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SHCC-strengthened RC panels under near-field explosions

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HIGHLIGHTS

- SHCC strengthened RC panels were tested under near-field explosions.
- SHCC-strengthened panels performed better as compared to the control panel.
- MMALE modeling to verify the experimental reflected blast wave parameters.
- FE model of the panels was developed to predict the structural responses.

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ABSTRACT

Recurrence of recent activities in terms of accidental and premeditated explosions around the world has drawn the attention of the engineering community to assess the vulnerability of existing infrastructure under blast loading and find suitable repair and retrofitting technologies. Thus, this study focuses on the application of strain-hardening cementitious composite (SHCC) as a strengthening material by evaluating the response of SHCC-strengthened reinforced concrete (RC) panels under near-field explosions (scaled distance around 0.58 m/kg$^{1/3}$) by spherical trinitrotoluene (TNT) charges as till now no study was conducted in this area. In total 5 panels, 1 control panel and 4 strengthened panels were tested under the same blast loading conditions. Two retrofit schemes (i.e., 'distal surface only' and both 'blast-incident and distal surfaces') were employed to retrofit the panels with a layer of SHCC. It was observed that the SHCC-strengthened panels perform better as compared to the control panel. Multi Material Arbitrary Lagrangian Eulerian (MMALE) with fluid-structure interaction (FSI) and Load Blast Enhanced (LBE) methodology available in LS-DYNA program were used to validate the blast wave parameters. Finally, three dimensional nonlinear finite element (FE) models were developed to compare the blast responses of the control and strengthened RC panels. This study as a whole will provide a guideline to the researchers and practicing engineers to deal with the blast retrofitting of RC structures.

1. Introduction

Due to the heightened level of terrorist attacks around the world, there is an urgent need to enhance the blast resistance of existing structures to minimize the damage and loss of life. When subjected to blast loading, many existing structures may not meet modern safety standards. Understandably, the replacement of these structures is sometimes not economically feasible. A probable alternative lies in the implementation of suitable repair and retrofit technologies for blast protection. Various fibre reinforced polymer (FRP) composites and cement-based materials can be used for retrofitting a structure. Repairing and retrofit materials play an important role in ensuring success and effectiveness of the retrofit. Moreover, compatibility between the repair materials and the substrate significantly affects the effective implementation of retrofit strategies. For repairing and retrofitting concrete structures, cement-based materials are generally considered suitable due to their compatible mechanical and physical properties. Also, from the blast protection point of view, the repair material must possess sufficient tensile strength, ductility, energy absorption capacity and scabbing and spalling resistance. Strain-hardening cementitious composite (SHCC) has the potential to possess most if not all the above-mentioned characteristics. Designed using micromechanical principle [1], it exhibits high tensile strain capacity, fracture energy and notch insensitivity, making it ideal for retrofitting existing structures under blast loading.

SHCC typically consists of water, cement, sand, fiber, and some common chemical additives. Coarse aggregates are not used as

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they tend to adversely affect the unique ductile behavior of SHCC. The mixing process of SHCC is similar to conventional concrete mixing as it contains a relatively small amount (2% or less by volume) of discontinuous fibers. Various types of fibers such as steel, carbon, polyethylene (PE) and polyvinyl alcohol (PVA) can be used for incorporation in the SHCC. Mono fiber SHCC containing high-modulus fibers (e.g., steel and carbon) generally exhibit high ultimate strength, whereas those containing relatively low modulus fibers (e.g., PE and PVA) exhibit the opposite behavior [2,3]. For blast retrofit SHCC, must possess sufficient ultimate strength and strain capacity. The challenge is to strike a balance between high ultimate strength and high strain capacity. Zhang et al. [4] developed a hybrid-SHCC (e.g., 0.5% of steel and 1.5% of PE fibers by volume) which can be used effectively to meet typical functional requirements of blast retrofit.

Numerous investigations on the behavior of FRP-strengthened RC panels and walls under blast loading are documented in the literature [5–10]. Moreover, aluminum foam and steel sheets can be used to reduce the damage of concrete structures under blast loading [11–14]. Explosive test was conducted by Ross et al. [5] on control and carbon fibre reinforced polymer (CFRP) retrofitted RC slabs. In general, they concluded that the retrofitting technique increased the blast resistance of the slabs tested. Similarly, Lawver et al. [7] performed some blast tests on control, CFRP and glass fibre reinforced polymer (GFRP) strengthened RC floor slabs. It was mentioned that the retrofitted slabs exhibited stiffer response as compared to the control slab. Muszynski and Purcell [8,9] reported on blast tests of RC walls strengthened with CFRP and an aramid/glass hybrid. Both retrofit materials performed well in reducing the residual displacement as compared to the control wall. It was also depicted that the hybrid was more effective than the wall with the same amount of CFRP. However information is not readily available on the response of SHCC-strengthened RC panels under near-field explosions by spherical TNT charge. Thus this study focuses on the application of SHCC as a strengthening material by evaluating the response of SHCC-strengthened RC panels under near-field explosions by spherical TNT charges as till now no study was conducted in this area. The first phase of testing involved testing a rigid steel plate fitted with pressure sensors along its longitudinal direction which was used to measure the reflected blast pressure and impulse under spherical TNT charges to which the panels will be subjected to. Thereafter, control and strengthened RC panels were tested to compare their blast responses (i.e., maximum mid-span displacement and failure mode). In addition, by making use of the developed FE model, the blast load was simulated in two ways; for the first case with the built-in blast load function (i.e., LOAD BLAST ENHANCED (LBE) [15] with spherical air burst assumption) available in LS-DYNA [18] was used whereas for the second case, the blast wave parameters were obtained from Multi-Material Arbitrary Lagrangian-Eulerian (MMALE) [16,17] and Lagrangian formulations coupled with the fluid-structure interaction (FSI) algorithm. In the first case, the reflected blast pressure history was computed from empirical equations (i.e., incorporated into LBE function) and applied to panel directly. In the latter approach, the explosive as well as the air were modeled explicitly (in 2D domain) with the blast wave propagating through the MMALE air domain impinges on the Lagrangian structures (here considered as rigid shell elements) through FSI. The reflected blast wave parameters at various points from the MMALE model were extracted and compared with

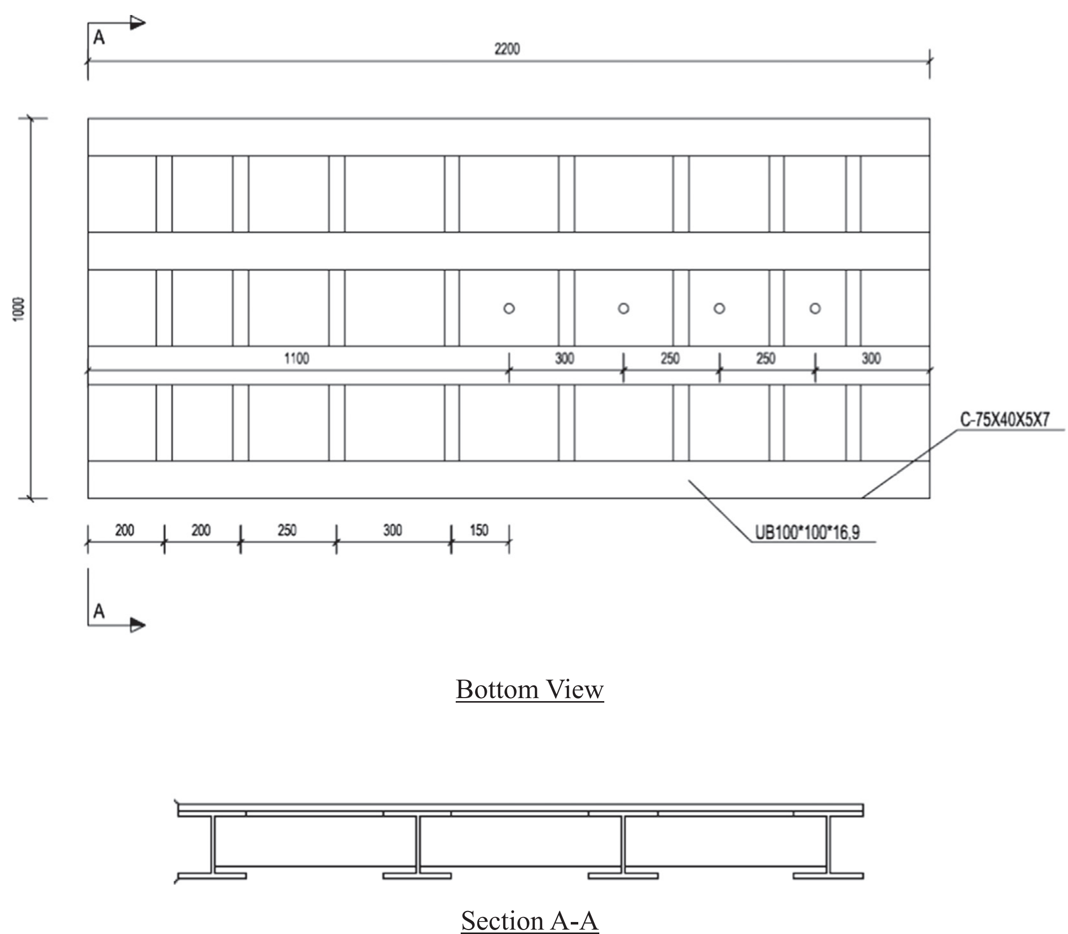

Fig. 1. Schematic of steel plate (Dimensions in 'mm').