PETROBRAS	TECHNICAL SPECIFICATION	Nº I-ET-3010.00-1350-960-PPC-001	
	CLIENT: UO-BS		SHEET: 1 de 21
	PROJECT: GREEN WATER ON SANTOS BASIN FPSOs		PT.128.01.11658
	AREA:		
DP&T	TITLE: GUIDELINE FOR FPSO GREEN WATER ANALYSIS		NP-1
			CENPES

REVISION INDEX

REV.	DESCRIPTION AND/OR AFFECTED SHEETS
0	ORIGINAL

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
DATE	05/07/2017								
PROJECT	PDDP/TEO								
EXECUTION	DANIELFC								
VERIFICATION	PDDP/TEO								
APPROVAL	CMAC								

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FORM OWNED TO PETROBRAS N-381-REV.L.

SUMMARY

1. INTRODUCTION

The water on deck effect, traditionally called by the naval architecture community as green water, is characterized by the presence of significant amount of sea water on the deck of an offshore structure or a ship. The denomination comes to differentiate the phenomenon from water spray occurrence (white water), which merely implies a requirement of waterproof facilities. Green water may represent considerable additional loads for offshore structures design and a risk for the crew safety. The occurrence of such phenomena is a relevant issue for ship or ship type platforms, because of their generally lower freeboard when compared to semisubmersibles or jackups.

The effect of water shipping is highly complex and the present rules and guidelines have simplified orientations, e.g.: ABS Guide for Building and Classing Floating Production Installations, DNV-GL, Rules for Classification and BV Rules for the Classification of Naval Ships. Most of them recommend the simplified analysis when scale model tests and numerical simulations are not available, what is still considered the most reliable tool to investigation the green water occurrence. Owing to historical concerns regarding navigation and turret moored FPSOs (Floating Production Storage and Offloading), the research and rules dedicated to green water is highly concentrated in waves reaching the vessel in the bow or near-bow area.

The present document aims to establish a guideline to green water analysis for ship type offshore structures, including specific orientations in cases either near the edge or out of the scope of present rules and guidelines, as well as to define the requirements for the results presentation for such analysis.

For FPSOs with the so called replicants hull type operating in Santos Basin - P66 hull with metocean conditions according to I-ET-3A26.00-1000-941-PPC-001 (revision D) the green water loads shall consider dedicated procedure according to I-PR-3010.90-1350-960-PPC-001 (revision D).

The green water analysis, as described in this document is a consequence analysis to be used as additional information for the Project of the platforms structures near the main deck. The design of such structures shall also meet the criteria described in DR-ENGP-II-P1-5.1-R.3 (General Criteria for Production Unit Arrangement) and DR-ENGP-II-P2-1.1-R.3 (Design Requirements for Production Unit Structure).

2. OBJECTIVES

The present technical specification has the following objectives:

- Define scope, methodology and criteria for green water analysis during the basic engineering design, FEED (Front End Engineering Design), detailed engineering design and operation of ship type offshore units;
- Support the analysis planning, development and follow-up by the involved institutions until its final approval;
- Define standardized content and minimum requirements for the analysis results report presentation.

3. SCOPE OF ANALYSIS

The green water analysis shall present the risk of shipping water, together with the expected water on deck height and water impact loads promoted by these events.

To accomplish the aforementioned tasks, the analysis shall evaluate the vessel wave interaction and estimate the minimum local water column height in comparison with the main deck vertical level using simplified numerical models. In cases where significant amount of water on deck are expected, it may be required detailed model tests, which could be complemented by CFD simulations. Based on the model tests and/or simulation results, the analysis shall be able to provide green water loads due to water impact on deck structures.

Note: Offshore structures with large operational freeboard (e.g.: semi-submersibles) may neglect green water effects based on the comparison of their freeboard with the relative motion under expected extreme wave heights.

The results to be presented may be categorized as follows:

STAGE 1: Relative Wave Elevation Estimation

Estimate of water on deck levels based on linear hydrodynamic models combining the local metocean data (wave conditions – Hs, Tp and incident direction) with the expected vessel loading conditions (draft and inertial characteristics) and heading. Depending on the results at this stage, it may be required further evaluations as described in Stages 2-4.

STAGE 2: Estimated Green Water Risk

Estimate the green water events associated probability of occurrence, in order to verify which one of the green water identified scenarios are tolerable in terms of risk analysis or if further investigation may be required through methodology described in Stage 3-4.

STAGE 3: Detailed Water on Deck Analysis

The details of water on deck may be required to be addressed by using model tests to be performed for the most critical conditions and vessel regions of the deck identified on Stage 1. The model tests shall provide:

- Water level measurements on critical regions surrounding the vessel hull;
- Water level measurements on critical regions on the deck;
- Visual observation of green water events, when applicable;

At this stage, the green water loads may be either directly measured or obtained by empirical correlations based on model tests results.

STAGE 4: Detailed Green Water Loads

Especially critical structures or areas with significant congestion may have their green water loads refined by using CFD models, what allows more complex representation of geometric structures and represents flow over the deck without the scale effects issues from model tests. The simulation results shall provide:

- Detailed pressure surrounding deck structures, with the possibility to provide pressure distribution along surfaces and dynamic loads, if required;
- Local green water loads including interference between nearby obstacles (shadow effects).

4. ABBREVIATIONS AND DEFINITIONS

Regarding the present technical specification, the following abbreviations and definitions shall be considered:

Abbreviations

CFD – Computational Fluid Dynamics;

FEED – Front End Engineering Design;

ITTC – International Towing Tank Conference.

Definitions

Green Water – Ingress of sea water on the deck, as a consequence of the wave-vessel interaction, when water level surpasses the vessel freeboard. In the present document, as well as in the scientific literature, this effect is also called water on deck occurrence or shipping water.

Loading Condition – Combination of vessel tanks filling levels that leads to specific draft and inertial characteristics.

Freeboard – Vertical distance from the main deck level until the mean sea waterline.

Turret Mooring System – Single point mooring system that allows the vessel to weathervane according to resultant of environmental loads.

Spread Mooring System – Multiple point mooring system that allows only discrete heading variation. For practical purposes, vessels moored with this system are considered fixed heading vessels.

Irregular Sea state - In oceanography, a irregular sea state is the general condition of the free surface on a large area body of water - with respect to wind waves and swell - at a certain location and moment. A sea state is characterized by statistics, being generally represented by the combination of multiple wave heights and periods.

Significant wave height (H_s) - The wave field is a combination of waves of different height, length and directions and the significant wave height is a useful way to describe the sea state. It has been defined to approximate the wave heights visually estimated by experienced mariners. The significant wave height (trough to crest) corresponds also the average of one third of the highest waves in a measured wave record.

Wave peak period (T_p) - The peak wave period is the wave period with the highest energy.

Scenario – Combination of vessel loading condition, heading and environmental effects selected for the investigation of green water risk and consequences.

Parties – Designer, Analysis Executor and Petrobras groups involved in the analysis execution and/or follow-up.

Designer – Technical team responsible for engineering project, which can be a conceptual Project, basic Project, FEED or executive Project. This team may be a Petrobras internal group or an external company.

Executor – Technical team responsible for the green water analysis execution. This team may also be a Petrobras internal group or an external company.

5. REFERENCES

The following documents shall be used in the analysis. The documents shall be used in their latest version as defined by PETROBRAS. The revision of each document shall be clearly mentioned in the analysis report.

a) 3D model of hull geometry;
b) Vessel loading conditions and heading;
c) Environmental conditions (Metocean);
d) General arrangement drawings;

Additional documents may be required for identification of relevant aspects such as:

– Hull detailed drawings including main deck inclination, stools, appendices such as riser balconies, fairleads, etc.

– 3D drawing of relevant structures;

Rules and Guidelines:

- ABS Guide for Building and Classing Floating Production Installations, Part 5A, Chapter 3, Section 2, Item 13.7 – Green Water on Deck, 2014.
- DNV-GL, Rules for Classification - Ships , Part 3 - Hull, Chapter 4 - Loads, Section 5, Item 2.2 - Green sea loads, 2016.
- BV Rules for the Classification of Naval Ships, Part B - Hull and Stability, Chapter 3 - Stability, Section 4 - Sea Keeping, 2011.
- ITTC, Experiments on Rarely Occurring Events, International Towing Tank Conference (ITTC) Recommended Procedures and Guidelines, ITTC 7.5-02-07-02.3, Revision 03, 2011.
- ITTC, Practical Guidelines for Ship CFD Applications, International Towing Tank Conference Recommended Procedures and Guidelines, ITTC 7.5-03-03-02, 2011.

Scientific References:

- HSE, Analysis of Green water Susceptibility of FPSO/FSUs on the UKCS, Prepared by BOMEL for Health and Safety Executive (HSE), Offshore Technology Report, 2001/005, 2001.
- Silva, D.F.C; Coutinho, A.L.G.A., Esperança, P.T.T., Green Water Loads on FPSOs Exposed to Beam and Quartering Seas, Part I: Experimental Tests, Ocean Engineering, Vol. 140, pp. 418-433, 2017.
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- Buchner, B., Green Water on Ship Type Offshore Structures. Ph.D. Thesis, Delft University, Delft, Netherlands, 2002.
- Greco, M., A Two-dimensional Study of Green water Loading, Ph.D. Thesis, Norwegian University of Science and Technology, Department of Marine Hydrodynamics, 2001.
- Xiao, L., Tao, L., Yang, J., Li, X., An Experimental Investigation on Wave Runup Along Broadside of a Single point moored FPSO Exposed to Oblique Waves, Ocean Engineering 88, pp. 81-90, 2014.
- Schiller, R.V., Pakozdi, C., Yuba, D.G.T., Stansberg, C.-T., Silva, D.F.C., Green water on FPSO Predicted by a Practical Engineering Method and Validated Against Model test data for Irregular Waves, Proceedings of the ASME 33rd International Conference on Ocean, Offshore and Arctic Engineering, OMAE2014-23084, San Francisco, USA, 2014.
- Silva, D.F.C., Rossi, R.R., Green Water Loads Determination for FPSO Exposed to Beam Sea Conditions, Proceedings of the ASME 33rd International Conference on Ocean, Offshore and Arctic Engineering, OMAE2014-24947, San Francisco, USA, 2014.

6. ANALYSIS MAIN RELEVANT ASPECTS

The green water analysis shall include the following minimum aspects:

- Hull geometry and loading condition;
- Local meteoceanographic data;
- Topside characteristics, especially for the main deck region.

7. SOFTWARE REQUIREMENTS

The numerical analysis shall be performed by well stablished codes in the industry. Examples of linear hydrodynamic models codes include WAMIT, AQWA and HYDROSTAR. For CFD analysis, it is worth to mention the software FLUENT, CFX, STAR-CCM+. Dedicated green water analysis tools developed according to JIP (Joint Industry Projects) such as Kinema and GreenLab may be adopted respecting their application scope. Other software may be adopted upon PETROBRAS authorization.

8. MODEL TEST REQUIREMENTS

When critical green water scenarios (as described in item 11) are identified, the vessel shall be tested on an ocean basin facility, where a reduced scale model test shall be performed. As a general rule, a maximum reduced scale of 1:100 is recommended. The ocean basin facility shall be approved Petrobras. The model test shall follow general requirements from ITTC guidelines.

9. METEOCEANOGRAPHIC CONDITIONS

The meteoceanographic conditions (essentially wave, wind and current) shall correspond to the ones expected for the offshore unit definitive location.

The analysis report shall present all considerations with respect to the environmental conditions considered. Additionally, all simplifications and neglected scenarios shall be presented and justified. At least a minimum of 8 directions shall be considered. The relative orientation between the incoming waves and the vessel shall be defined based on the vessel mooring system. For turret moored vessels, the typical headings shall be defined based on the environmental loads and submitted for Petrobras approval. For spread moored vessels the analysis shall be conducted for one fixed heading according to vessel design.

10. VESSEL LOADING CONDITIONS

The freeboard is a crucial aspect for green water analysis. The vessel draft and inertial characteristics shall be compatible with the data presented in motion analysis report, when applicable. As the green water scenarios tend to be more critical with lower freeboards, the maximum draft (minimum freeboard) shall be considered. Additionally and in order to avoid over conservative analysis, at least one intermediate draft shall be considered, usually called as most probable draft. The loading conditions shall be presented prior any further analysis and validated by PETROBRAS.

11. METHODOLOGY

The adopted methodology shall meet current international guidelines and standards with the additional requirements described herein.

The scenarios to be evaluated depend on partial results of each analysis stage. The flowchart presented in Figure 1 illustrates the different stages that may be required depending on the results obtained. The following sections will describe general guidelines for each one of the analysis stages.

The green water analysis shall consider the technical specification requirements herein described. Any modification on the following described tasks shall be presented for prior PETROBRAS evaluation.

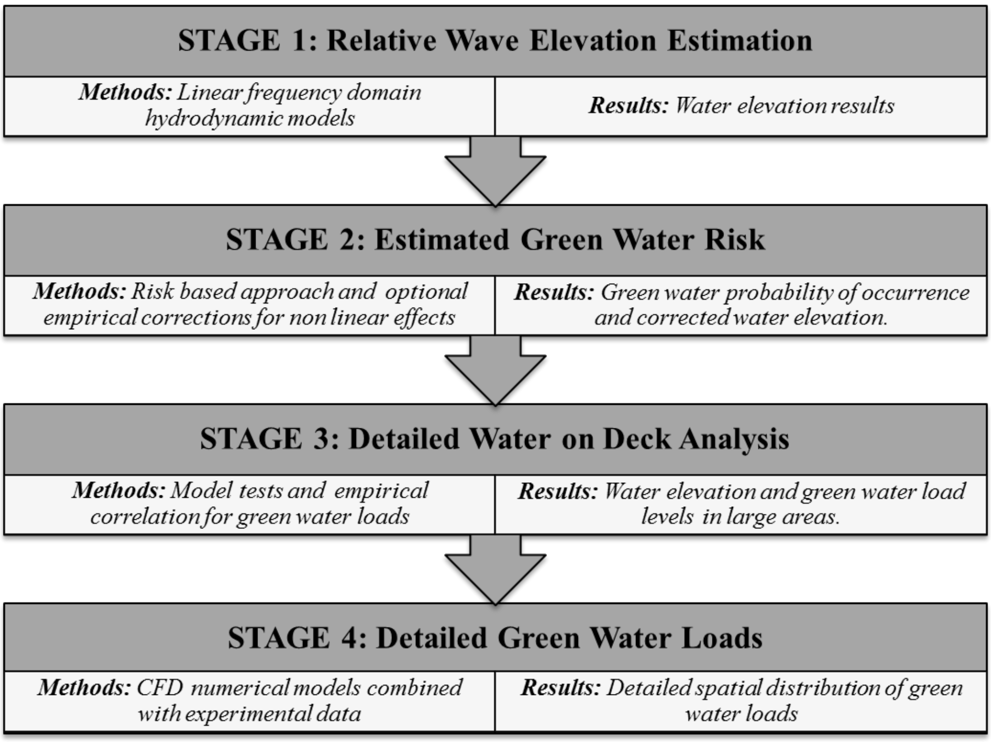

Figure 1 – Stages for green water analysis.

11.1. Stage 1: Simplified Water on Deck Analysis

In order to evaluate the green water occurrence, the first step shall simulate the wave vessel interaction by using linear hydrodynamic analysis, which is already the traditional approach for motion analysis. Linear hydrodynamics methods are usually based on the assumption that wave height is very small when compared to the wave length. The relative motion between the floater and the wave shall be determined for relevant points and sea states in the required loading conditions. This stage aims to estimate the freeboard exceedance for several combinations of wave parameters (significant wave height – H_s , wave peak period - T_p, incidence directions) and vessel loading condition.

11.1.1. Scenarios Selection

Based on the current technical specification for meteoceanographic conditions, operational (1 year return period) and extreme (100 years return period), for each incidence directions, significant wave height for each wave peak period shall be considered. The analysis shall be conducted for all headings and loading conditions defined in items 9 and 10, respectively.

11.1.2. Input Data

The vessel hull geometry shall correspond to be the latest project version. At this stage, the analysis shall include wave peak periods starting from 5s until the highest peak period presented in the wave meteoceanographic technical specification with increments of 0.5s. Annex A presents an example of H_s x T_p diagram for Southwest direction. The draft and vessel inertial properties shall follow the loading conditions as defined in item 10. In order to evaluate critical water elevation, local freeboard shall be considered including local obstacles (e.g.: forecastle, bulwark, etc.).

11.1.3. Numerical Modelling

The recommended simulation tools at this stage are linear frequency domain hydrodynamic models. The simulation shall provide local relative wave elevation, comparing the main deck vertical position with local wave elevation. Simulations with different panel mesh resolutions are recommended in order to ensure convergence of the body motions RAOs and, especially, the wave elevation amplifications at points near body surface, which is normally difficult to be reached. The use of software packages based on higher order formulation tends to help.

11.1.4. Results

The results shall include a minimum of 12 points surrounding the main deck. One point shall be positioned at the bow, one at the stern and 5 points along each vessel side. For all these points, the relative water elevation results shall be presented. An example of points distribution and results summary is presented in Annex B. The results at each point may be presented in terms of either absolute maxima or most probable maxima, depending on the post-processing strategy adopted, when a freeboard exceedance value higher than **1m** is obtained in any point, the analysis shall move on to Stage 2.

11.2. Stage 2: Estimated Green Water Risk

In order to verify the risk of green water occurrence and promote some refinement on the freeboard exceedance levels estimated in Stage 1, this Stage includes the evaluation of green water probability and additional corrections to consider non-linear effects in wave elevation calculation.

11.2.1. Green Water Probability

Based on the environmental condition return periods and an estimated probability of vessel loading conditions, the probability of the green water events identified in Stage 1 shall be calculated. When no studies with respect to the specific vessel and location under analysis are available, a default probability curve for vessel filling ratio shall be adopted (see Annex C). The estimated probabilities will support risk based analysis for the unit design to be done according to Petrobras Safety Philosophy (DR-ENGP-I-1.3-R.3).

11.2.2. Non-Linear Corrections (Optional)

Based on the executor expertise or using specialized software, the freeboard exceedance estimated in Stage 1 may be re-evaluated based on previous model tests or empirical factors. The formulation adopted shall have evidences of validation with cases that may be considered equivalent of the scenarios selected.

11.2.3. Results

The results at each point, including non-linear corrections (if available), may be presented in terms of either absolute maxima or most probable maxima, depending on the post-processing strategy adopted. At this Stage, the estimated probability of occurrence shall be presented as well. According to HSE (see reference in item 5), the vessel green water susceptibility may be classified as follows:

Table 1 – Green water preliminary risk classification based on simulation results.

Green Water Risk	Freeboard Exceedance
LOW	Under 3m
MEDIUM	Between 3 and 6m
HIGH	Above 6m

As a general rule, when medium or high green water risk is identified and the probability of occurrence is not tolerable (higher than a suggested limit **frequency of 10^{-3} per year**), the analysis shall proceed to Stage 3. However, the final decision shall be taken after the presentation of the Stage 2 results to Petrobras on the follow-up meeting F2 (see item 12.5).

11.3. Stage 3: Detailed Water on Deck Analysis

When Stage 2 indicates a considerable green water risk (Medium or High Risk in Table 1 combined with non-tolerable probability of occurrence), a model test is required to further investigation of the green water events. Considering strong non-linear effects expected during extreme green water events, the model test is still considered the most accurate tool in such analysis.

11.3.1. Scenarios Selection

The scenarios for model tests shall include the most critical wave peak periods (scenarios with the highest wave elevation) identified by linear hydrodynamic analysis. The significant wave height shall comprehend at least the 1-year and 100-year conditions for each wave incidence selected. The loading conditions shall include at least two drafts, namely the maximum and most probable draft. The wave relative orientation shall comprehend at least the three, regarding the highest relative elevations identified by the numerical model from Stages 1 and 2.

11.3.2. Input Data

The vessel geometry and loading conditions shall be compatible with the data used for Stages 1and 2 (item 11.1.2). Additionally, this stage requires a simplified representation of the main deck structures in order to investigate water on deck flow. The executor shall propose a deck geometric representation to be validated by PETROBRAS before the model tests.

11.3.3. Experimental Modelling

The model tests shall respect ITTC general guidelines. The hull model shall be represented with all appendence geometry (bilge keels, riser balcony, etc) and inertial characteristics. The irregular random sea conditions shall be represented by 3h storms with at least 3 seeds. The wave elevation shall comprehend wave probes as close as possible from side hull, as well as probes located on deck, at a minimum distance of 5m (full scale) from deck edge, so that the effective water on deck may be measured. The instrumentation shall include a minimum of 8 points surrounding the main deck. One point shall be positioned at the bow, one at the stern and 3 points along the vessel sides. If direct loads monitoring is included, an acquisition rate of 2kHz (model scale) shall be adopted. The model tests planning shall be presented to PETROBRAS before execution. The instrumentation for green water analysis may be included in seakeeping model tests campaigns, if the execution schedules are compatible.

11.3.4. Results

The results of water elevation and loads (when applicable), shall be presented in terms of absolute maxima and probability of exceedance (or events distribution). The number of events (when the water level surpasses the main deck level) registered during the experiments shall also be presented. A threshold for representative green water events must be chosen based on sensor and experiments characteristics.

Considering the most critical structures position on deck and green water events elevations, the impact loads may be estimated based in empirical correlations inspired in the analogy with dambreak theory, according to the procedure presented in Annex D.

11.4. Stage 4: Detailed Green Water Loads

The executor shall proceed to detailed green water loads evaluation when the previous calculated loads leads to significant additional hull and topside project redesign or protection installation on the unit main deck. Likewise, when significant shadow effects are expected, the detailed load analysis may be required to quantify the loads reduction or amplification in such cases. Detailed green water loads may also be required by Petrobras depending on the previous stages results.

11.4.1. CFD Modelling

CFD Simulations shall be performed according to ITTC Practical Guidelines for Ship CFD Applications (see reference in item 5), with presentation of grid and time step refinement studies, together with full description of the numerical models adopted. Usually FVM (Finite Volume Methods) combined with VoF (Volume Fraction) for free surface description is required, but other approaches are acceptable as long as validation studies are available in the scientific literature.

11.4.2. Local CFD Simulation

At this stage, the executor may run local CFD simulations representing the vessel geometry partially, with simple geometric forms to represent structures and boundary conditions at the deck edge based on experiments. For beam sea conditions, 2D CFD simulations may be adopted for load estimation. An example of such approach is described in Silva & Rossi (2014), see item 5. For this local simulation approach, the computational domain size and deck region geometric representation shall be either representative or more conservative than the global flow behavior expected.

11.4.3. CFD simulation of wave-vessel interaction

When considering detailed loads on near deck edge structures or even structures assembled on hull appendages, it may be required a CFD simulation including the wave vessel interaction. This simulation is typically very computationally time consuming and therefore shall be performed for small duration wave vessel interaction events (10-60s).

11.4.4. Results

At this stage it is expected to have maximum loads on detailed modelled structures. The results shall include also the time evolution of load distribution in terms of pressure acting in the modelled structures. By default all variables shall be considered in the prototype scale.

12. REQUIREMENTS FOR FOLLOW-UP MEETINGS

The follow-up meeting shall be performed as follows.

12.1. General Considerations

The green water analysis follow-up shall be done by the Designer with Petrobras participation.

Petrobras shall be communicated before the follow-up meetings and may participate through videoconference. The minutes of meeting shall be elaborated by the designer and their final version shall be attached as part of the final report.

Every validation decisions (e.g.: premises, environmental data, geometry definition) shall be presented in the final report as annexes. The validations shall be signed by each party involved.

12.2. Planning Meeting

Meeting with the objective of project summary, analysis scope clarifications, deliver of technical documentation, schedule adjustments, with the minimum agenda:

- Safety Moment – (designer);
- Project presentation to the executor (designer);
- Clarification of analysis scope, deliverables and minimum requirements (Designer and Petrobras);
- Deliver of technical documentation as described in item 5 (designer);
- Definition of the teams for analysis execution and follow-up, including the respectively attributions;
- Presentation of focal points for each party that will be always invited for the follow-up meetings;
- Schedule presentation for analysis execution, that shall be compatible with the project schedule (Executor and Designer);
- Definitions of venue for the follow-up meetings (Executor and Designer);

Planning meeting participants: Focal point of each party, executor technical team involved and discipline leader from designer that will monitor the analysis execution.

Note: The schedule shall include 20 working days for comments from Petrobras in the partial and final reports.

12.3. Documentation Analysis Meeting

Meeting with objective of analysis and validation of the required documentation to the green water analysis e elaboration of a list of task that shall be completed prior the analysis begin if applicable. The main objective is to avoid wrong premises or input data as a consequence of incomplete technical documentation.

The minutes of meeting shall include the pendency in documentation and deadlines to be attended by the designer, when applicable.

Note: the designer, as responsible for change management, shall inform to the remaining parties any project modification that impacts the green water analysis. The executor shall evaluate the impact of the informed modifications in terms of the analysis development and schedule. This information shall be formally sent to the Designer and informed to Petrobras.

Documentation analysis meeting participants: Professionals from executor involved and discipline leaders from designer responsible for analysis follow-up. Petrobras shall be invited for this meeting but the participation is optional.

12.4. Premises and Methodology Meeting

Meeting with objective of premises and methodology presentation and validation. The analysis executor shall presents clarify any relevant aspects with respect to the methodology proposed in this document, as well as present eventual exceptions and propose simplifications, when applicable. The presentation shall include:

- Vessel heading and relative wave directions;
- Eliminated scenarios: Justify the elimination of specific scenarios;
- Methodology for green water probability estimative.

The material shall be validated by the Designer and Petrobras. The premises and eventual simplifications shall be registered in the analysis report.

Note: This meeting may be done together with the documentation analysis meeting, when previous contact between the executor and designer indicates that the documentation is close to fulfill the requirements for the analysis development.

Premises and Methodology Meeting Participants: Professionals from executor involved and discipline leaders from designer responsible for analysis follow-up and Petrobras representative.

12.5. Follow-up Meetings

Meetings with the objective of designer follow-up in the analysis progress, with participation of Petrobras, where the methodology proposed in this document shall be followed (item 11).

The designer, in accordance with the executor shall present the follow-up meetings schedule. Table 2 indicates the follow-up meetings that shall be scheduled.

Table 1 – Follow-up Meetings

Meeting	Minimum Agenda	Ref. Item
F1	**Relative Wave Elevation and Green Water Risk** Water on deck elevation results. Probability of Occurrence (when applicable). Decision if model tests are required.	11.1 & 11.2
F2	**Detailed water on deck analysis - Model tests planning** Depending on previous results, presentation of model tests specification.	11.3.1 & 11.3.2
F3	**Detailed water on deck analysis - Model tests results** Presentation of model tests results and decision with respect to additional CFD analysis and scope.	11.3.3 & 11.3.4
F4	**Detailed green water loads** Presentation of CFD analysis results for critical structures.	11.4

Table 2 is based on Petrobras experience and assuming all four stages described in item 11 will be necessary, but the follow-up meeting schedule may be changed in accordance with all parties involved, as long as all methodology items are analyzed and validated.

Follow-up meeting participants: Professionals from executor involved and discipline leaders from designer responsible for analysis follow-up and Petrobras representative.

12.6. Final Report Presentation Meeting – Preliminary Version

Meeting with the objective of presentation of final report before its emission to Petrobras. The final report is a designer's responsibility. The final report shall include the executor's report complemented by the designer's project recommendations based on the obtained results. The document codification shall be in accordance with Petrobras Standard N-1710 and the format in accordance with N-381.

The presentation shall include a detailed analysis of implementing the recommendations into the referred project.

Final report presentation meeting Participants: Professionals from executor involved and discipline leaders from designer responsible for analysis follow-up and Petrobras representative.

13. ANALYSIS REPORT

The final report shall be written in English. All premises and simplification hypothesis adopted shall be presented in the report. Additionally the minutes of meetings shall be presented as annexes, especially the ones which refer to methodology validation. The presented graphs shall include axes labels, subtitles and indication of wave direction, when applicable. All data shall be present using the International Systems of Units. The graphs that support conclusions and recommendations shall be presented in the final report.

13.1. Preliminar Report

At least one preliminar report shall be presented to Petrobras by the Executor before the final report emission.

The preliminar report shall contain the following minimum scope:

- Selected and neglected scenarios (item 11.1.1);
- 3D geometric model (item 11.1.2);
- Preliminary results of Stage 1 analysis (item 11.1.4);
- Preliminary results of Stage 2 analysis (item 11.2.3);
- Indication of necessity to perform Stages 3 and 4 analysis (items 11.3 and 11.4).

13.2. Final Report

The final report shall contain all requirements of item 13.1, attend the comments to this document and additionally present the following data:

- Minutes of meetings (item 12);
- Verification List (if applicable) (item 16);
- Expected water on deck elevation based on linear hydrodynamic models (ANNEX B);
- Estimated green water probability, when applicable;
- Expected water on deck elevation based model tests, when applicable;
- Results of CFD simulation of water on deck loads, when applicable;

Additional revisions shall be planned in cases when Project changes modify the analyzed scenarios.

14. SCHEDULE

According to the Project complexity, analysis scope and overall contract schedule, the Designer and Executor shall define the required schedule. Minimally, the deadlines for partial and final report shall be presented during the planning meeting (item 12.2).

15. PROFESSIONAL QUALIFICATION REQUIREMENTS

Considering that hydrodynamics, model testing and CFD analysis are rather complex subjects and the green water analysis is part of the safety requirements of the offshore installation, the analysis shall be conducted by adequate technical staff, preferable part of Petrobras' service suppliers list.

16. VERIFICATION LIST APPLICATION

The Designer shall present a verification list as an evidence of the following-up on the executor activities. The verification list shall contain the requirements on the standards and guidelines cited in this document. The verification of each requisite shall have the identification and signature of the responsible for the verification.

17. INFORMATION SECURITY

The Designer and Executor shall have appropriate data security systems in order to guarantee integrity, reliability, traceability and confidentiality of Petrobras' information utilized in the analysis. All information shall be protected for at least five years.

18. ANNEXES

ANNEX A – EXAMPLE OF SIGNIFICANT WAVE HEIGHT DATA

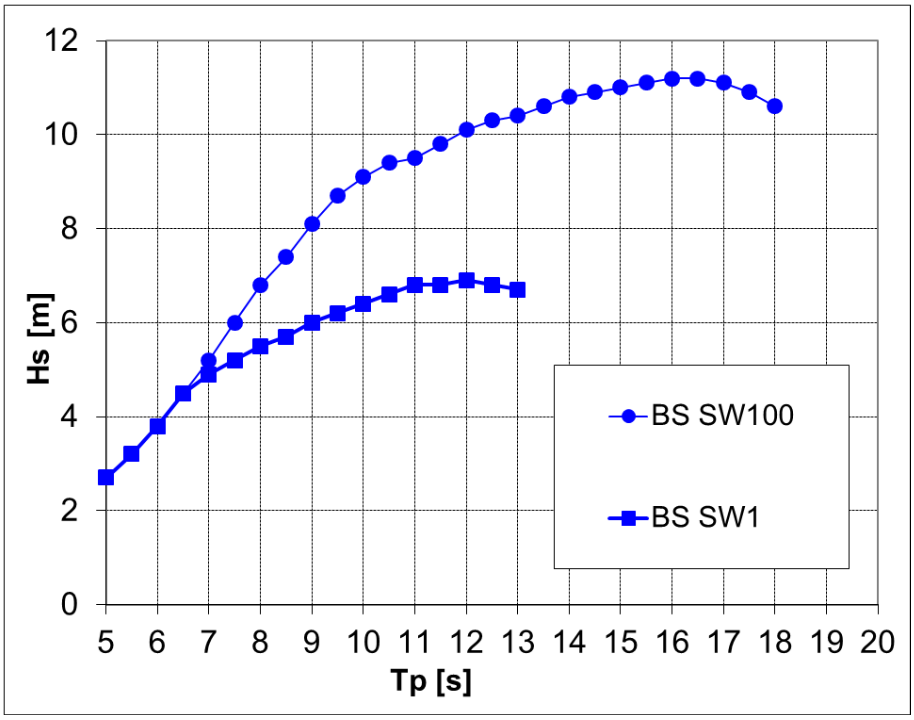

Figure A.1 – Tp x Hs for Southwest waves with return periods of 1year (SW1) and 100 years (SW100) based on Santos Basin Meteocenographic Data (I-ET-3A26.00-1000-941-PPC-001 – rev. D).

ANNEX B – EXAMPLE OF RESULTS FROM ELEVATION SURROUNDING THE HULL

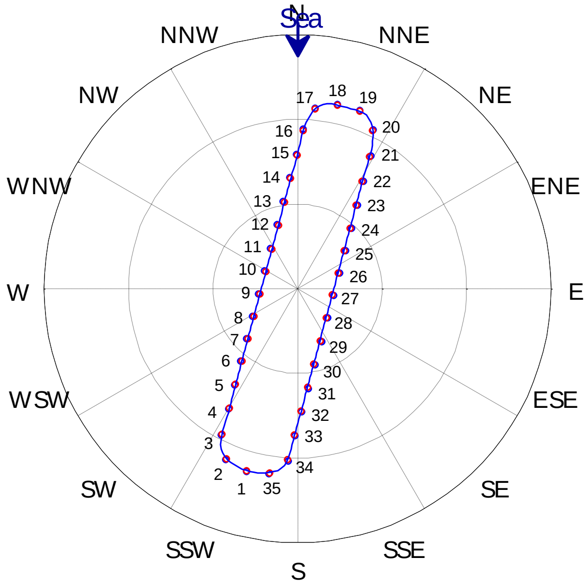

Figure B.1 – Example of vessel positioned in a fixed heading and points distribution for elevation evaluation in numerical simulations.

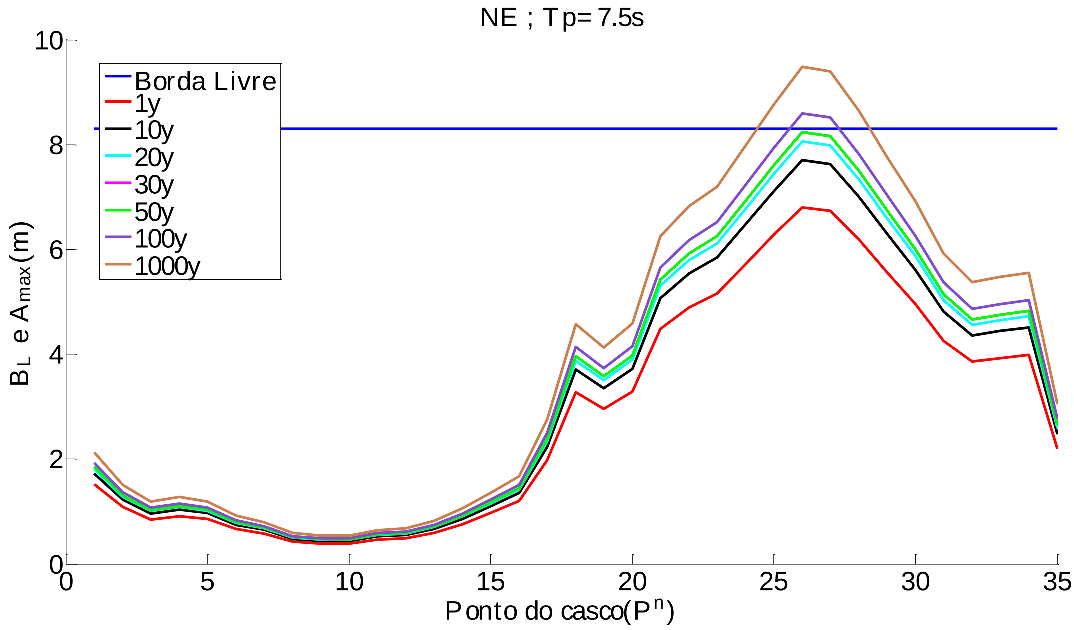

Figure B.2 – Example results presentation for NE waves with peak period 7.5s and significant wave height as a function of the return period. The points near the hull are presented in Figure B.1. The horizontal blue line represents the vessel freeboard.

ANNEX C – TYPICAL PROBABILITY OF FPSO LOADING CONDITION

The probability of a specific FPSO loading conditions depends on several factors, as for example logistic, environmental and operational aspects. Frequently it is not possible to evaluate all these aspects during early design phases and therefore, to compose the green water probability evaluation, a typical probability density function (PDF) based on Petrobras field data can be approximated by a Weibull distribution as follows:

$$PDF = 1 - e^{-\left(\frac{x-\mu}{\lambda}\right)^k} \quad \text{(Equation C.1)}$$

The Figure C.1 presents the comparison between the approximated distribution and the Field Data. According to the this adjustment, the Weibull parameters are (μ=0, λ=0.485 and k=2.624). If there is no available data for the FPSO under analysis, this data shall be used by evaluating the percentage loading which corresponds to the drafts under consideration.

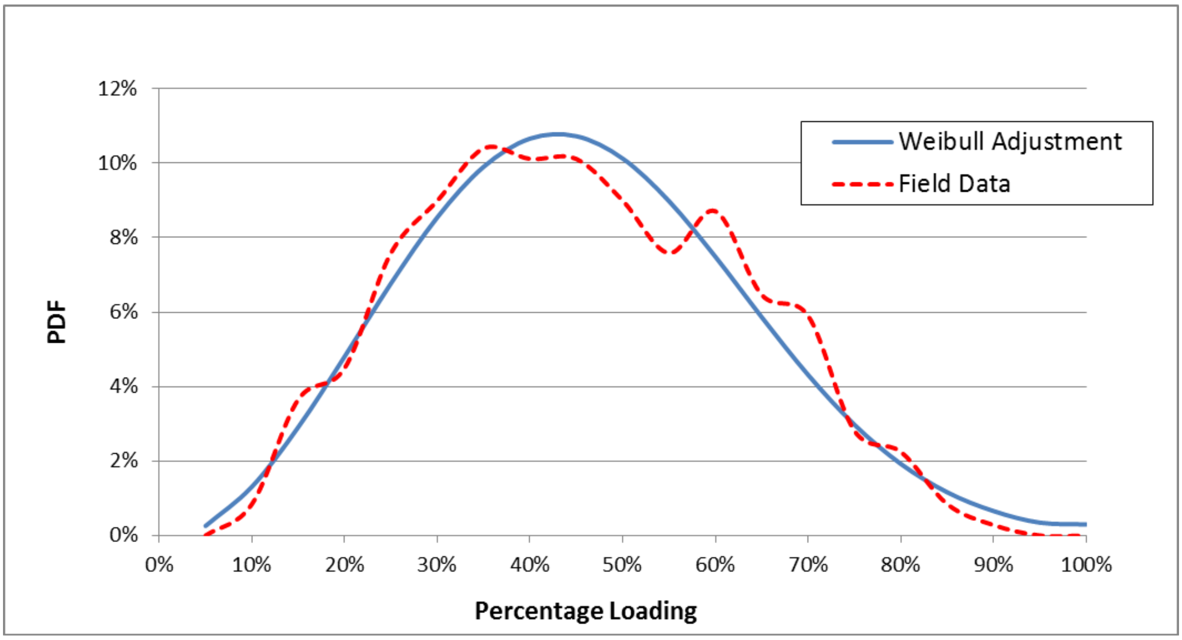

Figure C.1 – Approximated and Field Data for FPSO percentage loading.

ANNEX D – GREEN WATER LOADS BASED ON WATER ELEVATION

The green water loads may be estimated based on the analogy with a dambreak event, with corrections for the object elevation, as described in reference Silva & Rossi (2014) – see reference list in item 5. Considering the ingress of water with maximum elevation above the main deck level at the deck edge H_{max}, the loads are calculated by the following expression:

$$P_{gw} = \frac{2Cg\rho}{h}(H-\delta)\left(\sqrt{H_{dam}}-\sqrt{H}\right)^2 \qquad \text{(Equation D.1)}$$

where:

- ρ is the fluid density;
- g is the acceleration of gravity;
- H_{dam} = 9/4 H_{max} is the dam elevation;
- H_{max} is the maximum elevation at the deck edge;
- C is the drag coefficient;
- δ is the clearance between the obstacle bottom part and the main deck level.

The height H is defined as a function of H_{eff} (the local effective water elevation at object position – see Figure D.1), with three possible configurations: A – The object is above the water on deck flow and therefore will not experience any load from it; B – The object is partially exposed to the water flow and because of it will suffer the impact partially or C – the object is totally immersed in the fluid flow and will be submerged during the green water event. These situations are represented on Figure 14. If no detailed information for the water elevation on the deck is available (e.g.: model tests results), the H_{eff} shall be considered equal to $H_{max.}$

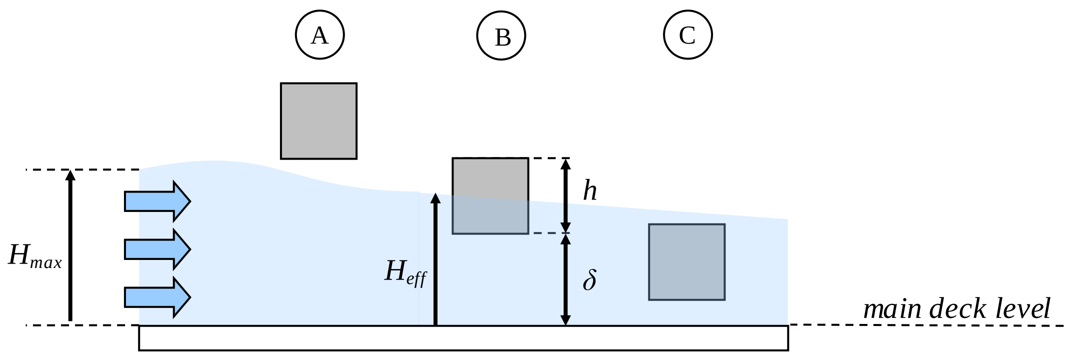

Figure D.1 – Vertical relative position of an object during a green water event.

The procedure to determinate the design load can be described as follows: First the water elevation is compared with the object elevation, in order to verify if this object will be exposed to green water loads. After that, one should verify if the water elevation for the maximum load is reached (H^* - Eq. D.2) or not. The flowchart illustrated in Figure D.2 summarizes the procedure and identify the situations A, B or C, according to Figure D.1. After choosing the proper elevation (H), the load is calculated by Eq. D.1.

$$H^* = \left(\frac{\sqrt{H_{dam}}+\sqrt{H_{dam}+8\delta}}{4}\right)^2 \qquad \text{(Equation D.2)}$$

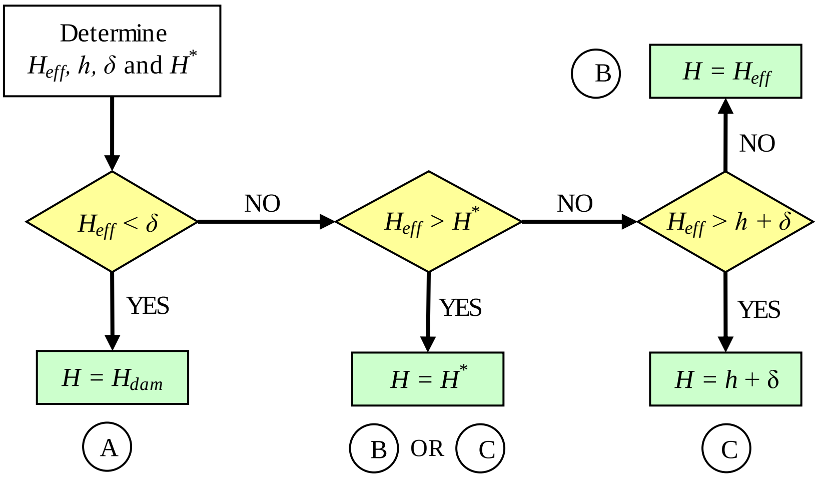

Figure D.2 – Flowchart for green water loads calculation.

If no specific information with respect to drag coefficients are available for the structures under consideration, it shall be adopted a drag coefficient of 2.0 for box shaped obstacles and 1.2 for cylindrical shaped. If the scope is restricted for small obstacles near the deck edge under influence of quartering or beam waves green water, the approach presented in Silva et al. (2017) – see reference list in item 5 – may be considered.

ANNEX E – GROUP OF VERIFICATION

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