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Estimation of Vessel Stopping Time During Collision With Offshore Riser Guard

A Finite Element Modelling Approach to Simulate Vessel Collision

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***Abstract*—In this paper, the modelling and the estimation of vessel stopping time during a head-on collision event against the riser-guard of a jacket platform is investigated using the general purpose FEM code, ANSYS Transient Dynamics. In the absence of collision data, impulsive force equation with assumed vessel stopping time will be tested until the desired system strain energy is achieved. Three scenarios with different assumed stopping time is to be investigated, of which one is presented in this paper. Accurate vessel stopping time will be used to determine the reaction forces during collision with riser-guards.**

***Keywords*—stopping time, support reactions, transient dynamics**

I. Introduction

In an effort to ensure continuous operation in the oil industry, offshore platforms receive frequent visits from support and supply vessels. Throughout these frequent visits, vessel collision is imminent. In the event of a collision, the damage on a platform can be extensive and potentially result in fatalities and explosions. Vessels colliding with offshore structures can be categorised as the following [1]:

1. Moored vessel
2. Joystick positioned vessel
3. Manoeuvring vessel
4. Disabled and drifting vessel

Steel riser-guards are tubular space frame installed on fixed jacket platforms to prevent vessel collision against risers. Protection for the risers is of extreme importance due to the flammable content it carries. The absence of riser-guard system was made obvious in July 2005 during the collision between a supply vessel and a platform at Mumbai High North field. The collision resulted in huge explosions and the whole platform was destroyed without any physical remains above the sea [2]. Based on the compilation of collision reports at the UK Continental Shelf, between the years of 1975 and 2001 a total number of 557 incidents involving vessels and fixed installations were recorded, of which 353 is due to supply vessels [3]. A summary of the statistic is presented in Table I. 63.4 % of the total collision incidents at the UK Continental Shelf involve supply vessels. Though threats from other vessels are still present, the associated probability of occurrence appears to be relatively small.

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Therefore, the need for it to be considered in the design of offshore platforms remains low.

TABLE I. SUMMARY OF COLLISION INCIDENTS BASED ON VESSEL TYPE ON THE UK CONTINENTAL SHELF FROM 1975 TO 2001

Vessel type	Supply Vessels	Stand-by vessels	Attendant vessels	Passing Vessels	Unspecified vessels
Number of Incidents	353	87	74	8	35
Percentage of occurrence	63.4%	15.6%	13.3%	1.4%	6.3%

As a precaution against collision, platforms on Malaysian waters are currently being installed with riser-guards. The conventional riser-guards consists of tubular steel space frames [4] which are designed to resist static forces equivalent to a collision on any part of the frame. Vessel collision has also been highlighted under section 10.2 of ISO: 19902 standards for Fixed Steel Offshore Structures [5]. Current design approach used for riser-guards in the PETRONAS Technical Standards [6] is an adoption of the boat fender design criteria which can be found under Section 4.11 of Design Criteria for Substructures [6]. At present, the conventional riser-guard system is designed based on the impact energy criteria presented in Table II.

The current design practice of conventional riser-guard is a mere adaptation of the boat fender design criteria with some minor modification can result in uneconomical or unsafe design. Unlike the conventional riser-guard, boat fenders have shock cells where reaction forces during boat landing can be monitored. This is however not the case for riser-guards, where they are designed only for accidental collision. Riser-guard steel members are allowed to reach plasticity to reduce lateral load effect on platform legs [7]. The conventional riser-guard is not designed in compliance to any specific standard or design as there is no such established requirements yet.

TABLE II. DESIGN IMPACT ENERGY OF CONVENTIONAL RISER-GUARD SYSTEM BY PTS

Vessel displacement (Tonnes)	Energy (MJ)
1000	1.00
1500	1.25
2000	1.80
2500	2.25

Reactions forces transmitted to the jacket legs during a collision event are important for further improvement of the riser-guard design. For the estimation of dynamic support reactions, the time taken for a colliding vessel to be stopped by the conventional riser-guard must be investigated. Proper understanding of the energy transfer mechanism and the support reactions of the riser-guard under impact is a prerequisite to the improvement of the conventional riser-guard for economic reasons and better protection under extreme events. However, due to the absence of data on the resulting reaction forces during vessel collision against the conventional riser-guard, further design improvements become a challenging task.

II. CONVENTIONAL RISER-GUARD SYSTEM ON OFFSHORE JACKET PLATFORMS

PETRONAS has been using a riser protection system that is similar to a boat fender system on their fixed offshore platforms in Malaysian waters. This simple system shown in Figure 1 consists of steel tubes welded against each other to form a mesh-like structure, shielding the risers against vessels.

Figure 1. Conventional riser-guard on fixed offshore platforms

Any vessel directly on course towards the risers is halted by the riser-guard. The impact energy will be dissipated by the riser-guard to the platform legs. Offshore steel beams under transverse impact have been studied using experimental technique and also finite element modelling approach [8-10]. However, no study has been published on the mode of dynamic reaction forces transmission to the jacket legs during vessel collision against the conventional riser-guard.

III. FINITE ELEMENT MODELLING

A. Structural Dynamics

For problems involving structural dynamics, the following equation of motion is used,

$$M\ddot{X} + C\dot{X} + KX = f(t) \quad (1)$$

where M, C, and K are the structural mass, damping and stiffness matrices [11].

ANSYS provides two approaches to solve the above equation of motion, namely Transient Dynamic Analysis (TDA) and Explicit Dynamic Analysis (EDA). Time integration is performed to solve the equation of motion for each analysis, which can be generally classified into implicit and explicit methods [11].

B. ANSYS Transient Dynamics Analysis (TDA)

TDA can be performed using the ANSYS Transient Structural (TS) platform which is available in ANSYS Workbench environment. FE modelling using commercial code ANSYS TDA has been used to conduct in-depth investigation on the load transfer mechanism from riser-guard to the jacket legs at an event of impact. This system uses the Mechanical ANSYS Parametric Design Language (APDL) solver and can be used to determine the dynamic responses of structural members due to time-dependent loads, which includes impulsive loading due to collision.

C. Impact Energy

Vessel on collision-course will possess kinetic energy which can be calculated using the following equation,

$$E_s = \frac{1}{2} m_s {v_s}^2 \quad (2)$$

where E_s is the kinetic energy of vessel, m_s is the mass of vessel plus added mass (kg), and v_s is the vessel velocity (m/s). The kinetic energy of the colliding vessel will be completely absorbed by the vessel and installation in the form of strain energy [12]. In reference to PETRONAS Technical Standards, in any collision event, the resulting impact energy is assumed to be dissipated by the riser-guard deformation. This assumption by PTS neglects energy dissipation by vessel deformation. Thus, the impact energy is fully absorbed by the riser-guard as strain energy.

D. Impulse Load

The governing equation for impulse load during collision is shown below,

$$F = m\alpha(v_i - v_f)/t \quad (3)$$

where m is the mass of vessel (kg), α is the added mass coefficient, v_i is the vessel velocity prior to collision (m/s), v_f is the final vessel velocity (m/s) and t is the time taken for the vessel to be stopped (s). For the estimation of impulse load, the time taken by vessel with initial velocity of 1.5 m/s to reach 0 m/s or the stopping time, t was varied until the total strain energy in the model is close or equal to the design impact energy. Two possible scenarios may occur in reality, which are broadside impact and bow/stern impact, which is depicted in Figure 2. Added mass coefficient, α is taken as 1.4 for broadside impact and 1.1 for bow/stern impact. However, for this study, only the maximum impact force which is from the broadside impact of a 2500 tonne vessel is considered.

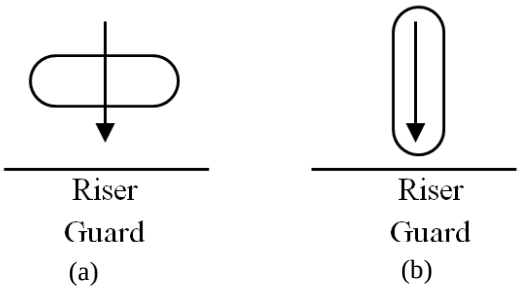

Figure 2. (a) Broadside collision and (b) bow/stern collision

Table III shows the simulated scenarios in this study with the impulsive load calculated using Equation (3) for a broadside impact of a 2500 tonne vessel at 1.5 m/s velocity with assumed stopping time taken for the vessel to reach 0 m/s velocity.

TABLE III. LIST OF IMPACT SCENARIOS TO BE STUDIED

Scenario	Assumed stopping time, *t* (s)	Impulsive load, *F* (MN)
1	0.8	6.56
2	0.6	8.75
3	0.4	13.13

Impulsive load application consists of two phases, which are the load increase phase and load decrease phase. The load increase phase is when the vessel comes into contact with the riser-guard until it completely stops, which is equal to the stopping time. The load decrease phase is when the vessel rebounds and moves away from the riser-guard.

E. ANSYS Design Modeller

Design modeller under the Mechanical Model can be used to model complicated geometry with ease. It also connects to all major CAD systems and this feature allows flawless transfer of data. The isometric view of the conventional riser-guard designed using ANSYS Design Modeller is shown in Figure 3. Symmetric boundary condition was applied to the model whereby only half of the model was considered in the analysis. This is only applicable if the load application is symmetric as well. Figure 4 shows the applied impulsive load on the highlighted members in the -z direction to simulate a broadside collision event.

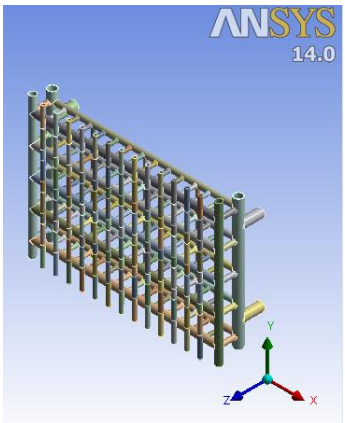

Figure 3. Isometric view of riser-guard model

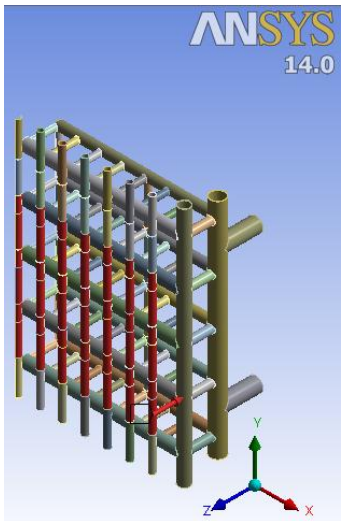

Figure 4. Impulse load application to simulate vessel broadside collision with riser-guard

F. Load Application

The highlighted members in Figure 4 lie in the waterline region and are exposed to direct impact from vessel. Triangular impulsive load was applied along the highlighted members using the bearing load option in ANSYS Workbench, to simulate impact scenario 1 from Table III. The load is applied in smaller steps as shown in Figure 5, to simulate collision scenario 1. Only half of the impulse load is applied for the symmetric model.

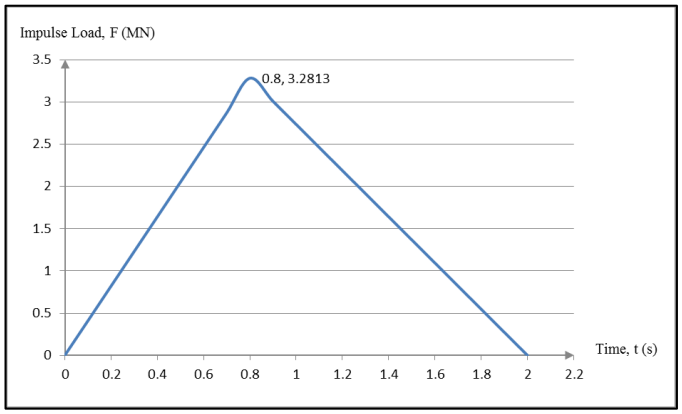

Figure 5. Triangular impulse load plot for collision scenario 1

During load application, it was assumed that the load increase phase occurs within 40% of the total simulation time while the load decrease phase takes place in the remaining 60% of the total time.

G. Contacts

The geometry is constructed to be multi-part bodies to enable better mesh control. The contact between each body is manually assigned with bonded and unbreakable option, where the concave surfaces are contacts and the convex surfaces are targets. A number of contact options are available in the

Workbench interface, namely bonded, frictional, frictionless, and no separation.

IV. RESULTS

The resulting deformation of riser-guard model is presented in Figure 6. Maximum deformation 4cm occurs at the centre of the model which is very much predictable with the given symmetrical geometry of riser-guard and load application. Stress distribution and the total internal energy of the riser-guard model are presented in Figure 7 and Figure 8 respectively.

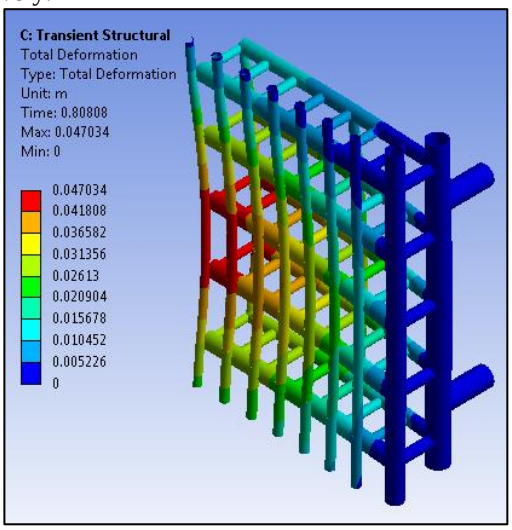

Figure 6. Deformation of riser-guard upon impact

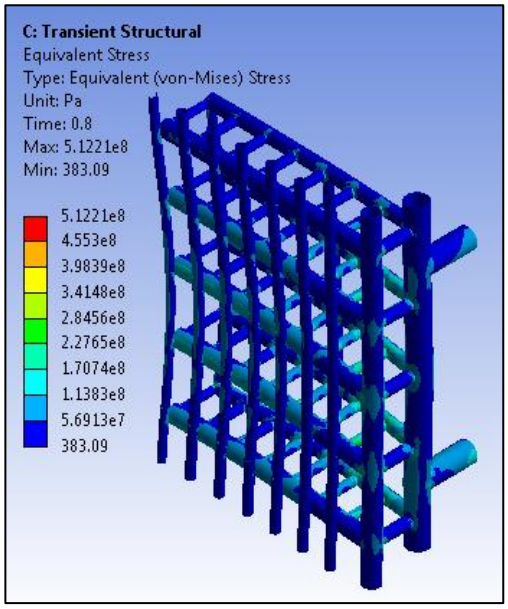

Figure 7. Stress distribution in riser-guard model during impact

Maximum stress recorded by the simulation is 512 MPa at the joint shown in Figure 7 and the impact produced maximum strain energy of 0.06 MJ for half model and thus 0.12 MJ for full model. Dynamic reaction forces resulting from the impulse load application is presented in Figure 9. The reaction forces show the amount of force in all the axes and also the total resultant force transferred to the supports of riser-guard. The result can be used as reference in designing new riser protection system.

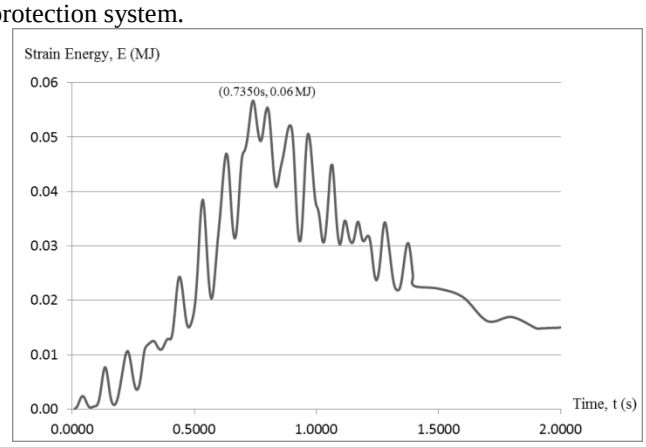

Figure 8. Total strain energy of riser-guard system

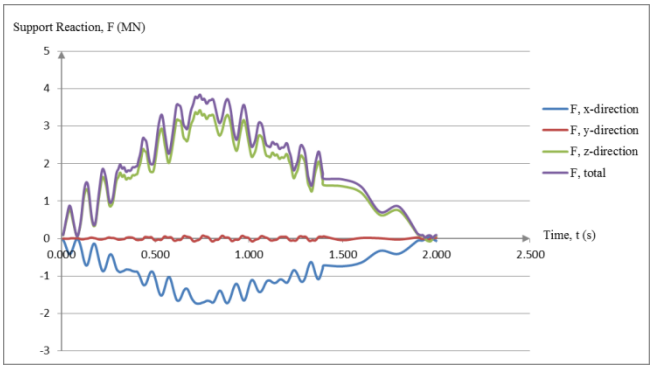

Figure 9. Reaction forces at fixed support

Maximum total reaction force recorded in the simulation is close to approximately 3.8 M while the load applied is 3.2 MN. The load applied and resulting reaction forces are v. This shows that the simulation achieved good convergence and the resulting strain energy from riser-guard deformation is reasonable. The negative values recorded in the simulation signify the direction of reaction forces. Total reaction forces are largely contributed by the forces in the Z-direction.

V. DISCUSSION

This study presents the results for the assumed stopping time of 0.8 seconds. The TSA model was able to successfully simulate structural deformation, stress distribution, and total strain energy of the riser-guard system under impulse load. The expected strain energy from this impact modelling is approximately 2.25 MJ, which is equal to the impact energy of a 2500 tonnes vessel, as specified by PTS. However, the simulation recorded 0.06 MJ of strain energy (0.12 MJ for full model) with good convergence. Converging simulation suggests that the model is in equilibrium state throughout the simulated period.

Based on the simulation results, the initial assumption of 0.8s stopping time is too high, resulting in strain energy much

lower than the kinetic energy of the vessel. Thus, energy conservation is not achieved and scenario 1 can be said to be most unlikely to happen for the desired vessel displacement and impact velocity. The simulation will have to be repeated with smaller stopping time.

Fluctuations in the resulting support reactions are due to the dynamics effect taken into consideration during the TDA simulation. This dynamic effect includes structural vibration during both load increase and decrease phase.

VI. CONCLUSION

The results from this study concludes that the assumed stopping time of 0.8 seconds for a 2500 tonnes vessel at impact velocity of 1.5 m/s is too low and did not result in the expected strain energy of 2.25 MJ, which is not in line with energy conservation law. This study concludes that the assumed vessel stopping time of 0.8 seconds does not represent the actual collision of a vessel. The study will be resumed with simulation of collision scenario 2 and 3.

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References

[1] R. Nataraja and K. Pemsing, “Impact Energy due to Supply Vessel Collision,” in International Symposium on Integrity of Offshore Structures (IOS '87), 3rd, Glasgow, 1987.

[2] N. K. Mitra, P. K. Dileep and A. Kumar, “Revival of Mumbai High North - A Case Study,” in 2008 Indian Oil and Gas Technical Conference and Exhibition, Mumbai, 2008.

[3] J. K. Robson, “Ship/platform Collision Incident Database (2001),” HSE Department of UK, Norwich, 2003.

[4] M. A. El-Reedy, Offshore Structures Design, Construction and Maintenance, 1 ed., C. I. diacriTech, Ed., Oxford: Gulf Professional Publishing, 2012.

[5] International Stadard (ISO: 19902), Petroleum and Natural Gas Industries- Fixed Offshore Steel Structures, vol. Edition 1, Switzerland: ISO, 2007.

[6] W. B. Shiiun, “PETRONAS Technical Stadards,” PETRONAS, Kuala Lumpur, 2012.

[7] M. A. El-Reedy, Offshore Structures Design, Construction, and Maintenence, C. I. diacriTech, Ed., Massachusetts: Gulf Professional Publishing, 2012.

[8] M. R. Bambach, H. Jama, X. L. Zhao and R. H. Grzebieta, “Hollow and concrete filled steel hollow sections under transverse impact loads” in Engineering Structures, vol. 30, no. 10, pp. 2859-2870, October 2008.

[9] M. Zeinoddini, G. A. Parke and J. E. Harding, “Axially pre-loaded steel tubes subjected to lateral impacts: an experimental study” in International Journal of Impact Engineering, vol. 27, no. 2002, pp. 669-690, November 2001.

[10] S. B. Menkes and H. J. Opat, “Tearing and shear failures in explosively loaded clamped beams” Experimental Mechanics, pp. 480-486, November 1973.

[11] E. Wang and T. Nelson, “Structural Dynamics Capabilities of ANSYS,” in DADFEM GmbH, Munich.

[12] S. Nouri, A. R. M. Gharabaghi and S. Mazaheri, “Analysis of Ship Collision with a Semi-submersible Platform,” in Eighth ISOPE Pacific/Asia Offshore Mechanics Symposium, Bangkok, 2008.

[13] H. Al-Thairy and Y. C. Wang, “A numerical study of the behaviour and failure modes of axially compressed steel columns subjected to transverse impact” Internal Journal of Impact Engineering, vol. 38, p. 732, March 2011.