Thin-Walled Structures 96 (2015) 1–10

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Blast performance of water tank with energy absorbing support

Yonghui Wang [a,*], J.Y. Richard Liew [a,b]

[a] Department of Civil and Environmental Engineering, National University of Singapore, Singapore
[b] College of Civil Engineering, Nanjing Tech University, Nanjing, Jiangsu, China

ARTICLE INFO

Article history:
Received 14 February 2015
Received in revised form
28 July 2015
Accepted 28 July 2015
Available online 5 August 2015

Keywords:
Water tank
Blast loading
Energy absorbing support
Numerical method
Response regime

ABSTRACT

The blast performance of water tank with an innovative energy absorbing support was studied to reduce the support reaction force and mitigate the damage on the water tank. The aluminum foam was adopted as the energy absorbing material, since it has high energy absorbing potential during crush plateau and safety backup zone after the compaction strain. Finite element model considering fluid and structural interaction in which the water is modeled using the Eulerian formulation and the steel tank by Lagrangian formulation is proposed. The proposed numerical model of water tank was verified by comparing the predicted results with the test results obtained from dynamic pressure tests on steel tanks filled with water. The numerical results showed that the support reaction force depends on the density and yield strength of the aluminum foams and the reaction force could be reduced significantly if softer aluminum foam was chosen. The total displacement of the water tank was increased by up to 38% due to the increase in deformation of the energy absorbing foam. The aluminum foam was proposed to absorb the blast energy and reduce the damage on the water tank. However, more damage on the water tank was observed when a very low density aluminum foam support was used. This was attributed to the increased external work done by blast loading which was higher than the energy absorbed by the aluminum foam support.

1. Introduction

In recent years, the extreme events and threats related to blast loading are on the rise even for non-critical buildings and infrastructures, which have sparked the urgent need for the costly blast resistant design or retrofit for future and existing buildings and infrastructures. However, the probability of blast attack can still be generally considered as low particularly for non-critical infrastructures and hence, it would be more appealing if the blast-enhancement design could be optimized by considering other aspects of the buildings' operations, such as sustainability and energy saving. An innovative water storage façade shaped in the form of a thin tank that can be used to harvest solar energy and reduce thermal heat penetration into buildings during normal daily operations [1,2] and at the same time is an effective protective layer in the event of blast attack was thus envisioned to achieve the multi-functional design. The experimental, numerical and analytical studies have been conducted to study the structural performance of water tank under dynamic pressure and blast loading in order to extend the multi-uses of water tank [3–6]. It was found from the numerical studies that the blast resistant capacity of water tank could be significantly increased by developing tensile membrane force when the water tank was imposed with axially restrained boundary condition [5]. However, the support reaction force was also increased, which may bring the difficulties on the support design. Hence, the water tank with energy absorbing support was proposed in this study in order to reduce the support reaction force and damage of water tank.

To reduce the damage of structures under blast loading, a number of energy absorbing devices and supports were developed [7–10]. The unidirectional passive damper (UPD), as shown in Fig. 1, was one of the energy absorbing supports, which could be applied to flexible blast resistant steel structures [7]. The UPD has different behaviors under tensile and compressive loadings, i.e. applying force to the frame and absorbing the energy when the frame moving away from its original equilibrium position but providing no obstacle when the frame moving toward its equilibrium position. The frame with UPD could therefore move back to its original configuration. It was also showed that the applied UPD could absorb the most internal energy if a structure was designed to have high lateral flexibility. A dissipative device for the blast mitigation of glazing facades supported by prestressed cables was developed by Amadio and Bedon in order to mitigate the critical components of the façade and absorb and dissipate part of the blast-induced stresses in the critical façade components [8]. In terms of energy absorbing support, the support with small

* Corresponding author. Fax: +65 67791635.
E-mail address: wangyonghui@nus.edu.sg (Y. Wang).

http://dx.doi.org/10.1016/j.tws.2015.07.022
0263-8231/

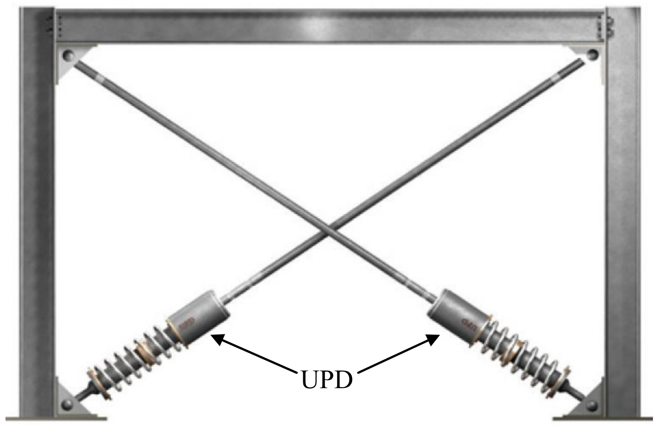

Fig. 1. The flexible frame equipped with unidirectional passive damper (UPD) [7].

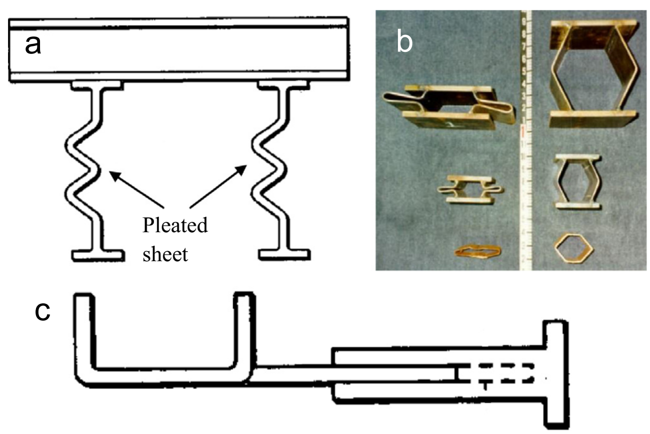

Fig. 2. Energy absorbing supports: (a) and (b) pleated sheet steel structure [9,10]; (c) sliding connector [9].

stiffness and large plastic deformation capacity is preferred, such as pleated sheet steel structure in Fig. 2(a) and (b) [9,10] and sliding connector in Fig. 2(c) [9].

The principle of using energy absorbing support to absorb and dissipate blast energy is that the energy absorbing support is designed with low stiffness but high plastic deformation capacity to transfer part of blast energy to the support through plastic deformation and also reduce the support reaction force. In this study, the aluminum foam was adopted as the energy absorbing material, since it is a commercial product and can be easily obtained. In addition, the stress–strain relationship can be easily obtained by conducting uniaxial compression test and therefore the support reaction force can be obtained if the compressed length (or compression strain) of aluminum foam is given. The typical stress–strain curve of aluminum foam in Fig. 3 mainly includes the energy absorber zone to absorb blast energy and safety backup zone to ensure the safety of support after severe compression of the aluminum foam. Hence, the aluminum foam is an ideal energy absorbing material [11,12] and can be used for the energy absorbing support.

The explicit code in LS-DYNA, which is suitable for modeling structures under high rate loading, was widely adopted to study the blast response of civil infrastructure, e.g. concrete panels [13–15], steel structures [16–19] and water storage tank [5,20]. In this paper, the LS-DYNA was also adopted to study the blast performance of water tank with energy absorbing support. The effects of energy absorbing support on the response of water tank were studied, including support reaction force, deformation, external

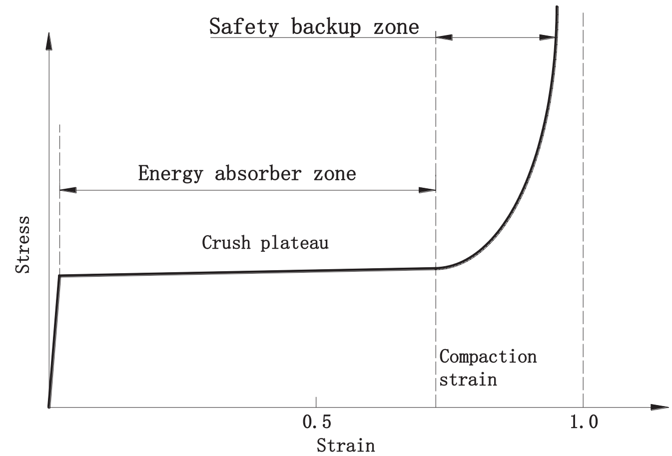

Fig. 3. Typical stress–strain curve of aluminum foam.

work and internal work of water tank. Besides, the effects of blast load duration (or response regime) were also discussed.

2. Finite element model

2.1. Energy absorbing support description

The water tank under dynamic pressure loading was tested and presented in Ref. [3] and the dimensions of the water tank are given in Fig. 4. The water tank was proposed to be installed at the outer skin of a building to achieve energy saving and blast resisting function and attaching the tank to the edge beam of a building is a convenient way for the installation. The schematic drawing of the installation of water tank is given in Fig. 5. As shown in Fig. 5(a), the I-beams, which are used to support the water tank and apply axial restriction, are fixed to the edge beam. The box-type end with cut-out rectangular holes for inserting I-beams is welded to the two boundaries of the water tank. Then, the water tank is positioned and the aluminum foam is inserted between the I-beam and the box-type end to reduce the load transferred from the water tank to the I-beams and absorb blast energy. Finally, the connecting plate is welded to the I-beams in order to restrain the rotation of box-type end and connect the top and bottom I-beams to ensure them deforming together. Besides, the connecting plate can also cancel part of the axial force from top and bottom tanks if both of them are simultaneously subjected to blast loading. The front view of the installation is shown in Fig. 5 (b) and the size and spacing of I-beam can be designed based on the support reaction force.

2.2. Material models

The explicit code in LS-DYNA [21] was adopted in this study to simulate the blast response of water tank with energy absorbing support. The Piecewise_Linear_Plasticity material model was adopted to simulate the stainless steel that was used to fabricate the water tank and box-type end. For this material model, an arbitrary stress versus strain curve and arbitrary strain rate dependency can be defined and the failure based on a plastic strain can also be defined. The input true stress–effective plastic strain curve shown in Fig. 6 was obtained from the tensile coupon test. In this material model, strain rate is accounted for by using the Cowper–Symonds model which scales the yield stress by a strain rate dependent factor: