Engineering Structures 172 (2018) 789–806

Contents lists available at ScienceDirect

Engineering Structures

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

Experimental and numerical investigation of a hollow cylindrical water barrier against internal blast loading

Wei Zhu[a], Guang-yan Huang[a,*], Chun-mei Liu[b], Shun-shan Feng[a]

[a] State Key Laboratory of Explosion Science and Technology, Beijing Institute of Technology, Beijing 100081, PR China
[b] The First Research Institute of Ministry Public Security, Beijing 100048, PR China

ARTICLE INFO

Keywords:
Anti-terrorism
Hollow cylindrical water barrier
Blast mitigation effect
Engineering application

ABSTRACT

A promising potential method of mitigating the blast effects caused by terrorist explosions is constructing a water barrier encircling an explosive found in public places. Eight in situ experiments were carried out to investigate the response and mitigation efficiency of hollow cylindrical water barriers against internal blast loading. Both the peak overpressure and the impulse along the side toward the base of the barrier were reduced mainly through reflection and diffraction of the blast wave. Numerical models corresponding to the experiments were developed using the commercial software AUTODYN and validated by the overpressure–time histories recorded in the experiments. The numerical results demonstrated that the water barrier enhanced the blast loading over the barrier, although it mitigated the blast loading along the side toward the base of the barrier. Parametric studies were carried out to comprehensively investigate the influences of the thickness, the height, and the inner diameter of the water barrier on the blast mitigation or blast enhancement effects. Adding a water cover on the top of the barrier was proved to be an effective way to eliminate the blast enhancement effects and efficiently improve the blast mitigation performance since it can substantially increase the kinetic energy extracted by the water barrier.

1. Introduction

Civilian infrastructure might be exposed to blast loading produced by terrorist attacks, which might cause heavy casualties and economic losses. Terrorist bombings that have occurred in the past few years have greatly heightened the awareness of constructing protective structures that safely dispose of suspected explosives or mitigate unpredictable explosions in public places [1–3]. Among such structures, using a water barrier encircling the explosive is a promising potential method because water is cheap and often readily available, and has been proved by extensive studies [4–8] to be effective in mitigating blast loading.

There are several mechanisms for water material to attenuate blast loading. One of them is evaporation of water, which has been proved to be the mitigation mechanism of water mist close to an explosive—the mist transforms the blast energy to water's internal energy through phase transformation [9–11]. An example of using water mist for mitigation is the work done by Willauer et al. [9]. They conducted explosion tests in a chamber by detonating a 50 lb equivalent of high explosives TNT and Destex without and with water mist preemptively sprayed into the space. The water mist reduced the impulse, initial blast wave, and quasi-static overpressure by as much as 40%, 36%, and 35% for TNT as well as 43%, 25%, and 33% for Destex, respectively. However, using water mist to mitigate blast loading in public places seems to be impractical.

Reflection and diffraction of the blast wave have been proved to be the mitigation mechanisms of rectangular (bulk) water barriers [12–15]. A rectangular water barrier, which is typically placed at one side of the explosive with a stand-off distance, can mitigate the blast loading behind the barrier. Chen et al. [15] performed experiments to study the blast mitigation of a rectangular water barrier, which was formed by filling water into thin plastic bags fixed to a hollow steel frame. They found that the reductions of peak overpressure achieved by the water barriers were quite close to those achieved by a rigid wall that were calculated in a numerical model proposed by Zhou et al. [16]. This finding indicated that the primary mitigating mechanism of a water barrier is similar to that of a rigid wall—the water barrier can reflect, diffract, and deflect the blast wave. One difference from the rigid wall was that the water barrier was destroyed during the explosion, since some energy from the blast wave was converted into kinetic energy of the water; this phenomenon is so-called momentum extraction effect. However, Chen et al. [15] clarified that momentum extraction is not a significant mitigation mechanism after comparing the results of the

* Corresponding author.
E-mail address: huanggy@bit.edu.cn (G.-y. Huang).

https://doi.org/10.1016/j.engstruct.2018.06.062
Received 7 January 2018; Received in revised form 26 April 2018; Accepted 18 June 2018

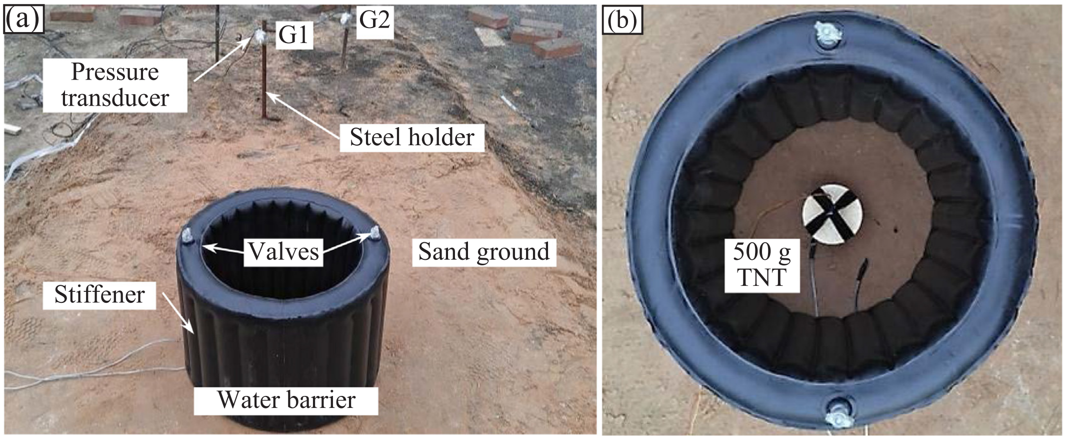

Fig. 1. (a) Photograph of the testing setup and (b) a 500 g TNT cylindrical charge located on the ground in the central axis of a hollow cylindrical water barrier.

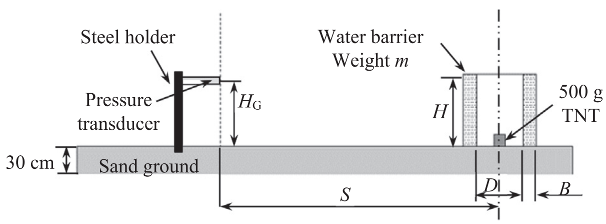

Fig. 2. A schematic diagram of the testing setup.

Fig. 3. Seven hollow cylindrical water barriers in the soft PVC containers.

Table 1
Testing matrix.

No.	Name	D/cm	H/cm	B/cm	m/kg	m_0/kg	Gauge location
T1	Water_28_11_5	28	11	5	5.7	0.17	G1 (S = 100 cm,
T2	Water_28_11_7	28	11	7	8.5	0.23	H_G = 30 cm)
T3	Water_28_31_5	28	31	5	16.1	0.48	/G2
T4	Water_28_31_7	28	31	7	23.9	0.54	(S = 150 cm,
T5	Water_28_31_10	28	31	10	37.0	0.62	H_G = 20 cm)
T6	Water_38_31_10	38	31	10	46.7	0.75	
T7	Water_48_31_10	48	31	10	56.5	0.91	
T8	No_water_barrier	–	–	–	–		

water barrier with those of the rigid wall. Bornstein et al. [4,17,18] carried out a series of experimental and numerical studies on mitigation of near-filed blast loading using rectangular water containers. They numerically proved that evaporation of water and momentum extraction were not significant mitigation mechanisms since the time-scale of the loading was too small.

The above-mentioned studies have given insight into the blast mitigation mechanisms and efficiency of a rectangular water barrier, but there are very limited quantitative studies on annular water barriers in the literature. An annular water barrier can encircle the explosive and interact with the blast wave in all side-on directions. The U.S. Army Corps of Engineers placed water bags around discarded explosives to mitigate their blast effect when testing a munitions demolition container for unexploded ordnance disposal and found that the gas pressure was reduced by 70% for a charge of 4 lb TNT [19]. Chong et al. [20] performed numerical simulations to study the blast mitigation effects of a water barrier around explosives in munitions storage facilities. They found that eliminating the air gap between the water and the explosive is more effective in reducing peak overpressure. They also concluded that increasing the water/explosive ratio could improve the blast mitigation performance, but there appeared to be an upper limit, beyond which the water provided no additional mitigation. In the above studies, the blast mitigation mechanisms of the water barrier encircling the explosive were not examined, and only side-on pressure at a certain height was considered.

The aforementioned research evidently demonstrated the outstanding blast mitigation performance of water. However, a water barrier might also result in enhancement of blast loading at a high location, especially over the barrier, considering that the dominant mitigation mechanisms might be reflection and diffraction of the blast wave. The numerical results of the rectangular water barrier obtained by Chen et al. [15] indicated the existence of blast enhancement at some high locations, but no detailed study was carried out. In some real application scenarios where the explosive is found indoors (e.g., in a subway station), the applicability of a water barrier that can encircle the explosive has not been evaluated since there is a lack of understanding of pressure distribution over the barrier, which concerns the safety of the building's roof.

In the current study, eight in situ experiments were carried out to study the response of a hollow cylindrical water barrier to the internal blast loading and the blast mitigation efficiency of the barrier. Numerical models were developed using commercial software ANSYS AUTODYN [21] and validated by the experimental results. The influence of the barrier parameters on the blast mitigation efficiency at different heights, including over the barrier, is discussed. A promising