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Investigating the resistance of reinforced barriers to high velocity projectiles

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ABSTRACT

The resistance of concrete barriers to high velocity projectile impact from firearms is a research topic that has been of interest for quite some time, with the first known study going back to the mid-18th century. Despite this long history, only a very limited number of the test results are available in the public domain due to their sensitive nature and strategic importance. This situation has made the development of precise models for predicting the effects of ballistic impact difficult, despite the recent availability of highly refined and powerful calculation tools. Many researchers are still convinced that a validated methodology does not currently exist for this type of problem due to the number of uncertainties. Within this context, the objective of the present work is to study projectile impact on barriers made of reinforced concrete with explicit Finite Element (FE) simulations. In particular, this paper presents a FE analysis that considers the full range of projectile class as defined in the ballistic standards. Results from simulation are also compared with experiments.

1. Introduction

Modelling the *dynamic* response of concrete structures to ballistic impact represents one of the most investigated, yet complicated, problems that must be approached in the field of the numerical simulation [1]. Damage caused by the deformation of concrete in dynamic situations often results in complex processes that are difficult to reproduce with the simplified mathematical models usually acceptable for metallic constructions [2]. One of the main difficulties arises from the fact that concrete exhibits anisotropy under fast dynamic loading, a feature characteristic of composite materials [3]. At the same time, studies must be undertaken with great care due to their potential importance in terms of public safety in defence [4], nuclear energy [5] and civil security [6] sectors, including anti-terrorism measures [7] and many others. Despite this importance, the accessible information for modelling dynamic phenomena is often rather limited, up to the point that engineers must predict structural behaviour with little or no relevant data [8].

Amongst the various numerical simulation techniques available nowadays, the Finite Element Method (FEM) provides reliable support to designers in light of the technical evolution that has taken place over recent years. An increase in computing power, together with the development of constitutive models better suited to the approximation of material response under various conditions, offer designers a tool capable of investigating even the most complex physical phenomena [9]. Often, however, models contain a series of parameters that, if incorrectly defined, may lead to large deviations between simulations and real-world outcomes [10]. It is then necessary to fall back on experiments, which in turn can be problematic due to both difficulties in reproducing conditions similar to those of actual interest and the intrinsic variability of experimental data. Firearms, explosives and noise are some of the potentially critical aspects that require attention during impact tests, which must take place in firing ranges [9] or appropriately equipped laboratories [11]. In addition, there is the complexity of building the concrete structures [12], often realized on site and complete with foundations, framework and reinforcing.

Approaching the problem from a different perspective, experiments may instead be utilized for the acquisition of data necessary to make predictive models more precise and reliable [10], rather than for direct evaluation of the effect of a particular projectile-structure combination. This merging between simulations and experiments can be performed on a limited number of relevant cases, with a successive extension of the investigation to additional scenarios of interest via FEM analysis. In this way, the number of experiments can be reduced and test conditions simplified [7,13].

The main scope of the present work is to propose a reliable methodology for the analysis of the ballistic impact on steel reinforced concrete structures that benefits from the numerical simulations with the aim at minimizing the need of experiments. Specifically, one ballistic test was used for an initial validation of the constitutive models. Then, all impacts were numerically investigated.

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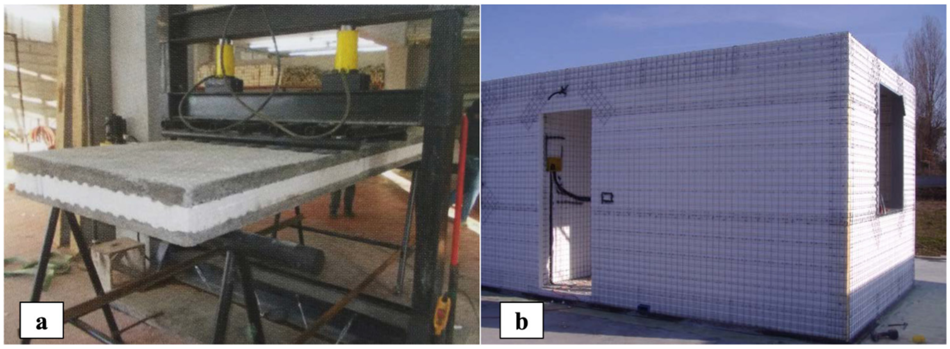

Fig. 1. (a) Concrete single panel during bending test; (b) example of construction realized using these panels.

2. Methods and materials

2.1. Panel composition

The study was based on a specific type of concrete construction panels, also used for the realisation of military structures (Fig. 1). The concept behind the system consists of off-site industrial production of panels that are then installed on site casting additional concrete. The base elements that make up the load-bearing structure include an *expanded-polystyrene sheet*, with density and thickness depending on the type of panel, and *drawn, galvanized, welded steel wire mesh*, mounted on both sides of the polystyrene panel and joined via steel connectors. Panel configuration varies depending on the specific application, with some aspects having a profound influence on the structural properties. The diameter of the reinforcing wiring, for example, can be modified according to the type of panel and the direction of the mesh. Where panels are not installed with structural functions, such as in the case of partitions, dividing walls and facades, a single panel is usually employed (Fig. 2a), whereas load-bearing elements require double panels (Fig. 2b).

The present work focuses on a panel realised by two concrete and one polystyrene layer. Though the final strength of the wall is strongly dependent on the thickness of both layers, this configuration represents a particularly suitable solution for obtaining good ballistic impact resistance. The study considers, in particular, a 180 mm thick panel comprising two 50 mm thick concrete panels separated by an 80 mm thick expanded polystyrene sheet. Fig. 3 shows this kind of panel structure in details.

Technical data relating to the reinforced mesh of the panel structure are given in Table 1. Mechanical properties for the base materials (steel, polystyrene and concrete), as reported in literature [14], are given in Table 2.

2.2. Ballistic standards

Experimental conditions for ballistic testing are generally chosen in accordance with standards. These standards provide specifications to investigate the protective resistance of materials in respect to specific weapons and threat levels. They typically cover both handguns and rifles, defining projectile calibre, velocity, shot placement, repetitions and so on. Such standards are issued by many organizations worldwide, even if the most relevant have been developed in USA and Europe.

In the present work, in particular, reference are made to the EN 1522 on requirements and classification of projectile protection offered by *windows, doors, shutters and blinds* [15] and to the EN 1523 on *test methods* [16]. These European Standards permit to define the ballistic test criteria and propose homogeneous classification schemes for the experimental evaluation of concrete wall response respect to impacts respect to a vast array of projectiles and firearms in both residential and military settings.

In particular, EN 1522/1523 include as classes of projectiles (Table 3):

- *.22 Long Rifle* (*LR*), a Lead Bullet (LB), cast with a Round Nose (RN), weight 2.6 g, fired from a pistol at 360 m/s (*Class FB1*).
- 9 mm *Luger*, a Full Steel Jacket (FSJ) around a lead Soft Core (SC) with a Round Nose shape, weight 8 g, fired from a pistol at 400 m/s, (*Class FB2*).
- .357 *Magnum*, a Full Steel Jacket, around a Coned Bullet (CB) with a Soft Core, weight 8 g, fired from a pistol at 430 m/s (*Class FB3*).
- *.44 Magnum*, Full Copper Jacket (FCJ), with Soft Core and Flat Nose (FN), weight 10.2 g, fired from a pistol at of 440 m/s (*Class FB4*).
- 5.56 × 45 *Nato*, in SS109 steel core, weight 6 g, fired from a pistol/rifle at 950 m/s (*Class FB5*).
- 7.62 × 51 M80, Full Steel Jacket around a soft core, weight 10 g, fired from a not automatic/automatic pistol/rifle at 830 m/s (*Class FB6*).

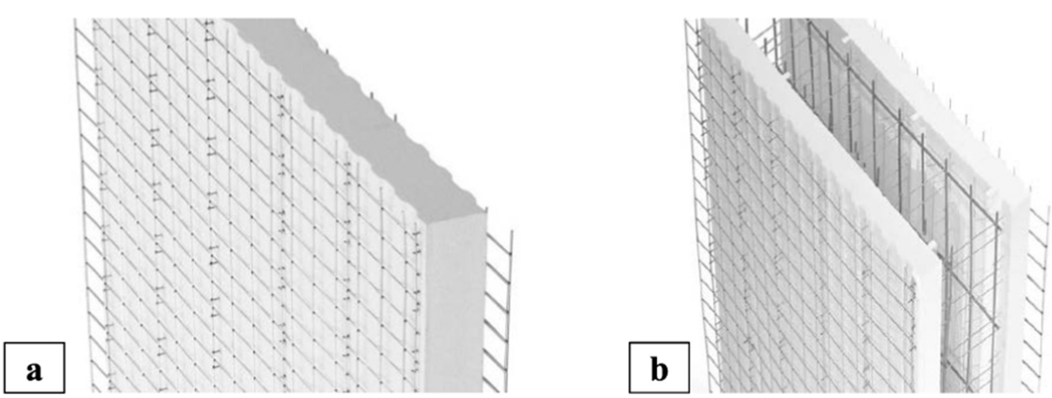

Fig. 2. Example of panel configurations: (a) single panel; (b) double panel.