Research on fracture mechanism of blast wall on offshore platform under impulse loading

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Abstract. In this paper, the fracture mechanism of the corrugated blast wall on offshore platform is analyzed and studied. Based on the experimental results of the typical corrugated blast wall, the fracture state is calculated by incremental pressure loading and the ultimate state is analyzed. The cracked joints have been strengthened and the anti-explosion performance compared with the original model. Results show that reasonable strengthening of the weak parts can effectively improve the overall ultimate anti-explosion capability of the corrugated blast wall. This research could be a reference for the design of structure protection.

1. Introduction

As the infrastructure of gas exploration and offshore oil, the safe operation of offshore platform is the premise of exploration and development. In most of the accidents from offshore platforms, the explosions caused by fuel leakage and fire hazard account for nearly the half.

Some significant accidents have serious consequences. On July 5, 1988, continuous explosions occurred on the Piper Alpha offshore platform[1]. On March 15, 2001, an explosion on the starboard side of the semi-submersible Petrobras 36, 125 km off the coast of the deep Campos Basin in southwest Brazil, eventually capsized the platform[2]. On April 19, 2010, the explosion and fire on the Deepwater Horizon oil rig resulted in the oil spill, which caused serious ecological damage[3]. It is particularly crucial to research the fracture performance of the blast wall in the area of offshore platforms.

Lots of researches on shock failure of structures have been carried out. Nurick G N[4] compared the tests with numerical results for fully fixed stiffened square plates subjected to blast loading. Rudrapatna N S[5,6] simulated deformation and failure of different kinds of stiffened plates respectively under blast loading. Feng Zhu[7] investigated failure of metallic sandwich panels under impulse loading. Langdon G S[8] analyzed plastic deformation and failure of profiled blast wall panels made by stainless steel. However, there are insufficient researches into the fracture mechanism of blast wall under impulse loading. Further investigations are necessary regarding the extremely mechanism of anti-explosion structures on offshore platforms.

The blast wall on offshore platform is used to save life and equipment by absorbing explosion energy. Based on pulse pressure test of 1/4 scale blast wall, a numerical studies of fracture mechanism have been carried out. The ultimate state is found and analyzed by increasing the peak pressure. From this analysis, the cracked joints are strengthened and compared with the original structure. The research shows that the reasonable strengthening cracked parts can effectively improve the anti-
explosion performance of the blast wall. Increasing peak pressure could be an auxiliary method for the design of anti-explosion structures.

2. Numerical modeling approaches

2.1. Schematic design of blast wall
A typical corrugated blast wall as shown in Figure 1 is composed by corrugated panel and connections, and its size is same as 1/4 scale model in Reference 10. The thickness of corrugated panel is 2 mm with stainless steel. The connection is composed of three angles with different thickness. The blast wall is 915 long, 880 mm wide and 195 mm height. The blast wall is fixed to foundation by connection[9,10].

![Figure 1](image)

Figure 1. Diagram of corrugated blast wall (a)Model scheme, (b)Dimension of corrugated panel, (c)Dimension of connection.

2.2. Material model
The Cowper-Symonds yielding model, as shown in Equation 1, is suitable for stainless steel in blast wall model, when the thermal effect is negligible. The large deformation and high strain change could be described accurately with proper parameters.

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

(1)

Where \( \dot{\varepsilon} \) is an equivalent plastic strain, \( \sigma_0 \) is the static yield strength, and D and q are material constants. The parameters of the stainless steel are shown in Table 1 [11,12].

| E (GPa) | P (Kg/m3) | \( \sigma_0 \) (MPa) | \( \nu \) | \( E_t \) (GPa) | \( \bar{\varepsilon} \) | D | q |
|---------|-----------|----------------------|-------|----------------|--------|-----|---|
| 210     | 7850      | 276                  | 0.3   | 1.254          | 25%    | 1704 | 5.2 |
2.3. Finite element model

1/2 symmetric Finite element model of blast wall is shown in Figure 2, which are simulated by plate elements. The element size is 10mm and number of elements is 7804.

![Figure 2. 1/2 symmetric model.](image)

2.4. Constraints and Loading

The bottom of blast wall are fixed and the symmetry side are constrained by y-direction translation and corresponding rotation. The distributed impulse loading on the blast wall is applied along the normal direction of elements. According to the Reference 10, the permanent deformation of center point is 23mm under the impulse pressure loading of 0.123MPa with 0.167 seconds. Therefore, this peak pressure is chosen as the initial value. The amplitude of the peak pressure P increases by 0.05 MPa when the applied time is constant until the explosion-proof structure is torn away. The incremental peak pressure is shown in Figure 3.

![Figure 3. Incremental peak pressure of distributed impulse loading.](image)

3. Results

3.1. fracture modes

The permanent deformations of the blast wall under each peak pressure P are shown in Figure 4. It can be seen that the bending of corrugated panel is not obvious under the experimental peak pressure of 0.123MPa. When the peak pressure exceeds 0.2MPa, the overall bending of the panel occurs, along
with the local buckling in the panel span. The local buckling phenomenon fade away when the peak pressure exceeds 0.4MPa. The main deformation of panel is a large overall bending. When the peak pressure is beyond 0.5MPa, the edges of corrugated panel are completely torn.

![Figure 4](image)

**Figure 4.** Permanent center deformation under different peak pressure.

3.2. Fracture mechanism

The plastic deformation of blast wall at different moments under the peak pressure of 0.5MPa are shown in Figure 5. The connections start the plasticity deformation firstly, and three plastic hinges occur at moment of 3 ms. At the moment of 4 ms, the stress concentration appears at the joints between panel and 4-mm angle. After 4.5ms, further fractures under higher loading have been formed at the joints.

Obviously, the reason of fracture is stress concentration at joints. When the corrugated panel is subjected to the impulse loading, a significant transverse deformation occurs at the middle of panel. The transverse deformation drives the adduction of connections and produces a high in-plane tensile effect at the joints. The bottom plates of corrugated panel are the transmission path of the main strain wave and bear the main tensile loading. With the higher loading, the plastic strain of joints exceed the rupture strain and it leads to a complete rupture. In the process of impact, the local buckling occurs in the middle of corrugated panel which doesn’t form a whole damage mode.
4. Strengthening effect
As discussed in 3.3, the fracture of joints limit the anti-explosion performance of blast wall. Therefore strengthening the joints should be considered. The fracture of joints are located at the sides of bottom plates and 4mm angles. The thickness of side plates are increased from 2mm to 4mm and the 4mm angle is increased to 5mm angle. The strengthened parts are shown in Figure 6.

Figure 6. Strengthening parts (a) sides of bottom plates (b) 4mm angle.
The strain distributions of blast wall under impulse loading of peak pressure 0.5MPa are shown in Figure 7. It can be seen that there are no cracks at the joints of blast wall after being strengthened. The blast wall withstand the impulse loading of 0.5MPa that cause the fracture before strengthening. Therefore, the weak parts of the blast wall have been significantly improved, and the ultimate anti-explosion capability has been improved.

Figure 7. Comparison on strain distribution under impulse loading of peak pressure 0.5MPa (a) before being strengthened (b) after being strengthened.

5. Conclusion
Based on the numerical investigation of the fracture mechanism of blast walls, key observations are indicated as follows:

The fracture modes of blast wall can be obtained by increasing the peak pressure of impulse loading. the weak parts of blast wall can be effectively improved by analyzing the fracture mechanism.

After the blast wall is strengthened, the weak parts of blast wall may be probably changed. So the fracture modes should be investigated by increasing the peak pressures once more if needed.

Although it is effective to increase the thickness to improve the anti-explosion performance of the structure, the joints of anti-explosion structure should be concerned in design.

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