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DDP-SRGE	TITLE: DROPPED OBJECTS AND SWINGING LOADS STUDY		NP-1 / ESUP

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DATE	MAY/13/2020								
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SUMMARY

1. ABBREVIATIONS AND DEFINITIONS

For the purpose of this specification, the following abbreviations and definitions shall be considered:

Abbreviations:

FEM - Finite Element Method

FPU – Floating Production Unit

MSF - Main Safety Function

PHA - Preliminary Hazard Analysis

SIGEM - Integrated System of Project Management;

TS - Technical Specification

Definitions:

Load on pendular movement - Load that undergoes lateral oscillation or pendular movement during the transport activity;

Scenario - It is an event considered at the point of interest having the combination of: hazard, causes, effects and associated risk classification, considering Frequency and Severity;

Impact energy - Energy generated by the transformation of potential energy into kinetic energy for the case of dropped objects or the movement of the load reaching a given point of the Unit, in the case of loads in pendular movement;

Exceedance curve - Graphical representation of the impact energies with respect to the frequencies in which they occur and that allow to correspond with the defined tolerability criteria;

In-field Vessels - Vessels that periodically attend the Unit, with purpose to meet operational needs of the Unit, such as: shuttle tankers, supply vessels, tugboats, flotels, rigs, among others;

Study Consulting - Responsible for the execution of Dropped Objects Study. Study Consulting may be an outsourced company hired either by the Designer or by Petrobras, or it can be the Designer itself or an internal Petrobras workforce;

Main Safety Function (MSF) - Function that a safety item shall fulfill to enable and/or guarantee the effectiveness of the emergency response strategy, escape and abandonment of the Unit during an accidental event. Included in this definition are other elements that shall be kept intact and functional in an accidental condition. These main functions are defined in item 8.4 of Safety Engineering Guidelines and shall remain available for one (1) hour after the beginning of the incident.

Involved Parties - Are the designer, the Study executor and Petrobras involved in the preparation or monitoring of the dropped objects study;

Designer - company responsible for the engineering design : basic design or detailing project, which may be Petrobras itself or contracted company to carry out the project;

Terminal velocity - Maximum falling velocity reached after equilibrium between gravitational and drag forces carried by the fluid (in this case air or water). If there are no additional disturbances, this velocity remains constant once hit during the object's fall.

2. INTRODUCTION

The Dropped Object Study is a Consequence Study used to evaluate the effects caused by falls during mechanical handling at the Floating Production Unit (FPU). It is also used to evaluate the risks of loads in pendular movement and the possible impacts from these oscillations. The scenarios evaluated are those identified in the Preliminary Hazard Analysis (PHA), classified as not tolerable in any of the dimensions (people, environment, assets and image of the Company) or moderates with severity category IV or V in the dimensions of people and assets, on the Main Safety Functions (MSF) of a FPU.

Based on the results of this study, preventive or mitigating measures shall be adopted and the frequency of impairments of the MSF shall be evaluated according to the scenarios of dropped objects and their consequences in the dimensions (people, environment, assets and image of the Company).

The MSF are defined in the Petrobras Safety Engineering Guidelines DR-ENGP-M-I-1.3.

In the execution of the study, the requirements for analysis and management of operational risks of the National Agency of Petroleum, Natural Gas and Biofuels - ANP, Secretary of Labor of Ministry of Economy, Petrobras standard N-2782 - Techniques Applicable to the Analysis of Industrial Risks and Safety Engineering Guidelines.

This Technical Specification (TS) defines the criteria for the development of the dropped objects study and the preparation of its respective report.

3. OBJECTIVES

This Technical Specification has the following objectives:

- Define the scope, methodology and criteria for carrying out the Dropped Objects Study for following phases: the basic design, detailing design and assisted operation of the FPU, hereinafter referred as to Unit. This TS may optionally be used as a guide in the operation phase of the Unit at the time of review of the study.
- Guide the dynamics for the planning, development and monitoring of the study by the parties involved and their final approval;
- Define the standardization, content and minimum requirements for presentation of the study report.

4. SCOPE OF THE STUDY

The study shall evaluate the dropped objects and impacts by loads in pendular movement in order to provide consistent information to:

- The design of systems to protect structures, equipment and accessories, in case there is no possibility of adopting other alternatives;
- The design of alternative routes of movement, other than by regions that impact MSF, operational areas and other places of passage or stay of people in the Unit;
- Evaluate the frequency of impairment of the MSF as a result of the scenarios of dropped objects and swinging loads.

- Consider in the study the movements occurring under operational conditions of the Unit. The activities related to the construction and assembly of the Unit are not part of the scope.

The following results shall be presented from the performed analyses:

4.1. Alternative routes of movement

Presentation of alternative routes during lifting and unloading of loads, aiming to avoid moving through areas that are congested or present high probability of dropped on MSF or areas of passage of people.

4.2. Alternative means of movement

It shall be indicated movement by alternative equipment in substitution of the equipment that, in principle, would be the preferential ones to carry out that specific movement.

4.3. Safeguards

Safeguards shall be proposed whenever necessary to prevent or mitigate the consequences of the event. In safeguards proposals, the type and characteristics of the safeguard and the place of application shall be clearly indicated.

4.4. Impairment Frequency of MSF

Calculate the frequency of impairment of the MSF by dropped objects and by loads in pendular movement and compare with the stipulated tolerability criteria.

The analysis of the above aspects shall be presented or referenced in the study report, in order to show that these aspects were duly considered and treated.

5. REFERENCE DOCUMENTATION

As inputs for the elaboration of the study, the following documents shall be considered, in its most up-to-date version and with status of RELEASED or RELEASED WITH COMMENTS by Petrobras at SIGEM or another electronic document management system defined in the contract. The review of each document to be used shall be clearly indicated in the study report.

a) 3D model of the Updated Unit;

b) Meteoceanographic data;

c) Safety Plan that indicates the MSF (fire fighting system, escape routes, lifesaving appliances, muster stations, passive protection, etc.);

d) Reports of Risk Analysis already carried out for the Unit, mainly PHA (topside and submarine);

e) Equipment list;

f) Drawings of general arrangement and arrangement of the modules indicating location and TAG of the equipment, location of the primary structures and location of the central pipe rack, etc.;

g) Subsea arrangement drawings;

h) Study of Mechanical Handling and Load Movement Plan

Note: The Mechanical Handling Report shall contain at least the characteristics of all loads handled by the crane (dimensions, weight, etc.) and their respective routes, including positioning of service and support vessels, if applicable, and movement frequency.

Reference Bibliography:

[1] DR-ENGP-M-I-1.3 - Safety Engineering Guidelines;

[2] DNV-RP-F107 - *Risk Assessment of Pipeline Protection*;

[3] N-2782 - Techniques Applicable to the Analysis of Industrial Risks;

[4] N 1710 - Codification of Technical Engineering Documents;

[5] N 381 - Execution of Drawings and Other Technical Documents.

Additional documents shall be provided for the identification of other relevant aspects, such as:

- Indication of mechanical handling locations and capacity of the Unit's cranes;
- Indication of main characteristics (mass, center of gravity and dimensions) of typical loads to be lifted in the Unit;

6. RELEVANT ASPECTS OF ANALYSIS

The dropped objects study shall consider at least the following aspects:

- Type of operation performed;
- Characteristics (weight, size, etc.) of the loads involved in the operations;

- The frequencies related to each operation;
- Consider routes for approaching service and support vessels;
- Consider the impact on sensitive areas of the Unit;
- The geometry and physical arrangement of the evaluated region;
- The geometry and physical arrangement of subsea lines and equipment in the near to the Unit;

7. SOFTWARE REQUIREMENTS

The dropped objects study shall be developed with the use of CFD tools to conduct the simulations and shall comply with the requirements of the Safety Engineering Guidelines.

If the need for the use of tools for impact modeling in the structures, equipment and lines, may be used software with finite element method (FEM), software ANSYS, USFOS, SACS may be used. Any other specific software to the analysis shall be submitted for prior validation by Petrobras.

8. WEATHER CONDITIONS

The meteorological conditions to be used in the study shall be those of the final location of the Unit. The use of the meteoceanographic data in the study shall comply with the Safety Engineering Guidelines. In the study report a table shall be presented with the directions of the wind, speeds of each wind direction, as well as the calm condition and all the considerations adopted in relation to the environmental data used in the study.

The most frequent wind speed shall be obtained from the weighted average of the most frequent speed values in each of the eight directions. The weighting is performed by the number of occurrences of each most frequent velocity considered in the calculation. When frequency values or number of occurrences are provided by speed ranges, use the average value of the speed range. The same considerations made for wind speeds shall also be made for marine currents and a table shall be presented with the assumptions adopted.

9. STUDY METHODOLOGY

The methodology to be adopted in the study of dropped objects shall meet the requirements established in this TS. Any deviation from the methodology shall be presented for analysis and prior validation by Petrobras.

The study shall follow the steps outlined below:

9.1. Selection of Scenarios

The selection of the scenarios to be evaluated in the study shall be carried out on risk-based; in this way, the scenarios shall originate from the following sources of information:

9.1.1. Originated from PHA

The dropped objects study considered the accidental scenarios identified in the PHA, whose risk categories for "People" or " Asset " dimensions are classified as Moderate in severity categories IV or V, and Not Tolerable (all categories of severity and all dimensions), according to the Risk Tolerability Matrix presented in Safety Engineering Guidelines.

9.1.2. Additional Scenarios

Accidental scenarios that have not previously been evaluated in the PHA, identified during the study development, but are categorized as relevant according to item 9.1.1, shall also be considered in the dropped objects study, as well as scenarios caused by changes in the design and operational changes.

Orientation for scenario selection:

• Scenarios of load drop and impact of swinging loads on the process plant;

• Scenarios of load dropping and impact of swinging loads on MSF;

• Scenarios of load dropping and impact of swinging loads on sensitive areas of the Unit such as: riser balcony, risers, riser pipe rack, central pipe rack, mooring system, depressurising system, lines and equipment with large inventories of hydrocarbons, chemical storage areas, etc.;

• Scenarios of loads dropping on the submerged riser area and anchor lines;

• Scenarios of load dropping on service and support vessels.

The Study Consultant shall include in the report a table with all scenarios identified, including the PHA scenarios and the additional scenarios, correlating them with the impacted items as described above.

The following steps shall be taken in the development of the study:

9.2. Collection of failure data

Crane failure probability data and its components shall be obtained from fault databases. The chosen database shall be representative for the project in question considering the type of crane used, type of platform and other characteristics of the Unit, etc., and shall be agreed with Petrobras.

9.3. Determination of Wind Profile

Wind speed shall be represented by a typical boundary layer profile over the ocean. Depending on the location to be considered, a profile based on a power law according to Reference [2] of item 5, may be used, and it shall be validated at the premises definition meeting.

9.4. Determination of Marine Current Profile

The current profile used shall correspond to the technical specification of meteocenographic data indicated by Petrobras or regarding the location as close as possible to the final location of the Unit under analysis. For conservative determination of maximum lateral excursion of objects, it shall be assumed that the different directions of extreme current along the depth are aligned, forming a unidirectional profile. The annual return period for the current profile shall be used. If intermediate values are required in addition to the available depth quotas, the available profile shall be linearly interpolated to obtain these values.

9.5. Collection of Mechanical Handling Data

An analysis of the Unit Mechanical Handling Report shall be performed to support the analysis of dropped objects and impacts of swinging loads on the MSF in order to enable the following steps. All mechanical handling routes shall be identified and loads carried through them shall be typified (frequency, weight, geometry, etc.).

9.6. Analysis of the Dropped Objects on the Unit and Service and Support Vessels

9.6.1. Frequency of Fall

The load drop frequency (F1) is defined by the frequency of load movements multiplied by the failure rate of the equipment.

The frequency of falling of a load on a MSF or area of interest of the Unit (F2) is obtained by the product between the frequency of fall per load (F1) and the fraction of path over the MSF or area of interest in relation to the length of the trajectory traveled by the load.

The total frequency of dropped objects on an MSF or area of interest (FT) shall be represented by the sum of F2 frequencies. These F2 frequencies may be stratified by the load's impact energy range, in order to aid in the calculation of the impairment frequency (item 9.10).

Another approach for the calculation of the drop frequencies may be performed by analysis of the crane's area of activity, considering minimum and maximum crane boom range in relation to the area occupied by the MSF or area of interest, such as: the fraction of the area of a given module in relation to the area of operation of the crane, considering the frequency of fall per load (F1), defined above.

The frequency analysis shall consider the type of movement, which may be only internal to the Unit or by transshipment to another vessel. In the case of transshipment, the fractions of falling at sea, on the other vessel or on the Unit itself shall be considered.

In the assumptions meeting, a cut-off line may be defined for the drop frequencies considered to be very low, at the discretion of Petrobras.

9.6.2. Trajectory of Objects

The report shall comprise and clearly indicate all trajectories of displaced objects, based on the Mechanical Handling Report of the Unit (item 9.5), that may affect the items described in 9.1.2.

9.6.3. Impact energy on the Unit, Service and Support vessels

The calculation of the energy of impact can be deduced from the concept of conservation of energy, assuming that the object is non-deformable, where the kinetic energy is transformed integrally in energy of internal deformation of the structure.

The kinetic energy of dropped object is given by Equation 1 indicated below:

$$Ec = \frac{1}{2} \times m \times v^2 \qquad \text{(Equation 1)}$$

Whereas:

m = object mass in the air (kg);

v = fall speed (m/s).

The velocity of impact of the object in the air is given by Equation 2:

$$v = \sqrt{2 \times g \times h} \qquad \text{(Equation 2)}$$

Whereas:

g = gravitational acceleration (m/s²)

h = falling height of the object (m)

With kinetic energy and structural rigidity in the direction of impact application, the impact force can be deduced for linear quasi-static analysis. For this, it is necessary to obtain the displacement of the structure, equating the kinetic energy with the elastic potential energy and thus obtaining Equation 3.

$$Ec = \frac{1}{2} \times m \times v^2 = Ep = \frac{1}{2} \times k \times \Delta^2 \quad \text{(Equation 3)}$$

Whereas:

k = rigidity of the structure in the direction of impact application (N/m);

Δ = displacement of the structure in the direction of impact application (m);

Ep = Elastic potential energy (J).

With the displacement calculated from Equation 3, the value of the impact force can be obtained from Hook's law.

The procedures indicated from Equation 3 may only be used if the stresses produced by the impact force do not exceed the material flow limit, otherwise a non-linear analysis shall be performed.

9.7. Analysis of Dropped Objects at Sea

Although it is expected that the frequency of dropped objects at sea will be lower than the other scenarios, it shall also be considered, especially in the presence of subsea systems around the unit under analysis.

9.7.1. Frequency of Fall

In the absence of a specific survey, the frequency of dropped objects at sea as presented in reference bibliography [2] of item 5. should be used as a basis. It shall be considered a drop point by crane, chosen in the region between the deck of the service and support vessel and the platform lay-down area where the object may fall directly into the sea. The probability of reaching a given subsea system is then defined as proportional to the area occupied by the subsea system in a circular ring defined by a lateral excursion interval.

9.7.2. Trajectory of Objects

The trajectory of the objects at the sea during their fall is extremely dependent on their shape and mass distribution, being able to acquire purely vertical movements, with great lateral displacement or oscillating, even without considering the local current conditions.

The downward trajectory of the object at sea shall be calculated according to the reference bibliography [2] of item 5, where it is recommended to adopt a normal distribution for the lateral excursion, with angular standard deviation defined as a function of the shape and mass of the object.

9.7.3. Trajectory in Deep Waters

In deep water scenarios, here established as water depth (LDA) > 180 m, the current profile shall be considered additionally for an estimate of the maximum lateral excursion, according to the methodology described in ANNEX A, which takes into account a current profile variable as a function of depth. The current profile to be considered shall be in accordance with the data defined in item 9.4. This same annex presents an example of results obtained with this methodology.

9.7.4. Underwater Impact Energy

The energy available for impact shall be calculated as the kinetic energy of the falling object. In general, this energy may be calculated by the terminal velocity of the object, reached after about 50 m to 100 m deep. The energy may then be calculated by:

$$E_{VT} = \frac{1}{2}\left(M + C_{AV}\rho V_D\right)U_{VT}^2 \quad \text{(equation 4)}$$

whereas: $U_{VT} = \sqrt{\frac{(M-\rho V_S)g}{1/2\,\rho A_V C_{DV}}}$ $U_{VT} = \sqrt{\frac{(M-\rho V_S)g}{1/2\,\rho A_V C_{DV}}}$ (equation 5)

and:

M	Object mass
g	gravitational acceleration (9.8 m/s^2)
ρ	Specific seawater mass (1020 kg/m^3)
Vs	Object solid volume (for the buoyancy force calculation)
Vd	Volume shifted by object (for additional mass calculation)
A_V	Area projected in vertical direction
C_{AV}	Additional mass coefficient of the object in vertical direction
C_{DV}	Object Drag Coefficient in the vertical direction

Depending on the chosen scenarios, the evaluation of lateral and vertical kinetic energy may be necessary. This calculation is done in an analogous way (ANNEX A), but the lateral velocity tends to vary according to the current profile.

9.8. Impulse estimate by swinging load

For each component described in item 9.1, the pendulum impact frequencies shall be calculated. For the calculation of these frequencies, the information of the data base shall be used, considering the unit arrangement and the mechanical handling plan.

9.9. Calculation of accidental load due to dropped object

From the scenarios surveyed in item 9.1, the information on the load movement report, the load movement plan, meteoceanographic data and the Unit's movement, the accidental impact load shall be calculated by dropped objects on the described elements in item 9.1.

The energy needed to generate the impairment of each MSF analyzed shall be provided by the designer through technical analysis of each specialty involved (structures, mechanics, piping and subsea engineering). The calculations of energy needed to generate impairment shall be submitted to Petrobras for validation at meeting R2, as provided in item 10.4.

When it is not possible to establish the impairment energy of an MSF or area of interest, the MSF frequency shall be considered equal to the total frequency of dropped objects in the MSF or area of interest (FT).

The methodology used for the scenarios of fall on the submerged area of the risers, including the trajectory of the load at sea and the energy necessary to generate impairment thereof, shall be presented to Petrobras for validation. Industry standards and good practices, such as the methodology described in reference literature [2] of item 5. shall be adopted.

9.10. Calculation of the impairment frequency

The impairment frequency is the sum of the total frequency of dropped objects in an MSF or area of interest (FT) and the total pendulum impact frequency whose impact energies exceed the resistance of the elements listed in item 9.1. Calculations of the impairment frequency of each of these elements shall be presented in tables.

The impairment frequency obtained for each analyzed MSF shall be compared with the Tolerability Criteria established in the Safety Engineering Guidelines, reference [1] of item 5. Recommendations shall be made to reduce the frequency and / or severity of the scenarios evaluated until the impairment frequency is below the established Tolerability Criterion.

10. REQUIREMENTS FOR MONITORING MEETINGS

The study monitoring meetings shall follow the guidelines below.

10.1. General Considerations

The monitoring of the development of the study shall be carried out by the team of the Designer with Petrobras participation in the cases mentioned in this specification.

The monitoring meetings shall be held in the office of the Study Consulting, with the exception of the planning and analysis of the project documentation meetings, which shall be carried out at the Designer's office. The meeting local may be changed by common agreement between the parties involved. Petrobras, at its discretion, may attend meetings by videoconference. The Designer shall provide the necessary resources for the monitoring meetings, including facilities for the participation of Petrobras, either in person or via videoconference.

The meeting minutes shall be made available as a project document or included as an annex to the report in its final review.

All validation decisions (of premises, of data, of geometry among others) shall be included in the final study report as an annex. The validations shall be signed by those responsible for each party involved.

10.2. Planning Meeting

Meeting for the summary presentation of the project, clarification of aspects related to the objectives and scope of the study, delivery of project documentation, evaluation and necessary adjustments in the work schedule and resources required for the study, where the minimum agenda shall be:

- Safety briefing - (Designer);

- Presentation of the Project for the Study Consulting - (Designer);

- Clarifications on objectives, scope of analysis and requirements of the study (Designer and Petrobras);

- Sizing the teams of the designer and executor of the study that will participate in the preparation and follow-up of the study, with the definition of the matrix of responsibilities;

- Presentation of the focal points of each involved party and identification of the responsible of each discipline of each involved party that will participate in the follow-up meetings and the validations required in this TS;

- Presentation of the planned schedule for the execution of the study in accordance with the project schedule (Study Consulting and Designer);

- Definition of locations, resources needed and duration of monitoring meetings (Designer and Study Consulting).

Participants in the planning meeting: The focal points of the parties involved, the Study Executives involved, and the designers' disciplinary leaders responsible for the follow-up of the study shall be involved.

Note: The schedule shall include the deadline of twenty working days for comments on the reports (partial and final) by Petrobras, as well as the deadline for implementing the comments made.

10.3. Meeting of Documentation Analysis, Definition of Assumptions and Methodology

Meeting for the analysis and validation of the project documentation required for the development of the Study and preparation of the pending list, if any. The objective is to avoid errors and rework in studies due to possible failures or omissions of information in the documentation, which will serve as the input database for the study.

This meeting aims to validate the scenarios of dropped objects to be simulated, to consolidate the premises defined in this TS and other additional ones not covered herein and in the Safety Engineering Guidelines, and shall comprise at least the following:

- Deleted scenarios: justifying, agreeing and documenting deleted scenarios;
- Definition of possible MSF to be impacted.

From the analysis of the document list of project and documents provided, the Consultant may request clarification and clear questions about the information contained in the documents. In case of identification of pending documents or the need to provide other documents, the Designer shall inform the deadline necessary to solve the pending issues and/or to send the documents, in a way that does not affect the schedule for the study.

At the end of the meeting, the Study Consulting shall sign an accepted document containing the pending list, if any.

Assumptions shall be defined by mutual agreement between the parties involved and shall be included in the study report.

In addition to the premises and methodology, the Designer shall confirm the basic information for the start of the study, such as meteorological conditions, displaced load, arrangement of risers (subsea and surface - arrangement at risers' balcony) and the MSF shall be evaluated in the study. The information shall be ratified or rectified by Petrobras.

The designer, as responsible for project change management, shall inform the other parties involved of any change in the project that affects the study. Documents changed as a result of the project changes affecting the study shall be sent to the Study Consulting. As a result of such, the Study Consulting shall evaluate the changes and report the impacts of the changes in the analysis and schedule foreseen. It shall also presents the proposed premises for the development of the study and its doubts about the methodology proposed in this TS. The Designer with the participation of Petrobras shall clarify the doubts.

Participants in the meeting for analysis of documentation, premises and methodology:

Participant's study professionals involved and the discipline's design leaders shall be involved in the follow-up of the study. This meeting is optional for Petrobras.

10.4. Monitoring and Validation Meetings

Meetings to accompany the study by the Designer with the participation of Petrobras where the items provided for in the methodology shall be addressed.

The Designer in agreement with the Study Consulting, and considering the schedule for the study, shall present the agenda of meetings to follow up the development of the study. The meetings shall contemplate the study steps foreseen in item 9 (Methodology) of this TS. Monitoring and validation meetings shall be provided in Table 1 below:

Table 1: Monitoring and validation meetings

Item	Minimum Agenda	Ref.
R1	Validation of input data - Considered loads, expected movement for operation and trajectories	9.5
R2	Presentation of the Partial Report, containing calculations and results of frequency and severity, etc.	9.8
R3	Presentation of the Final Report (preliminary version), containing, in addition, conclusions and recommendations	9.9

Table 1 is based on Petrobras' experience, and the number of meetings may be altered by mutual agreement between the parties involved, provided that all the items that compose the methodology and that require validation are addressed, as well as the analysis of results and recommendations are discussed and evaluated for their applicability to the project.

Participants in monitoring and validation meetings: Participant professionals involved in the study and the discipline leaders of the Designer and Petrobras responsible for the follow-up of the study shall participate.

10.5. Final Report Presentation Meeting – Draft Version

Meeting to present the final report (draft version) before its issue to Petrobras. The final report is the responsibility of the Designer. The final report shall include the report of the Study Consulting plus the treatment of the study recommendations to be implemented in the project by the Designer. The codification of the report and its stamp shall identify the designer as originating from the document. The coding shall be in accordance with Petrobras N-1710 and the format in accordance with N-381.

The presentation shall focus on the main accidental events, the main results, conclusions and recommendations of the study. The treatment given to each of the study recommendations shall be addressed. Participants in the study report presentation meeting: The single points of the parties involved, professionals from Study Consulting responsible for the study and the discipline leaders of the Designer and Petrobras responsible for the follow-up of the study shall be involved. At this meeting, it is recommended the participation of professionals from operation and maintenance of the Unit.

11. STUDY REPORTS

The final report shall be issued in Portuguese and English. The report shall comply with the content required in Item 8.6 of the Safety Engineering Guidelines and as specified in this document.

All assumptions of simplification and premises adopted shall be presented and explained in the corresponding part of the report. In addition, the minutes of the meetings shall be presented in annex, especially those that have validation of stages of the methodology. The charts and figures of the reports shall be presented with the respective scales, captions, the rose of the winds, and predominant direction of the wind. For the elaboration of the tables, graphs and figures, the units of the International System shall be applied – SI.

All charts and figures that support the conclusions and recommendations of the study shall be presented in the final report.

11.1. Partial Report

At least, one partial report shall be submitted by the Study Consulting to Petrobras for comments prior to the issuance of the final report.

The Partial Report shall contain at least the requirements:

- Description of the scenarios analyzed;
- Table with loads carried;
- Type of operation performed;
- Characteristics (weight, size, etc.) of the loads involved in the operations;

- The frequencies related to each operation;

- Trajectories of objects;

- Approach routes for service and support vessels;

- Calculation of energy needed to generate impairment of each MSF.

11.2. Final Report

The Final Report corresponds to the issuance of the report under review 0. It shall contain all the requirements of item 11.1, and take into account the comments made to the Partial Report, and additionally contain:

- Attached meeting minutes (item 10.1);

- LV attached (item 14);

Additional revisions shall be provided for any changes in the project that impact the study, or in the event that failures in the final emission are identified.

12. DEADLINES

According to the complexity of the project, the scope of the study and the deadlines established in the contract shall be defined by the Designer, in agreement with the Study Consulting, the deadlines required for the study and the issuance of the partial and final reports. These deadlines shall be included in the schedule mentioned in item 10.2 of this TS.

13. QUALIFICATION TO CARRY OUT THE STUDY

Due to the complexity involved in the methodology and the use of the CFD software applicable to the Dropped Object study, and also due to the importance of this study for the safety of the Unit, the elaboration was done by a qualified company, belonging to Petrobras' contractual list of suppliers. LCF).

14. APPLICATION OF THE CHECKLIST (LV)

The Designer shall provide a checklist (LV), which shall be included as an annex to the report, as a follow-up to the activities of the Study Consulting. The LV shall contain the requirements of the Safety Engineering Guidelines and the requirements of this TS. The verification of each requirement shall have the identification and signature of the person in charge of the verification The verification of the part relating to the adequacy of load movement or preventive or mitigating measures shall be included in the project documentation or as an annex to the report. In case it does not count as an annex, this documentation shall be referenced in the study report in a specific item, with a clear indication of how and where the study recommendations were met.

15. INFORMATION SECURITY

In addition to the provisions of the Safety Engineering Guidelines, the Project Designer and the Study Consulting shall have a data security system that guarantees the integrity, reliability, traceability, confidentiality and inviolability of the data contained in the study and the data provided by Petrobras. All information shall be preserved against accidental or information security events for at least five years.

ANNEX A

METHODOLOGY FOR CALCULATING TRAJECTORY OF FALL AT SEA IN DEEP WATER, CONSIDERING THE CURRENT PROFILE

Assuming the fall of an object randomly, without changes in its orientation along the trajectory, the forces acting on the object immersed in a fluid are represented in the free-body diagram of Figure A1.

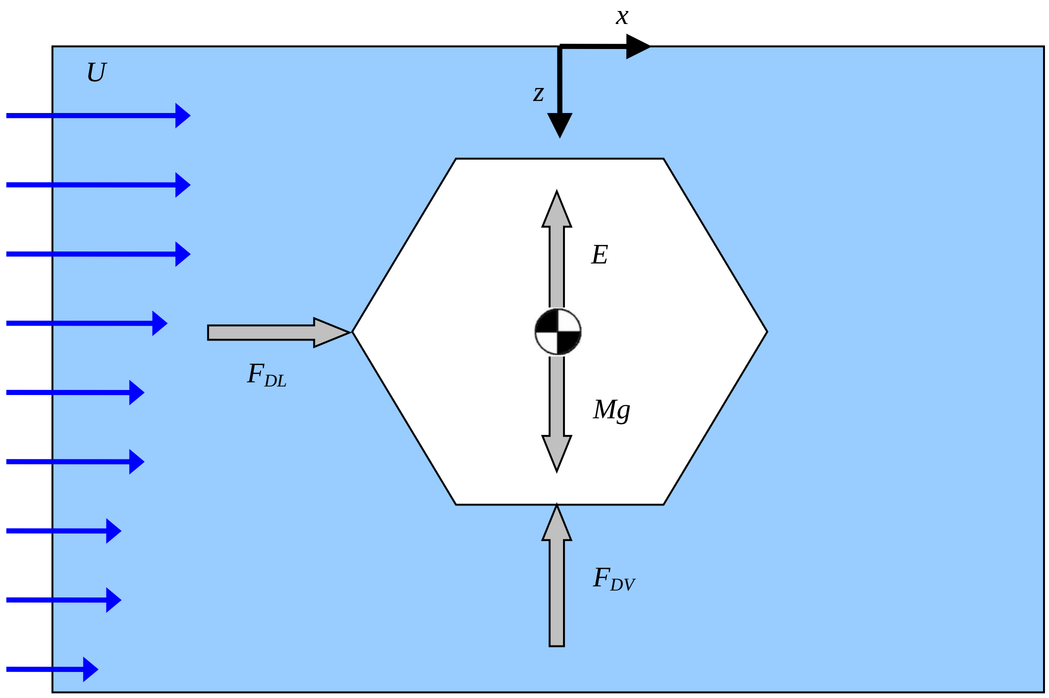


Figure A1 - Free body diagram for a free falling object at sea.

The linear momentum balance equations, assuming motion in the plane (2D), may be written as:

In vertical direction

$$Mg - E - F_{DV} = Mg - \rho g V_s - \frac{1}{2} A_V C_{DV} U_V |U_V| = (M + C_{AV} \rho V_d) \frac{d^2 z}{dt^2}; \text{ com } U_V = \frac{dz}{dt}$$

In lateral direction:

$$F_{DL} = \frac{1}{2} C_{DL} A_L U_{LR} |U_{LR}| = (M + C_{AL} \rho V_d) \frac{d^2 x}{dt^2}; \quad \text{com } U_{LR} = U_{cur} - U_L \text{ e } U_L = \frac{dx}{dt}$$

whereas:

M	Object mass
g	gravitational acceleration (9.8 m / s^2)
ρ	Water specific mass (1020 kg / m^3)
V_s	Solid object volume (for the buoyancy force calculation)
V_d	Volume displaced by object (for additional mass calculation)
A_V	Area projected in vertical direction
A_L	Area projected in the lateral direction
z	Vertical displacement of the object
x	Lateral displacement of the object
U_V	Vertical object speed
U_L	Lateral object speed
U_{cur}	Lateral velocity of current (varying as a function of depth)
U_{LR}	Relative velocity between object and fluid in lateral direction
t	time
C_{DV}	Drag coefficient of the object in vertical direction
C_{AV}	Additional mass coefficient of the object in vertical direction
C_{DL}	Drag coefficient of the object in the lateral direction
C_{AL}	Additional mass mass of the object in the lateral direction

Considering that the hydrodynamic coefficients of the object (C_{DV}, C_{AV}, C_{DL}, C_{AL}) as constants along the trajectory and assuming that motion starts with speed equal to zero and with the GC of the object on the water surface, it is possible to integrate the previous equations and determine an approximation for position and velocity of the object over time.

With these considerations, the vertical velocity has analytical solution, being able to be written like:

$$U_V = \alpha \tan^{-1}(\beta t)$$

whereas:

$$U_{VT} = \sqrt{\frac{(M-\rho V_s)g}{1/2\ \rho A_V C_{DV}}} \quad \text{and} \quad \beta = \sqrt{\frac{(M-\rho V_s)g\ 1/2\ \rho A_V C_{DV}}{M + C_{AV}\rho V_d}}$$

The lateral displacement shall be calculated at each depth, considering the need to update the current velocity value as a function of depth. The maximum lateral excursion envelope of the object is given by the solid of revolution of the resulting trajectory profile (see Figure A2).

The hydrodynamic coefficients (additional mass and drag) shall be obtained by analogy with the experimentally tested forms and with results described in the literature, for example, in the recommendation DNV-RP-H103 and the reference BLEVINS (1984).

Knowing the velocities of the object, one may also determine the vertical and lateral impact energy, which in this case corresponds to the kinetic energy of the object, given by the equations:

$$E_V = \frac{1}{2}\left(M + C_{AV}\rho V_D\right)U_V^2 \quad \text{(vertical impact)}$$

$$E_L = \frac{1}{2}\left(M + C_{AL}\rho V_D\right)U_L^2 \quad \text{(lateral impact)}$$

Table A 1 - LOAD EXAMPLE

Object	Mass	Solid Volume	Displaced Volume	Vertical Designed Area	Lateral Designed Area	C_d Vertical	C_a Vertical	C_d Lateral	C_a Lateral
	ton	m^3	m^3	m^2	m^2	-	-	-	-
Small Container 8	8.00	1.03	36.25	5.85	14.63	0.90	0.30	1.15	1.32

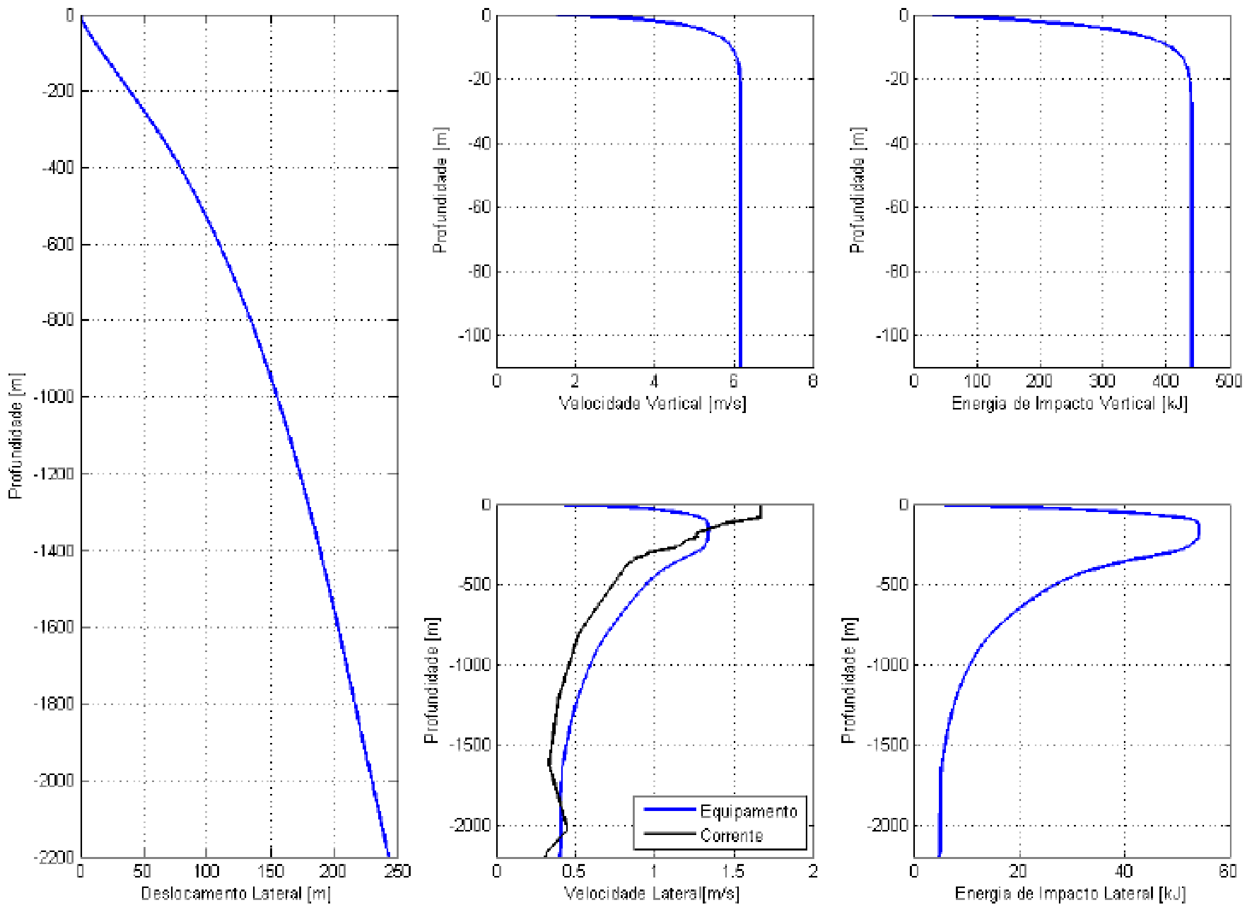
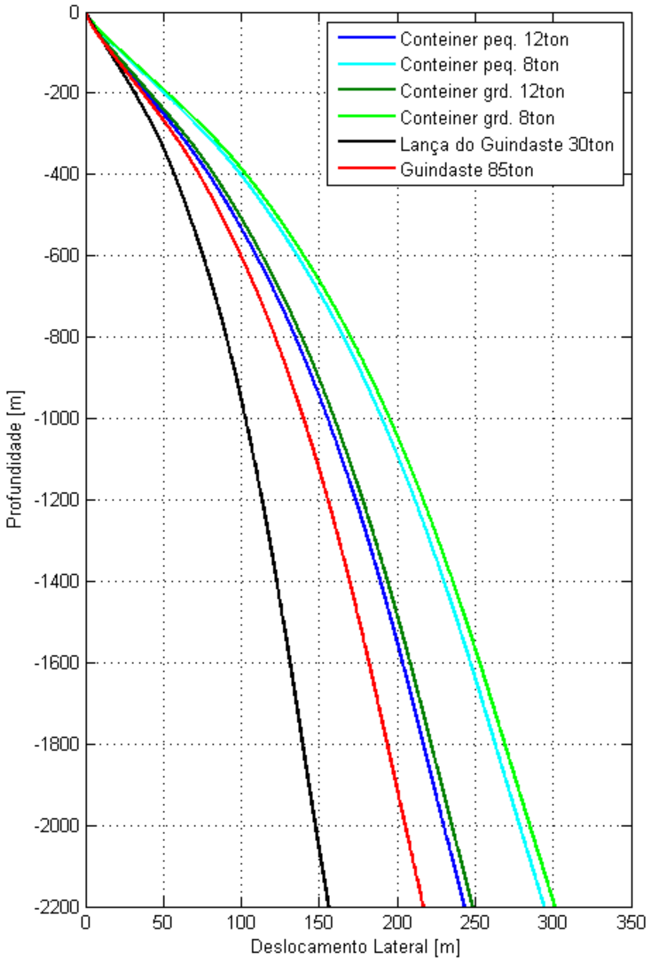


Figure A2 - Example of container fall analysis under extreme current action with return period of 100 years in the Santos Basin. Above: analysis parameters; Below: results in graphic form.



Object	Mass	Terminal speed	Vertical Impact Energy	Lateral Displacement	Lateral Displacement
Depth (m)				300	2200
	ton	m/s	kJ	m	m
Small container 8	8	5.05	240	75	285
Small Container 12	12	6.15	440	60	240
Large container 8	8	4.95	230	80	300
Large container 12	12	6.00	415	63	250
Crane boom	30	9.25	1360	45	160
The crane (Boom + Base]	85	6.85	2370	55	215

Figure A3 - Example of a comparative analysis of the dropped objects in a scenario of fall under action of extreme current with return period of 100 years in the Santos Basin. Above: extreme trajectory of objects; below: table with impact energy results for two depths.