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A Direct Calculation Approach for Designing a Ship-shaped FPSO's Bow Against Wave Slamming Load

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ABSTRACT

Wave slamming is a recognized hazard to FPSOs. Severe slamming may cause damage to structures and possible flooding of compartments. The consequences of wave slamming can be mitigated through a combination of enhancing structural design and implementing preventative operation procedures. The design of a FPSO is dependent on the installation site. This requires direct calculation tools, however a complete analysis system does not seem to be available. This paper presents a direct calculation approach, which may be used for designing shell scantlings of a FPSO's bow against wave impact loads. This approach includes determining ship motions relative to waves, calculating wave slamming pressure, analyzing structural responses, and judging acceptance of a design. This approach is based on some engineering programs and analytical formulae; therefore, it is also a practical engineering analysis methodology. Its practicability is demonstrated by applying it to the design of a FPSO's bow for three different installation sites. The approach is applicable to both new constructions and conversions, and can be used for investigating damages due to wave slamming.

KEY WORDS: FPSO; risk mitigation, slamming, impact, plastic deformation.

INTRODUCTION

Hydrodynamic impact loading accounts for more than 10% of structural damages for conventional vessels. It has been a design consideration to prevent such damages and/or minimize the resulting consequences. Major classification societies have established rules to address slamming for commercial ships, which are based on experiences and many investigations using first principal technology.

More and more ship-shaped FPSOs are seen in offshore

oil exploration. They are similar in many ways to oil tankers. Wave slamming may also cause damage to hull structures. Damages were reported in FPSOs' bow structures that are believed due to the severe slamming load (MacGregor et al. 1999). Relevant design standards generally rely on long-term experiences gained from commercial ships (e.g., ABS 2000).

A FPSO is to serve a specific field for a specific time span, which is different from commercial ships generally designed for unlimited services of approximately 20 years. Because of this mission and site dependency, it is not fully justified to apply the experiences of oil tanker designs to FPSOs. Direct calculation approaches provide more detailed information with respect to specified service life and installation sites, and are, therefore, more suitable to be used as design tools for FPSOs.

A direct calculation approach to help design for slamming does not seem to be available in a complete form. The purpose of the present study is to present a direct calculation approach, which may be used in the design stage. The engineering methodology uses a series of practical engineering tools to calculate both loads and structural responses, based on which structural scantlings may be determined.

RISKS

Wave slamming is a recognized hazard for FPSOs. Severe wave slamming may cause indentation or rupture of shell plating, buckling or detaching of supporting members, significant deformation of main supporting members, collapse of bow structures (forecastle, members supporting mooring systems), or collapse of hull girder. These structural damages may result in flooding of some compartments, damage to topside equipment, deck houses or others mounted on/near the bow, damages to mooring systems, or loss of the entire vessel.

Figure 1 shows a profile of a FPSO's bow and portion of its No.1 Tank. The shadowed area is where hull structures are probably susceptible to wave slamming damage.

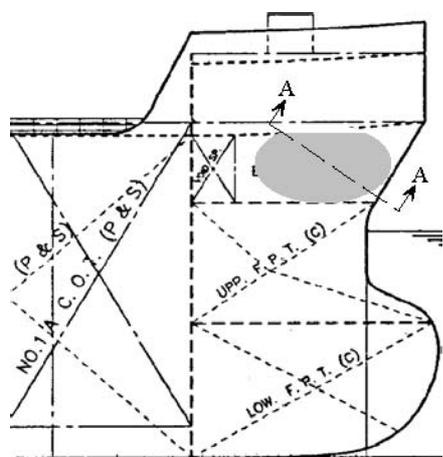


Figure 1. Bow and No. 1 tanks typical of a FPSO (The shadowed area is susceptible to wave slamming damage. Refer to Fig. 3 for reference to AA section in the case study)

Indentation and rupture of shell plating and severe local deformation of supporting members are very likely. Indentation of shell plating is the most frequently reported. Design for minimizing this damage requires reinforcement to shell platings, or increased steel weight, which also has economic consequences.

Failure of main supporting members may be likely. Relatively speaking, there are fewer reports on heavily deformed web frames and stringers, though local buckling of web plates between stiffeners is seen in some damage reports. There are very limited design standards regulating the global strength of main supporting members and the entire bow structure for possible impact loads.

Failure of hull girder due to slamming induced loads is the least likely for FPSOs of ship shape, though the consequences are the severest. For many vessels of tanker shape, the hull girder forward of the midship portion has a certain safety margin above the increased longitudinal bending moment due to the slamming loads.

For a FPSO stationed in a specific site, towing it away to avoid an extreme environmental weather condition is not an option. If turret moored, a FPSO will see increased likelihood of being subject to larger wave slamming loads, as it heads against the weather. A severe wave-slamming episode cannot be avoided. Practically, the consequences of a slamming can be mitigated through a combination of enhancing structural design and implementing preventative operational procedures.

This study addresses the design of shell plating against slamming pressure. This is a hazard of high frequency that may lead to possible flooding of fore peak compartments, a risk to the persons working there and the equipment etc. stored in these compartments. Impact pressure considerations for other structural members, such as frames, stringers and decks, are relatively less critical than for shell plating, though important for overall structural integrity. Similar direct calculation approach is possible, but is not discussed here in this paper.

A DIRECT CALCULATION APPROACH

A direct calculation approach starts with a seakeeping analysis to calculate the maximum relative velocity of the ship relative to waves, a wave impact analysis to determine the design slamming pressure, and applies this load to the structural design to obtain the structural responses. The design is evaluated according to the limits prescribed to the maximum structural responses and the allowances for corrosion wastage.

This section is a brief outline of the proposed direct calculation approach. Many details of every analysis steps are described in the following sections. This direct calculation approach is also a practical analysis system, as it uses some engineering programs and easy-to-use analytical formulae.

The practical engineering analysis system used in this study includes PRECAL (NSMB CRS 1998) for ship motion analysis, CRSLAM (NSMB CRS 1996) for slamming pressure, and a closed-form formula for structural response, which are accompanied with an acceptance criterion for judging the structural scantlings. The most probable extreme value for relative velocity is determined using SPECTRO (ABS 1999).

Approximately, the slamming pressure can be expressed as the following equation (Ochi 1973):

$$p = \frac{1}{2} \rho k v^2 \quad (1)$$

where, p is the slamming pressure, ρ is the density of water, k is the local pressure coefficient, v is the relative velocity between the FPSO's bow surface and waves.

This equation is used here for representing the time history of slamming pressure, a sample of which is in Fig. 2. The local pressure coefficient k is a function of time and location; it is, by definition according to Eq. (1), given by dividing the time history by $0.5\rho v^2$.

The key to the prediction of the velocity relative to waves is the calculation of the vessel's motion at bow, which can be obtained through a seakeeping analysis. The rigid body motion theory for a ship in waves gives

a fairly accurate estimate of this relative velocity. The extreme values for the relative velocity can be obtained using statistics theory. Site-specific wave data, wave spectrum, and exposure time are taken into account in this step of analysis.

The local slamming coefficient k correlates the relative velocity with the slamming pressure. This can be calculated using theories developed from tests on dropping symmetrical ship sections on to calm water. The calculated k is averaged over the extent of a plate panel, which becomes relevant to a structural strength analysis.

Maximum deformations of shell plating are used to measure the magnitude of structural responses, as most probably a severe slamming causes plastic deformation in shell plating. The maximum deformations depend to a large extent on the peak slamming pressure. Extensive studies have given very useful information. Some close form solutions are available.

The acceptance criterion is based on structural responses in term of the maximum deformation, or the load-carrying capacity. Also, this criterion needs to address corrosion wastage. The criterion may be deterministic or probabilistic, and may be selected based on risk analysis of possible consequences.

With a direct calculation approach, a design can be judged on a more realistic scale. The major advantage is that loads reflect the site-specific environmental conditions, which can not be fully prescribed by design standards that are mostly "generic".

RELATIVE VELOCITY

The relative velocity in Eq. (1) refers to the one normal to the section that is of interest. Equation (1) is based on studies of dropping tests on a calm water surface. Most of these dropping tests measured the relative velocity in a vertical direction, which is the same as the velocity of the dropping object since the water is at rest. Applying the methodology developed from these dropping tests requires us to use the velocity component normal to the section analyzed.

The relative velocity at a specific location mainly comes from the vessel's motion that is a result of all six degrees of freedom, including pitching, heaving, rolling, etc. A vessel's relative velocity at bow can be calculated using PRECAL, a linear 3D panel code based on wave diffraction theory. It analyzes a vessel's motion, and calculates the regular wave Response Amplitude Operators (RAOs) for relative velocity at the vessel's bow, and many other parameters that are related to the hydrodynamic performance of a ship in waves.

By applying extreme value analysis (Ochi 1973), the magnitude of the most probable extreme relative velocity for design purpose can be predicted. This would give the largest impact pressure most likely to occur, as Eq. (1) shows that the largest relative velocity corresponds to the largest slamming pressure. The relative velocity becomes the maximum when the vessel's bow is pitching down into a wave trough.

The relative velocity will be strengthened because of the wave motions of fluid particles. In an open sea, a vessel's velocity relative to a wave is not the same as that to fluid particles. It is the fluid particles that impact a vessel bow. It collides with the vessel's bow at a higher velocity, producing a higher level of impact pressure. The relative velocity between a vessel and fluid particles is more relevant for a wave slamming.

There are two types of laboratory tests: drop tests and wave tests. In a drop test, a ship section is dropped into calm water, under which surface the fluid particles do not move. The dropping object's velocities relative to the water surface or to fluid particles do not differ.

These two components, the vessel's relative velocity at bow and the velocity of fluid particles, are the major contributions, and are, therefore, considered in the present analysis. Other velocity components, such as that in the vessel's transverse direction, are not considered if the severest wave slamming takes place when the vessel heads into the weather.

Components from ship motion and fluid particles are projected to the plane perpendicular to the analyzed section, and the relative velocity normal to this section is obtained, which is the v in Eq. (1).

SLAMMING PRESSURE

Most pertaining analytical studies treat a wave slamming impact as a two-dimensional wedge falling on to calm water. Comprehensive surveys of the state-of-the-art are presented by Jensen et al. (2000), Faltinsen (2000) and Shin (2000). Advanced numerical solutions such as Xu et al. (1998) give satisfactory predictions of the time history and spatial distribution of the impact pressure in a slamming process. Some of these numerical methods have been applied in investigations of slamming damage and development of relevant design standards; many are regarded as being very efficient.

Among all available methods, those that require limited data preparations are preferable and can be included in a direct calculation analysis approach. The boundary element method can be used. The numerical method predicts the slamming on blunt bodies that penetrate an initially calm free water surface. The problem is

formulated in the time domain solving a boundary value problem at each time step. Given the body geometry, initial inclination and relative velocity, the slamming pressure can be calculated which is a function of both time and space. This pressure, when averaged over the extent of a plate panel of shell plating, becomes relevant to the behavior of plate panels of shell plating.

Figure 2 shows a typical time history of pressure that is averaged over the extent of a plate panel, which will be used in structural response analysis. The time history of slamming pressure is characterized by a rapid rising peak and a decaying tail, which is averaged over the extent of a plate panel.

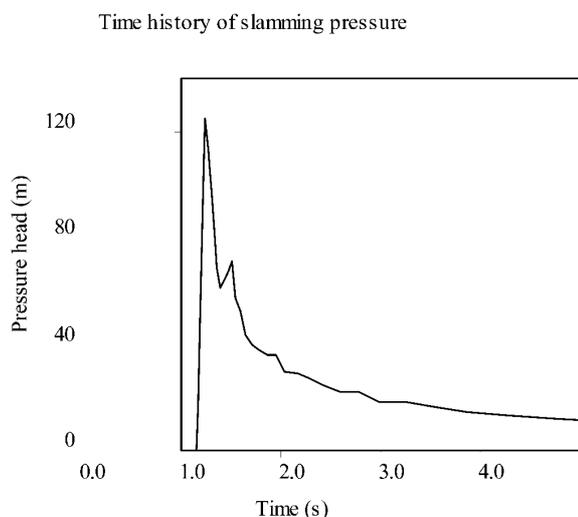


Figure 2.

A typical time history of slamming pressure.

STRUCTURAL RESPONSE OF IMPACTED PLATES

For a structural response analysis, a time history of slamming pressure may be idealized as a rectangular or triangular pulse, or an exponentially decaying pulse; the last can be replaced by either of the first two. These idealized pressure models (rectangular and triangular) need two parameters to define, i.e., peak pressure and duration. Under certain circumstances, a rectangular impulse gives almost the same maximum structural response, which does not show large dependence on the duration of the pressure impulse (Paik et al. 2000).

Shell plating that is exposed to water slamming may have permanent set-in; the shell plating dishes in between longitudinals and web frames. The damaged plate exhibits highly inelastic behavior, and the stresses in some portions of shell plating exceed the material's yield stress. The material may be treated as elastic-plastic or rigid-plastic in analysis. When the impact energy is much larger than the elastic strain energy, the response of a plate is similar with either elastic-plastic or rigid-plastic material. For many wave-slamming

cases, this condition is satisfied, and a rigid-plastic method is regarded as very efficient. In fact, the rigid-plastic method has demonstrated good agreements with many experiments.

With the rapid advances in FEM techniques and computer technology, numerical simulations emerge as very powerful tools and have been reported more and more frequently (e.g., Caridis and Stefanou 1997, Lee et al. 1998). Many commercial FEM softwares give reliable results for impacted plates. As a promising alternative to a rigid-plastic method that predicts mostly the global behavior, such as the permanent deformations, a numerical approach gives additional information such as strain and stress distributions within the plate, and captures the vibratory changing patterns of responses. Nevertheless, the magnitude of the permanent deformations is of a major concern, and predictions by a rigid-plastic method and a numerical method are not widely different for many cases.

Before embarking on analytical solutions, it is necessary to decide whether the problem can be treated dynamically or quasi-statically. A simple criterion has been established that is based on comparing the impulse duration with the plate's natural period. If the impulse duration is longer than the natural period of the impacted plate, the response of the plate is expected to be static. If the reverse is true, the response will be dynamic. Analytical solutions are available for these two different cases (Jones 1973).

A wave slamming lasts ten to several hundred milliseconds. The natural period of a plate panel of shell is several milliseconds or shorter. The surrounding water increases the natural period of the plate, but this increased period is still shorter than the slamming duration. It is found that the response of shell plating is probably quasi-static. The peak pressure of a slamming impulse is, therefore, the most relevant, and the duration can be left out of discussions.

SOLUTIONS TO STRUCTURAL RESPONSES

This section describes analytical solutions to structural responses of shell plating. The same for frames, stringers and decks is possible, but is not explored here.

Under the impact of wave-slamming, shell plating deforms between the supporting members. The supporting members are generally designed to provide enough support to shell plating, and not fail prior to shell plating. Because of this, the assumption of being clamped at all edges is used when analyzing the behavior of a plate panel of shell.

A rectangular plate collapses in a shape very similar to a roof. The theoretical collapse model for the entire plate consists of two triangular regions and two

trapezoidal regions. These four regions behave as rigid bodies separated by plastic hinges. An upper solution has been derived to the static collapse load of a fully clamped rectangular plate (Jones 1989):

$$p_c = \frac{48M_0}{b^2(\sqrt{\beta^2 + 3} - \beta)^2}, \quad (2)$$

where, p_c is the static collapse pressure of the plate, M_0 is the plastic bending moment per unit length given by $M_0 = \sigma_0 t / 4$, β is the aspect ratio given by $\beta = b/a$, σ_0 is the material's yielding strength, and a , b , and t are the plate's longer and shorter edges, and plate thickness, respectively.

This analytical solution is valid for infinitesimal displacements where the governing equilibrium equation is obtained using the original undeformed configuration. A slamming impacted plate panel may be displaced considerably from its initial position, and the slamming pressure may be larger than the static collapse pressure. The equilibrium equation for infinitesimal displacements no longer controls the behavior, and the influences due to finite displacements should be accounted for.

An approximate solution has been derived (Jones 1989) for a fully clamped rectangular plate subjected to a uniform pressure, taking into account geometrical changes and membrane forces:

$$\frac{p}{p_c} = 1 + \left(\frac{W}{t}\right)^2 \frac{\xi_0 + (3 - 2\xi_0)^2}{3(3 - \xi_0)} \quad \text{for } \frac{W}{t} \leq 1, \quad (3a)$$

$$\frac{p}{p_c} = 2\left(\frac{W}{t}\right)\left(1 + \frac{\xi_0(\xi_0 - 2)(1 - t^2/3W^2)}{3 - \xi_0}\right) \quad \text{for } \frac{W}{t} > 1, \quad (3b)$$

where, p is the uniform external pressure, p_c is the static collapse pressure of plate determined by Eq. (2), W is the maximum permanent deformation of the plate, $\xi_0 = \beta(\sqrt{\beta^2 + 3} - \beta)$, β and t are the same as in Eq. (2).

Though the response of a slammed plate panel can be efficiently treated as quasi-static, the dynamically changing pressure causes changes in the material's properties. In an impact, the strain rate increases compared to a static load, which in turn causes an increase to the material's yield strength and a decrease to the rupture strain.

It is recognized that including the material's strain rate sensitivity to a static solution would adequately account for the influences from a dynamic impulse. It is convenient to substitute the yield stress in Eq. 2 with a value that is determined based on an averaged strain rate in the impacted plate. One such formula is the

following (Paik et al. 2000):

$$\frac{\sigma_{od}}{\sigma_o} = 1.0 + \left(\frac{V_o W}{12\sqrt{2} \cdot H b^2}\right)^{1/q}, \quad (4)$$

where, σ_{od} is the estimated yield strength taking into account the material's dynamic effects, σ_o is the material's yielding strength under static condition, V_o is the initial velocity of the plate, H and q are coefficients empirically determined based on test results. Values of H and q are 40.4 / second and 5 for mild steel, and 3200 / second and 5 for high tensile steel, respectively.

For shipbuilding steel, the strain rate sensitivity has a limited effect on the yielding strength, and may be ignored. This gives a relatively conservative estimate of strength.

MAXIMUM PERMANENT DEFORMATION

A limit to the maximum permanent deformation provides a means to decide the acceptance of shell plating thickness. Excessive permanent deformation produces a very high strain within a plate and large membrane forces, which have to be held by adjacent supporting members. Rupture of shell plating may result, or failure of supporting members.

A panel of shell plating develops a membrane state to hold the large wave impact load. These mechanisms have been acknowledged to be advantageous. The lower bound for the acceptable permanent deformation is a half plate thickness. Deformations less than this are more relevant to the bending capacity of the plate, and deformations beyond this are associated with membrane stresses.

Some tend to accept permanent deformation as large as 1.5 times plate thickness. This seems to be the largest that can be viewed as acceptable for designs for normal operation conditions. Of course, steel plates can extend extensively and sustain deformations much larger than plate thickness (Wang 2002). However, this extensive plastic deformation capacity is only useful for casualty operations, when the structures are expected to absorb impact energy in accidents such as a collision or grounding (Wang et al. 1999, 2001).

It would be very helpful to know the permanent deformation corresponding to rupture occurrence. Very detailed distribution of strain incurred in a plate has to be known in addition to a gross value of strain. Numerical solutions are required in order to obtain detailed distribution of strain, based on which correlation between local rupture with global deformation can be derived. But it is not likely that a

plate will rupture when its maximum deformation is 1.5 times the plate thickness.

Shell plating with permanent deformations of about 0.5 to 1.5 plate thickness can carry lateral loads from water pressure.

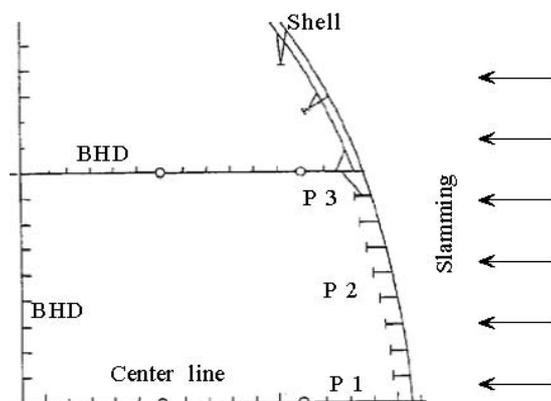


Figure 3.

The A-A section cut from the FPSO's bow

CORROSION ADDITION

Thickness reductions due to corrosion are not avoidable for marine structures. As a design allowance for this structural deterioration, a corrosion addition is usually added to the plate thickness determined based on design loads. Traditionally, corrosion additions in design standards are based on experience. A recent trend is to use risk analysis techniques to analyze gauging data. Results of these studies shed light on the risk levels embedded in the present design standards, which eventually will lead to improving related design standards.

Ship-shaped FPSOs are new with limited history; extensive data and experiences are not available. Practically, corrosion additions for tankers provide a good source, which may be applicable to FPSOs for certain situations.

Many factors to be considered include the vessel's service life (and the trading history if it is a conversion), coating system, coating application procedure, usage of internal compartments, inspections and maintenance, etc. Proper values for corrosion additions are not yet established.

ACCEPTANCE CRITERIA

In a deterministic format, a structure should be designed to have the strength (capacity) greater than the loads acting on it (demand). The slamming pressure is determined according to Eq. (1). The capacity can be assessed using Eq. (3) if the finite displacement is allowed for, or Eq. (2) when the collapse of the plate is to be prevented. As long as the supporting members are

strong enough and do not fail in a wave slamming, the shell plate functions as an envelope to prevent flooding of internal compartments. The extensive load-carrying capacity of shell plate panels beyond yielding point may be utilized. It seems reasonable to allow for maximum permanent deformation being equal to the plate thickness. This gives enough margins against possible rupture of shell plating, while not giving up the aesthetics of the vessel. Plates with maximum permanent deformations less than the plate thickness are expected to fit for their supposed function.

A comparatively more conservative design is to have the shell plating not collapse under wave slamming pressure. The strength of plates is calculated using Eq. (2), and is required to be greater than a design slamming pressure. This design slamming pressure is characteristic of the influences of the severest slamming pressure on the structural response, which may be taken as the peak pressure calculated using the direct calculation approach.

The corrosion additions may take values similar to oil tankers. For the forepeak spaces exposed to severe wave slamming, a 1.5 mm may be added to the scantlings determined according to the predicted slamming pressure, to provide allowance for corrosion.

As a common case, a direct calculation approach has built-in uncertainties associated with the many assumptions and analysis tools. Allowances for these uncertainties are realized through the use of safety factors. The reliability approach or risk analysis approach may provide rational explanations, but this is not discussed here. Safety factors are not introduced in this article.

A CASE STUDY

The aforementioned approach is applied to the bow of a FPSO about 230 meters long and 45 meters wide. This FPSO is converted from an oil tanker. An internal turret is fitted in the No. 1 Tank. Figure 1 is the bow and part of the No. 1 tanks of this FPSO.

As a demonstration of the direct calculation approach, a section cut from the bow is analyzed; Fig. 1 shows the location. Wave slamming loads are calculated for the hull form of this section, section AA, which is shown in Fig. 3. Section AA forms a plane that is perpendicular to the ship's stem.

The full loading condition is considered. Head sea condition is analyzed as the FPSO can weathervane heading into the seas. The slamming pressures and structural responses are calculated for three selected plate panels, locations of which are shown also in Fig. 3. Panel P1 is at the centerline of the ship; and panels P2 and P3 are about 4.5 and 8.1 meters off the center

line, respectively. Table 1 has some details of these panels.

Table 1.

Three selected plate panels of shell plating in the FPSO's bow (Figs. 1 & 3)

I.D. for plate panel	P1	P2	P3
Off centerline (m)	0.5	4.5	8.1
Space (mm)	910	915	920
Material	Mild	Mild	Mild

Assume that this FPSO is deployed in West Shetland. The design wave height is 18 meters. Searching through the wave spectrum Johnswap, the vessel's maximum relative vertical velocity at bow is found to be 15.5 m/s, corresponding to an extreme wave height of 33.3 meters and a wave period of 12.5 seconds. Table 2 summarises this environmental condition.

Table 2.

Environmental conditions for West Shetland in the analysis

Significant wave height (m)	18
Extreme wave height (m)	33.3
Wave period (s)	12.5
Relative velocity at bow (m/s)	15.5

The largest slamming pressure does not occur right at the stem, or panel P1. Panel P2 is subjected to the largest slamming pressure, which is about double the pressure at panels P1 and P3. Table 3 has some analysis details for slamming pressure and corresponding scantlings that are obtained using the present direct calculation approach. The plate thickness is determined taking into account the finite displacement effects (Eq. (3)), or according to the collapse strength (Eq. (2)). Shell plate panel at P2 should be properly reinforced to resist this impact load. Depending on the safety levels a designer puts to place, shell plate panel at P1 and P3 may also need reinforcement, but this is not discussed here.

Table 3.

Scantlings of the three panels for the environmental conditions corresponding to West Shetland

Plate panel I.D.	P1	P2	P3
Peak impact pressure (kN/m ²)	737	1258	638
Thickness based on Eq. (3) (mm)	20.5	26.0	19.5
Thickness based on Eq. (2) (mm)	23.0	30.0	22.0

Note that the scantlings in Table 3 provide bases for comparison. Though using ABS design criteria (ABS 2000) gives very similar required scantlings, Table 3 should not be regarded as acceptable by any design standard.

If this vessel is an oil tanker and sails in the North Sea, it may also encounter wave slamming. For a service life of 20 years, the slamming pressure calculated following the same approach is similar to those in Table 3. From the slamming standpoint of view, the environmental condition off West Shetland is similar to the open sea North Atlantic. This approach is also applicable to an oil tanker design.

A comparative study is attempted to look at the difference in shell scantlings of this FPSO's bow at different installation sites. This FPSO is assumed to be in West Shetland, Gulf of Mexico, and Offshore Brazil. Table 4 summarises the results of this comparative study. The required plate thickness is at its maximum in West Shetland, followed by the Gulf of Mexico, then offshore Brazil. As a result, lesser steel is needed if the vessel is operated in offshore Brazil.

Note that the required thickness based on wave slamming is only one of the many factors that a designer has to consider. Wave slamming becomes the governing factor for some areas where the slamming loads exceed the normal design load. A sketch of the areas prone to slamming damage is shown in Fig. 1. In this case study, panel P2 needs reinforcement because of slamming consideration, while panel P3 may not depending on the installation site.

Table 4.

Environmental conditions at three different sites and the corresponding scantlings of panel P2

Site of the FPSO	West Shetland	Gulf of Mexico	Offshore Brazil
Significant wave height (m)	18.0	12.7	7.8
Wave period (s)	12.5	9.0	8.0
Vertical relative velocity at bow (m/s)	15.5	12.5	8.1
Impact pressure (kN/m ²)	1258	1051	636
Thickness based on Eq. (3) (mm)	26.0	24.0	19.0
Thickness based on Eq. (2) (mm)	30.0	27.5	21.5

CONCLUSIONS

Wave slamming may cause rupture of shell plating resulting in possible flooding of forepeak compartments of a FPSO. The risks can be mitigated through enhancing structural design and implementing preventative operational procedures. One of the keys to these efforts is to develop rational procedures taking into account the site-specific conditions and design service life.

A direct calculation approach is presented that may be used for analyzing slamming pressure and structural responses of shell platings of a FPSO's bow. This is also a practical analysis system, including some engineering programs and easy-to-use analytical formulae. It was demonstrated by applying it to the design of shell scantling of a FPSO's bow for some installation sites.

The presented direct calculation approach may be used for design of new constructions and conversions. It can also be used for investigating damages due to wave slamming.

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