An Approach of Stability and Motion Response Analysis of an FPSO to Consider its Global Performance

Ricardo Barreto Portella, *PROJEMAR*

Victor de Andrade Kameyama, *PROJEMAR*

Cristiane Mendes Freire, *PROJEMAR*

Roberto de Oliveira Goulart, *PETROBRAS / CENPES*

ABSTRACT

For a Floating Production Storage and Offloading (FPSO) intended to operate as a permanent unit at a fixed location, a complete dedicated design in terms of motion response and vessel stability has to be performed considering the specific site conditions in order to analyse the expected operational behaviour of the vessel.

The main idea here is to obtain a combination of stability limits for an FPSO unit with the predicted motion analysis for typical operation conditions, defining an operational region where the FPSO shall be maintained in order to guarantee that the global performance will be in accordance with the predicted analysis. Based on the minimum GM curve derived from intact and stability analysis, new maximum and minimum GM curves are derived based on mass properties combinations where the motion response will be permanently inside the design parameters.

Keywords: *FPSO; Stability; Motion Analysis; Global Response*

1. INTRODUCTION

Reviewing the usual procedures adopted to conduct stability analysis and global motion response analysis of FPSOs / FSOs, one realizes that the stability analysis normally considers the Unit as a ship calculated for unrestricted service. On the other hand, the global motion analysis normally considers the Unit as a permanent floating structure under the action of the specific site environmental conditions.

It is easy to understand that the stability of a ship-shaped offshore unit shall be similar to the stability limit of a ship with the same hull forms, but the motion analysis is normally performed for the expected operational load conditions, not for the stability limit of the unit.

For offshore floating units that are not able to store oil on board, like a semi-submersible platform, the stability limits are quite close to the expected load conditions, as there are few possibilities to vary the load of the unit and the mass properties do not change very much.

On an FPSO, the oil storage capacity weight is much larger than the vessel lightweight and consumables combined. The different possible combinations of the cargo tanks loading can result in considerable different mass distributions for the same draft.

This paper describes a procedure that was used on the global motion and stability analysis of the FPSOs / FSOs, where the main idea is to define operational limits for the cargo loading in order to assure that the vessel operates under the parameters considered during the design phase.

2. MOTION ANALYSIS

The intent of an FPSO motion analysis is to evaluate the global motion performance of the Unit when operating at the designated under the design environmental conditions.

Normally a 3D diffraction analysis is required for a motion analysis. The basis of this calculation is the diffraction / radiation method, which calculates frequency dependent hydrodynamic coefficients, waves excitation forces and moments by the use of a three-dimensional source/sink distribution technique, where the amplitudes and phase angle of the dynamic motion responses of the unit are calculated for the six degrees of freedom.

Due to the non-linearities involved on the motion motions response of a large displacement unit, the hydrodynamic model has to be calibrated with, preferably, results obtained in model tests.

Comparing the motions Response Amplitude Operations (RAOs) of a ship shaped large displacement FPSO obtained in a regular waves model test program with those obtained on analytical programs normally quite reasonable differences are found especially regarding the roll motion response.

Bilge keels, risers and mooring systems are strongly related to the motions damping and are their contribution to the overall damping is very difficult to be analytically obtained. The use of model tests as a comparison tool to help the understanding of the physical phenomena, or at least to obtain adjusting coefficients, is up to now the most reliable way to obtain analytical motion results consistent with the FPSO motion behaviour.

Figure 1 illustrates a 3D panel model used for the hydrodynamic analysis of an FPSO unit, showing that a more detailed mesh is a indicated for the area close to the sea surface and for the region where the hull shape is strongly modified (change on the normal vector).

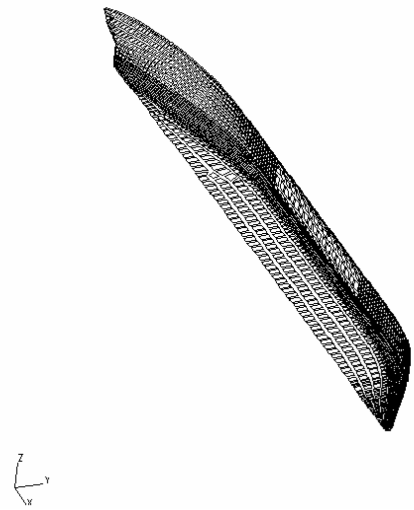

Figure 1 – FPSO 3D panel model

The design Environmental conditions used on the analysis shall be obtained for the specific site where the unit is intended to operate. The design wave frequency motion responses shall be derived considering all the main compass site environmental directions. In some cases, additional verifications shall be performed for the occurrence of swell conditions, where the amplitude of the waves are smaller than the extreme sea states, but as these waves have longer periods that are closer to the FPSOs natural periods, the amplitude of expected motion response can be much larger.

3. MODEL TESTS

To calculate an FPSO global motion response is not an easy task, even using the most advanced software available on the market.

In view of this, model tests are usually required to confirm the effectiveness of the mooring system, to verify the global motion response and to provide data for analysis software calibration.

From extensive model tests programs where calibrations for analysis software were tried to be obtained, it was observed that the FPSOs roll motion behave as described by Himeno, i.e., the roll damping is not merely a quadratic nonlinear form, but it depends on the roll amplitude and on the frequency in a much more complicated manner. A behaviour that is not easy to calculate using the normal software available in the market.


Figure 2 –FPSO Model Tests

4. STABILITY ANALYSIS

The ship stability analysis has to be conducted based on the Resolutions IMO A-749 [1] and on the Mobile Offshore Drilling Units Code (MODU Code) [2], analyzed as a surface unit. Basically the design criteria are the same applicable for ocean going ships on unrestricted service.

The operational loading conditions considered on the stability analysis are defined to cover the normal sequences used for loading / unloading of the FPSO. Operational practice sequences, with typical tanks filling, are considered according to the owner practice.

Damage stability analysis are conducted to verify the aspects of the ship stability in damage conditions, in accordance with the 1966 ILLC Reg.27 [3] criteria, MARPOL 73/78 (including MEPC 14 (20) Resolution) [4] criteria and IMO - 1989 MODU Code [2] criteria.

Normally, a Maximum Allowable KG curve is obtained for the Unit in a hypothetical even keel condition based on the intact and damaged stability limits in order to allow a quick evaluation of the stability for any loading condition.

This curve is the base for the development of the operational limits of the FPSOs that combine not only the FPSOs stability, but also the hull girder strength and the global motion response.

4.1 Maximum and Minimum Allowable KG Curves

Maximum and minimum allowable KG curves are proposed in order to define an operational behaviour where the vessel will keep its global motion response inside the parameters considered for the FPSO design.

Based on the expected loading conditions and the stability limits defined, three (3) parameters, shall be taken into account to define reasonable limits for the KG of the operational loading conditions:

First, is the lightweight estimation, witch can vary upwards or downwards during the design and construction of the FPSO. This is especially important in a conversion, where it is considerably difficult to have consistent lightweight estimative on the beginning of the FPSO design.

Second are the variations on the tanks filling that can significantly modify the loading condition centre of gravity and radius of gyration.

Third, inside reasonable operational limits, are the extreme conditions that could result in excessive motions (due to high KGs) or accelerations (due to low KGs) shall be avoided.

The combination of these three (3) parameters with the maximum allowable KG curve derived directly from the stability analysis are the basis of the development of the "extreme" loading conditions to be considered as the design limits in terms of the vessel global motions response.

These conditions shall be verified in terms of trim, stability, shear forces and bending moments to be realistic loading conditions and their radius of gyrations shall be calculated accordingly to calculate correct global motion responses.

4.2 Calculation Methodology and Criteria

The main idea is that the maximum and minimum allowable KG curves shall be constructed to guarantee an adequate operational behaviour for the FPSO during its normal operation.

The following methodology and associated criteria is being proposed to establish adequate limits to compose the maximum and minimum allowable KG curves:

- A complete loading / offloading sequence of loading conditions with adequate trim shall be defined based on the expected lightship weight of the unit showing compliance with the maximum allowable hull girder shear forces and bending moments.
- For each loading condition (for each operational draaught) defined by the FPSO loading / offloading sequence, a variation on the oil distribution shall be performed to obtain maximum and minimum KG and Rxx possible to be obtained for each draught. The loading conditions shall be limited by physical and operational limits, in particular maximum allowable shear forces and bending moments and maximum operational trim / heel;
- A potential upper and lower lightship weight vertical moment variation, which is considered possible to occur during the FPSO construction shall be defined;
- Compliance with the stability limits shall be checked for the allowable KG upper bound limit.
- In order to define adequate upper and lower KG limit curves, combinations of several FPSO operational drafts shall be evaluated, covering the total range of possible operational loading conditions.
- For each loading condition, different tank filling scenarios are evaluated to generate the most onerous upper and lower bound loading conditions KGs.

Figure 3 shows an example of the composition that leads to the upper and lower KG limit curves and figure 4 an example of the maximum and minimum KG curves witch define the upper and lower bounds where the FPSOs shall operate to be in compliance with the adopted design criteria. Being loaded inside these limits the FPSO shall operates covered by the premises established during the design phase.

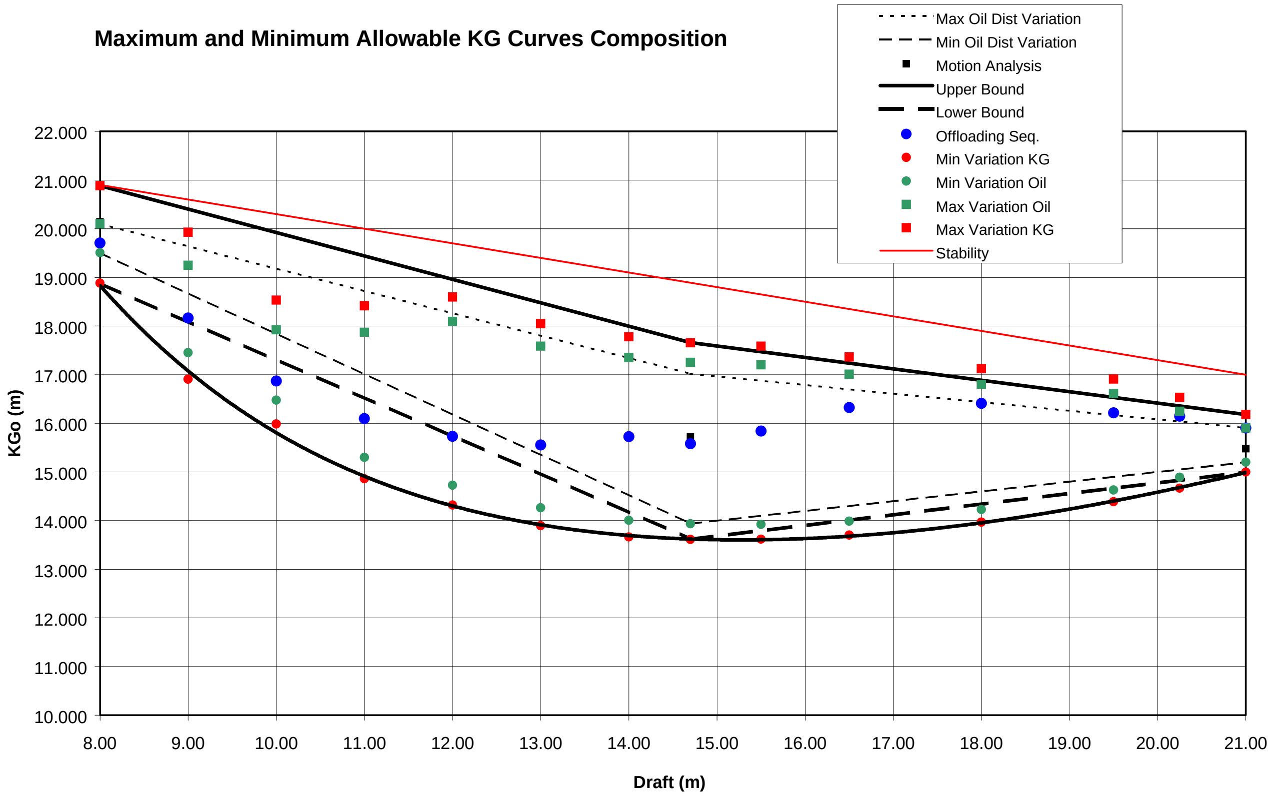

Figure 3 – Allowable KG Curves Composition

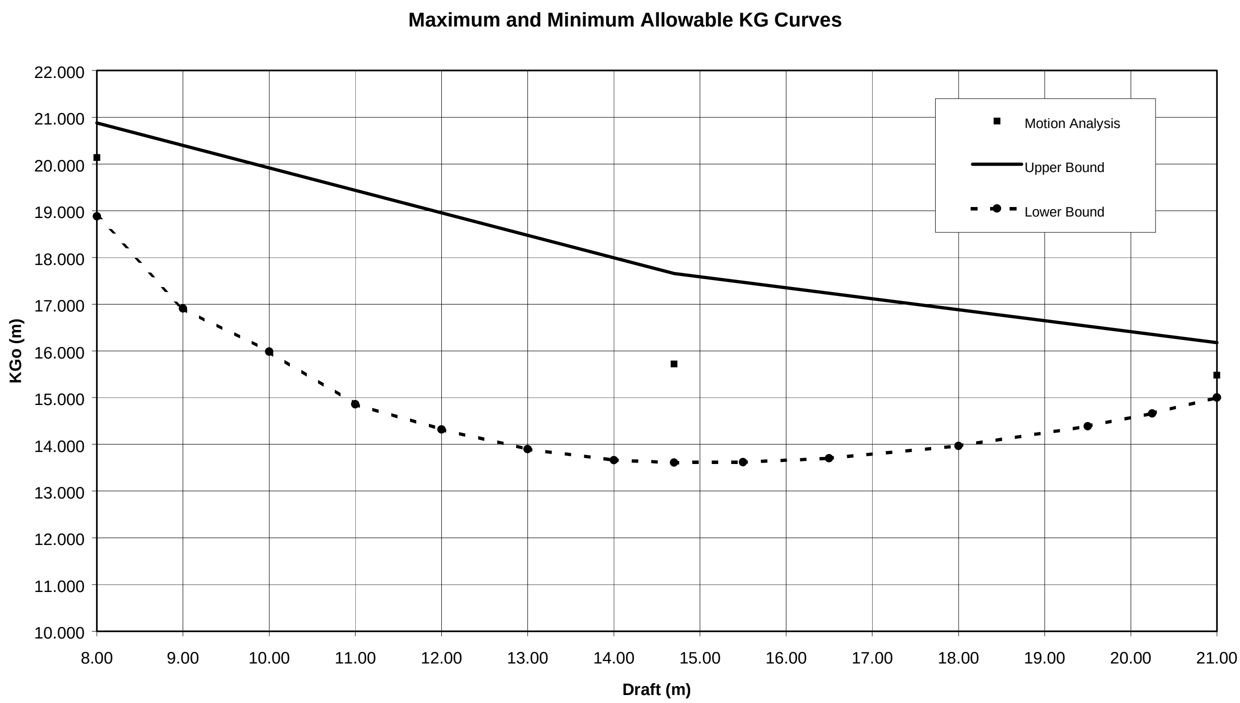

Figure 4 – Maximum and Minimum Allowable KG Curves

5. DATA FOR STRUCTURE, MOORING AND RISERS ANALYSIS

To assure that the complete FPSO design is in line with the operational range defined by the motion and stability analysis it is necessary to provide adequate data to be used on the correlated analysis.

The FPSOs structure, mooring and risers analyses shall be feed by the motion analysis results with acceleration values and motion transfer functions. These are to be in line with the expectations of the global motion analysis, and shall cover what we call the "feasible operational range". To do this, two (2) additional sets of motion data, one related to the maximum allowable KG curve and one related to the minimum allowable KG curve, shall be calculated for each design loading condition. Acceleration values and motions RAOs shall be determined be determined considering both curves in order to be used as input data on the correlated analysis.

In order to guarantee the integrity of the FPSO structure, the hull structure design including the global structure analysis and the process plant structure design shall be conducted considering the higher loads derived from the complete set of design load conditions obtained on the FPSO motion analysis, which includes the maximum and minimum KG curves.

On the same way, the mooring system design and analysis and risers system design and analysis shall also be verified in order to assure that both systems will work properly when the FPSOs experience any load condition inside the operational range.

6. MAIN CONCLUSIONS

The calculation methodology proposes basically to combine the Global Motion Analysis and Stability Analysis of an FPSO Unit in order to obtain design parameters that will be in line with the expected operational behaviour of the Unit.

This approach was used on the FPSOs P43 / P48 projects and was considered a step forward that ensured that the operational motion response of the FPSO when in the field would be within the expected motion response used in the engineering design.

The FPSOs P43 and P48 are the two first VLCC units with a spread mooring system to operate in Campos Basin, where is subjected to the action of a quite complex environment that includes direct beam sea conditions and bi-modal sea states. After the installation of the two Units the first notice received from the field indicates that the FPSOs has a very good motion behaviour and the observed motions response are very much in line with the values predicted during the design phase, showing the efficiency of the adopted methodology.

The use of this methodology resulted in the identification of loading conditions that otherwise would not been taken into account during the FPSOs structure design and also to identify and to eliminate potential resonant loading conditions that would lead the FPSO to motions higher than those used during the design.

Considerations of the FPSO operational and stability limits during the global performance analysis allow both the structure and equipment to be dimensioned for the most onerous loading conditions that may not otherwise have been captured.

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