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Açık Deniz Yarı Batık Yapılarının Çarpışma Analizi

Özgür Özgüç

ozguco@itu.edu.tr

İstanbul Teknik Üniversitesi, İstanbul, Türkiye

ÖZET

Açık deniz yapı birimleri, insan yaşamı, çevresel felaketler ve yapının tamamen kaybı gibi ciddi etkilere ve kayıplara yol açabilecek karmaşık tesisler olarak bilinir. Ayrıca, inşaat ve bakım masrafları çok yüksek olduğundan, tüm hizmet ömürleri boyunca tam olarak çalışır durumda tutmak önemlidir. Bu çalışmada, dikey bir kazık yarı-batık bir açık deniz yapısının yanına çarptığında ortaya çıkan yüklerin bir çarpışma analizi yapılmıştır. İki düzlem incelenmekte olup, örneğin, ponton tarafına paralel düşey kazık ve dikey kazık ile ponton kenarı arasındaki küçük bir açıya sahip bir eğimli platform kılıfı gibi bir düzlem darbe durumu. Mevcut çalışmadan elde edilen sonuçlar ve görüşler özetlenmiştir.

Anahtar kelimeler: Dikey deniz kazığı, yarı batık platformları, çarpışma analizi, yaralanmış yapı.

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Impact Analysis of Semisubmersible Pontoon – Pile

Özgür Özgüç

ozguco@itu.edu.tr

Istanbul Technical University, Istanbul, Turkey

ABSTRACT

Offshore units are known as complex facilities that can lead to serious impacts and losses, such as human lives, environmental disasters and the complete loss of the structure. In addition, since the cost associated to their construction and maintenance is very high, it is important to keep them fully operational throughout their whole service life. In this study, an impact analysis is performed that the loads arising when a vertical pile strikes against the side of a semisubmersible pontoon structure. Two cases are being investigated, such as one plane impact case with the vertical pile parallel to the pontoon side and one tilted platform case with a small angle between the vertical pile and the pontoon side. The results and insights developed from the present work are summarized.

Keywords: Vertical pile, semi-submersible platform, impact analysis, damaged structure.

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1. Introduction

Experiences with offshore and other structures show that catastrophic accidents often are initiated by human errors that cause accidental actions that escalate progressively into undesirable consequences. Robustness may be achieved by specific Accidental Collapse Limit State (ALS) criteria. A quantitative, semi-probabilistic ALS procedure has been introduced for offshore in terms of a survival check of damaged structural systems. The risk analysis methodology on which the procedure rests, is described with an emphasis on determining the characteristic accidental actions with due account of possible risk reduction actions. Since the ALS procedure is based on an alternate path approach, methods for predicting the initial accidental damage and the survival of the damaged structure need to account for nonlinear structural behaviour (Moan T, 2009).

Nemati and Azarsina (2016) analyzed the impact of a wind turbine offshore supply vessel with 5 different mass displacements numerically. The effects of static preload weight of turbine blades and environmental loads such as wind, wave, sea current and the water pressure are accounted on the turbines before hitting the ship dynamics, in terms of the structural behaviour. Parameters such as power and momentum of support, around the turbine horizontal displacement, stress and strain Von-Mises different parts of turbines in different loading conditions compared together and the results are discussed.

A review of accidents involving collisions between ships and offshore platforms was carried out. There are reports and publications that present numbers, statistics and even details of the most important collisions between ships and offshore platforms, especially considering the North Sea region, but publications about accidents in Brazilian waters are rare. Thus, this work reports the few existing publications that consider this problem in Brazilian waters and shows the results of eleven years of collecting data of collisions on Petrobras' platforms (Amante DM and Estefen SF, 2018).

Čekerevac et al., 2017 identified new opportunities for the development of innovative mitigation strategies for the devastating effects associated to accidental actions in offshore platforms, considering the most recent developments in terms of innovative materials and of structural analysis approaches. In this context, this paper discusses the current trends in research and the future challenges related to this issue. This serves to identify the possible methods for improvement of the existing structural mitigation measures.

Pericard Y, and Halse KH, 2017 performed structural impact analyses to give a scientific foundation for an evaluation of the consequences of a possible collision. This work is based on Non-Linear Finite Element Analysis (NLFEA) of the interaction between the platform supply vessel (PSV) and the platform. Due to heavy calculations, only the ship section located close to the crash zone has been modelled and additional masses have been included on each side of this section in order to get the correct ship inertia. These additional masses correspond to the mass of the remaining part of the ship structure. Moreover, the sideways ship motion is modelled with a prescribed initial velocity, and does not contain hydrodynamic response calculations. The NLFEA software package HyperWorks is used to perform the numerical simulations.

In this study, an impact analysis is performed that the loads arising when a vertical pile strikes against the side of a semisubmersible pontoon structure. The results are to serve as basis for design of a fender system for the vertical piles. The strength and arrangement of the analysed pontoon structure correspond to a semisubmersible with a length of about 90-100m and a displacement of 25000-30000 tonnes.

The vertical pile is assumed infinitely stiff (rigid). The pile is assumed to strike the side of the pontoon at the midpoint between transverse web frames. This is the weakest part of the pontoon structure.

Two cases are being investigated, such as one plane impact case with the vertical pile parallel to the pontoon side and one tilted platform case with a small angle between the vertical pile and the pontoon side. The platform tilt angle has been determined by the transverse overturning moment on the semisubmersible due to the wind loads acting (max 200 tonnes). A striking or tilt angle of 5 degrees has been predicted.

2. The Method of Analysis

Two computer routines for calculation of the loads arising in connection with bow and broadside ship collisions developed by Det Norske Veritas (DNV, 2009). The routine BOWCOLL is used to estimate the loads and deformations of a bow striking against a rigid wall. The routine SIDECOLL estimates the resistance of a ship side against penetration by a rigid object (e.g. bow). The two routines are briefly described below.

3. BOWCOLL Routine

In the BOWCOLL routine, the crushing resistance of the bow may be predicted by use of a model originally developed by Amdahl, 1983, or a similar model developed by Yang and Caldwell, 1988. Both approaches involve calculation of the energy dissipated during deformation of the structure.

An explicit solution for estimation of the crushing load according to Amdahl's model is shown below.

$$\sigma_C = 2.42 \cdot \sigma_0 \cdot \left(\frac{n_{AT} \cdot t^2}{A} \right)^{0.67} \cdot \left\{ 0.87 + 1.27 \cdot \frac{(n_C + 0.31 \cdot n_T)}{n_{AT}} \cdot \left[\frac{A}{(n_C + 0.31 \cdot n_T) \cdot t^2} \right]^{0.25} \right\}^{0.67} \quad (1)$$

The total crushing load, P_C, is found by multiplying by the associated cross-section area of the deformed steel material of the side structure,

$$P_C = \sigma_C \cdot A \quad (2)$$

$\sigma_C =$ Average crushing strength of deformed part of the side structure (MPa)

$\sigma_0 =$ Dynamic strength of the steel material (MPa)

$t =$ Average plate thickness of the considered cross-section (m)

$A =$ Cross-section area of the deformed steel material (m^2)

$n_C =$ Number of cruciforms that the deformed cross-section of the side consists of as shown in Figure 1.

$n_T =$ Number of T-sections contained by the distorted cross-section

$n_{AT} =$ Number of Angle- and T-sections contained by the distorted cross-section

Further, checks are being made that the folding lengths during deformation of the structures do not exceed the spacing between longitudinal girders or depth of transverse web frames by Amdahl, 1983.

According to their method the crushing load of plate structures can be determined from,

$$\begin{aligned} P_m = {} & 1.178 \cdot \frac{\sigma_o}{H} \cdot \sum_{i=1}^{n_f} b_i \cdot t_i^2 + 0.215 \cdot \sigma_o \cdot H \cdot \sum_{i=1}^{n_{AT}} t_i + 6.935 \cdot \sigma_o \cdot \sum_{i=1}^{n_{AT}} t_i^2 + 0.265 \cdot \sigma_o \cdot H \cdot \sum_{i=1}^{n_T} t_i \\ & + 0.589 \cdot \sigma_o \cdot \sum_{i=1}^{n_T} t_i^2 + 0.75 \cdot \sigma_o \cdot H \cdot \sum_{i=1}^{n_C} \sum_{1}^{4} t_i + 0.375 \cdot \sigma_o \cdot H \cdot \sum_{i=1}^{n_C} \sum_{1}^{4} t_i \end{aligned} \quad (3)$$

The two last terms of Eq. (3) refer to dissipated energy in cruciforms where the energy contributions are summed up over the 4 flanges of the cruciforms.

P_m = Mean crushing load of structure (MN)

σ_o = Mean value of the yield and the tensile strengths of the steel (MPa)

b_i = Width of the i-th plate flange (m)

t_i = Thickness of the i-th plate plange (m)

H = Folding length of the distorted cross-section

n_C = Number of basic cruciforms that the distorted cross-section consists of

n_T = Number of basic T-sections in the considered cross-section

n_{AT} = Number of Angle-and T-sections in the considered cross-section

n_f = Total number flanges of Angle-, T-sections and cruciforms

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4. SIDECOLL Routine

In the SIDECOLL routine, the impact load arising during distortion of the ship side has been estimated by adding up the crushing resistance of distorted decks and bulkheads and the resistance due to membrane tension forces developing in the shell plating, decks and bulkheads. The crushing and membrane tension resistance are considered separately and are assumed to be uncoupled (Pettersen and Valsgård, 1983).

The crushing resistance the side structure is calculated by use of the same approach and energy assessments as described for the bow impact, Eqs. (1) and (2), or Eq. (3).

It is further assumed that the deformations of the side structure will follow the shape of the striking object penetrating into the side. The object is in this connection assumed to be rigid. No thorough equilibrium considerations of the plastic forces are made to verify the assumed deformation pattern of the side structure is appropriate, but some coarse checks are made.

In addition to the crushing load the deformation resistance caused by the membrane tension forces in the shell plating and in the distorted deck and bulkheads is calculated. The contribution to the collision load from the tension in the shell plating is,

$$P_{TS} = \int_{o}^{h_d} 2 \cdot \sigma_y \cdot t_{px} \cdot \sin\alpha \cdot dz + \int_{0}^{l_d} \sigma_y \cdot t_{pz} \cdot (\sin\beta_u + \sin\beta_l) \cdot dx \qquad \varepsilon \le \varepsilon_{\mathrm{br}}$$

$$P_{TS} = 0 \qquad \varepsilon \ge \varepsilon_{\mathrm{br}} \tag{4}$$

P_{TS} = Resistance due to membrane tension in ship side

σ_y = Yield stress

t_{px} = Equivalent thickness of side plating in longitudinal direction.

α = Horizontal slope angle of the indentation

h_d = Damage height (height of indent)

l_d = Damage length (length of indent)

z = Distance in vertical direction

t_{pz} = Equivalent thickness of side plating in vertical direction

β_u = Upper vertical slope angle of the indentation

β_l = Lower vertical slope angle of the indentation

x = Distance in the longitudinal direction

ε = Strain in ship side

ε_{br} = Rupture strain of steel plating

The equivalent plate thicknesses are represented by the thickness of the plating plus the cross-section area of the stiffeners divided by the spacing. The deformation resistance due to tension forces arising in distorted deck and horizontal stringers is calculated from,

$$P_{TD} = 2 \cdot \sum_{ndck} 0.5 \cdot \sigma_y \cdot t_{pd} \cdot \delta \qquad \varepsilon \le \varepsilon_{\mathrm{br}}$$

$$P_{TD} = 2 \cdot \sum_{ndck} 0.5 \cdot \sigma_y \cdot t_{pd} \cdot \delta_{br} \qquad \varepsilon \ge \varepsilon_{\mathrm{br}} \tag{5}$$

P_{TD} = Deformation resistance due to membrane tension in distorted decks/stringers

t_{pd} = Thickness of distorted deck/stringer plating

δ_{br} = Maximum indentation of deck/stringer at which rupture started

$ndck$ = Number of distorted decks/stringers

and the resistance of the tension forces in the transverse bulkheads and web frames,

$$P_{TB} = 2 \cdot \sum_{nbhd} 0.5 \cdot \sigma_y \cdot t_{pb} \cdot \delta \qquad \varepsilon \le \varepsilon_{\mathrm{br}}$$

$$P_{TB} = 2 \cdot \sum_{nbhd} 0.5 \cdot \sigma_y \cdot t_{pb} \cdot \delta_{br} \qquad \varepsilon \ge \varepsilon_{\mathrm{br}} \tag{6}$$

P_{TB} = Deformation resistance due to membrane tension in distorted bulkheads/web frames

t_{pd} = Thickness of distorted bulkhead/web frame plating

$nbhd$ = Number of distorted bulkheads/web frames

The total impact load due to indentation of the side structure of the ship, P_{Side}, is correspondingly found by adding up the contributions from the crushing and membrane tension loads,

$$P_{Side} = P_C + P_{TS} + P_{TD} + P_{TB} \tag{7}$$

The absorbed energy, E_{Side}, is estimated by integration of the load-deformation relationship,

$$E_{Side} = \int_0^{\delta} P_{Side} \cdot d\delta \tag{8}$$

The deformations of the side of the ships are determined by the undeformed shape of the striking objects. No corrections of the side-indentations are made for actual deformations of the striking objects.

In case the striking object is a supply ship, the energy absorbed by deformation of the striking bow may be calculated based on the simple bow resistance curve given in Yang and Caldwell, 1988.

$$E_{Bow} = f(P_{\max})$$

$$P_{\max} = \left[P_{Side}\right]_{\max} \tag{9}$$

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E_{Bow} = Energy absorbed by deformation of bow structure (MNm)

$P_{\max}$ = Plastic deformation resistance of bow, which is equal to the maximum penetration resistance of the side of the struck ship (MN)

L_S = Length of striking ship (Lpp) (m)

The total energy absorbed during the impact, E_{IMP} , is found by adding up the contributions of the two ships.

$$E_{IMP} = E_{Side} + E_{Bow} \tag{10}$$

Apart from the load and energies involved with deformation of the ships, the model is used to calculate the extent of the damages to the side structures. The damages are described by the length, breadth, vertical position and area of any hole in the ship side and the penetration depth of the striking object. For each object indenting the side up to two holes may be created, one vertical hole related to membrane tensions and stretching of the side in the horizontal direction, and one horizontal hole related to membrane tensions and stretching in the vertical direction.

Correspondingly, a conventional bow may create two holes in the ship side while a bulbous bow which represents two indenting objects, may create up to four holes in the side, see illustration in Fig. 2. For large indentations of a bulbous bow the upper and lower vertical holes will merge into one single hole (upper hole).

For estimation of rupture and damage extents the elongations and strains in the horizontal and vertical directions of the shell plating are calculated at the locations of the decks and stringer levels and at the positions of the transverse web frames respectively. For simplicity, the indentations are assumed to vary linearly in-between deck levels and web frames.

Initial rupture is predicted to occur when the maximum strain in the horizontal or vertical direction exceeds a given rupture strain for the steel material. The magnitudes of the strains are,

$$\begin{aligned} \varepsilon_x &= \frac{\sqrt{\Delta x^2 + \delta I(\Delta x, z)^2} - \Delta x}{\Delta x} \\ \varepsilon_z &= \frac{\sqrt{\Delta z^2 + \delta I(x, \Delta z)^2} - \Delta z}{\Delta z} \end{aligned} \tag{11}$$

ε_x = Mean value of the horizontal strain inbetween neighbouring web frames

ε_z = Mean value of the vertical strain inbetween neighbouring decks or horizontal stringers

Δx = Longitudinal distance between web frames (web frame spacing)

Δz = Vertical distance between neighbouring decks or horizontal stringers

$\delta I(\Delta x, z)$ = Incremental variation of indentation between neighbouring web frames

$\delta I(x, \Delta z)$ = Incremental variation of indentation between neighbouring decks

The elongations of the plating in the horizontal and vertical directions at the various deck levels and web frame stations are,

$$S_x(z) = \int_0^{l_d} \sqrt{dx^2 + dI(x,z)^2}$$
$$S_z(x) = \int_0^{D_u} \sqrt{dz^2 + dI(x,z)^2} \qquad (12)$$

$S_x(z) =$ Elongation (total length) of the side in the horizontal direction at elevation z

$S_z(x) =$ Elongation (total length) of the side in the vertical direction at location x

$x =$ Longitudinal location (web frame station)

$z =$ Vertical location (deck level above keel)

$I(x,z) =$ Indentation of shell

$D_u =$ Vertical distance to uppermost deck

$l_d =$ Horizontal length of the damaged part of the shell structure

The size of the holes is estimated by integration of the elongations that exceed the rupture elongation of the shell plating,

$$A_V = \int_0^{D_u} \left[S_x(z) - S_{crx}(z) \right] \cdot dz$$
$$A_H = \int_0^{l_d} \left[S_z(x) - S_{crz}(x) \right] \cdot dx \qquad (13)$$

$A_V =$ Area of vertical hole

$A_H =$ Area of horizontal hole

$S_{crx}(z) =$ Elongation (total length) of the side at which rupture in the horizontal direction occurred at elevation z

$S_{crz}(x) =$ Elongation (total length) of the side at which rupture in the vertical direction occurred at location x

The corresponding lengths of the vertical, Vl, and horizontal, Hl holes are,

$$Vl = \int_0^{D_u} H(z) \cdot dz$$
$$H(z) = 1.0 \quad \text{for} \quad \left[S_x(z) - S_{crx}(z) \right] \geq 0.0$$
$$= 0.0 \quad \text{for} \quad \left[S_x(z) - S_{crx}(z) \right] \leq 0.0$$

$$Hl = \int_0^{l_d} H(x) \cdot dx \qquad (14)$$
$$H(x) = 1.0 \quad \text{for} \quad \left[S_z(x) - S_{crz}(x) \right] \geq 0.0$$
$$= 0.0 \quad \text{for} \quad \left[S_z(x) - S_{crz}(x) \right] \leq 0.0$$

The widths of the vertical, Vb, and horizontal, Hb, holes are,

$$Vb = \left(S_x(z) - S_{crx}(z) \right)_{\max}$$
$$Hb = \left(S_z(x) - S_{crz}(x) \right)_{\max} \qquad (15)$$

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For cases or indentations where the uppermost deck or the bottom of the struck ships are being deformed, the membrane tension in the vertical direction is assumed to vanish and any horizontal rupture of the plating will cease to grow ("horizontal" damage extents kept constant for increasing indentations). Consequently, if rupture has not occurred before the deck or bottom structure is being deformed, no horizontal hole will develop.

The present routine can only handle the effect of membrane tension forces in single skin structures in a realistic manner. For double hull designs, the estimated deformation loads will only be appropriate for indentations up to the location of the inner skin and provided the inner skin does not move during this deformation stage. For larger indentations, the routine may underestimate the penetration load somewhat due to neglecting of the inner skin tension forces.

The out of plane bending resistance of stiffened panel are neither taken into account. This will underestimate the distortion load at the initial deformation stage. However, for indentations exceeding the order of the stiffener height this plastic bending resistance will disappear.

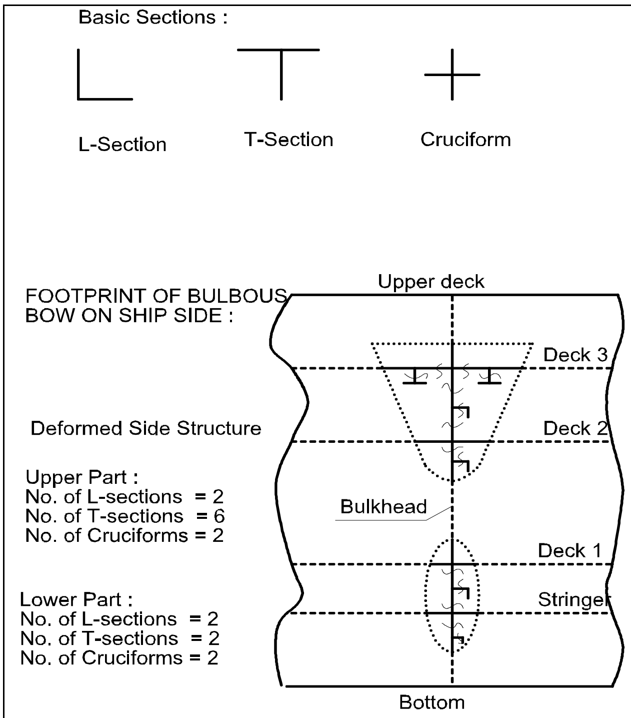

Figure 1. Footprint of bulbous bow on ship side.

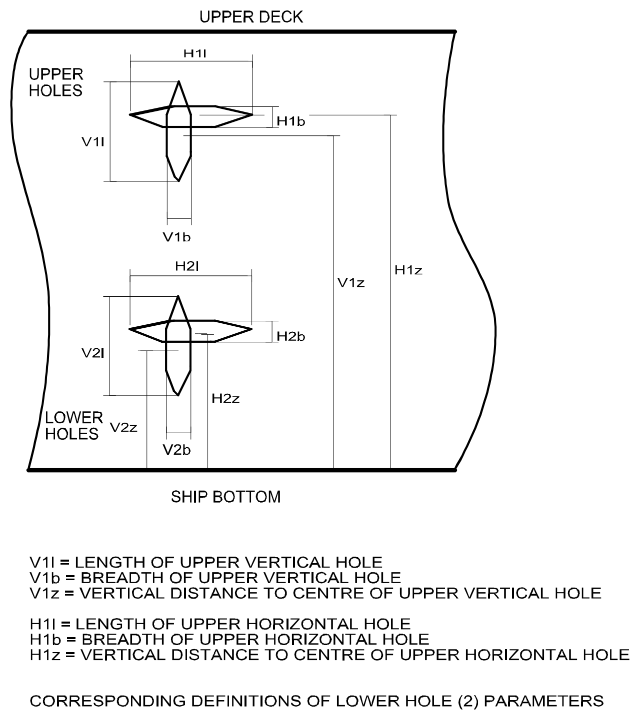

Figure 2. Horizontal and vertical holes in ship side.

5. Striking Conditions

The characteristics of the considered pile are given in Table 1.

Table 1. The main particulars of the pile.

Pile diameter:	1.0 m
Pile position:	Vertical
Pile strength:	Rigid

The selected semisubmersible corresponds to a vessel with a displacement of 25000-30000 tonnes and with an overall length of about 90-100 m and main particulars for semisubmersible and pontoon structures are given below Table 2 and Table 3.

Table 2. The main particulars of semisubmersible platform.

Overall length:	90 – 100 m
Breadth:	70 – 75 m
Operating draught:	22 – 24 m
Displacement:	25000 – 30000 tonnes

It is noted that the pontoons are assumed to be of rectangular shape with rounded corners.

Table 3. The main particulars of the pontoon structure.

Pontoon height:	7.0 – 8.0 m
Pontoon width:	14.0 – 15.0 m
Shell thickness:	16 – 17 mm
Stiffener spacing:	0.6 – 0.7 m
Stiffener dimensions:	L300*100*12*16 (typical)
Web frame spacing:	2.5 – 3.0 m
Web frame thickness:	12.0 – 13.0 mm

The vertical pile is assumed to strike the side of the pontoon at the midpoint between transverse web frames (weakest part of the pontoon structure). Two striking conditions have been investigated, one plane impact case with the vertical pile parallel to the pontoon side and one tilted platform case with a small angle between the vertical pile and the pontoon side (rotation of platform about the longitudinal platform axis). The tilt angle represents the effect of transverse platform motions and wind forces. It is assumed that the platform motions will be small for the considered cases.

By assuming a maximum transverse wind force of 2 MN (200 tonnes) and an overturning moment of about 75 MNm (7500 tm) on the semisubmersible a tilt angle of 5 degrees of the platform has been predicted.

6. Results and Discussion

The results show that the plastic deformation resistance of the considered pontoon structure will vary with the striking (tilt) angle. The highest loads will occur when the pile and the pontoon side are parallel at the impact, i.e. contact over the total height of the pontoon side.

On the other hand the average contact pressure on the pile when penetrating into the pontoon side will not vary significantly with the striking angle. In order to prevent plastic deformations of the pontoon structure in case of impacts of semisubmersibles of 25000 – 30000 tonnes displacement it is suggested that the fender system is designed to deform when exposed to a contact pressure of about 2.0 MN/m^2. No analysis has been made of the required fender stiffness to prevent structural damages on semisubmersible of smaller sizes than 25000 – 30000 tonnes. The estimated deformation resistance of the pontoon for the 5 degrees tilted platform case is shown in Fig. 3.

The load increases as the pile penetrates into the pontoon until rupture of the side plating starts at an indentation of about 0,4m. The associated absorbed deformation energy is shown in Fig. 4. The

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footprint of the contact area between the pile and the pontoon is illustrated in Fig. 5 for some selected indentations.

The associated average crushing or contact pressure on the pile is shown in Fig. 6 The contact pressure in Fig. 6 will start to drop when rupture of the pontoon shell plating begins, i.e. at an indentation of about 0.4 m, which corresponds to a contact area of about 4.5m^2.

The corresponding results for the plane or parallel impact case are shown in Figs. 7 through 10. The deformation load of the pontoon in Fig. 3.5 is higher than for the tilted platform case shown in Fig. 3 Rupture of the shell plating will occur at an indentation of about 0.4m. The absorbed deformation energy of the parallel impact case is shown in Fig. 8. The footprint of the contact area between the pile and the pontoon for the parallel impact case is illustrated in Fig. 9 for some selected indentations.

The average contact pressure on the pile for the parallel impact case is shown in Fig. 10. Before rupture of the pontoon shell plating occurs, i.e. drop in the curve at 5.5 m^2 in Fig. 10, the smallest average contact pressure is about 2.0 MN/m^2. It can be seen from Fig. 6 and Fig. 10 that the average contact pressures for the tilted and parallel impact cases are fairly similar until rupture begins.

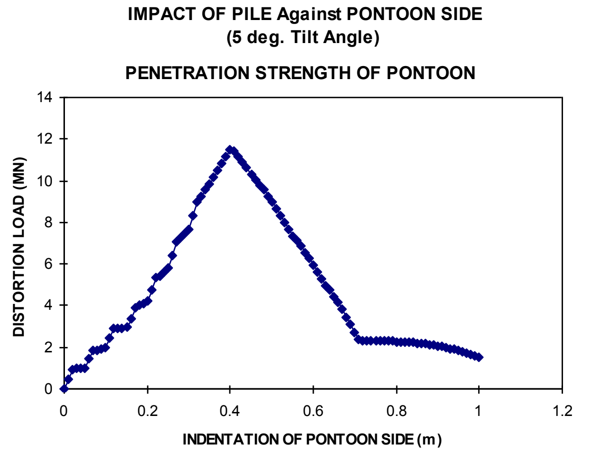

Figure 3. Force-Indentation relationship.

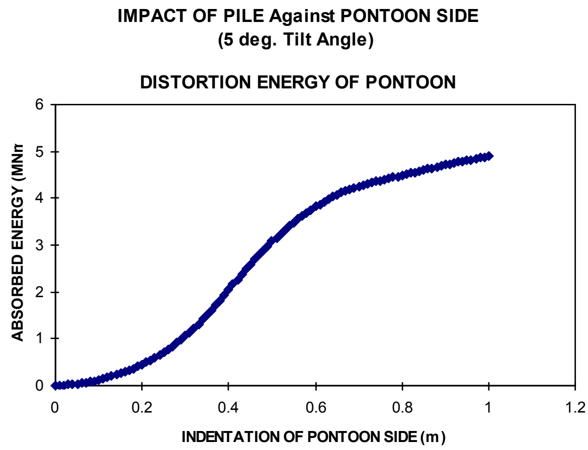

Figure 4. Absorbed energy versus indentation of pontoon.

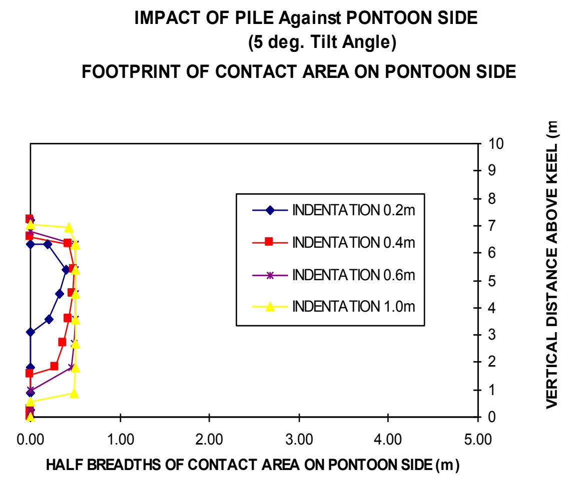

Figure 5. Footprint of contact area between pontoon and pile.

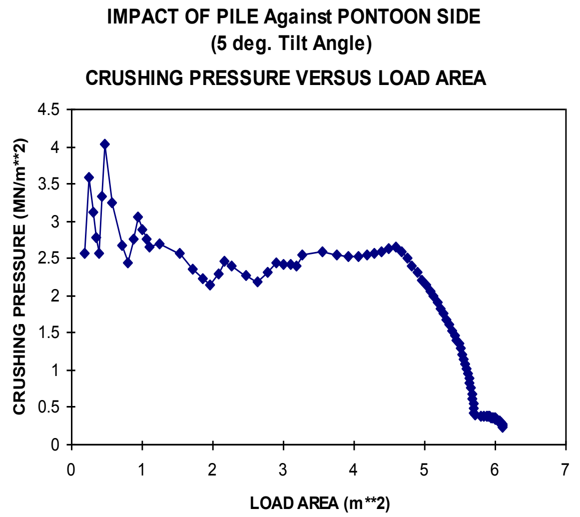

Figure 6. Contact pressure on pile.

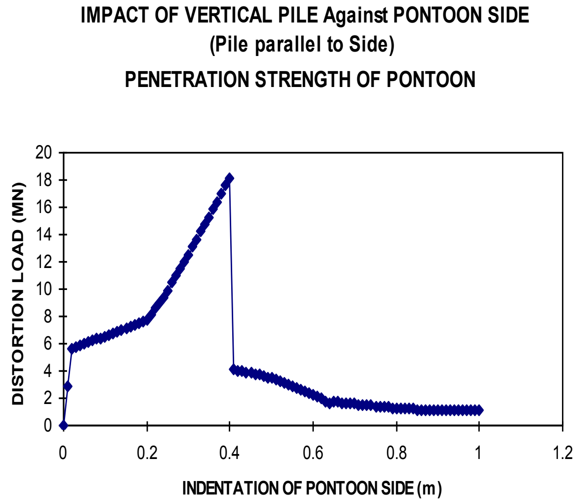

Figure 7. Force-Indentation relationship.

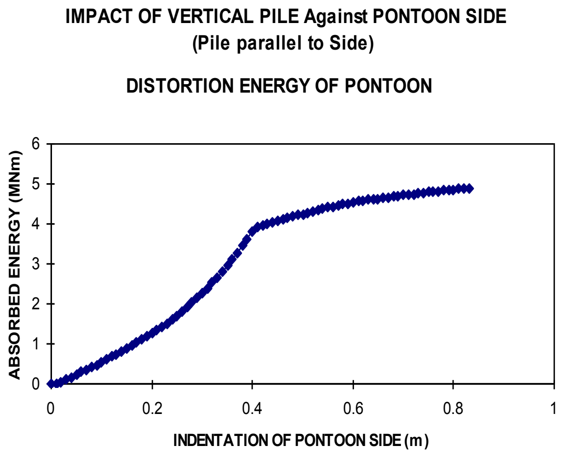

Figure 8. Absorbed energy versus indentation of pontoon.

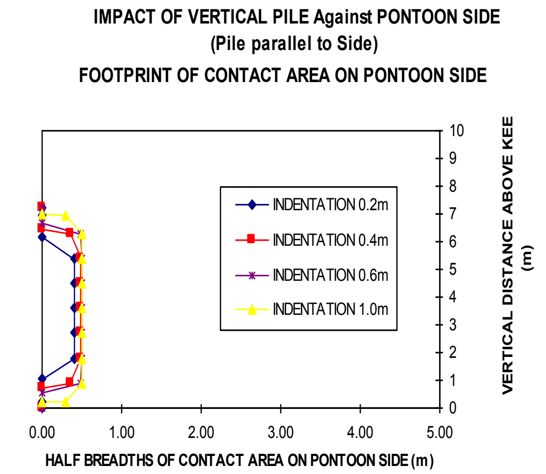

Figure 9. Footprint of contact area between pontoon and pile.

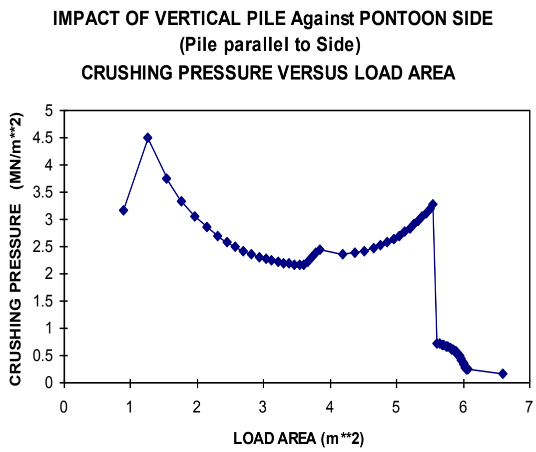

Figure 10. Contact pressure on pile.

The plastic deformation resistance of the considered pontoon structure will vary with the striking angle between the side of the pontoon and the struck vertical pile (angle in the vertical plane). The highest loads will occur when the pile and the pontoon side are parallel at the impact, i.e. contact over the total height of the pontoon side. On the other hand the average contact pressure on the pile when penetrating into the pontoon side will not vary significantly with the striking angle.

In order to prevent plastic deformations of the pontoon structure in case of impacts of semisubmersibles of 25000 – 30000 tonnes displacement it is suggested that the fender system is designed to deform when exposed to a contact pressure of about 2.0 MN/m2. No analysis has been made of the required fender stiffness to prevent structural damages on semisubmersible of smaller sizes than 25000 – 30000 tonnes.

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