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EXPERIMENTAL STUDY OF BLAST RESPONSE OF RC SLABS WITH EXTERNALLY BONDED REINFORCEMENT

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ABSTRACT

The present paper discusses experimental work on the efficiency of externally bonded reinforcement (EBR) on reinforced concrete (RC) slabs under blast loads using an explosive driven shock tube (EDST). This study focuses on four tests which have been performed on simply supported RC slabs retrofitted with carbon fiber reinforced polymer (CFRP) strips and subjected to explosions for the same pressure and impulse. Pressure transducers are fixed at the end of the tube to measure the pressure of each experiment. Maximum deflection and strain distribution in the concrete and CFRP strips are recorded using digital image correlation (DIC) measurements. Due the explosion, the RC slabs are submitted to a dynamic vibration in both directions and during the first inbound displacement phase, the kinetic energy of the retrofitted specimen is stored as elastic strain energy in CFRP strips. All this elastic strain energy stored in FRP strips is violently released as kinetic energy during the rebound phase of the slab. The results indicate that EBR increases significantly the flexural capacity and the stiffness of RC slabs under blast loads.

KEYWORDS

Blast loading; Externally bonded reinforcement; Explosive Driven Shock Tube; Dynamic response; RC slab.

INTRODUCTION

Many types of exiting RC structures are not designed to resist an explosion and upgrading of structural robustness is becoming necessary because of the industrial accidents and terrorist attacks that happened all over the world and cause severe damage and loss of life. Recently, a number of studies have been conducted on the use of CFRP EBR to strengthen RC structures against blast loading (Maazoun, Matthys, and Vantomme 2016). Crawford and John (2013) conducted tests on six reinforced concrete columns strengthened with CFRP for resisting to blast loads. They stated that the main benefit of wrapping a reinforced concrete column with CFRP resides in the increase of strength and ductility of the concrete. Muszynski et al. (2003) tested two reinforced concrete walls which were retrofitted with carbon fibres and with aramid (Kevlar) fibres. The walls were subjected to the blast wave resulting from the detonation of 830 kg TNT at a standoff distance of 14.5 m. They reported that the reinforced elements retrofitted with carbon and aramid FRP respectively showed a reduction of 25% and 40% of the maximum deflection at mid span of the wall, compared to unstrengthened reference specimens. Silva et al. (2007) used CFRP for strengthening RC slabs on either one side only or on both sides. They concluded that slabs retrofitted with CFRP on both sides exhibited better blast resistance than those retrofitted on only one side. They explain this behaviour by the better resistance against negative bending moments due to rebounding of the slab. The present study focuses on four tests which have been performed on simply supported RC slabs retrofitted with CFRP strips, subjected to explosions for a constant charge weight. Maximum deflection and strain distribution in the concrete and in CFRP strips are recorded using DIC measurement.

EXPERIMENTAL ASSESSMENT

Four RC slabs are casted in laboratory conditions with the following dimensions (Maazoun et al.): length 2.3 m, width 0.3 m and thickness 0.06 m. The average compressive strength (cubes with side length 150 mm) and the Young's modulus of the concrete are f_{cm} = 53 N/mm^2 and E_C = 36400 N/mm^2. The main reinforcement is composed of 6 bars of 6 mm diameter. The steel has a characteristic yield strength of f_y =500 N/mm^2 and Young's modulus of E_s=210,000 N/mm^2. Fig. 1 shows the slab reinforcement details.

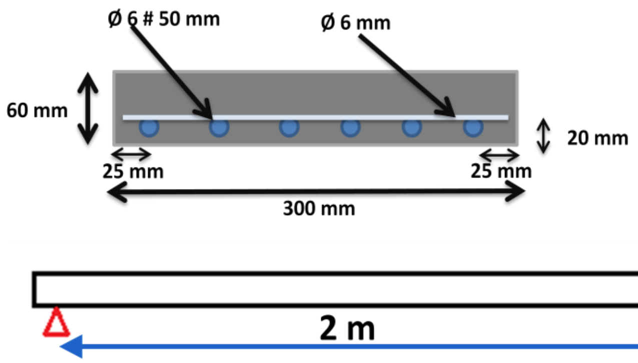

Fig.1: *RC slab details.*

Four RC slabs are tested; the slab A1 is used as a reference specimen, the slabs A2, A3 and A4 are retrofitted with 1 CFRP strip, 2 CFRP strips and 4 CFRP strips respectively. Fig. 2 shows the tested specimens (Maazoun et al.). The CFRP strip bonded on the specimens, has a length of 1.96m, thickness of 2.5 mm and a width of 15 mm. The tensile strength and Young's modulus of the CFRP (as reported by the manufacture) are 2800 N/mm^2 and 165,000 N/mm^2, respectively.

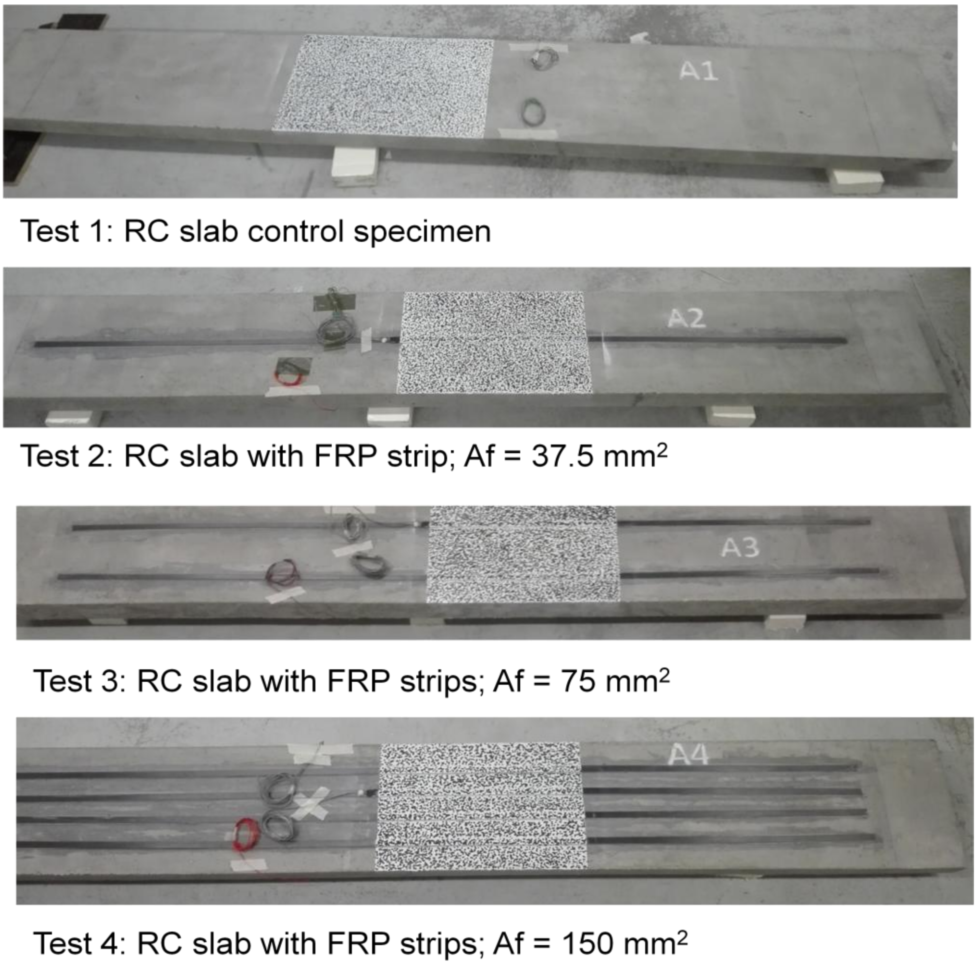

Fig.2: *Experimental specimens*

Experimental setup for blast tests

In this study an EDST is used with a square section to generate a plane blast wave (Ousji et al. 2015); the width is 300 mm, the thickness of the tube wall is 5 mm, and the length is 1.5 m. The reflected pressure is obtained by detonating 40g of C4 at the entrance of the tube. A series of experimental tests are performed using the experimental setup shown in Fig. 3.

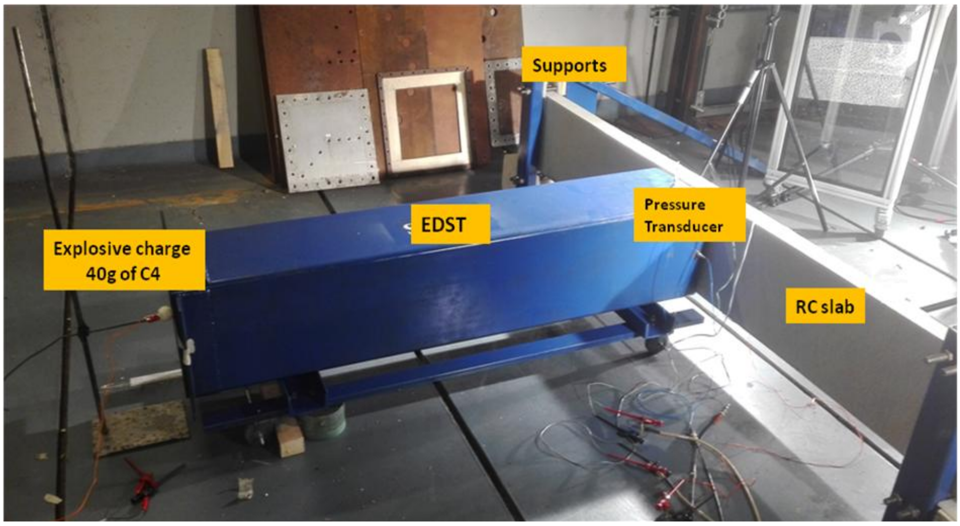

Fig.3: *Experimental setup for blast tests.*

Instrumentation

Fig. 4 shows the experimental equipment used in the blast tests. DIC measurements are used to measure the maximum deflection and the strain evolution on the CFRP strips and the concrete at the mid span of the RC slab during the explosion. Also, three strain gauges of 10 mm length with a nominal resistance of 120 Ω are used. Two of them are bonded on the steel reinforcement at 0.1m from the mid span of the slab before casting the concrete and the other strain gauge is glued on the CFRP strip at 0.1 m from the mid span of the slab. To measure the incident pressure at the end of the tube of each experiment, two pressure transducers are fixed at the end of the tube.

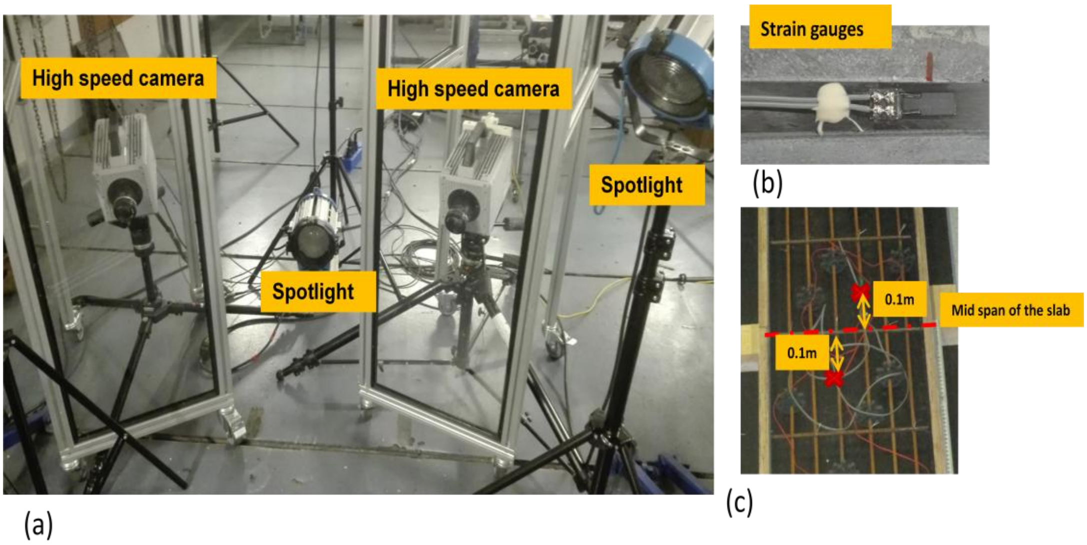

Fig.4: *(a) Stereo vision setup of two high speed camera for DIC measurements; (b) strain gauge bonded on CFRP strip; (c) strain gauges glued on steel rebars before casting the concrete.*

EXPERIMENTAL RESULTS AND DISCUSSION

Maximum deflection at the mid span of the slab

An experimental investigation is conducted to study the effect of EBR as a retrofit technique to improve the blast resistance of RC slabs. The results of this study confirm that EBR significantly increase the flexural strength and stiffness of the RC slab. In all the tests, a reduction in the maximum displacement for all specimens retrofitted with EBR is observed (a reduction of 42% to 48 % for Slabs retrofitted with 2 strips, 4 strips respectively) as shown in Fig. 5.

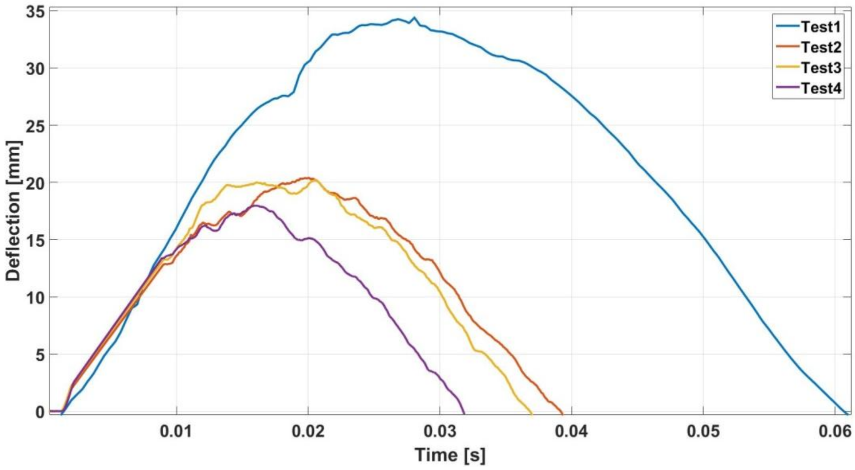

Fig.5: *Deflection time histories for experimental tests with DIC measurement.*

Strain distribution in the steel reinforcement and CFRP strips

The blast wave reaches the slab at 1.4 ms with a reflected pressure of 3 MPa as shown in Fig. 6. At time 1.4 ms, the blast wave hits the RC slab and generates a high strain in the steel rebars and CFRP strips and this explains the first peak of strain recorded in the tests. Moreover, at the end of all the curves, a perturbation of the signal is recorded, this is due to the impact of the RC slab with the EDST during the rebound phase. All the results after the impact of the slab with the tube are not taken into account.

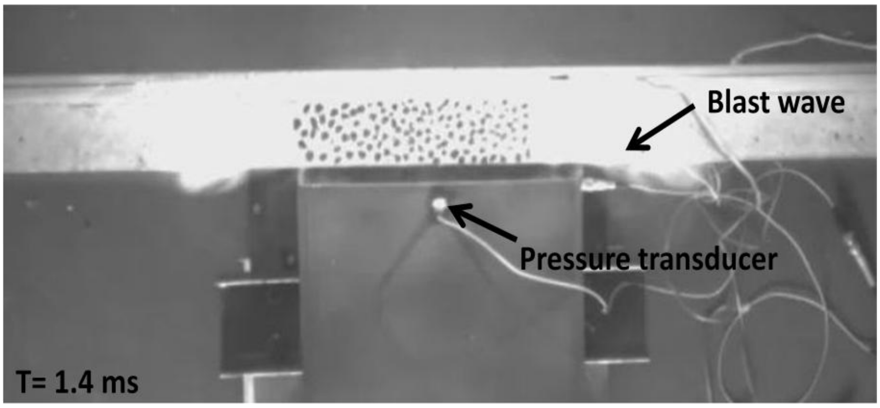

Fig.6: *Reflected pressure history*

Increasing the amount of CFRP as EBR, decrease the strain on the steel rebars. A reduction of 48% and 62% of the strain in the steel reinforcement for test 3 and test 4 are recorded. Fig.7 shows the evolution of the strain in the CFRP strip is higher than the strain in the steel rebars during the explosion.

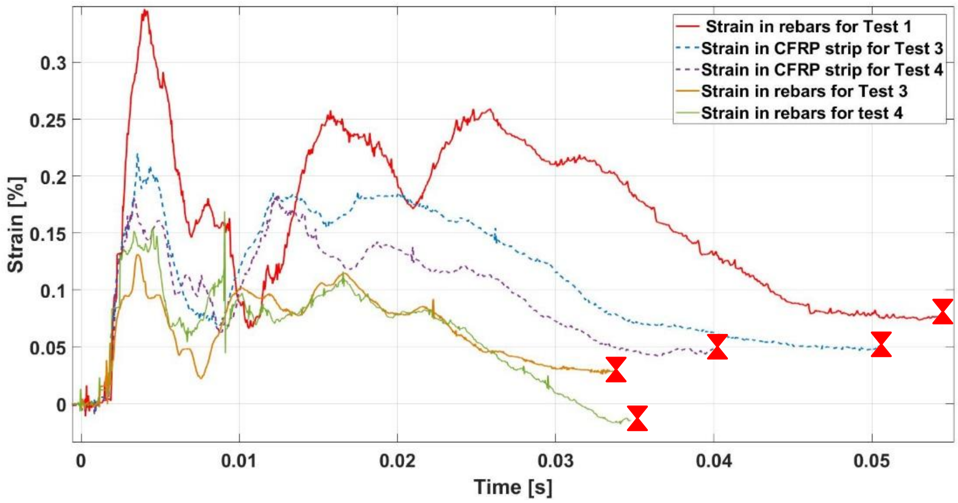

Fig.7: *Evolution of the strain in the steel rebars and in CFRP strips during the inbound phase (impact with the tube)*

Crack distribution of the blasted specimens

During the explosion, the control specimen reaches a maximum deflection of 28 mm. Flexural cracks are observed at the plastic hinge region of the slab. The crack propagation in the retrofitted slabs with one CFRP strip experienced higher number of tensile cracks with smaller widths compared to the control specimen. Moreover, the RC slab with 2 CFRP strips, cracks are almost invisible, the RC slabs with 4 CFRP, no cracks are observed. Fig. 8 shows the distribution of the strain on the concrete and CFRP strips from the DIC measurements, when the slabs reach the maximum deflection.

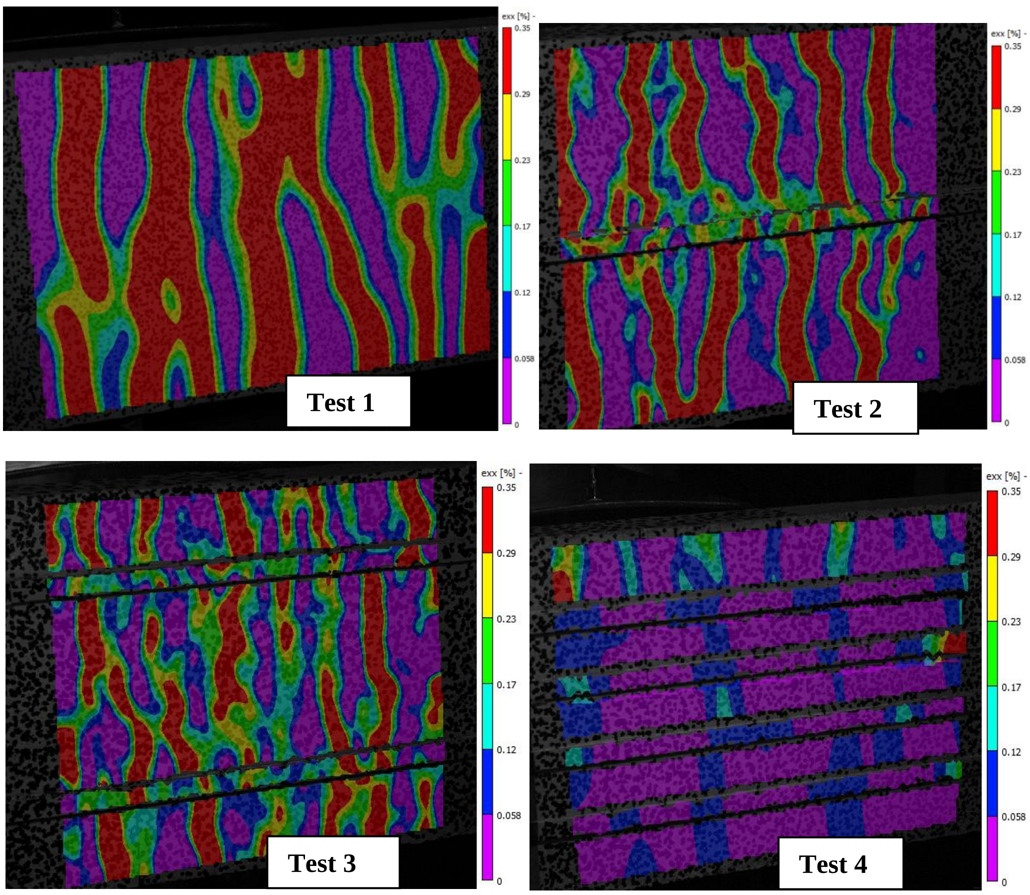

Fig.8: *Strain distribution on the concrete and the FRP strips using DIC measurement .*

Using the DIC measurement, four points are selected at the midspan of the slab for test 4, to record the evolution of the strain in the CFRP strips during the explosion. CFRP strips generate a uniform distribution of the stress across the slab as shown in Fig. 9 and this explains the multiplication of tensile thin cracks on the retrofitted specimens.

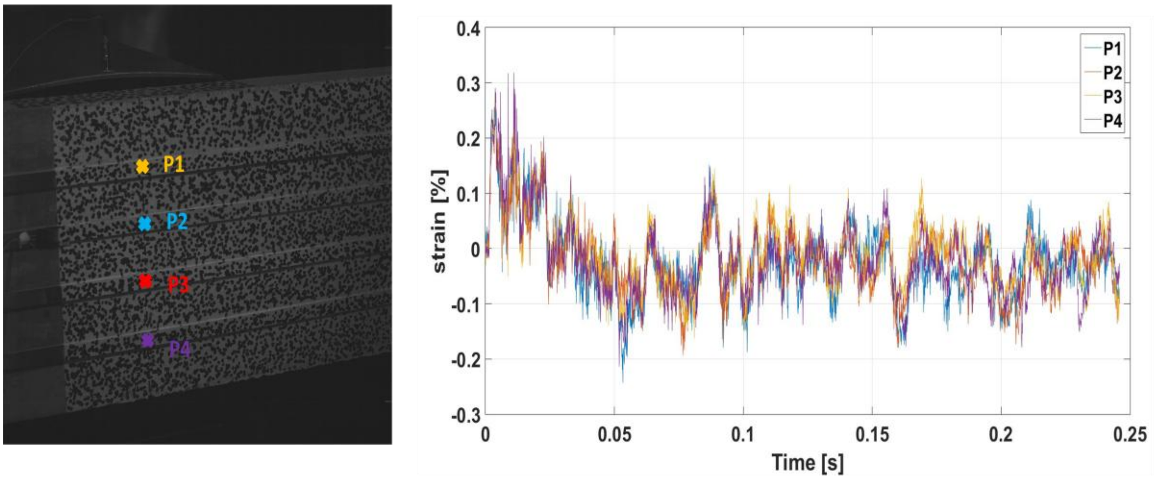

Fig.9: *Strain distribution in the CFRP strips for test 4.*

Load deflection diagram

After blast testing, three-point bending tests are carried out to obtain the load deflection diagram for the control slab and the slab retrofitted with 2 CFRP strips. The slabs are simply supported and a concentrated load is gradually applied at the mid span of the slab until failure as shown in Fig. 10.

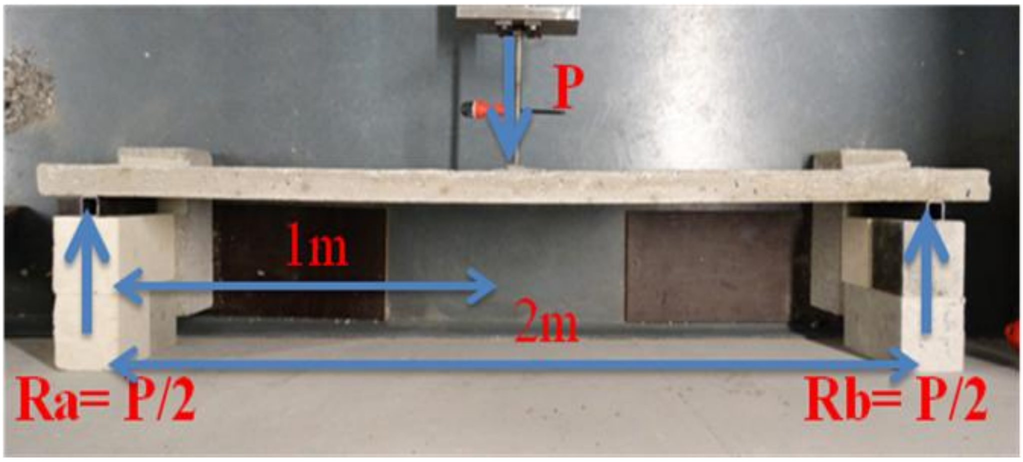

Fig.10: *Experimental set-up of static tests*

The reference slab fails by yielding of the steel followed by concrete crushing and the strengthened slab fails by CFRP debonding after the internal steel had already yielded and a premature debonding occurred. When the debonding occurs, the strengthened slab behaves as the reference slab with having the same ductility. Fig.11 shows a comparison of the load deflection diagram. The strengthened slabs show considerable increases of the failure load, up to 210% of enhancement.

The objective of blast enhancement is to increase the strain energy (area under load deflection diagram). If the strain energy exceeds the kinetic energy of the blast, the RC slab survive to the explosion and using CFRP as EBR increases the flexural strength of the specimen, and its blast energy storage capacity.

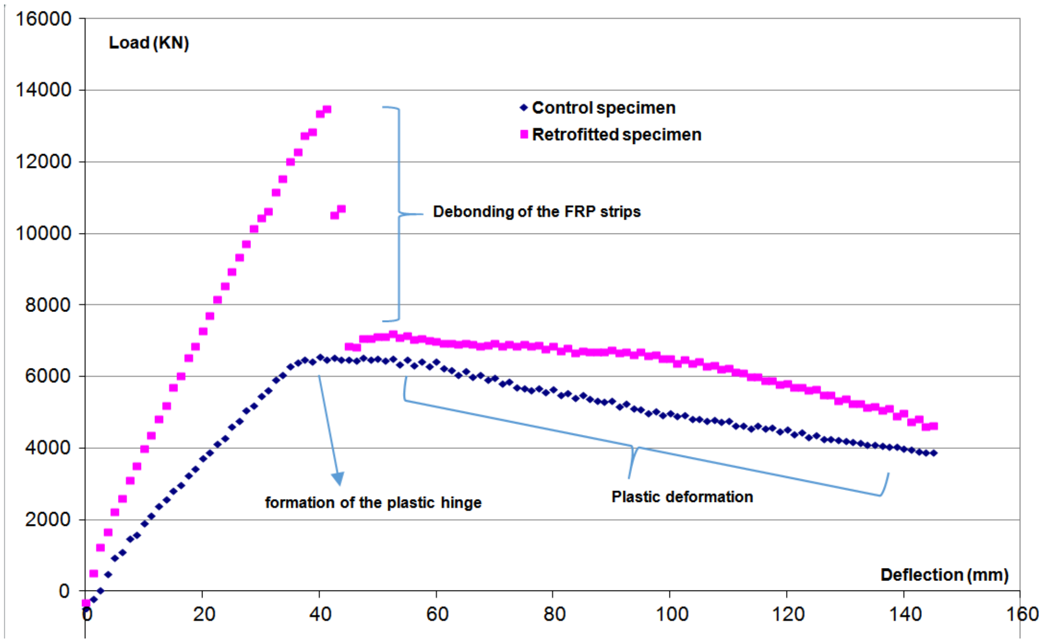

Fig.11: *Load-deflection diagram*

CONCLUSIONS

This study presents the experimental results of simply-supported RC slabs with EBR under blast loads and discusses practical aspects related to the measurement of blast response of retrofitted RC slabs (combining a EDST configuration with the feasibility of using DIC). The EBR increases the flexural resistance of the RC slab and leads to a smaller deflection at the mid span of the slab. A reduction of 42% and 48 % for the slabs retrofitted with 2 strips, 4 strips respectively**.** CFRP strips generate a uniform distribution of the energy (stress) across the slab and this explains the multiplication of thin tensile cracks on the retrofitted specimens.

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