Engineering Structures 111 (2016) 199–216

Contents lists available at ScienceDirect

Engineering Structures

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

Numerical investigation of a water barrier against blast loadings

Li Chen [a,*], Qin Fang [a], Li Zhang [a], Yadong Zhang [a], Wensu Chen [b]

[a] State Key Laboratory of Disaster Prevention & Mitigation of Explosion & Impact, PLA University of Science and Technology Nanjing, Jiangsu 210007, China
[b] Centre for Infrastructural Monitoring and Protection, School of Civil and Mechanical Engineering, Curtin University, Australia

ARTICLE INFO

Article history:
Received 12 August 2014
Revised 2 December 2015
Accepted 13 December 2015
Available online 6 January 2016

Keywords:
Water barrier
Blast loading
Polyethylene container
Engineering application

ABSTRACT

Water is a potentially promising material for blast mitigation. The commercially available polyethylene containers filled with water was feasible to be constructed as water barriers against blast loadings. In this research, numerical studies were carried out to investigate the mitigation effects of the water barrier that is a polyethylene container filled with water. A developed numerical model was calibrated and validated against a number of field blast tests. The numerical results indicated that the water barrier provided good mitigation effect against blast loadings and therefore it has the potential to be widely used in the areas where potential blast attacks are expected. Parametric study was also performed by the validated numerical model. The effects of water/charge scaled distance, water barrier scaled height and water barrier scaled thickness on the blast mitigation effects were clarified, and the blast mitigation mechanism was discussed. Some empirical formulae of those key design parameters were derived based on the experimental and numerical results. An applicable optimum construction principle of the polyethylene water barrier against blast loadings was proposed to maximize its blast mitigation effect, based on a modified equivalent static load method.

1. Introduction

Engineering structures might be exposed to blast loadings including accidental gas explosions and/or terrorist attacks during their service life, which might cause heavy casualties and economic losses. Since the 9.11 terrorist attacks and 8.12 explosion in Tianjin, safety concerns about civilian or military structures under blast loadings have been paid great attention. A variety of protective techniques is developed against increasing accidental explosion and terrorist attacks [1–3]. Among them, using the water material (e.g. water spray and water barrier) is a potentially promising method for the blast mitigation with advantages of easy construction and low cost.

Generally, there are two ways for water to mitigate the blast loadings. The first one is the so-called heat effect. If the water was splashed to droplets or mist, i.e. water spray, the water spray with large contact area could absorb a large amount of blast energy; transform it into the internal energy and evaporate. The blast mitigating effects of water spray have been confirmed by various tests conducted by the US Bureau of mines [4] and the University of Wales [5]. It was found that the initial droplets size was an important factor and the water sprays were helpful in suppressing detonation. Gerstein et al. [6] reported that the water sprays could quench detonations and prevent detonation propagating in natural gas-air mixtures. Zalosh and Bajpai [7] found that the spray effect was strongly dependent on the droplet size, and increased by an order of magnitude as the mean droplet diameter increased from 20 μm to 100 μm. This study highlighted the need for fine water sprays or mist.

The second way is the so-called momentum extraction effects. Because of the far different wave impedances between the free air and the aqueous water barrier, the water barrier could construct a water boundary that could transmit, reflect and diffract blast wave in the air. Some blast energy detoured around, and some transformed into kinetic energy of water droplets during the interaction with aqueous water. A number of studies have shown the effectiveness of aqueous water barrier in mitigating the blast loadings when placed in contact or close contact to an explosive charge. A review of this work is provided by Kailasanath et al. in literature [8]. The scientists in the Naval Civil Engineering Laboratory (NCEL) [9] and U.S. Army Corps of Engineers (USACE) [10] placed water bags closely around the TNT explosive to test the explosion mitigating effects quantitatively. Up to 89% reduction of the average quasi-static pressure was obtained in the tests. Small-scale experiments conducted by Resnyansky and Delaney [11] found an 80% reduction in the peak incident pressure for an explosive charge encased in water. Chabin and Pitiot [12] preliminarily evaluated the effectiveness of water wall.

---

* Corresponding author.

http://dx.doi.org/10.1016/j.engstruct.2015.12.015

Recently, Chen et al. [13] conducted nine small-scale blast experiments in the explosion chamber to investigate the mitigation mechanism of water material at a standoff distance to the TNT explosive. The water wall was formed by water-filled thin plastic bags fixed in a hollow steel frame. It was found that approximate 90% reduction in the peak incident pressure could be obtained, and the mitigation efficiency mainly depends on water/charge scaled distance and water wall scaled height. Further analysis of this experiment was extended by Zhang et al. [14], and a one-dimensional non-steady flow theoretical model was developed, which confirms the momentum extraction effects of the water wall on the attenuation of peak incident pressure. Bornstein et al. [15] carried out similar blast tests on plastic water container, clarified that it has insufficient time for the filled aqueous water to breakup into spray from containers, and evaporate providing significant heat effects. The primary mitigation contribution of the water barrier at a standoff distance to the explosive is the momentum extraction. Numerical simulation has been adopted as an effective way to study the behaviors of the water barrier under blast loading conditions since the field tests are often costly and time-consuming. A number of previous researches have demonstrated the ability of numerical simulations to deliver reliable predictions of aqueous water under blast loadings [13,14].

The aforementioned research evidently demonstrated the outstanding blast mitigation performance of water material. However, the water spray technique is limited to the ancillary facilities and environment, and is not always applicable in the real scenario. Actually, the location and time of an accidental explosion or terrorist attack are difficult or impossible to predict in advance. The commonly convenient solution is to erect a water barrier in advance to separate the explosive. However, most of the available literatures focus on the mechanism and efficiency of water material, but very limited in the design principle and real engineering application of water barrier.

Since the commonly available polyethylene container filled with water was proposed to construct the water barrier [15,16], a fine numerical model of the water barrier was developed by AUTODYN-3D in this manuscript. The developed numerical model was validated against a number of field blast tests. Some empirical formulae of relative designing parameters were presented based on the numerical results. An optimum construction principle of the water barrier was proposed on the base of a modified equivalent static load method. It benefits the design of the proposed water barrier in engineering application.

2. Finite element model of the water barrier

The commercially available polyethylene containers, as shown in Fig. 1, are widely used as fences to resist the impact from vehicles. Although it has been proved that, the water barrier provides less blast mitigation effects than traditional rigid blast wall [16–18]. However, it is very convenient to construct the water barrier with those polyethylene containers against explosion, which possesses the advantage of efficient construction and low cost.

The schematic diagram of the numerical analysis is described in Fig. 2. Three similar polyethylene containers filled with water are located side by side between a rigid structure and the TNT explosive. Nine pressure-monitoring gauges are arranged evenly on the outside surface of the structure to record the blast loadings. Varying the dimension and position of the water barrier in the numerical model is potentially to achieve the best mitigation effects.

Owing to the geometric symmetry, the finite element model was built in a half in the commercial software AUTODYN-3D

Fig. 1. Typical polyethylene water containers.

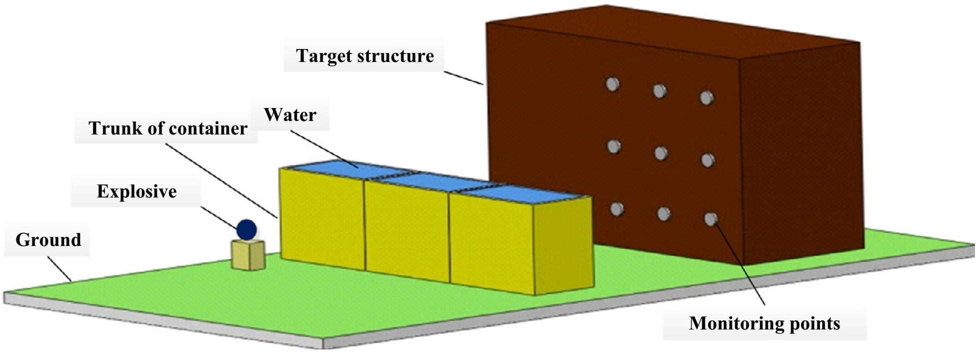

Fig. 2. Schematic diagram of numerical analysis.