International Journal of Impact Engineering 57 (2013) 1–6

Contents lists available at SciVerse ScienceDirect

International Journal of Impact Engineering

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

Perforation experiments of concrete targets with residual velocity measurements

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A R T I C L E I N F O

Article history:
Received 12 March 2012
Received in revised form
12 November 2012
Accepted 21 January 2013
Available online 4 February 2013

Keywords:
Perforation
Ballistic limit
Concrete target
Acceleration measurements
Residual velocity

A B S T R A C T

Perforation experiments of concrete by steel projectiles have been carried out. The projectiles' initial velocity out of the gun bore was measured with electric probes. A high-speed digital camera system was used to photograph the penetration events. The residual velocities of the projectiles were acquired using foil screen targets, which was designed and built by us. The launch acceleration in the gun bore and the deceleration during the perforation event was recorded with an acceleration transducer. Several perforation tests using concrete targets of different thicknesses were conducted with a nominal striking velocity of 400 m/s. The residual velocity and kinetic energy consumed versus the target thickness was analyzed. The perforation limit was also obtained.

1. Introduction

Concrete structures have been used extensively in protective structures, buildings, bridges, nuclear power stations, etc. Penetration and perforation of concrete targets by projectiles has drawn close attention by weapons-development and engineering protection departments. In the past century, many researchers have contributed to the current understanding of impact effects on concrete targets with experimental study, theoretical analysis, engineering models, and numerical simulation.

Hanchak and Forrestal's [1] perforation experiments of reinforced concrete slabs were often used in numerical simulations [2–6] to validate the constitutive models. More recently, Forrestal and Luk [7] reported deceleration data for six experiments using soil targets and observed peak rigid-body decelerations of 1200G. Forrestal and Frew et al. [8] conducted two sets of concrete penetration tests with deceleration-time measurements. Unosson and Nilsson [9] carried out the perforation experiments of high performance concrete targets by steel projectiles with a Doppler radar to monitor the projectiles' pre-impact velocity history and a high-speed camera to capture the projectiles' residual velocity.

Chen, Fan and Li [10] developed a general three-stages model for the concrete target, i.e., initial crating, tunneling and shear plugging, that was based on the dynamic cavity expansion theory and plug formation theory. The perforation thickness and ballistic limit of the concrete targets that are subjected to rigid projectile impact were obtained by Li and Tong [11]. The normal perforation of reinforced concrete target by rigid projectile was also studied by Chen, Li, et al. [12] and the theoretical predictions have a higher degree of accuracy than the model suggested by Dancygier [13,14]. Li et al. [15] summarized a range of concrete penetration/perforation empirical formula.

While there are large numbers of experimental semi-infinite concrete targets penetration data [16–21], experimental results concerning the perforation of concrete targets are relatively scarce, especially concerning residual velocity and deceleration time measurements.

In this study, we conducted a set of perforation experiments with a single-channel acceleration data recorder. A 152 mm gas-gun was chosen as the loading system. The projectile and several concrete targets were designed and produced for the tests. The initial velocity out of the gun bore was measured with electric probes. A foil screen target measuring system was designed and built to obtain the residual velocity, which has minor measurement error and is less expensive than the acceleration transducer. The striking and the residual velocities of the projectiles were also acquired using a high-speed digital camera system. The kinetic energy consumed versus the target thickness and the kinetic energy consumed per meter thickness of the target versus the target thickness is obtained. The damage of the concrete targets is shown and the damage mode is discussed.

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http://dx.doi.org/10.1016/j.ijimpeng.2013.01.007

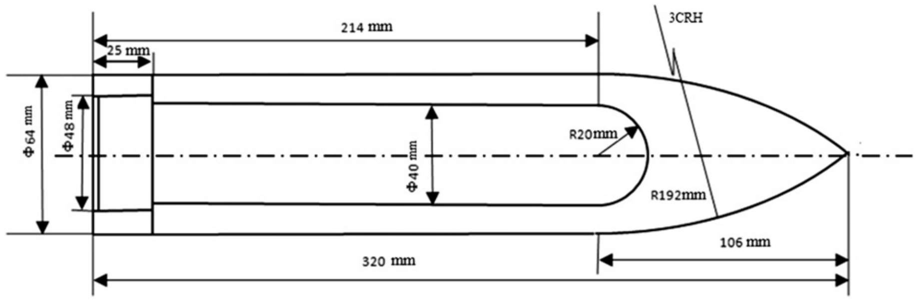

Fig. 1. Projectiles' geometry and dimensions.

2. Projectiles

The projectiles, dimensioned in Fig. 1, were machined from 35CrMnSiA steel. The 35CrMnSiA steel is a type of low alloyed high-strength steel with high hardenability. This steel has high strength and toughness after heat treatment and work hardening. Therefore the projectiles suffered a small deformation during the penetration process and can be regarded as rigid projectiles. The nominal mass of the projectiles is approximately 4.8 kg. The projectiles were designed to contain a single-channel acceleration data recorder. Therefore, we were able to record the launch acceleration in the bore of the gun and the deceleration during the perforation event. The experimental sabot was also designed and the projectile and the sabot can be separated through an impact-stop technique. A photograph of the projectile with the sabot and the obturators is shown in Fig. 2.

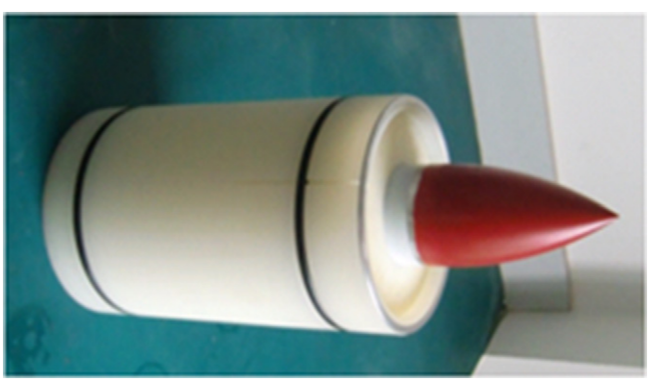

Fig. 2. Photograph of the projectile with the sabot and the obturators.

A 152 mm gas-gun was chosen to launch the projectiles to a nominal striking velocity of 400 m/s. The electric probes were used to measure the initial velocities of the projectiles just out of the barrel. There are always some differences between the striking velocities and the initial velocities because the projectiles are fitted with sabots and obturators that need to be stripped from the projectiles through the impact-stop technique and because the projectiles would travel some distance before impacting the targets. We recorded the striking velocities and attitudes of projectiles in front of the concrete targets with a high-speed camera system. One of the impacting processes is shown in Fig. 3.

To confirm the reliability of the acceleration data, we integrated the acceleration in Fig. 4 and obtained the velocity history for shot No.1 before the projectile impacting the concrete target, which is shown in Fig. 5. The history of the displacement versus time in Fig. 6 was also acquired through the integration of the velocity history. The striking velocity achieved through the integration of the acceleration is 405.7 m/s, while the initial velocity achieved

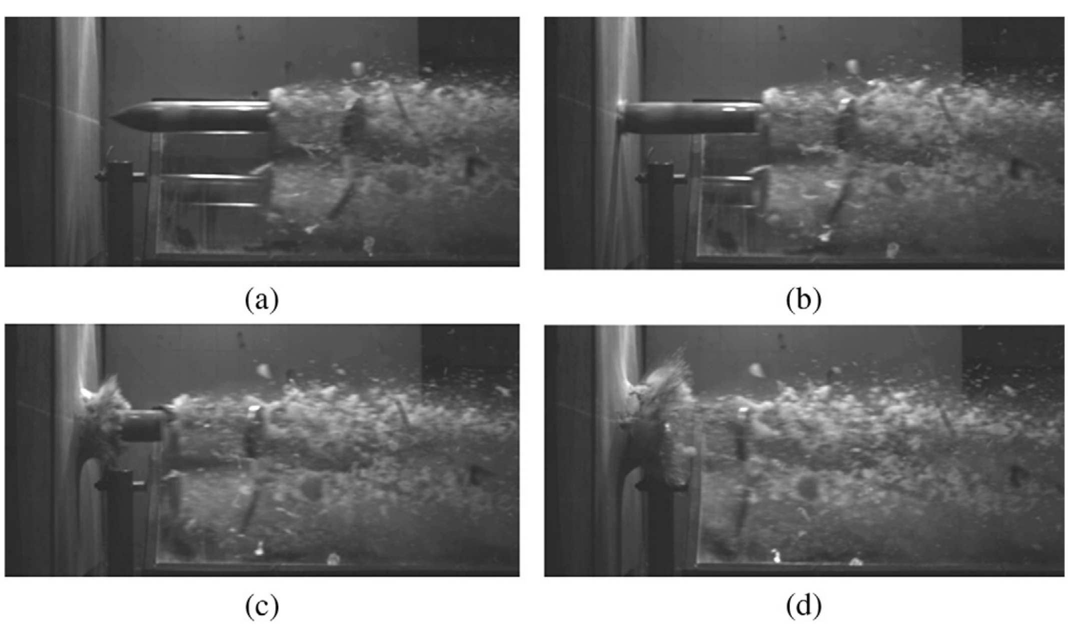

Fig. 3. Projectile penetrating into a concrete target recorded with the high-speed camera system.