Residual Anti-Explosion Performance of The Corrugated Blast Wall For Offshore Platforms after Explosion

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Abstract. The study of multiple explosion resistance in offshore platform is important in the rescues of life and equipment. To evaluate residual anti-explosion performance of blast wall, numerical investigations are conducted suffering twice sequential blasts. Then comparison with analytical results under the single blast with the same impulse load is implemented. Results show that different from the single blast, the blast wall is bent as a fold after the second blast. There are three kinds of plastic hinge after the second blast due to the latent plastic hinge caused by the first blast. The prediction of residual ultimate resistance shows that additional plastic hinges strengthen the anti-explosion capability. The second blast evaluation is instructive to reinforce the structure and to set the passive plastic hinges

1. Introduction

In the process of offshore oil and gas development, many catastrophic accidents have occurred, including fire, explosion and platform structure failure, resulting in considerable economic losses and environmental pollution. Through investigation of a large number of offshore platforms accidents, it is found that quite a few platforms are usually faced with the continuous blasts after the first one happened.

On July 5, 1988, the accident of the Piper Alpha offshore platform happened from a first explosion which was followed by a fire. Because of the flooding, all pumps were submerged and out of function. There is no fire water to put out. Inevitably the fire got bigger. After 20 minutes, the first gas riser burst and a large amount of leaking gas exploded when it caught fire[1]. On March 15, 2001, an explosion occurred on the starboard side of Petrobras 36, a semi-submersible platform located 125km off the coast of Campos Basin in the deep sea, southwest of Brazil, causing a fire. There was an explosion on the platform when the columns were subjected to the excessive pressure. After the columns of the platform injected with oil and gas, a large explosion happened, which eventually led to the platform capsize[2]. On April 19, 2010, the diesel engine room of Deepwater Horizon offshore platform first exploded and caught fire. Due to the high pressure, the safety valve of the mud pump was opened. The oil and gas gushing from the pump room caused the fire in the pump room, which spread and caused a series of explosions[3].

Blast walls are used to reduce the impact of a potential gas explosion on the temporary refuge by mitigation of the explosive energy. To strengthen the capability of blast wall is a useful solution. J.W.Boh et al.[4] presents a passive impact barrier system placed at a certain offset behind the walls. Nwankwo E. et al.[5] designed a composite patch on the blast resistance of profiled blast walls and also presented the development of a rapid assessment tool which provides understanding of the effect of the
composite patch. Christian W. et al. [6] carried out an investigation of the influence of inclined angle of Vee stiffener used on blast wall structure. The results showed that an alteration of inclined angle has a considerable effect on the dynamic response of the blast wall structure. These methods have a certain reinforcement to the blast wall, however the study of residual performance of blast wall after explosion is insufficient.

In this paper, numerical investigations on residual ultimate performance of corrugated blast wall under twice distributed pressure loading were conducted. In contrast to the first blast, deformation and strain distribution of the second blast are acquired. This study provide reference for the protective structure design of offshore platforms.

2. Numerical Model

2.1. Initial design model of corrugated blast wall

A typical blast wall is made by corrugated plate and connection. The blast wall model shown in Figure 1 is in compliance with the experimental scheme [7]. The test blast wall design is based on a non-symmetric trapezoidal deep trough profile, angle connections top and bottom and free sides. The corrugated part is 880 mm wide, 915 mm long and 40.5 mm deep. The whole part thick is 2 mm. The connection is 195 mm deep and 35 mm long. It is composed of 3 mm and 4 mm stainless steel angles welded to a 12 mm thick angle that formed the primary framework. The mass of the blast plate made of stainless steel is 41.5 kg. For the test results, the 10.27 Kpa·s distributed impulse is selected for the simulation, which caused a 22.2 mm permanent deformation of the mid-point [7].

![Figure 1. Test blast wall(a) model (b) dimension of corrugated part (c) dimension of connection](image)

2.2. Material model for FEM analysis

Stainless steel is used in the test model. The Cowper-Symonds yielding model as shown in Equation 1 is suitable for describing the properties of stainless steel structures if the thermal deformation effect is negligible. This model accurately describes large deformation of the material and high strain change.

\[
\frac{\sigma_y}{\sigma_0} = 1 + \left( \frac{\dot{\varepsilon}}{D} \right)^{\frac{1}{n}}
\]

(1)
In Equation 1, $\sigma_0$ is static yield strength, $\dot{\varepsilon}$ is equivalent plastic strain, and D, q are material constants. The parameters of steel are presented in Table 1[7].

| E(GPa) | $\nu$ | $\rho$ (Kg/m3) | $\sigma_0$(MPa) | $\dot{\varepsilon}$ | D | q |
|-------|------|---------------|--------------|----------------|---|---|
| 210   | 0.3  | 7850          | 276          | 17.76%         | 2720 | 5.78 |

2.3. Finite element numerical model of the blast wall
The finite element models of corrugated blast wall are shown in Figure 2. The model are simulated by plate elements, and all elements are defined by pshell. The element number is 20252. Point 1 is midpoint of whole panel and point 2 is the joint between panel and connection. The result of these evaluation points are used to measure the deformation and energy absorption of blast wall.

![Finite element model](image)

**Figure 2** Finite element model (a) whole model (b) half model

2.4. Loading and boundary conditions
The bottom of finite element model is fixed. The distributed impulse loading is applied to the faceplate along the y-direction. The distributed impulse loading is a double triangular shock wave, with a peak value of 123 kPa. The applied time is 0.167 seconds. Each impulse is 10.27 Kpa·s, so the total impulse is 20.54 Kpa·s. The distributed impulse loading and constraints are shown in Figure 3.

![Distributed impulse loading and constraints](image)

**Figure 3** Distributed impulse loading and constraints (a) The distributed impulse loading and constraints (b) The pressure and impulse applied on the models

3. Study on residual anti-explosion performance
In order to illustrate the residual anti-explosion performance, the stable states at 0.99 s and 2 s are selected after two distributed impulse loading is finished respectively. Deformation and strain distribution are selected to evaluate anti-explosion performance after two blasts.

3.1. Deformation
Deformations of blast wall during the first blast(0-0.99 s) and the second blast(1-2 s) are presented in Figure 4-5. The whole panel gets maximum deformation at 0.01 s and 1.01 s, which are corresponding to the peak pressures. The subsequent trends of two blasts are quite different. The middle part is recovered at 0.99 s, but the free sides are not. Evidently, the maximum deformation occurs at the free
sides. The connection is stretched vertically through the flexible angle. As to the end of the second blast, the whole panel is bent as a fold. The cross section collapsed along the highly strained region at the centre of the panel. The deformation of connection is concentrated mainly in two areas: a) the plastic hinge between 3 mm flexible angle and 4 mm angle, b) the plastic hinge along the rigid angle weld-line.

3.2. Deformation history
Deformation history on evaluation points on blast walls is shown in Figure 6. The point 1 presents deformation of blast wall. It can be seen that the deformation peaks occurs at 0.01 s and 1 s, which are corresponding to pressure peaks of two blasts. The stable deformation appears at 0.99 s and 2 s, but the decline histories are quite different. The first decline history is from 58 mm to 23 mm. On the contrary, the second decline history almost has no fluctuation and gets stable at 134 mm immediately. The point 2 shows deformation of connection. Although the deformation peaks occurs at 0.01 s and 1 s, the stable values at 0.99 s and 2 s are quite approximate. The energy absorption of connection could be estimated by deformation history of point 2 directly, but the energy absorption of corrugated panel need to be measured by deformation difference.

![Figure 4 Deformation of the first blast](image1.png)

![Figure 5 Deformation of the second blast](image2.png)
The difference of deformation history is shown in Figure 7 for point 1 and point 2, which reflect the energy absorption of corrugated panel. The deformation differences of two blasts are folded into one minute for the sake of comparison. Due to the middle panel recover, the deformation difference caused by the first blast is almost disappeared. As to the second blast, the deformation difference is steady from the beginning to the end. This mean the panel absorbed more energy during the second blast than the first blast. So the strain distribution is necessary to find out the difference of energy absorption between two blasts.

3.3. Strain distribution

Strain distribution under two blast loading cases are shown in Figure 8-9. When the plastic strain of any element exceed 17.76%, the element will disappear to indicate the partial failure of blast wall. Evidently, most plastic strain occurred on the connection. Furthermore, some elements disappeared at the 4 mm angle near the panel. Although the middle part of panel were recovered at 0.99 s, large plastic strain appeared at the cross section of bottom flange due to the flange buckling and folding.

During the second blast, the plastic strain areas of panel and connection continued to expand. The panel collapsed symmetrically along the cross section with flange folding and flange buckling, which is shown in Figure 5-d. The plastic hinge at the corner of 4 mm angle start to tear. So does the plastic hinge along the rigid angle weld-line.
4. Conclusion
Numerical investigations on residual performance of corrugated blast wall under distributed pressure loading were conducted. Key observations include:

- After the second blast, the whole panel is bent as a fold. This deformation mode is caused by the flange buckling and folding which are made by the first blast.
- There are two obvious plastic hinges on the connection, which could be observed in strain distribution during the second blast.
- The second blast evaluation is useful to check the weakness of blast walls. It is also helpful to reinforce the structure, including the place where the plastic hinges of connection will occur.

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