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Response of high performance concrete plates to impact of non-deforming projectiles

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Abstract

The relatively recent technology, which enables the production of high strength concrete (HSC), makes HSC a prospective material for the construction of impact-resisting barriers. However, current penetration formulae are based on test data of normal strength concrete (NSC) and their extrapolation to higher concrete strengths is unsafe. The response of 80×80 cm high performance concrete (HPC) plate specimens to an impact of non-deforming steel projectiles was examined in an experimental study. The tests were planned with an aim to observe the influence of the concrete mix ingredients and amount and type of reinforcement on the performance of HSC under this type of loading. The variants that were examined were the aggregates (different types and maximum size), addition of micro-silica (MS) and steel fibers, and reinforcement details. The main findings show that design of HPC barriers to withstand impact loads involves several aspects. These are aimed at achieving enhanced properties of the structural element, where only one of which is the concrete's compressive strength.

Keywords: High performance concrete; Perforation; Steel fibers; Aggregates; Non-deforming projectile

1. Introduction

One of the loading types that protective structures are designed to withstand, is the localized impact of missiles or projectiles. The structural performance, as well as the capability to resist impact loads, makes reinforced concrete a common engineering solution in the design of protective barriers. The parameters that are involved in the design process are the barrier's geometry (mainly thickness), and the concrete properties, which commonly reduce to a single representative parameter, which is its uniaxial compressive strength. In an earlier test series of relatively small-scale ($40 \times 40 \times 5\,\text{cm}^3$) plates [1] it had already been observed that the concrete strength might not be the only parameter to be considered in that respect. These tests showed that the response of the impacted specimens depended not only on the concrete uniaxial compressive strength but also on some parameters of its composition such as the amount of steel fibers, the hardness of the front layer's

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aggregates, and the amount and density of the reinforcement near the rear face. Early experimental results of a following study of high strength concrete (HSC) specimens [2] examined different concrete mixes and showed that the concrete mixture components, such as aggregate type, use of micro-silica (MS), or use of fibers, have to be considered in the design process as well as the concrete strength. They also indicated that increased damage due to increased brittleness associated with increased concrete strength is reduced by the use of steel fibers or different reinforcement arrangements. The importance and different influences of the HSC mix ingredients on its impact resistance has also been reported by Zhang et al. [3]. An improved impact resistance of concrete mixtures that included steel fibers was also observed by Almansa and Canovas [4] and by Ong et al. [5]. Li et al. [6] include reinforcement and aggregate size among concrete parameters that may affect its resistance to impact, however they also observe that, ‘‘most of the published empirical formulae do not explicitly account for the amount of reinforcement and aggregate’’ [6]. Thus, the concrete mixture ingredients and amount and type of reinforcement may enhance the performance of HSC and make it more suitable for this application.

During, the last decade an ongoing research is being carried out at the national building research institute (NBRI), Technion-Israel Institute of Technology, aiming at understanding the effects of concrete composition on its impact resistance. Some earlier results were reported in Yankelevsky and Dancygier [2,7].

This paper presents the results of an extensive experimental research phase. Following the previous series of test [1], where 40×40 cm thin plate specimens made of concrete with fine aggregates only were tested with 25 mm diameter, 165 gr projectiles, further tests were performed with larger 80×80 cm specimens, impacted by 50 mm, 1.5 kg projectiles. The current tests were aimed at further exploring the above-described trends, through specimens that are closer in dimensions to real (i.e., full scale) structural members and are made of common concrete composition. The research approach was based on the examination of different specimens that were prepared with different mix properties and reinforcement arrangements, yet having similar uniaxial compressive strength. Therefore, according to current knowledge these different specimens are expected to respond similarly to the same impact conditions. That is, the different performance modes that were identified in the experimental study are solely due to the concrete ingredients whereas existing formulae would predict identical behavior.

2. Experiment

Comparative tests were conducted on various square $800 \times 800 \times 200$ mm reinforced concrete plate specimens (Fig. 1) that were subjected to an impact of similar steel projectiles, accelerated to different velocities by means of a gas gun system. The use of the same projectile in all the experiments at velocities that were controlled by the gas-gun overpressure, enabled comparison of their response, which was evaluated according to their perforation resistance and to the damaged area caused at their front and rear faces. The plate specimens were cast vertically in polymer coated plywood forms. In all the specimens, the mesh arrangement ensured that none of the reinforcement bars crossed the plate's center and hence that the projectile would not hit (or push) any of the mesh steel bars. The concrete cover of the reinforcement meshes was 15 mm on each side.

2.1. Materials and examined parameters

Control normal strength concrete (NSC) specimens were made of ready-mixed concrete of a specified nominal compressive strength f_{ck} of 30 MPa (cube strength at 28 days), a slump of 5″ and coarse crushed dolomite aggregates of 22 mm maximum size. The water/cement ratio was about 0.65 and the cement content was about 290 kg/m^3. This is a commonly used mix for structural purposes in Israel. The reinforcement of these specimens consisted of standard deformed steel bar meshes (400 MPa nominal yield strength and a minimum ultimate strain of 12%): ϕ8 mm@200 mm (considering the 15 mm concrete cover the reinforcement ratio ρ was 0.14% each way, where ρ is calculated with respect to the plate's effective depth) near the front (impacted) face, and ϕ8 mm@100 mm ($\rho = 0.28\%$ each way) near the rear face.

The influence of the following HSC mixture ingredients on its performance under impact was examined in this study: addition of MS, of 60 and 30 mm hooked-end steel fibers (with aspect ratios of 67 and 60,