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The blast alleviation effects of a hybrid barrier system with triple energy absorbers

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ABSTRACT

Blast walls on offshore topsides are designed to protect personnel and critical equipment. The traditional design that relies on the panel as the sole energy absorber is difficult to achieve the code compliances. While studies on dual absorber system such as foam cored sandwich panels overlook the boundary effects. This study investigates the blast alleviation effects of a hybrid barrier system with triple energy absorbers (i.e. panel, foam and springs), in which the foam and springs are placed at the supports to prevent weld rupture. Accordingly, a novel design concept is proposed by using flexible supports filled with polymethacrylimide foam and rotational springs, allowing the wall to slide/rotate a certain distance/angle to release the high stresses at supports and meanwhile dissipate blast energy through material deformations. The panel deflection, energy absorption and weld rupture of the proposed system are the focal points. An analytical model based on beam vibration theory and virtual work theory has been developed, in which the boundary conditions at each support are simplified as a translational spring and a rotational spring. Finite element method has been applied to corroborate the analytical model. In addition, the interaction effects between the three absorbers have been investigated through energy absorption breakdowns. In the end, a numerical comparison study with the traditional design has been presented to demonstrate the privilege of the proposed system in minimising weld rupture risk due to the high stresses being realeased through controlled displacements and rotations at supports.

1. Introduction

Blast resisting structures have been widely used in civil and military sectors to mitigate explosion effects. Blast walls in the offshore platform are critical structural elements to protect personnel and critical equipment from hydrocarbon explosions. Different from onshore concrete blast walls that rely on high stiffness and large weight to resist blast loading, in offshore circumstances, the requirements for blast walls are more rigorous that they should be lighter, more robust, and are able to maintain their integrity during blast events.

Stainless steel profiled panel is an excellent choice for offshore blast wall due to its easy fabrication, considerable ductility, and good corrosion and fire resistance. As the sole energy absorber during a blast, the dynamic structural performance of the profiled

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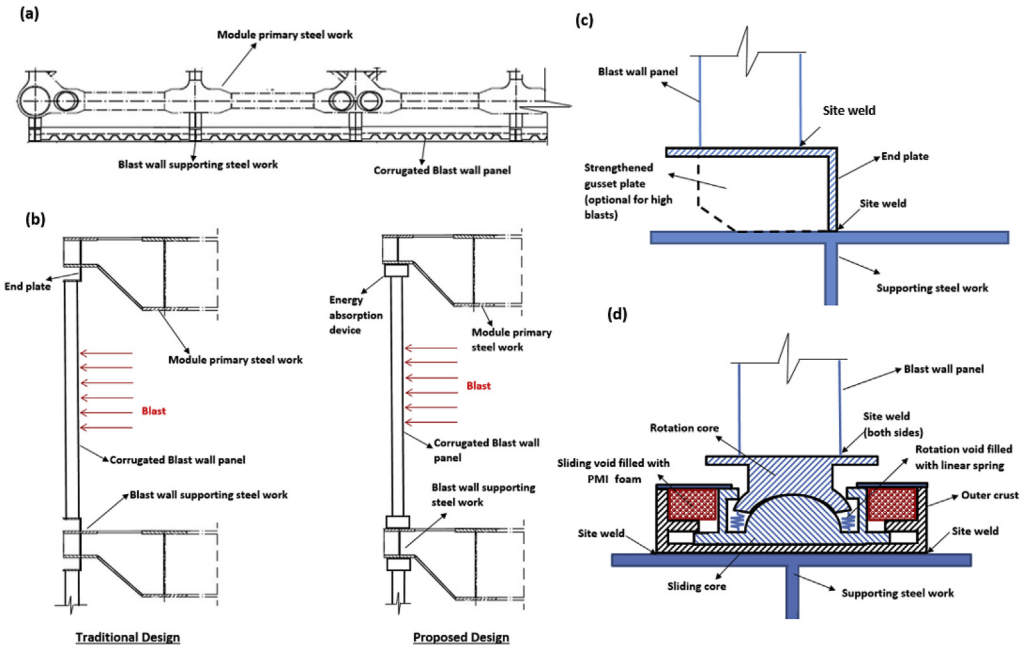

Fig. 1. Comparison of traditional design and proposed design: (a) Blast wall top view; (b) Blast wall side view; (c) Traditional design connection; (d) Energy absorption support of proposed design. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

panel has been studied intensively. Boh et al. [4] compared the structural responses among three profiled sections (deep, intermediate, shallow) and concluded that the ductile performance of the intermediate section outweighed the other two sections. The influences of the end connections on the overall performance of the panel were studied by Schleyer et al. [3] through a series of field tests using 1/4 scale stainless steel profile panels with three different angle end plate lengths. It was concluded that larger displacements were produced by higher flexibility supports, however, the increased flexibility of the panels with longer angle connections could delay the onset of panel membrane behaviour.

In 2003 (revised in 2007 afterwards), Oil and Gas UK and Health & Safety Executive (HSE) [7] issued a new guidance for offshore explosion risk mitigation and blast resistance design. Analogous to earthquake assessments, the guidance requires blast walls to be designed to sustain two level of events, strength level blast (SLB) and ductility level blast (DLB). The former represents a more frequent design event (10^{-3} exceedance per annual) where it is required that the blast walls do not deform plastically and remain operational, while at the latter load level (10^{-4} to 10^{-5} exceedance per annual), plastic deformation is acceptable provided that blast walls remain in-place and the explosion event is not escalated. In order not to provoke escalation, the maximum wall deformation shall be limited to the clearance to critical equipment, pipelines and structural members located nearby to prevent collision. Normally a maximum allowable deflection of 300 mm is adopted in design. Plastic strains shall in no case exceed 5% at connection to prevent weld from tearing out.

In traditional design, blast wall connections that consist of welded endplates are extended from the supporting plate girders as shown in Fig. 1 (a). This design may be adequate for weak blasts with overpressure less than 1 bar. However, recent large scale explosion tests indicated that the blast wall overpressure could be as high as 4 bar for a typical offshore topside module [22]. Under such condition, the traditional design is no longer sufficient because blast wall is likely to undergo large plastic deformations and develop membrane actions. Under high blast loading, the connections are subjected to translational shear forces and in-plane membrane (axial) forces. In the meantime, connections shall undertake large rotations for the blast wall to deform and absorb energy, which makes the connections extremely vulnerable for rupture. Local strengthening with gusset plates (see Fig. 1 (c)) may be required for strong blasts (e.g. 2 bar–4 bar). Although the strengthened connection can reduce the blast wall deflections, it may also yield larger membrane forces at welded connections, where stress concentrations may occur and rupture propagates progressively, leading to failure mode shifted from ductile bending to brittle shear or tensile rupture at supports. These behaviours coincide with the monolithic structural failure mode II (tensile tearing) and mode III (shear failure) at supports defined by Menkes and Opat [23]. Therefore, using the profiled panel as the sole energy absorber is difficult to achieve the code compliances.

As a result, new designs with dual energy absorbers have been developed and studied. Nwankwo et al. [8] proposed a hybrid system of a stainless steel blast wall with carbon fibre reinforced plastic (CFRP). Both analytical and numerical models were developed to study the hybrid system of strengthened blast wall. Results indicated that compared to un-strengthened panels, an average reduction of 33% mid-span displacements were obtained by the strengthened panels. Boh et al. [10] introduced the passive impact barrier to be installed at a certain offset behind the blast wall panel. Numerical models with contact effects, weld failure and large plasticity were created, the results implied that the passive barriers could delay the tearing of the horizontal welds. Sandwich panel