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DEVELOPMENT OF OPERATIONAL LIMIT DIAGRAMS FOR OFFSHORE LIFTING PROCEDURES

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ABSTRACT

Lifting operations with offshore cranes are fundamental for proper functioning of a platform. Despite the great technological development, offshore cranes load charts only consider the significant wave height as parameter of environmental load, neglecting wave period, which may lead to unsafe or overestimated lifting operations. This paper aims to develop a method to design offshore crane operational limit diagrams for lifting of personnel and usual loads, in function of significant wave height and wave peak period, using time domain dynamic analysis, for a crane installed on a floating unit. The lifting of personnel with crane to transfer between a floating unit and a support vessel is a very used option in offshore operations, and this is in many cases, the only alternative beyond the helicopter. Due to recent fatal accidents with lifting operations in offshore platforms, it is essential the study about this subject, contributing to the increase of safety. The sea states for analysis were chosen covering usual significant wave heights and peak periods limits for lifting operations. The methodology used the SITUA / Prosim software to obtain the dynamic responses of the personnel transfer basket lifting and container loads on a typical FPSO. Through program developed by the author, it was implemented the automatic generation of diagrams as a function of operational limits. It is concluded that using this methodology, it is possible to achieve greater efficiency in the design and execution of personnel and routine load lifting, increasing safety and a wider weather window available.

INTRODUCTION

Offshore cranes are present in most of the platforms nowadays, no matter they are fixed or a floating unit, and also in a great variety of construction and supply boats. They are used to lift a wide range of loads, including food, pipes, containers and personnel.

Offshore cranes are also used to perform lift operations for construction and maintenance aboard the offshore unit.

Because these operations involve high risks, all lifts should be designed and planned to mitigate the danger and increase reliability, preserving lives, loads and equipment involved.

In the design, planning and execution of the lift, one should ensure that equipment and accessories will not be overloaded; there will be no load collisions with any obstacles, including the crane itself; the load will not be subjected to excessive speeds and accelerations among other undesirable situations.

The information generally available to the owner of the crane or who will do the design of the lifting is limited to the load charts and some operational limits as significant wave height (Hs), maximum wind speed, maximum angles of trim and band. So, it is not taken into account a number of other factors that can directly influence the safety of lifting, as wave period, platform heading, minimum and maximum length of the crane cable, speed of lifted load, among other factors.

OFFSHORE CRANE OPERATIONAL LIMIT DIAGRAM

It is proposed in this paper the “offshore crane operational limit diagram” (OCOLD), that has the goal to take into account

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all factors that affects the lift operation, considering these effects in only one diagram, where an envelope that satisfies all safety criteria is established, and will be used in decision-making for planning, design and execution of the lift operation.

The OCOLD can be used in design and planning of the lift, showing the values of Hs and Tp that meet the operational requirements previously established, and once defined Hs and Tp, one can define a weather window, based on metocean data available for the location of operation. It is possible to reverse the procedure, that is, based on metocean data and expected Hs and Tp for the location, it is possible to establish the operational parameters that may limit the lift procedure, like radius of operation, weight of load, speed of the lifted load, among others.

The OCOLD can also be used before routine lifts to ensure that an operation can be conducted within the safety envelope for a specific environmental and operational condition.

This methodology can be applied to any floating unit like FPSO, semisubmersibles, spars, construction vessels and also in fixed platforms.

Preparation of the OCOLD

The necessary information of the floating unit for the preparation of OCOLD are: platform's response amplitude operator (RAO) for movements at correspondent draft, crane position in relation to the movement center of platform, minimum and maximum cable length during operation, minimum radius and maximum radius of operation as well as the load weight to be lifted.

For environmental loads, one must provide the wave spectrum of the geographic region considered. The wind effect, directly on the load, is not considered in this paper and its effect on the unit, is taken into account indirectly in the heading of platform.

It is also necessary the input of the operating limits and limits established by the technical standards and manufacturers of lifting equipment. The operating limits can be various, as established by the operator of the platform and may limit for the lifted load: inclination, speed and load acceleration, proximity to obstacles such as ship's side or superstructure (offset limitation). Different values for limits may be established: nominal values, which exclude additional factors of safety, values for safe operation, which include factors of safety, and values for emergency operation, which reduces the nominal values for an accepted level in emergency situation.

For example, codes, guides and standards for offshore lifting of personnel can define maximum significant height (Hs) for operation [1], and crane manufacturer, also based on international standards, may also define maximum trim and heel angle for the offshore unit, as well as safe working load (SWL) and others. Figure 1 shows the flowchart for OCOLD preparation.

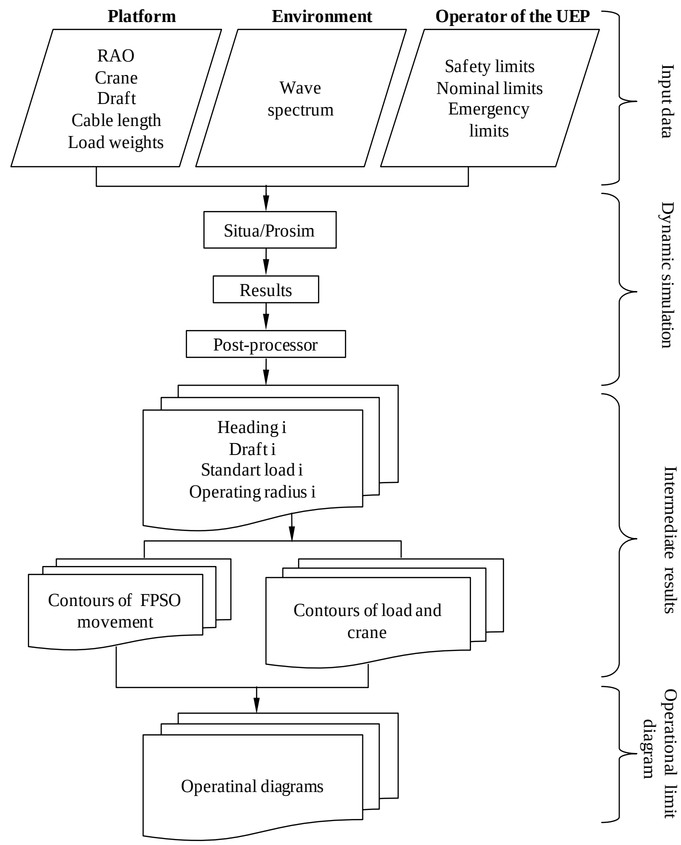

Figure 1. Flowchart for offshore crane operational limit diagram.

Regarding lifting of personnel using baskets, since 56% of accidents occur by collision [2], limits may be established with multiple safety volumes, negative or positive, where the basket cannot achieve at if it is negative, or cannot get out of it if the volume is positive. This concept was developed by Roncetti [3] for lifting and rigging simulation applied in shipbuilding and offshore construction.

The consideration of this limit in preparing the OCOLD may be made as follows: in the non-linear dynamic analysis stage, for each load case, the violation of each safety volume is checked and if it is violated, this case is not represented in the diagram. The contour is formed with the combinations of maximum Hs that meet the geometric limits. This outline does not have scalar value.

From the input data, it is elaborated the structural model for dynamic simulation in SITUA / Prosim [4]. The load cases are variations of Hs and Tp pairs which, together with the selected spectrum, generate the wave load that will act on the floating platform.

It is possible in a single structural model, to include all parameters combinations as headings, crane cables with different lengths, different radius of operation, different loads, among others, allowing to obtain in single execution of the program, all results necessary to generate de diagrams.

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After the dynamic simulation, the results, called intermediaries, are separated and processed by the post-processing module developed by the authors, whose source code is found in [5]. For each set of data that defines a diagram, it is performed the calculation of extreme values of the predefined limits, such as speed, acceleration, displacement, axial force in cable, etc. These calculations are done for each load, radius of operation and cable length.

Next, it is calculated by linear or quadratic interpolation, a contour diagram as function of Hs and Tp for determining each operating limit. Figure 2 illustrates an example of diagram with contours in function of Hs and Tp, highlighting the contour of the basket speed for safety operation limits, nominal operation limits and emergency operation limits. All values of this diagram are the extremes values found for each Hs and Tp pair, varying the length of the crane cable.

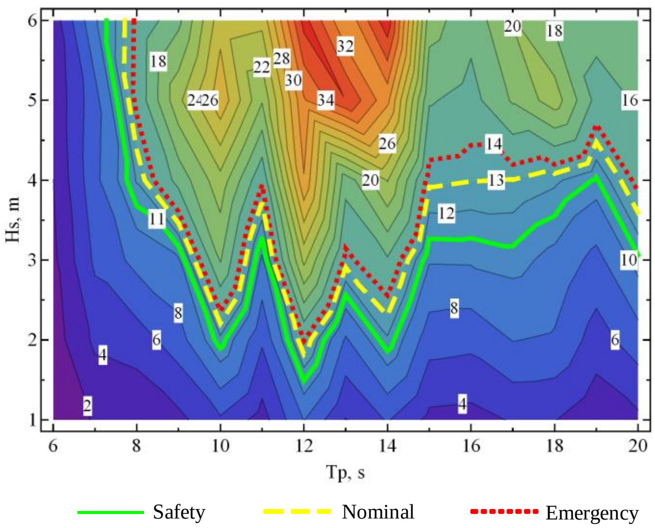

Figure 2. Example of contour plot showing a diagram with contours of extreme values for transport basket speed.

Once obtained the contours for each operating limit, it is calculated the safe envelope that corresponds to each Tp, the highest value of Hs that is below of all thresholds simultaneously. It may be generated how many diagrams that are necessary to cover load weights ranges, radius of operation ranges, most probable platform or ship headings and other parameters.

Once prepared the OCOLD, it can be used indefinitely, provided there is no change in initial parameters. Decision making for routine lifts can follow the flowchart shown in Figure 3.

Once known parameters of the lifting operation, such as operating radius, load weight, heading and other previously established, one choose the corresponding diagram prepared based on this lifting configuration. Then, known Hs and TP, one check if this pair is within the safety area of the envelope. If it is, the lift operation can be executed. Otherwise, if it is possible to change any parameter, such as operating radius, load weight or other, a new check is done. If it is not possible to change operational parameters, it is necessary to wait for more favorable sea condition or abort the operation.

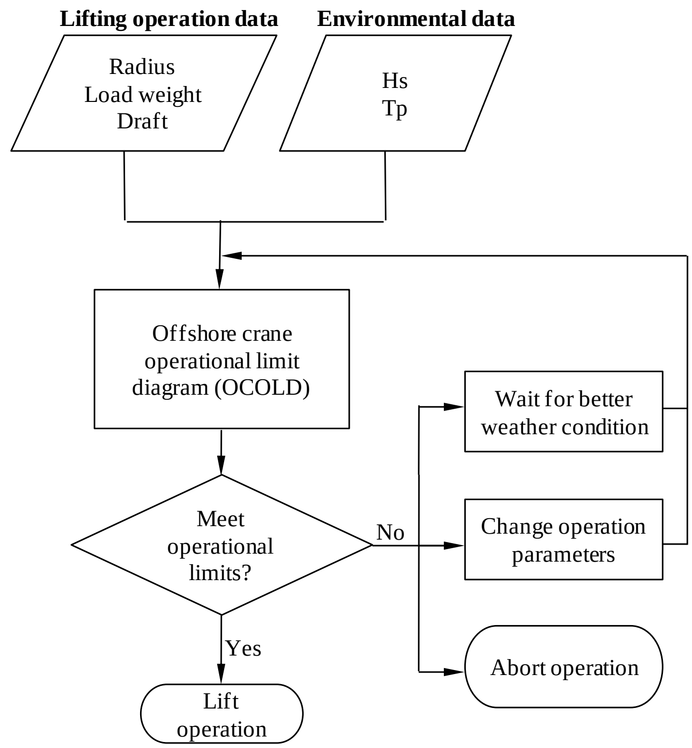

Figure 3. Flowchart for decision-making using the OCOLD.

APPLICATION OF THE OCOLD

To demonstrate the application in lifting operations of the offshore crane operational limit diagram (OCOLD), a real FPSO data is used, considering a personnel lift operation and a routine lift of an offshore container.

FPSO and Crane Parameters

The characteristics of the FPSO are listed on Table 1 and Figure 4 illustrates the FPSO dimensions and parameters used on this paper.

The structural model for dynamic analysis considered that the crane has a rigid structure. This consideration do not affect the final results significantly due to low resonant periods of the real crane, ranging from 0,04 seconds to 0,33 seconds for the first six modes of vibration, not considering the pendulum modes. The cable of crane was modeled using truss elements. A detailed analysis can be found in [5].

To determine the environmental loads, it was considered only the effect of waves, ignoring the wind and the current. JONSWAP wave spectrum adapted to the Campos Basin [4] was used and the combination of Hs and Tp pairs based on values shown in Table 2 resulted in 90 load cases. These values

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of Hs and Tp are within a range of interest for the lifting activities, whose values are framed in periods of 1 year recurrence, suitable for operating situations according to ISO 19901-6 [7].

Table 1. FPSO Parameters.

Parameter	**Value**
Type of hull	VLCC
LOA (m)	335,0
Breadth (m)	54,5
Moulded Depth (m)	26,00
Free board (m)	5,00
Deadweight tonnage (DWT)	270.000
Draft during lift operation (m)	21,0
X_0 (m)	100,0
Y_0 (m)	25,0
β	90°
Radius of operation, R (m)	20,0
Heading	30°

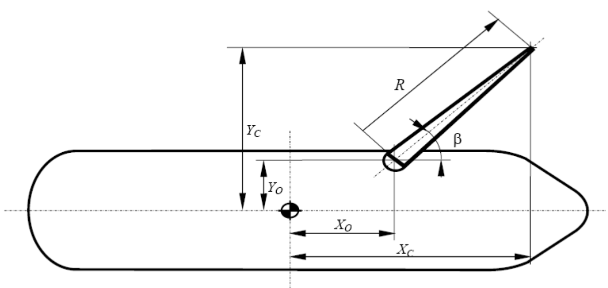

Figure 4. Dimensions and parameters of FPSO [6].

Operational Limits

For the generation of OCOLD, it is necessary the establishment of operational upper limits as speed, acceleration, displacement, forces, floating unit movements, among others, defined by the platform operator and based on technical standards.

The operational limits considered in this paper are shown in Table 3. Note that for the offshore container lifting, there is no need to establish different operational situations (nominal, safety or emergency), as it is recommended when lifting personnel.

The limit of the basket speed is determined using [8] and the speed limit for the container is arbitrated. The roll threshold and dynamic amplification factor (FAD) were taken as the API Specification 2C (API, 2004) and the threshold value for pitch is arbitrated.

Table 2. Lifting operation parameters.

Parameter	**Value**
Radius of operation (m)	20 and 30
Angle β	90°
Crane cable length (m)	13 to 38
Total weight to be lifted, considering 1 person, basket and rigging (kN)	4,91
Heading	30°
Wave peak period for load cases (s)	6 to 20
Significant wave height for load cases (m)	1,0 to 6,0

The limits of the safe working load (SWL) are typical values for real offshore cranes, configured for lifting of personel or cargo as each case.

Table 3. Operational limits used to prepare the OCOLD.

Parameter	**Operation type for lifting of personnel with transport basket**			**Offshore container**
	Safety	**Nominal**	**Emergency**	
Basket bottom speed (m/s)	8,0	8,5	9,0	15,0
Roll	1,5°	2,0°	2,5°	2,0°
Pitch	4,0°	5,0°	5,0°	5,0°
Hs (m)	2,0	2,5	3,0	3,0
SWL (kN)	8,0	8,5	9,0	67,0
DAF	1,25	1,3	1,4	1,4

Other operating limits can be included depending on the type of lifting operation to be performed. In case of lifting of personnel, it may be included as a limiting factor, not only velocity and acceleration but also the angle of inclination to the vertical of the transport basket. Also, for any case, one can consider if the basket or load are submerged, the maximum offset of load, maximum offlead and sidelead of the crane cable and other limits.

RESULTS

After the dynamic analysis, the results were joined and processed by software developed by the authors. For each load case and limiting parameter, an extreme value analysis was conducted to establish the envelope for each parameter.

Movement of the FPSO

In OCOLD composition, the motion limits for surge, sway, heave and yaw of the FPSO are not considered, although their effects are considered in the dynamic analysis. Figure 5 shows

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the contour plot of extreme values, highlighting safety, nominal and emergency operation.

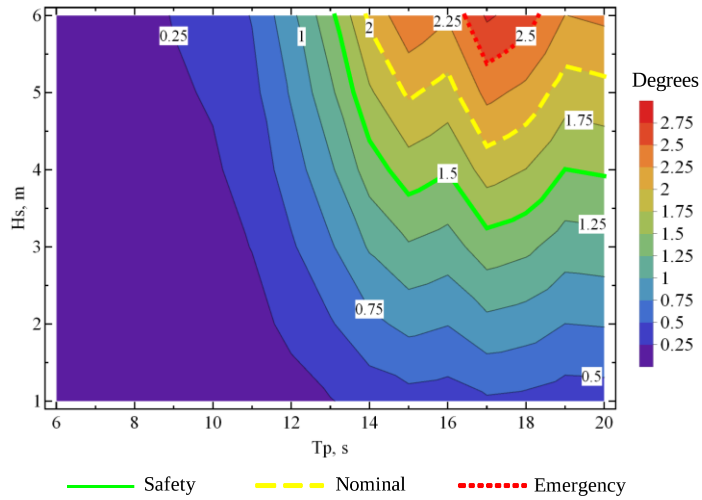

Figure 5. Diagram with limit contours of extreme values for FPSO roll.

For pitch movement, all contours are above the value for Hs equal to 6,0 meters, so no plot is needed.

Although it is not considered in this paper the verification of collision or submersion of the load, an example of the path of the load is show in Figure 6. The study of trajectory of load is useful to know how far it will be from obstacles or water.

One note that based on load path shown in Figure 6, amplitude for load case 47 is greater than for load case 48, even with lower Hs. That is explained by the movement of load that tends to whip more intensely.

Force in crane cable

For calculating the maximum extreme value for axial force acting on the cable during lift operation, an analysis of 90 time series for each cable length was conducted, determining the extreme maximum value for each combination. For lifting one person, the extreme maximum force in function of Hs, Tp and cable length is shown in Figure 7. Radial values are the length of crane cable, and contours are the axial force for each combination of Hs and Tp.

In this case, the maximum static force to the cable length of 15 meters, including the load is 3.95 kN and a cable length of 40 meters, the maximum static force is 4.91 kN.

It is noted that for Hs up to 4.0 meters there is no significant amplification of tensile force in cable comparing to static force, with a maximum of 7.0 kN, occurring in cable length of 40 meters, load case 39, Hs 3.0 meters and Tp 12 seconds, which is the heave resonant period. The corresponding dynamic amplification factor is 1.43.

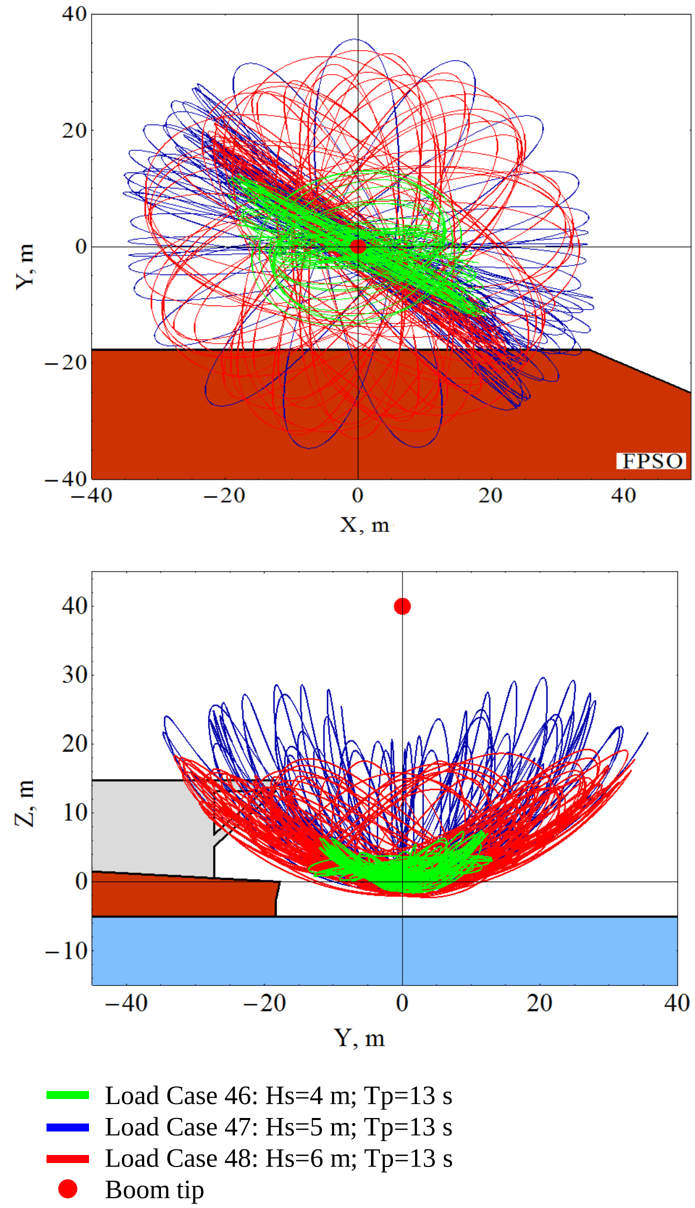

Figure 6. Top view and lateral view for bottom of transport basket path for 3 load cases.

It is also shown that, in some situations the force decreases with increasing length of the cable, for example Hs exceeding 6.0 m and Tp equal to 11.0 seconds (load case 36), with the axial force for 32.5 meters long larger than the axial force for 35.0 meters long. The natural period of pendulum of the shorter cable is 11.4 seconds almost equal to the resonant period of heave, which is 11.5 seconds justifying the results found.

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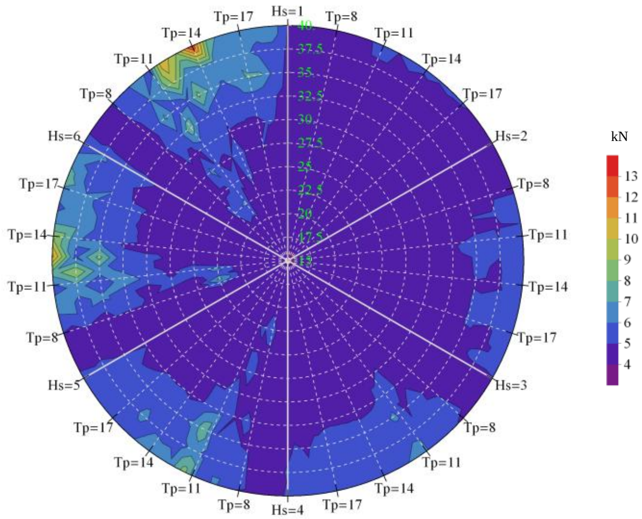

Figure 7. Extreme values for axial load in crane cable in function of Hs, Tp and cable length.

To calculate the contour diagram for axial force in crane cable, a similarly procedure to create the plot shown in Figure 7 is conducted, but with a rectangular layout, and adopting as a force value for each pair of Tp and Hs the maximum value among all cable lengths. The graph thus has one dimension less (cable length) than the polar plot.

Figure 8 shows the diagram with contours of the operational limit for axial force in cable.

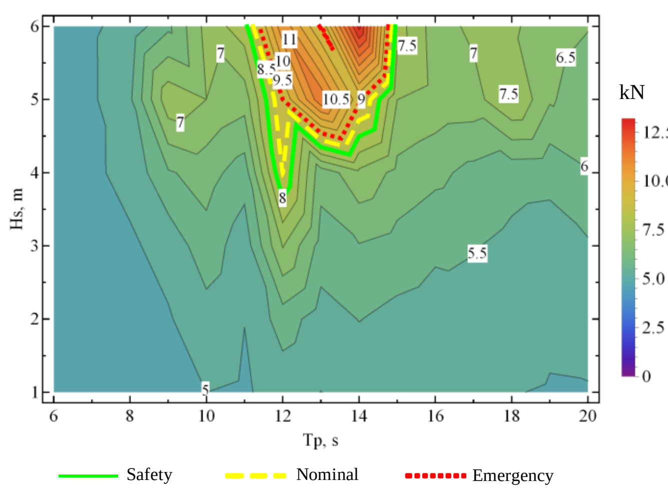

Figure 8. Diagram with limit contours for extreme values for axial load in crane cable, in function of Hs and Tp.

Dynamic amplification factor (DAF)

Based on axial force in cable and based on the static load for different cable lengths, one can draw the contour plot of the dynamic amplification factor (DAF) and establish operating limits. For each point of the diagram, the static reference value corresponds to the cable that had the highest tensile force. Figure 9 shows the contour plot of the DAF and the operational limits.

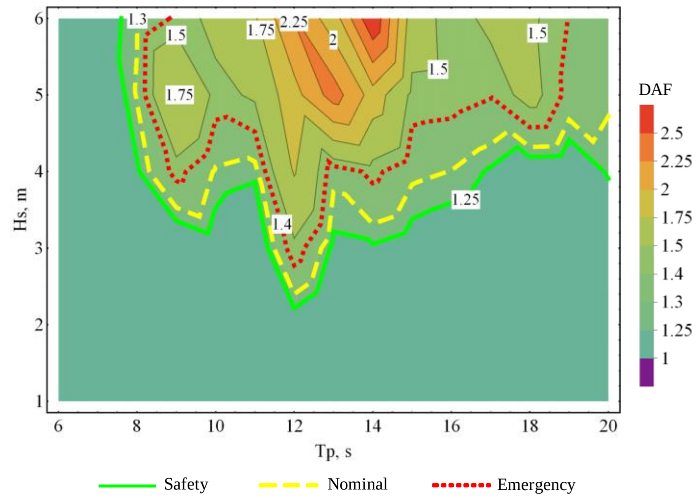

Figure 9. Diagram with limit contours for dynamic amplification factors (DAF) for axial load in crane cable, in function of Hs and Tp.

Once calculated the operational safety contours, nominal and emergency for each threshold considered, it is performed the calculation of the envelope for each operating situation. The envelope is formed by calculating for each value of Tp, the largest value of Hs that is lower than all values in contours of operational situation analyzed. The envelope is automatically calculated by post-processing program.

It is noted that, currently, technical standards define Hs limits for the lifting of personnel [1], and these limits are considered in the calculation of the envelope. The limitation of Hs value by the crane safe working load, from load chart, is taken into account indirectly by limiting the force in the cable.

Figure 10 shows the contours of the limits adopted for the nominal operation, which is obtained without using the factor of safety. The yellow region indicates the permitted operational area, which meets all of the nominal limits, in this case, limited by Hs and the transport basket speed.

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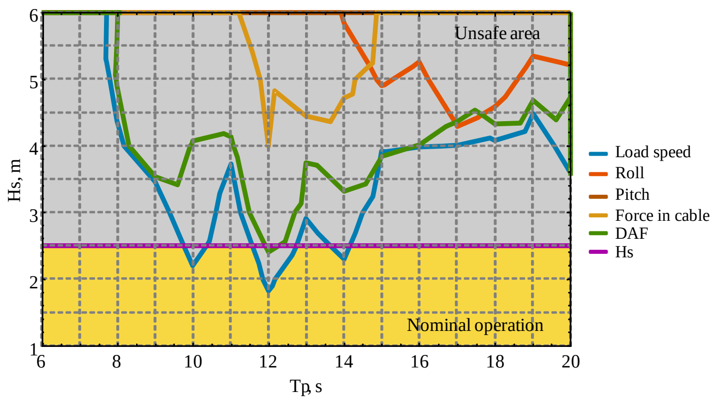

Figure 10. Intermediary operational diagram with limit contours and envelope for nominal operation.

Figure 11 shows the contours of the limits used for the emergency operation, which is constructed using less conservative values, but still within a controlled risk situation at the discretion of the FPSO operator. The orange color region indicates the permitted operational area, which meets all the limits of the emergency operation, in this case, limited by Hs and the transport basket speed.

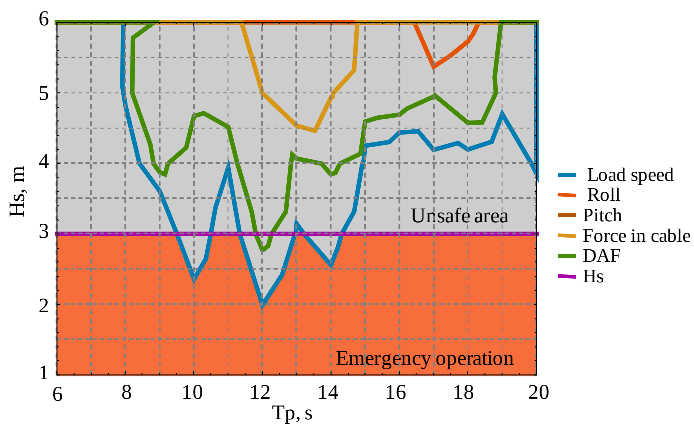

Figure 11. Intermediary operational diagram with limit contours for emergency operation.

Figure 12 shows the contours of the limits used for safety operation situation or safe operation, which is established using more conservative values than the nominal ones, to compensate process variation and uncertainty in the determination of natural periods, wave heights, RAO of the vessel, among others, at the discretion of the FPSO operator. The green area is the permitted operating area, which meets all the limits of safety operation, in this case limited by Hs and transport basket speed.

It is noted that in all cases, operating constraints were Hs and speed of transport basket and thus should have their threshold well evaluated, in order to not allow false unsafe operations or not to allow false safe operations that, in fact, are unsafe. It was also noted that in no condition occurred immersion of load, which is clearly identified in time series by the force in cable or the position of the basket in relation to the wave height.

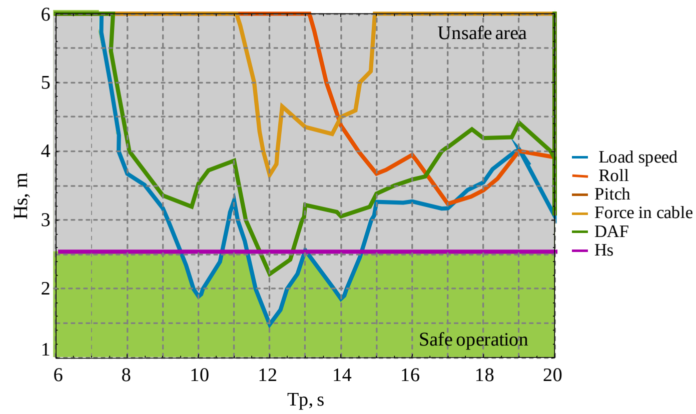

Figure 12. Intermediary operational diagram with limit contours for safety operation.

Final OCOLD

Once established the envelopes for each operational situation, one can assemble them into a single diagram called offshore crane operational limit diagram or OCOLD. In this diagram, the representation of the operational limits contours is no longer necessary.

An OCOLD diagram should be developed for each condition and parameters of the platform, crane and load. In this case, this paper took into account the RAO at 21 meters draft, the radius of operation of 20 meters, the load weight (1 person more equipment), maximum Hs, maximum and minimum crane cable lengths and heading. Figure 13 shows the resulting OCOLD for the presented case.

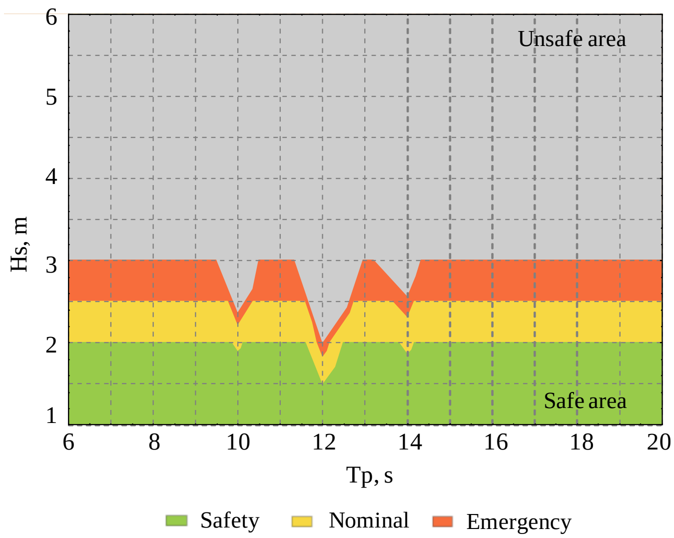

Figure 13. OCOLD including limitation of Hs.

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For any pair of Hs and Tp that intersects below the chosen operational condition (safety, nominal or emergency), the operation for lifting of personnel can be held.

The presented OCOLD considers Hs limitations for safety, nominal and emergency operations, using values 2.0, 2.5 and 3.0 meters respectively, as shown in Table 3.

It is observed in the above OCOLD that the rules limiting Hs equal to 2.0 meters are violated for Tp equal to 12 seconds and Hs of 1.8 meters for nominal operation and Hs of 1.5 meters for safe operation.

The purpose of this paper is that the Hs parameter be not considered directly as a contour for operational limitation but, along with Tp, has its effects considered in dynamic response of load, cable and crane. By doing so, all operating regions expand, increasing the weather window available. Figure 14 shows the OCOLD without limitation of Hs.

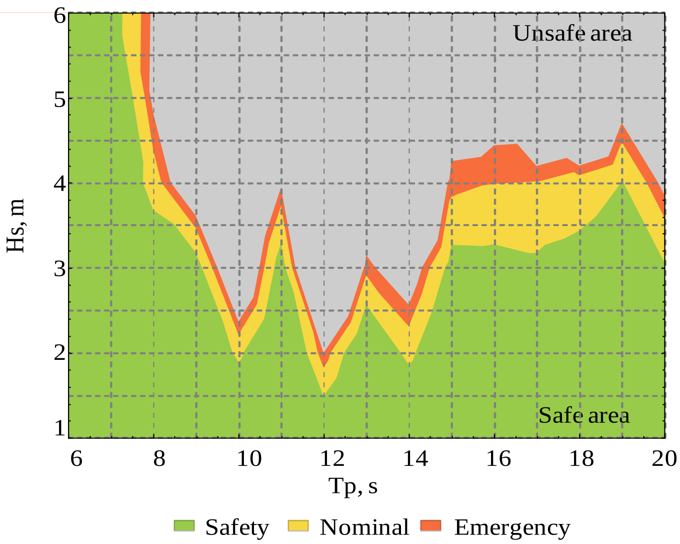

Figure 14. OCOLD excluding limitation of Hs.

The allowed value of Hs expands significantly compared with OCOLD considering limitation of Hs (Figure 13), mainly below 9 seconds and values above 15 seconds, showing that when the wave period is outside the range of resonant periods of the FPSO and crane cable, it is possible to use larger wave heights without compromising the safety of the operation for the analyzed case.

Offshore Container Lifting Operation

For lifting the offshore container, the procedure is analogous to lifting personnel, making the adoption of appropriate operational limitations. In this case it is not necessary or usual the establishment of emergency or safety operations, since nominal values of limits already includes the factor of safety for each component of lift.

It is shown in Figure 15 intermediate operating limit diagram with contours for offshore container lifting, for nominal operation considering the limitation of Hs. One note that the limitation, for periods for less than 11 seconds is given by the speed, up to 15 seconds it is given by DAF, up to 18.4 seconds, by roll movement and above this valve DAF is limiting again.

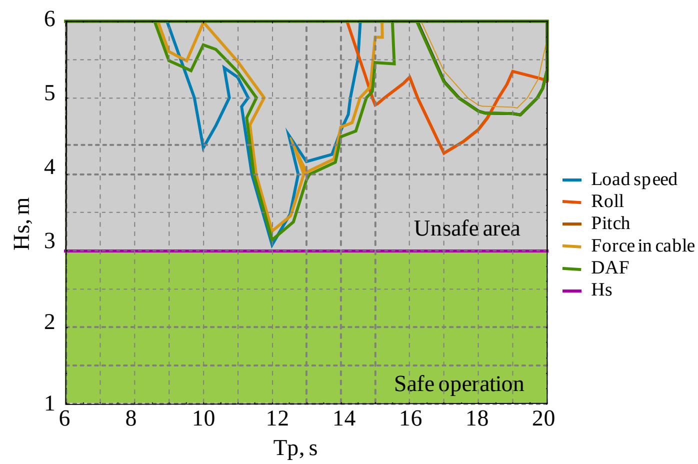

Figure 15. OCOLD including limitation of Hs, configured to lift general cargo.

Figure 16 shows the OCOLD without limitation Hs, suggesting high operating clearance with Hs extension beyond the crane load chart.

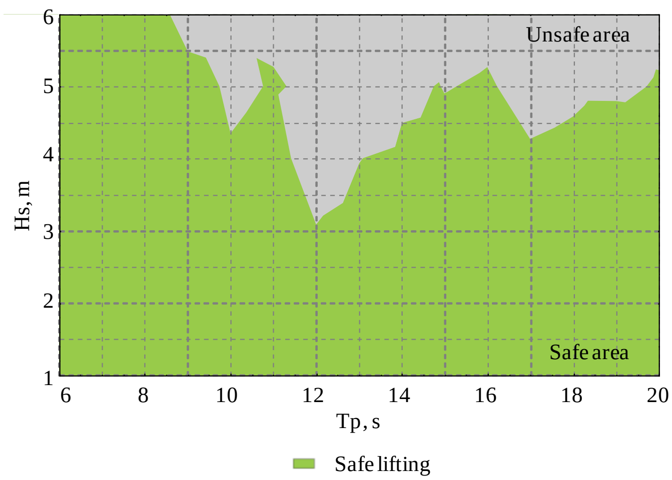

Figure 16. OCOLD excluding limitation of Hs, configured to lift general cargo.

PRACTICAL APPLICATIONS

Next are presented two practical applications of OCOLD developed using the methodology described above for typical situations in offshore platforms.

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Application 1

It is assumed that an offshore platform needs to perform the lifting one person. The peak wave period (Tp) measured by the radar installed on the FPSO ranges from 8 to 9 seconds and Hs ranging from 2.0 to 3.1 meters, depending on the wind speed. It should be checked whether it is possible to perform this operation for safety situation.

Application 2

The FPSO is subjected to incidence of swell and sea with Tp ranging from 16 to 17 seconds and Hs ranging from 3.5 to 4.1 meters. Due to a medical emergency, because of an accident in supply boat that serves the unit, a crew member needs to be carried on board the FPSO. It should be checked whether it is possible to perform this lifting operation in emergency situation.

Solution

Figure 17 of shows the OCOLD with limitation Hs and operational areas (Hs and Tp ranges values) for the proposed applications.

It can be seen in Figure 17 that in both applications one can't do the lifting. In Application 1, the minimum measured value Hs is equal to the Hs of the safety operating limit, prohibiting the operation. In the second application, due to Hs restriction, the operational area is completely in the unsafe region, also impeding the operation.

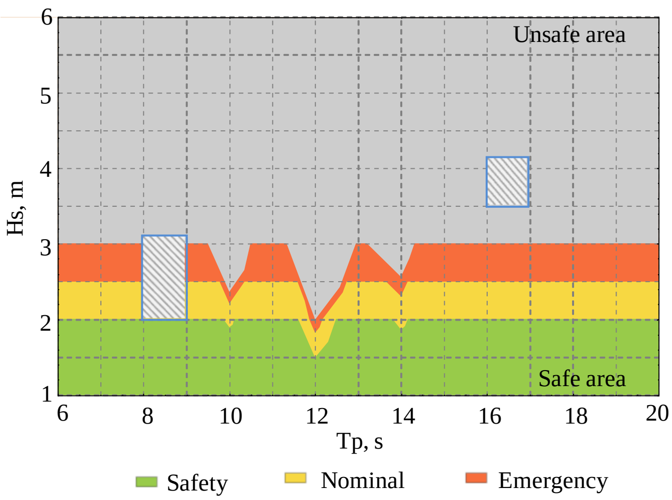

Figure 17. OCOLD including limitation of Hs, configured to lift personnel, highlighting the necessary area for each application.

Figure 18 shows the OCOLD without Hs limitation, expanding the permissible values, making the two operations possible.

Figure 18. OCOLD excluding Hs limitation, configured to lift personnel, highlighting the necessary area for each application.

CONCLUSIONS

As in most of cases, lifting operations do not consider the effect of wave period and other important factors, it is concluded that OCOLD can improve the safety of offshore lifting operations showing that an operation would be risky if not considering all parameters involved in lifting. By the other hand, OCOLD can optimize the use of equipment and provide a wider weather window, allowing operations that a simple analysis would not permit.

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REFERENCES

[1] STANDARDS NORWAY. NORSOK Standard R-002: Lifting equipment. Lysaker, Norway, 2012.

[2] CATHERALL, Roger. Incidents with marine personnel transfer. Aberdeen 2013, available: http://www.reflexmarine.com/industry-expertise/crew-transfer-safety/ accessed 14-May-2014.

[3] RONCETTI, Leonardo. A software do design and management of lifting operations for shipbuilding and offshore construction. In: Pan American Conference of Naval Engineering, Maritime Transportation and Ports Engineering, 2011, Buenos Aires.

[4] JACOB BP, BAHIENSE, R.A., CORREA, F.N., JACOVAZZO, B.M., 2012a. Parallel Implementations of Coupled Formulations for the Analysis of Floating Production Systems, Part I: Coupling Formulations. Ocean Engineering 55 206-218, doi: 10.1016/j.oceaneng.2012.06.019.

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[5] RONCETTI, Leonardo. 2014. Development of operational limit diagrams for offshore lifting procedures. (In Portuguese). Dissertation (Master's degree in Civil Engineering) of COPPE/UFRJ, Rio de Janeiro, Brazil.
[6] LANGEN, I., THAN, T. K., BIRKELAND, O., RØLVÅG, T. Simulation of dynamic behavior of a FPSO crane. Paper. 2003.
[7] International Organization for Standardization ISO 19901: petroleum and natural gas industries - Specific requirements for offshore structures, part 6: Marine operations. Geneva, 2009.
[8] National Aeronautics and Space Administration (NASA). Issues on human acceleration tolerance after long-duration space flights. Technical memorandum. Houston: NASA, 1992.
[9] International Marine Contractors Association (IMCA). Guidance on the transfer of personnel to and from offshore vessels: IMCA SEL 025, IMCA M 202. United Kingdom, 2010.

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