valid variant of a Spectral-based Fatigue Analysis method by “over specifying” the elements of an approach. However, there is a need to be clear about the basic minimum assumptions that are to be the basis of the method employed and some of the key details that are to be incorporated in the method to produce results that will be acceptable to ABS. For this reason, most of the remainder of this Guide addresses these topics.

The main assumptions underlying the Spectral-based Fatigue Analysis method are listed below:

- i) Ocean waves are the main source of the fatigue-inducing loads acting on the structural system being analyzed. The fatigue damage from other loading sources can be considered separately.
- ii) In order for the frequency domain formulation and the associated probabilistically-based analysis to be valid, load analysis and the associated structural analysis are assumed to be linear. Hence, scaling and superposition of stress transfer functions from unit amplitude waves are considered valid.
- iii) Nonlinearities, brought about by nonlinear roll motions and intermittent application of loads such as wetting of the side shell in the splash zone, are treated by correction factors.
- iv) Structural dynamic amplification, transient loads and effects such as springing are insignificant for a typical FPSO hull structure, and hence, use of quasi-static finite element analysis is valid, and the fatigue inducing stress variations due to these types of load effects can be ignored.

Also, for the particular method presented in Appendix 3, it is assumed that the short-term stress variation in a given sea-state is a random narrow-banded stationary process. Therefore, the short-term distribution of stress range can be represented by a Rayleigh distribution.

The key components of the Spectral-based Fatigue Analysis method for the selected structural locations can be categorized into the following components:

- Establish Fatigue Demand
- Determine Fatigue Strength or Capacity
- Calculate Fatigue Damage or Expected Life

These analysis components can be expanded into additional topics, as follows, which become the subject of particular Sections in the remainder of this Guide.

The topic, “Establish Fatigue Demand” is covered in Sections 2 through 7 and part of Appendix 3. The topics “Determine Fatigue Strength or Capacity” and “Calculate Fatigue Damage or Expected Life” are covered in Sections 8 and 9, respectively. Reference can be made to Section 1, Figure 1 for a schematic representation of the Spectral-based Fatigue Analysis Procedure.

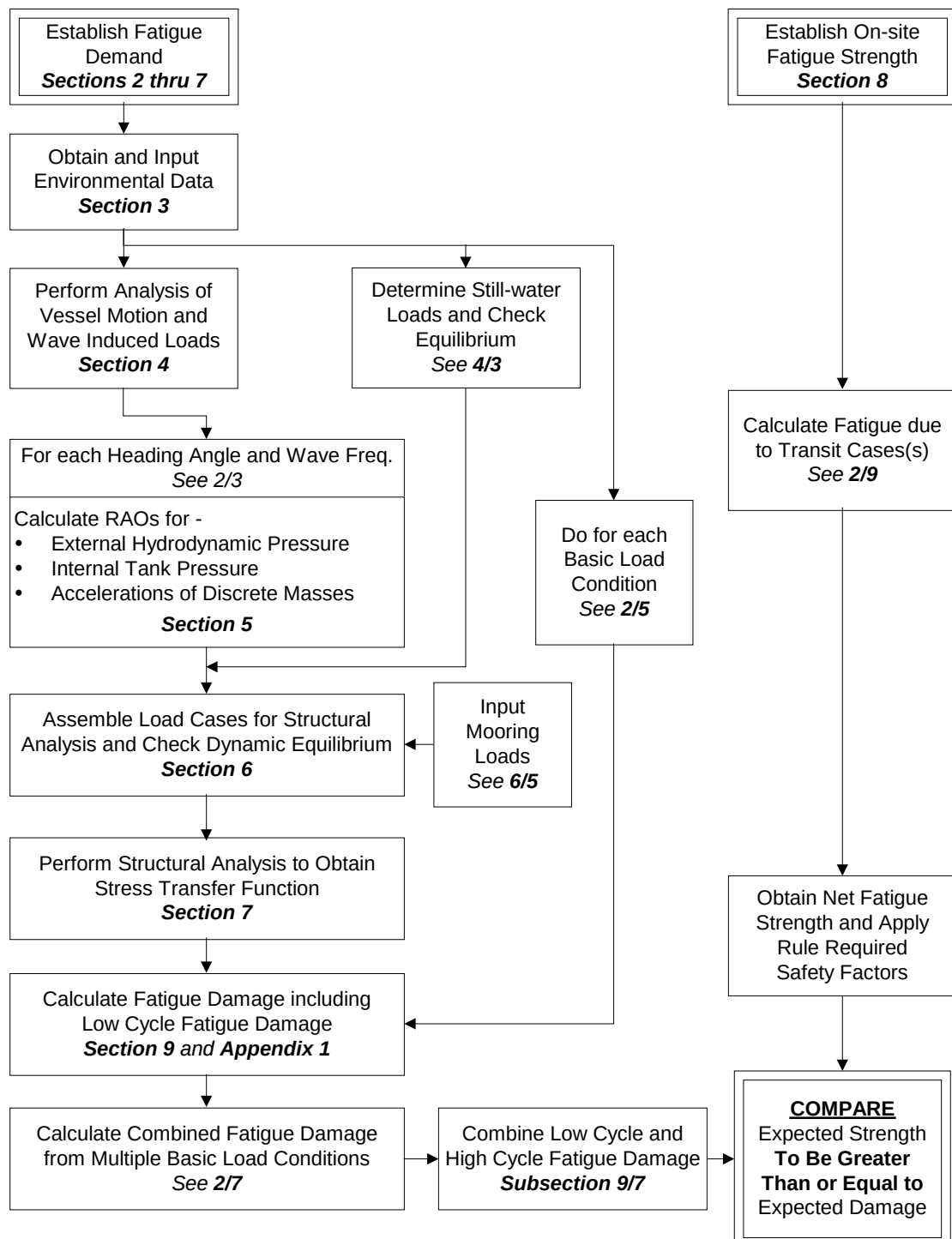
A purposeful effort is made in this Guide to avoid complicated formulations, which will detract from the concepts being presented. The most complex formulations are those relating to the calculation of fatigue damage resulting from the predicted stress range. These formulations are presented in Appendix 3. It is often at this formulation level that valid variations of a method may be introduced, and for that reason, it is emphasized that the contents of Appendix 3 are provided primarily to illustrate principle, rather than as mandatory parts of the Spectral-based Fatigue method.

9 Data to be submitted

The submittals for review should include:

- i) A contract which clearly defines owner’s specification other than standard requirement, or other critical information
 - ii) Site metocean data
 - iii) Principal Dimensions, Lines and Trim/Stability booklet
 - iv) Key drawings (General Arrangement, Midship section, Shell expansion, Construction profile and Deck plan)
 - v) More drawings for Forebody/Aftbody, Typical bulkhead and Engine room
 - vi) DLA analysis report detailing findings and identifying any inconsistencies, assumptions, and corrective actions
 - vii) Seakeeping input/output files including DLPs’ RAO and their extreme values
 - viii) Structural FE model and its analysis results
- and
- ix) SFA Procedure document
 - x) Site metocean data, motion analysis, RAO’s etc.
 - xi) Fatigue screening report to indicate details to be checked and those to be omitted, if screening analysis is performed
 - xii) S-N curve selection for analyzed details
 - xiii) SFA report detailing findings and identifying any inconsistencies, assumptions, and corrective actions

FIGURE 1
Schematic Spectral-based Fatigue Analysis Procedure
(For Each Location or Structural Detail)





SECTION 2 Establishing Fatigue Demand

1 Introduction

Sections 2 through 7 address the procedures used to estimate the stress transfer functions or stress RAOs at a structural location that is the object of the fatigue assessment.

3 Stress Transfer Function

With ocean waves considered the main source of fatigue demand, the fundamental task of a spectral fatigue analysis is the determination of the stress transfer function, $H_{\sigma}(\omega|\theta)$, which expresses the relationship between the stress at a particular structural location and the unit amplitude wave of wave frequency (ω) and wave heading (θ).

It is preferred that a structural analysis be carried out at each frequency, heading angle, “Basic Loading Condition” (see Subsection 2/5) and vessel speed, if applicable, employed in the spectral analysis, and that the resulting stresses are used to directly generate the stress transfer function.

Normally, the frequency range to be used is 0.2 to 1.80 radians/second, in increments not larger than 0.1 rad/s. However, depending on the characteristics of the response, it may be necessary to consider a different frequency range. The wave heading range is 0 to 360 degrees, in increments not larger than 30 degrees.

Note: The pertinent frequency range and increment applicable to other types of floating offshore installations may be different.

5 Basic Loading Conditions

The Basic Loading Conditions relate to the probable variations in loading that the hull structure of the FPSO will experience during its on-site service life and for the transit case(s). The main parameters defining a Basic Loading Condition are tank loading/ballast arrangements, hull draft and trim, and significant variations in topside equipment loads. These parameters have a direct influence on the “static” stress components of the hull’s response, but they also affect the wave-induced cyclic stress experienced at a structural location. There are two direct ways that this influence is felt. First, this influence is felt in the magnitudes and distributions of masses and restoring forces in the determination of global and local accelerations and rigid body displacements, which in turn affect the wave-induced load effects employed in the structural analysis. Secondly, the variation of draft affects the areas of the hull that will be subjected to direct external pressures, and the magnitude and distribution of these pressures.

7 Combined Fatigue from Multiple Basic Loading Conditions

Because of the variability in Basic Loading Conditions and its effects on the fatigue damage predictions, it is necessary to consider more than one basic case in the fatigue analysis. As a minimum for the analysis of post-installation on-site conditions, two cases are to be modeled and used in the Spectral-based Fatigue Analysis process. The two required cases are ones resulting from, and representing, the probable deepest and shallowest drafts, respectively, that the installation is expected to experience during its on-site service life.

Note: *Suggested Approach:* In some (so-called “Closed Form”) formulations to calculate fatigue demand, the fraction of the total time on-site for each Basic Loading Condition is used directly. In this case, potentially useful information about the separate fatigue damage from each basic loading condition is not obtained. Therefore, it is suggested that the fatigue damage from each basic loading condition be calculated separately. Then the “combined fatigue life” is calculated as a weighted average of the reciprocals of the lives resulting from considering each case separately. For example, if two basic loading conditions are employed, and the calculated fatigue life for a structural location due to the respective basic loading conditions are denoted L_1 and L_2 , and it is assumed that each case is experienced for one-half of the FPSO’s on-site service life, then the combined fatigue life, L_C is:

$$L_C = 1/[0.5(1/L_1) + 0.5(1/L_2)]$$

As a further example, if there were three basic loading conditions L_1 , L_2 , L_3 with exposure time factors of 40, 40 and 20 percent, respectively; then the combined fatigue life, L_C is:

$$L_C = 1/[0.4(1/L_1) + 0.4(1/L_2) + 0.2(1/L_3)]$$

9 Transit Cases

The fatigue demand arising from anticipated FPSO transit cases (usually only the FPSO voyage to the installation site) is to be determined.

During assessment of the fatigue damage accumulated during transit cases, the effects of vessel speed are to be included in the evaluation of stress RAOs and the number of stress cycles.

Note: As in the previous Note, it is suggested that the fatigue demand produced by the transit case(s) be calculated separately.

The extent to which fatigue analysis is to be performed for the transit cases associated with an FPSO with a classification notation **Disconnectable** (see 1-1-2/5.1 of the *FPI Rules*) will be specially considered.