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STATE-OF-THE-ART IN THE FIELD OF BLAST AND IMPACT RESISTANCE OF FIBRE REINFORCED CONCRETE

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Abstract

Due to its mechanical properties, fibre reinforced concrete can be used in a structures subjected to blast and impact loading.

The paper presents a comprehensive state-of-the-art review in the field of blast and impact loading based on detailed review of recent publications. Up-to date publications are cited, testing methods, specimen dimensions and the most important results are listed and compared. Trends in the research are named.

Keywords: blast, impact, fibre reinforced concrete

1. Introduction

Recent terrorist attacks on transport and civic infrastructure raised research activities focused on increasing blast performance of these structures.

Reinforced concrete is a brittle material and accordingly not suitable for use in blast-resistant structures. Loading caused by blast overpressure wave causes spalling of concrete; the ejected debris can cause fatalities in very large distance from the blast.

Increased structural blast performance minimizes the risk of progressive collapse and thusly reduces fatalities and material loses.

The research in this field started in middle 1990's and was accelerated by terrorist attacks in Oklahoma (1995) and in New York (2001).

2. Improving structural blast and impact resistance

There are several ways of improving blast and impact resistance of reinforced concrete (RC) structures or structural elements.

The most simple one is increasing the structural stiffness by adding mass. This method produces very robust and expensive structures and can be therefore regarded as ineffective.

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The second method improves ductility i.e. the blast performance of RC structures by adding fibres (steel or plastic).

The third method of improving structural blast resistance is by additional retrofit measures. Steel plates, carbon strips, etc. are glued at the most endangered structural elements. These measures are low weight, very effective but expensive.

The fourth method improves structural resistance by providing bigger standoff from the hypocenter by e.g. road barriers.

3. Overview of recently published experiments

Research is the field of blast resistance of concrete is usually divided up into two phases: the experimental program is undertaken in the first phase, which results are than used for calibration of numerical models in the second one.

Coughlin and Musselman [1] focused on blast performance of a concrete vehicle barrier used for providing offset from endangered structures. They compared various fiber contents and materials (carbon fiber reinforced concrete (CFRC), nylon fiber reinforced concrete (NFRC), both at 1,5% fiber content, synthetic/steel fiber mix (SS) (high fiber volume 5% and low fiber volume 3,8%). The damage was much smaller than at the compared RC specimens and decreased with the increased fiber content, the increase stopped from fiber volume 3,8%. Even 1,5% fibers showed beneficiary effect on the blast performance and dimensions of the ejected debris.

Zhou and Kuznetsov [2] compared the blast damage of RC and high strength steel fibre concrete (HSSFC) specimens on simply supported slabs (1x1,3x0,1m). HSSFC performed better at both surfaces.

Silva and Lu [3] focused on the use carbon fiber reinforced polymer (CFRP) strips at one / both surfaces of a RC slab (1,2x1,2x0,9m). The CFRP strips placed on the soffit of the specimens did not show great beneficiary effect. The CFRP strips placed on both surfaces specimens showed great beneficiary effect.

Ong [4] focused on impact resistance of fiber RC slab (1x1x0,05m) against a low velocity projectile caused by a 43kg hammer falling from 4m. He studied the effect of various types and dosages of fibers (polyolefin, polyvinyl alcohol (PVA) and steel, all at 0,5%, 1% a 2%). RC comparative specimen was completely destroyed during the tests, while the steel fiber reinforced slabs performed well.

Robins and Austin [5] focused on the used of FRC in the pavements used for vertical take-off and landing (VTOL). The 5% of steel fibers increased the fire resistance of the concrete slab.

Millard [6] and Wu a Oehlers [7] focused on high performance concrete fibre reinforced concrete (HPFRC).

Millard [6] describes dynamic behavior of HPFRC, the experiments were focused on dynamic bending and shear dynamic increase factor (DIF). Bending tests simulated distant explosion loading and impact & projectile loading, shear tests simulated near-face explosions. The specimens were subjected to three-point bending by a 30,1 kg steel hammer. The steel fiber content was 1,5%, 2,0% a 6%. The DIF decreased with the increasing fiber content.

Wu and Oehlers [7] focused on blast performance of ultra-high performance fibre concrete (UHPFC) slab, reinforced ultra high performance fibre concrete (RUHPFC) and a RC slab externally retrofitted by fibre reinforced polymer (FRP) plates. The specimens were 2-sides supported slabs (2x1x0,1m) with a span of 1,8m. The blast resistance of UHPFC and normal reinforced concrete was the same, the FRP plates added on the loaded side decreased damage of the slab.

Mosalam [8], Schenker [9] and Nam [10] focused on improving blast resistance of RC structures by external retrofitting.

Mosalam [8] analyzes a two-way RC slab (2,64x2,64x0,076 m) subjected to blast loading. The slab was retrofitted by CFRP strips (0,46m wide, 0,584 thick) and loaded by three blasts (0,45, 56,7 and 453,4 kg of TNT). The use of CFRP strips at the loaded surface decreased the deflection by 40%, the CFRP strips at both surfaces reduced deflection by 72%. The author studied the chase of natural frequencies due to the blast loading. The retrofitted specimen showed lover reduction of natural frequencies which denotes of higher residual structural stiffness.

Schenker [9] focused on the use of aluminium foam as a coating of the blast adjacent concrete surface. He tested the effect on RC slabs with span of 3m. The specimens were loaded by 1000kg TNT blast in 20m distance. The alulminium foam was able to absorb large portion of the blast energy and thusly decrease damage of the RC slab.

Nam [10] focused on the use of glass fibre reinforced polymers (GFRP) in improving blast resistance of concrete. Within his experiments, he used a simply supported RC slab (1x1x0,07m) loaded by 33,4kg ANFO (82% TNT equivalent). The surface adjacent to the blast was retrofitted by GFRP strips (0,5m wide) in both dimensions. The use of GFRP decreased the deflection from 12 to 8mm.

Buchan a Chen [11] produced state-of-the-art focused mainly on blast-retrofitting of masonry structures.

4. Summary of the experiments

Table 1 provides summary of the most important blast experiments performed in the last 10 years.

Tab. 1: Summary of blast experiments.

Autor / topic	**Specimen**	**Retrofitting material**	**Charge weight (kg) / Standoff (m)**
Coughlin and Musselman [1] Retrofitting leads to better results of blast resistance of specimens	K-1 Concrete barrier	-	Secret information
	CFRC	Carbon fibres 1,5%	Secret information
	NFRC	Nylon fibres 1,5%	Secret information
	SS-H	5% Synthetic/steel fibres	Secret information
	SS-L	3,8% Synthetic/steel fibres	Secret information
Zhou and Kuznetsov [2] Steel fibres increase blast resistance	RC Slab 1,0x1,3x0,1m	-	Composition: B 0,5 kg
	SFRC	Steel fibres	Composition: B 0,5 kg
Silva a Binggeng Lu [3] Retrofitting is effective only if specimen is retrofitted on both sides	One way RC slab 1,2x1,2x 0,9 m	-	1,35 kg RDX at distance of 0,3 m
	CFRP	Carbon fibres plate (one (tension) side)	1,35 kg RDX at distance of 0,3 m
	CFRP	Carbon fibres plate (both sides)	1,35 kg RDX at distance of 0,3 m
	SFRP	Steel fibres plate (one (tension) side)	1,35 kg RDX at distance of 0,3 m
	SFRP	Steel fibres plate (both sides)	1,35 kg RDX at distance of 0,3 m
Ong [4] Steel fibres had the best retrofitting effect	POFRC Concrete slab 1,0x1,0x 0,05 m	Polyolefin fibres	43 kg hammer from 4 m
	PVAFRC	Polyvinyl alcohol (PVA) fibres	43 kg hammer from 4 m
	SFRC	Steel fibres	43 kg hammer from 4 m
Robins a Austin [5] Less spalling of concrete surface with steel fibres	Concrete slabs SFRC	Steel fibres	VTOL aircraft motor temperature

Tab. 1: Summary of blast experiments (continiued).

Autor / topic	**Specimen**	**Retrofitting material**	**Charge weight (kg) / Standoff (m)**
Millard [6] DIF is equals to 1,0 on concrete specimens with steel fibres	HSFRC	High strength fibre reinforced concrete (steel fibres)	Flexural and shear dynamic experiment
Wu a Oehlers [7] The best retrofitting effect had a specimen with EB CFRP on both sides	Concrete slabs UHPFC	Ultra high performance fibre concrete	3,4 kg Composition B 0,75 m
	RUHPFC	Reinforced Ultra high performance fibre concrete	20,1 kg Composition B 1 m
	EB CFRP Normal concrete	Externally bonded Carbon fibre reinforced polymer (2,8 mm thick carbon plates)	5,1 kg Composition B 0,92 m
Mosalam [8]	Two way CFRP concrete slab 2,64x2,64x0,076 m	Carbon fibres strips 0,584 mm thick	0,45 kg, 56,7 kg and 453,4 kg of TNT equivalent
Schenker [9] Foam absorbed a lot of blast energy and saved the concrete	Concrete slabs	Aluminium foam with steel plate	1000 kg TNT 20 m
Nam [10]	Concrete slab GFRP 1,0x1,0x0,07 m	Glass fibre reinforced polymer plates on upper side	33,4 kg ANFO

5. Conclusions

This paper presented review of research in the field of blast and impact resistance of fibre concrete, ultra high performance fibre concrete and on retrofitting concrete structures with externally bonded polymers or another materials. These measures increase blast and impact resistance or ductility, reduce fragmentation and spalling of concrete structures loaded by dynamic loading.

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