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Recent Advances in Protective Elements of Offshore Structures

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***Abstract:*— Fixed offshore platforms play a central role in the production of petroleum in many regions around the world including South China Sea and Gulf of Mexico. Structural design, construction and efficient maintenance of these offshore structures are often challenging for those engineers involved. Various protective features are included in the design and construction of offshore structures to enhance the structural integrity and robustness of these platforms. In this paper, research and developments in two key protective features of offshore structures are presented. One common protective element used in a fixed platform is riser-guards to protect risers from accidental impact from supply vessels. Existing design practices for these riser-guards are based on the design guidelines of boat fenders used for naval structures. Some significant research conducted by the author's team on the area of performance assessment of conventional riser-guards will be presented in this paper. Prospect of innovative design for riser-guards using new materials will also be discussed. Another protective structural element known as Blast Wall is used on topside of fixed offshore platforms to protect key installations and personnel from accidental explosions. The structural behavior and performance of these blast walls is vital to safeguard the people working and key assets on an offshore platform. In depth research conducted by the authors on the performance and also on the damage assessment techniques for these blast walls will also be presented in this paper.**

***Index Terms* :-- Offshore platform, impact load, blast wall, riser-guard.**

I. INTRODUCTION

Fixed offshore platforms are the central part of oil production in some parts of the world. Many of these platforms which are suitable for shallow to mid-depth can be found in the South China Sea and in the Gulf of Mexico. Structural integrity and reliability of these offshore structures are essential to ensure uninterrupted production of crude oil. Two common challenges on the structural safety of these structures come from the accidental impact from supply vessels to the risers or from accidental explosions on the topside of a platform.

Statistics show that collisions events have contribute significant risk situations than other risk pointed out for an offshore platform. Approximately 10 percentage of the annual damage cost for an offshore installation is related to supply vessel collisions [1]. Although, the consequences of most offshore collisions have been minor to date, a ship collision is potentially can be an accident of highly serious character [2].
A considerable number of research and investigations regarding different aspects related to offshore blast walls have been carried out since the Piper Alpha oil rig accidental explosion in 1988. Recent incidents like explosion on 20 April 2010 in Gulf of Mexico [3] highlight the necessity of comprehensive study and analysis of performance of offshore blast walls.

This paper present the background and the current advancements achieved in the area riser protectors and in the field of response and damage assessment of offshore blast walls. These recent advances have the potential to improve the safety of fixed offshore platforms significantly.

II. OFFSHORE RISER GUARDS

Supply vessels visit offshore platforms frequently to deliver essential supplies and provide support throughout the service life of a platform. There is a high possibility of supply vessels to impact the vertical pipes also known as risers transporting crude oil from reservoir to the processing facilities on board of a platform. Risers are required to be protected from accidental impacts from supply and other vessels as they carry highly flammable liquid. The protective structure used to safeguard risers are known as riser protector or riser-guard. Conventional riser-guards are made of hollow steel tubular consisting of tubular members designed to protect risers from accidental vessel impact. A typical riser-guard used for fixed platforms is shown in Fig. 1.

These steel space frame riser-guards are designed to resist static forces equivalent to a vessel collision [4]. The design of conventional riser-guards is often dictated by the design principles for boat fenders and the main objective of these riser protectors is to prevent the supply and support vessels visiting the platforms from impacting the risers.

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Vessel collision with offshore structures has been highlighted in many design manuals and standards for offshore structures design [1, 5-7]. The main focuses of those studies were based on the structural response of the overall offshore structure. The application of boat fender design guidelines and due to lack of proper understanding of the behavior and performance of riser-guard under accidental impact could have resulted a significant over design of riser protectors for offshore platforms. Due to enormous weight and size of conversational riser-guards, the repair or replacement cost of these riser-guards are also significantly high along with the initial cost.

III. ADVANCED ANALYSIS OF RISER GUARDS

The clear need for better understanding of the behavior of riser-guards under vessel impact and desire for innovative and economic design of offshore riser guards had instigated the research initiatives by the authors and their team. The studies conducted by the research team was primarily focused on better understanding of riser-guard behavior and ways to improve the current design practices for offshore riser-guards for fixed platforms.

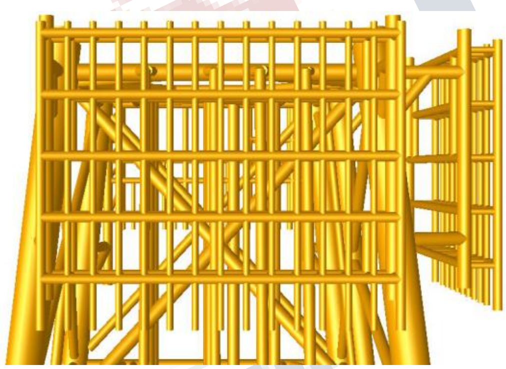


Fig.1. Conventional riser-guard on fixed offshore platform [8]

Proper understanding of collision mechanism between riser-guards and a vessel is central to better understanding of structural behavior of riser-guards. The impact force generated from a collision depends on vessel mass, velocity at impact, and the time taken by the vessel to stop. Det Norske Veritas (DNV)[1] and PETRONAS Technical Standards [9] suggest impulse-momentum approach to estimate the impact force from a collision. The recommended deformation curves suggested by DVN for establishing impact force is given in Fig. 2. The study by the research team on load transfer mechanism and structural response indicated [8] that more efficient and light weight riser protection can be designed for fixed offshore platforms.

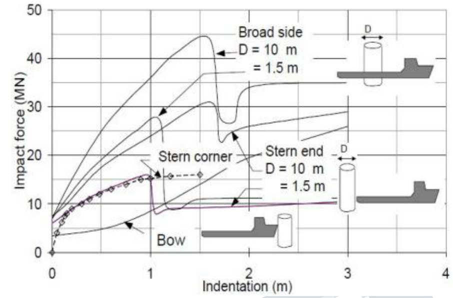
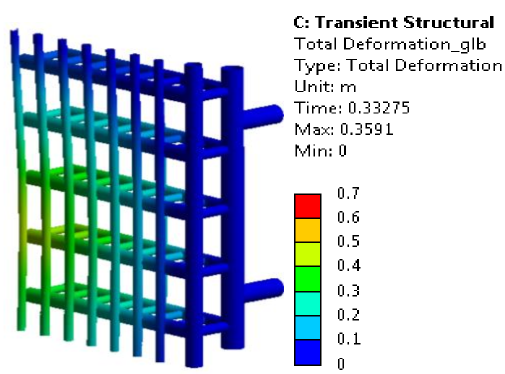


Fig. 2. Recommended deformation curve in DNV [1]

One of the main challenges for more economic and innovative design of riser guards was proper damage assessment techniques for riser guards in the event of a collision with offshore supply vessels. To establish a better understanding of the structural response and corresponding damage of conventional riser-guards, numerical systematic investigations were performed using transient non-linear finite element analysis by the authors [10-11]. This investigation was aimed at assessing the adequacy of the protection provided by the conventional riser-guard and to ascertain the damage level under its maximum capacity in energy dissipation. General purpose finite element software ANSYS Mechanical was used to conduct transient non-linear analysis to perform structural response calculation and corresponding damage assessment. Fig. 3 presents the maximum deformation of riser-guards for both broadside impact and bow impact. The study found that the broadside impact results in global structural deformation and the impact energy is dissipated by global structural displacement. Local denting was found to be the predominant mode of energy dissipation for the case of bow impact.



(a)

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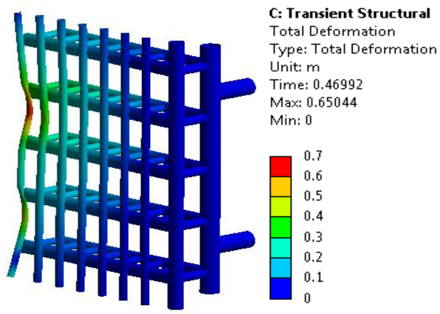

(b)

Fig.3. Maximum deformation of riser-guard for: (a) Broadside vessel impact and (b) Bow vessel impact [10]

The numerical investigation on the damage patterns in structural members, especially in the element joints, demonstrated the strain values were much lower than the failure limit for the case of bow impact. For the case of broadside impact, the strain values were much higher compared to bow impact case. Fig. 4 shows the total strain at a critical strain resulting from a broadside vessel impact on a riser-guard. The total strain resulting from a vessel bow impact on a critical joint was found to be significantly lower. The results from this investigation concluded that the conventional riser-guard does not only provide sufficient protection under accidental vessel impacts, but also indicates toward an overly-designed protection system which possesses much higher capacity than the design requirements for offshore oil producing regions in South China Sea[10]. Further study is ongoing on determining the actual capacity of riser-guard in terms of maximum impact energy sustainable prior by dynamic pushover analysis. The structural response parameters are expected to be presented as a baseline for further design optimisation, and as well as development of an alternative riser protection system for better economy and efficiency.

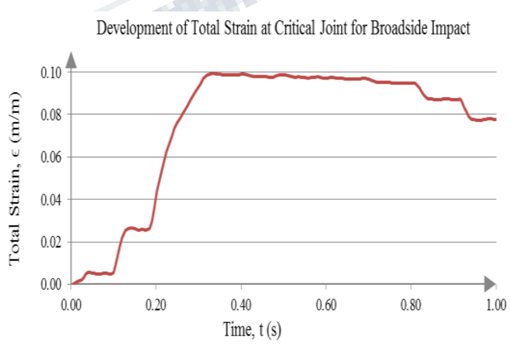

Fig. 4. Total strain at critical joint resulting from broadside vessel impact [10]

IV. OFFSHORE BLAST WALLS

Offshore blast walls are installed on the topside of a fixed platform to protect onboard personnel and key equipment from any possible accidental explosion. The consequence of accidental explosion on offshore structure can be extremely hazardous and causes serious casualties, property losses and marine pollution. A number of major accidents involving accidental explosions have already been reported. The impact of overpressure from explosions and that of elevated temperature from fire are the primary concern in terms of the actions [3].

Offshore blast walls are commonly made of stainless steel for its light-weight and corrosion resistant ability. These blast resistant barriers are requisite to protect personnel and critical systems from the consequences of an accidental explosion and subsequent fire on the topside of a fixed offshore platform. Typically, stainless steel blast walls are made of about 12m wide and 4m high, with corrugations running top to bottom [12]. In modern days blast walls are usually welded top and bottom and down both sides to the primary steelwork through angle connections. The top and bottom connections usually consist of two angles welded together and to the structural steelwork of the platform. An existing blast wall of an offshore platform has been shown in Fig. 5.

Fig. 5. Existing blast walls of an offshore platform [13]

Offshore blast walls are mostly designed using simplified analytical tools like single degree of freedom (SDOF) method. Common design guidelines for these walls allow the use of SDOF models for analysis and design of blast walls due to its simplicity and less resource intensiveness. Design guidelines like Technical Note 5 (TN5) [14], unified facilities criteria manual (UFC 3 -340-02) [15] and protective design center technical resort [16] prescribe the use of SDOF model analysis for design. The SDOF analysis employs the global deformation or displacement as primary response parameter. Thin plate structures like stainless steel blast walls when subjected to high impulsive pressure loads can experience severe damage in a particular region without experiencing a significant global deformation. In the

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idealization of resistance functions for SDOF models often involve significant simplification of material behavior. Thus, the consideration of only the global displacement and use of simplified material model for analysis and design of offshore blast walls can result in inefficient design and economy.

V. MODELLING AND DAMAGE ASSESSMENT OF OFFSHORE BLAST WALLS

There is a lack of presence of well accepted design guidelines based on extensive and detailed research on the behavior and damage pattern of typical offshore blast walls. Due to absence of in-depth understanding of structural response of blast walls under different blast loads has the potential to contribute design of blast walls which are significantly over designed or inadequately designed to provide desired level of protection. In order to achieve a better understanding on the behavior of typical blast walls under different accidental explosions a detailed investigation was conducted by Rahman et at. [17]. In this study by the author and his team utilized a computational fluid dynamics (CFD) approach coupled with non-linear finite element analysis to predict the effect of different realistic explosions on typical blast walls. A parametric study was also performed to investigate variation in the behavior of blast walls with change in parameters related to explosion and blast wall. To advance the results further, a study to explore structural responses of conventional offshore blast wall was conducted using both non-linear finite element approach and elasto-plastic SDOF system. Commercial finite element package ANAYS version 14.5 was employed to model blast walls. Appropriate technical guidelines were used to predict the actual scenario of explosion as well as blast pressure and wave propagation to present more realistic loads for an explosion scenario. Based on the study, an in-depth modelling techniques and procedures is presented in Rahman et al. [18]. The material nonlinearity and strain-rate effects were included in the analysis to obtain realistic response of the blast walls.

Stainless steel is commonly used as the preferred material of choice for offshore blast walls for its high ductility ratio, considerable energy absorption ability against impulsive loading and excellent corrosion resistant behavior. Stainless steel is also preferred for its high yield and ultimate strength and long strain hardening behavior. To improve the performance of blast walls several research were carried out since 1988 after Piper Alpha explosion. Most of these studies were based on simplified analysis techniques.

Blast pressures are highly impulsive and short duration, hence analysis results based on elastic response calculation based on over simplified pressure pulse is expected to be less realistic in producing the structural response of a typical blast wall.

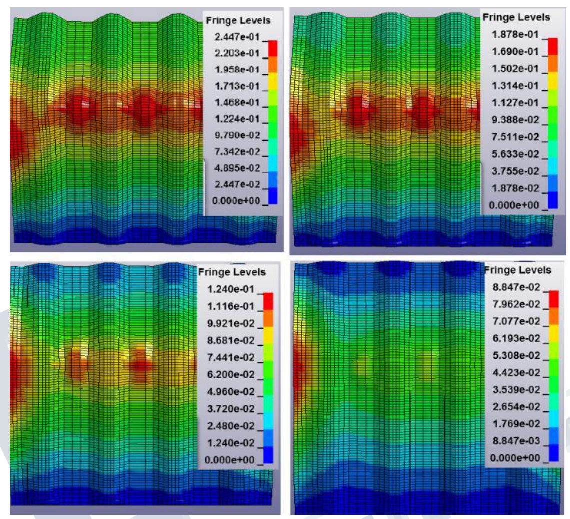

Fig.6. Total deformation contour under blast pressure [17]

Detailed non-linear finite element analysis with realistic blast pressure can produce reliable structural response of offshore blast walls. A full scale finite element model of stainless steel blast wall developed using widely accepted finite element package LS-DYNA by the authors [19]. Advanced material models and analysis techniques were employed to incorporate strain-rate effects and material non-linearity to study structural behavior and performance of offshore blast walls under high impulsive pressure loading. The numerical model was verified against available experimental results. The verified model was used to study structural response and effect of support rigidity for offshore blast walls.

Structural responses of an offshore blast wall under highly impulsive loading for SDOF analysis and non-linear finite element analysis (NFEA) is presented in Fig. 7. The comparison clearly shows that the peak deformation values for both the analytical approaches can be similar, but the peak response time is different and post-peak response is different. Although, the peak deformations can be similar, but SDOF analysis fails to provide damage distribution on the blast wall.

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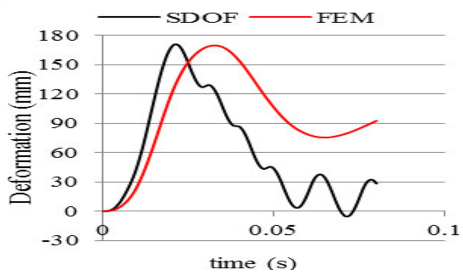

Fig. 7. Deformation histories obtained using SDOF analysis and NFEA for 133 kPa peak pressure

The developed non-linear finite element model was found to produce remarkable close deformation and damage patterns as observed in a past experiment. Detailed on the model verification can be found in Syed et al. (2016)[19]. The deformation shape and Von-mises stresses for a blast with 256 kPa pressure is presented in Fig. 8.

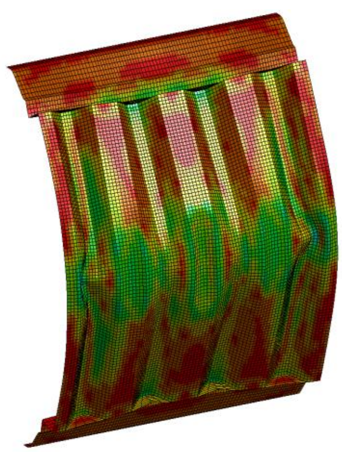

Fig. 8. Von-Mises stresses for 256 kPa pressure, 3.86 kPa-s impulse [19]

An extensive parametric study was conducted using the verified finite element models to construct pressure-impulse (P-I) diagrams for different deformation levels. These P-I curves or iso-damage lines can be used as a quick assessment tool to determine possible level of damage of similar offshore blast walls due to different high impulsive pressure loading caused from different explosion scenarios. Fig. 9 shows the P-I diagrams developed for different levels of maximum deflection for a blast wall.

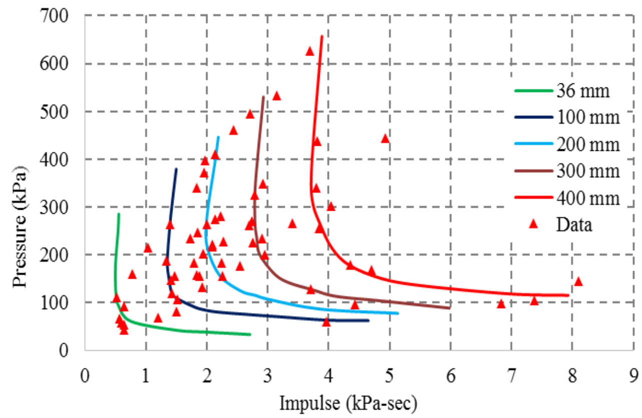

Fig. 9. Pressure–Impulse diagram for various deflection levels for different pressure profiles [19]

CONCLUSION

This paper highlighted the gaps in knowledge related to two key protective aspects of offshore fixed platforms. Fixed offshore platforms are vital in many parts of the world for exploration of oil and gas from shallow to mid-depth sea beds. Hence, structural integrity and protection against possible failure or damage is important. Riser-guards and offshore blast walls are two keep protective features used in offshore platforms. The authors and the team conducted significant research at different aspects of these two protective structures of offshore platforms. The researched conducted and also some ongoing research in these areas are presented in this paper. The researches by the team have significantly contributed in understanding the response and damage pattern of offshore riser-guards under accidental vessel impact. Conventional riser protectors were established to be considerably over designed. The damage from bow impact was established to be more local and broadside impact was found to produce more global damage.

Performance of conversional blast walls were also investigated. Structural response and structural damage of offshore blast walls were also studied. In-depth understanding of the response of blast walls under accidental explosion on topside of a fixed platform was studied. Simplified damage assessment tools in the form of pressure-impulse diagrams were also suggested.
Overall, this paper present significant researches in the fields of protective features of offshore platforms are discussed.

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