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Projectile penetration of reinforced concrete blocks: Test and analysis

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ABSTRACT

Concrete blocks are usually used to provide protection against incidental dynamic loadings such as the impact of a steel projectile. This paper presents results of an experimental test and numerical investigation of reinforced concrete blocks' penetration resistance. Investigation test was conducted experimentally using a steel blunt-nose projectile with a diameter of 23 mm and a mass of 175 g with striking velocity about 980 m/s hitting concrete blocks reinforced by different number of layers of woven wire steel mesh (Ferrocement).

Nonlinear three-dimensional numerical simulation of the investigation test was carried out using AUTODYN which is probably the most extensively code dealing with penetration problems. A comparison was conducted between the results of the numerical model and the experimental test measurements and show relatively good agreement.

The main findings show that the penetration depth and the damage in the front and rear face of target specimens exhibit an overall reduction with using wire meshes as a reinforcement. On the other hand, the results showed that increasing the reinforcement ratio has slight influence on the perforation resistance and face damaged area.

1. Introduction

Concrete is widely used as construction material for military and civilian applications because of its relatively high effect and economic, it is often used as protection layer in fortified structures for missile impact. Since the attach will be an unexpected extreme load, it results in both local and overall dynamic response of the block. Different from plain concrete in which mainly the strength dominates its ability of resisting penetration, reinforced concrete may be influenced by both the concrete strength and the amount of reinforcement. The penetration/perforation process of reinforced concrete includes initial cratering, tunneling and rear cratering, the same as that of plain concrete.

Plenty of studies were conducted on behavior of reinforced concrete targets subjected to missile impact. Studies mostly focus on how to prevent excessive local damage and collapse of the block. These include using different types of block materials, different arrangement of reinforcement of reinforced concrete block, providing a steel plate, etc.

From the previous studies, the main factors affecting the penetration resistance of concrete are the compressive strength, the tensile strength and the strain rate [1–6]. The depth of penetration is mainly determined by the compressive strength and the strain rate dependent. Response of concrete in compression and the strain rate in tension were of great importance when studying spalling and scabbing of projectile impacts. So projectiles penetration/perforation of reinforced concrete targets, used to improve the tensile strength and strain rate, have been receiving remarkable attention recently [7–9].

One of the most important ways to enhance the concrete properties is the Ferrocement which, improves the resistance of the concrete slabs to fragmentation, and increases the ability of the slabs to withstand impact loads [10–13]. This paper employs the explicit dynamic finite element code 3D-AUTODYN to analyze the behavior of reinforced concrete blocks during projectile penetration. [14–17].

2. Test program

Comparative penetration tests were conducted experimentally on various square plain concrete and Ferrocement specimens. The projectile used in this study was blunt-nose steel penetrator 23 mm diameter and 64 mm length as shown in Fig. 1. The material properties of the penetrator were 475HB for Brinell hardness, 1726 MPa yield Strength, 1900 MPa ultimate strength, and 7% for strain at fracture. The impact velocity was measured and reported for every shot with electro-optical velocity measurement device and it was about 980 m/s.

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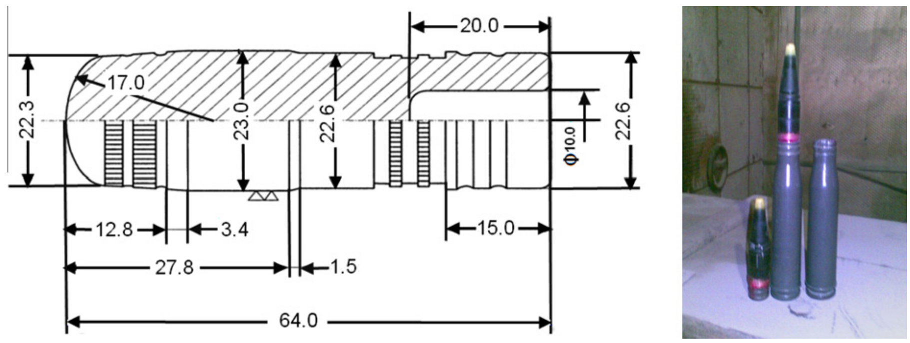

Fig. 1. Dimensions in millimeters for 23 mm API missile.

2.1. Materials

Two main materials are used in this study. First, concrete blocks with mix proportions for one cubed meter by weight were 350 kg Portland cement, 700 kg sand, and 1400 kg dolomite with 19 mm maximum aggregate size. The adopted water/cement ratio by weight was 0.5. Mechanical properties of used concrete were 2350 kg/m3 for mass density, 35 MPa compressive strength, 3.1 MPa tensile strength, and 29 GPa for modulus of elasticity.

Second, 500 × 500 mm galvanized woven wire mesh of 50 mm square opening and 2.0 mm diameter was used to reinforce the concrete blocks. The mechanical properties of steel with alloy No. 1006 used in this study which, obtained from material data sheet were 7850 kg/m^3 for mass density, 250 MPa yield Strength, 360 MPa ultimate strength, and 210 GPa for modulus of elasticity.

2.2. Specimens

Four target specimens with dimensions of 550 × 550 mm were constructed. One specimen was unreinforced (plain) concrete considered as a control specimen, and three reinforced concrete specimens reinforced by different number of woven wire steel mesh (Ferrocement) layers.

Unit block thickness was 200 mm with reinforcement mesh from front side and rear side. Each specimen consists from two unit blocks to form 400 mm total thickness. Dimensions and details of used wire mesh and specimens are presented in Fig. 2 and Table 1.

2.3. Penetration resistance test

The blocks were mounted on a stationary stiff steel frame in front of the gun as far as 50 m, where the surface (550 × 550 mm) was normal to the missile path and the thickness (200 mm) was parallel to path of missile. These specimens were supported by the steel frame along their perimeter to prevent movement in both directions. Then they were fired by the projectile 23 mm, as shown in Fig. 3, with care take that penetrator does not strike the wire mesh. The impact velocity was measured and reported for every shot.

3. Finite element analysis models

Three dimensional simulation for the penetration and perforation of reinforced concrete target were performed depending on the set of the test data. The finite element models were built for the four specimens SC2, SW1-1, SW1-2 and SW2-3 which were presented in Table 1.

3.1. Description of the mesh

Lagrange processor has been used in AUTODYN for the analyses. In this paper two classes of target blocks were considered. Unreinforced (plain) concrete, and reinforced concrete (Ferrocement), projectile and the concrete target are modeled as Lagrangian meshes in all models, while the reinforcing steel bars (meshes) were described as beam elements in Ferrocement models. All parts were symmetric on $X = 0$ planes to reduce the size of the computational domain. The geometry of the projectile, concrete target and steel mesh will be described below.

3.1.1. Projectile mesh

The geometry of the projectile part, as shown in Fig. 4, was defined using a structural Lagrangian mesh, and was divided to 13 nodes in the *I*-direction, 7 nodes in the *J*-direction and 26 nodes in the *K*-direction. The IJK-index corresponds to the Cartesian coordinate system.

3.1.2. Plain concrete mesh

For model SC2 of plain concrete material (Conc.35 MPa) were defined using a structural Lagrangian mesh, everyone was divided to 46 nodes in the *I*-direction, 91 nodes in the *J*-direction and 41 nodes in the *K*-direction. Zoning technique was used to densify the meshes in critical regions. Fig. 5 shows the geometry and meshing of model SC2.

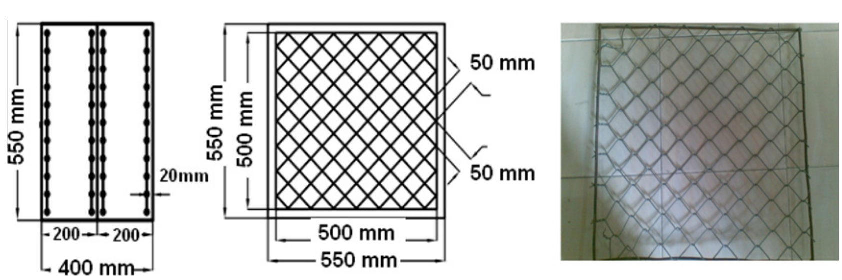

Fig. 2. The dimensions and details of wire mesh and specimens.