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Shock wave attenuation by geotextile encapsulated sand barrier systems

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This paper presents a laboratory scale experimental technique to study the performance of the encapsulated sand barrier systems in mitigating shock waves. The geotextile encapsulated sand barrier systems are made of cubical wire mesh formwork lined with geotextile and form a thick protective barrier when filled with granular materials. In the present study, dry sand particles of size varying from microns to few millimeters (fine and coarse) are used as infill granular material. Spherical shaped glass beads are also used as the infill material to study the influence of shape of the infill particle on the attenuation behavior. The process of shock wave attenuation by the sand barrier, with and without the geotextile facing formwork is examined. The experiments are performed using a conventional shock tube, where shock waves with incident Mach number in the range of 1.29–1.70 are generated. The experimental results show that the presence of geotextile layer has contributed significantly towards shock wave attenuation. The geotextile also plays an important role as a regulator, which is able to deliver gradual pressure rise at the downstream end of the barrier.

1. Introduction

Upon explosion, a high intensity shock wave front arises, causing physical damage to structures and destruction of lives. Structural steel and reinforced concrete structures are commonly used as protective structures against explosion. Although these structures have high tolerance in mitigating the blast, upon extreme blast loads, the structures collapse leading to generation of debris particles and sharp fragments. Most of the concrete and steel structures are permanent and involve considerable time and labour for the construction. Alternately, sand bags are commonly used as protective barrier walls. The function of the temporary wall is to shield against the blast/shock effect from various sources like terrorist attacks, battle field and accidental detonation of stored explosives, munitions etc.

Geotextile contained sand barriers are prefabricated type of protective structures which are cost effective, easy to setup and easily mobilizable to different site conditions. Moreover, these barriers do not undergo brittle failure like concrete walls upon blast impact (Ng et al., 2000). One such commercially available product which has found extensive use in military application is HESCO Bastion Concertainer wall barriers (Scherbatiuk and Rattanawangcharoen, 2008). The concertainer barriers are cubical baskets made of stainless steel wire mesh lined with nonwoven geotextile and they form a protective barrier system upon filling with locally available granular material like sand and gravels (see Fig. 1a–b). The granular barrier system also finds use in various industrial and commercial applications. For instance, they are used as ventilation seals in the mining industry (Fig. 1c) to protect the mine workers from the violent explosions and prevent the outburst gases entering the confined working chambers (Sapko et al., 2009).

Geotextiles are widely used in geotechnical engineering as a separation and reinforcement medium (Ling et al., 2003; Koerner and Soong, 2001). Under purview of geotextile-granular interaction, researchers have extensively studied the effects of particle shape and size (Athanasopoulos, 1993; Afzali-Nejad et al., in press), interlocking behavior between geotextile and sand particles (Lee and Manjunath, 2000) and interfacial frictional characteristics of sand and the reinforcing materials like geotextile and wire mesh (Vangla and Latha, 2016). In addition, research has been conducted by various researchers to assess geotextile as a protective reinforcement medium (e.g., Koerner et al., 1996; Narejo et al., 1996; Tognon et al., 2000; Bathurst et al., 2006; Wu and Hong, 2009; Portelinha et al., 2014; Guler and Selek, 2014; Liu et al., 2014;

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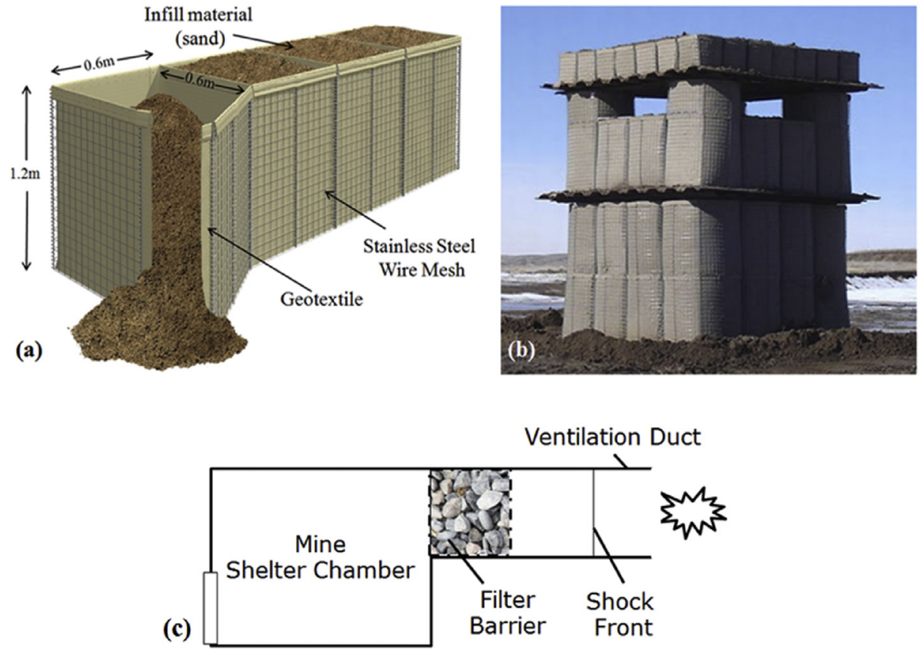

Fig. 1. a–c. (a) An illustrative figure of HESCO Bastion concertainer wall (0.6 × 0.6 × 1.2 m) (b) HESCO bastion units used as a bunker in war field (HESCO, 2010) and (c) Granular particles used as ventilation seals in ducts of mining chambers.

Palmeira and Tatto, 2015; Costa et al., 2016; Hong et al., 2016; Jiang et al., 2016). Most of these experiments were performed under quasi static loading or cyclic loading conditions. Some references on the geotextile used as protective wall are available (Yogendrakumar and Bathurst, 1992; Pieri, 1998; Rose et al., 1998; Smith, 2010). However, the role of geotextile as a blast mitigating medium is not much explored. Among the few available literature, Scherbatiuk and Rattanawangcharoen (2008) have performed full scale field blast test on free-standing, soil-filled, geotextile-lined HESCO concertainer walls and reported displacement-time histories on the wall for different blast pressures. Ng et al. (2000) have carried out several detonation experiments on geosynthetic reinforced soil wall and reinforced earth wall with precast concrete facings and compared the damage patterns between them. Further, Zhiwei (2009) has performed full scale field blast test on geosynthetic faced reinforced soil wall using 5 tons and 27 tons of TNT. Blast induced soil displacements and the overall performance of a reinforced soil wall was studied extensively using strain and pressure measurements on the walls, which are placed at different stand-off distances (30 m, 60 m and 90 m) from the source of the blast. Although, the full scale field blast testing using explosives closely relate to the real site blast conditions, there are some limitations: i) Field blast experiments are very expensive and are highly vulnerable to accidents, ii) Instrumentation and measurements involve a tedious process and in many cases the sensors are damaged and iii) Repeatability is difficult to achieve.

Numerous literature are available on the shock/blast wave attenuation through granular medium alone (Van-der Grinten et al., 1985; Engebretsen et al., 1996; Ben-Dor et al., 1997; Britan et al., 1997, 2001, 2007; Lv et al., in press). Shock tube has been extensively used in the laboratory experiments. Researchers have used various type of granular medium as an obstacle to mitigate the incoming shock wave. Engebretsen et al. (1996) have considered plastic and glass spheres as granular particles and studied the effect of the material density and particle size on the attenuation phenomenon. A series of shock tube experiments were carried out by Ben-Dor et al. (1997) on various types of granular materials (potash, polysterene, nylon, sand etc.) by measuring the pressure in front and inside the granular layers. It was observed that the impact of shock wave has generated a transmitted wave in the granular media (resulting in the compaction of the granular particles) which is governed by gas filtration. Britan et al. (2001) have used ceramic granules of $ZrSiO_4$, steel balls and glass beads as a barrier medium for shock wave attenuation; the transmitted shock through the granular medium was analyzed with respect to the length of the sample and the air gap between the protective structure and the granular sample. In similar experiments, Britan et al. (2007) and Van-der Grinten et al. (1985) have performed shock tube experiments by using long granular sample of length 2.5 m and 1.85 m respectively. Researchers have also investigated the impact of shock wave on various kinds of textile and fabrics. Heffernan et al. (2006) have considered lightweight textile membranes like tarpaulins, synthetic fiber etc. in mitigating the blast wave. They have also proved that woven textile provide better resistance to blast wave when compared to nonwoven textile. The reflection and propagation of shock wave in textile like satin, muslin and polycotton were experimentally investigated by Hattingh and Skews (2001). Instead of the expected attenuation, pressure amplification was observed at region adjacent to the textile layer. The authors have justified the amplification with the two involved mechanisms: i) the transmitted shock wave reflecting back and forth between the end wall and the textile ii) generation of compression waves due to the piston like movement of the textile (Hattingh and Skews, 2001; Skews et al., 2010).

From the above cited literature, it is obvious that granular particles are widely used as attenuating medium for shock waves. Also, most of the previous studies seem to focus on using uniformly shaped smaller size particles having diameters in the range of 0.5 mm–2 mm. The present study considers non-uniform mixtures of local sand with the particle size ranging from 4.75 mm to as small as 75 μm. An encapsulated sand barrier model is developed by using wire mesh and geotextile, as the facing formwork for the infill sand particles. The barrier models are tested in the laboratory using a shock tube. Shock tube is a device used to generate shock