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BLAST PERFORMANCE OF FRC SPECIMENS WITH STEEL FIBERS OF LOW DUCTILITY

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Abstract: *Due to improved ductility, fibre-reinforced concrete (FRC) shows better performance under blast and impact loading compared to conventionally reinforced concrete. Also higher concrete strength shows better blast performance. The full scale blast tests of FRC and reinforced concrete specimens were performed in cooperation with the Czech Army corps in the military training area Boletice. The tests were performed using real scale reinforced concrete precast slabs (6x1.5x0.3m) with varying fiber content, fiber type, fiber strength and concrete strength class and 25 kg of TNT charges placed in distance from the slab for better simulation of real in-situ conditions. The paper presents conclusions from three sets of tests from years 2010, 2011 and 2013: eleven specimens were tested in total. Two specimens of different concrete strength were tested as reinforced concrete specimens to provide comparison to the nine FRC specimens of different fiber content (0.5% and 1%): polypropylen fibers (length 54 mm, strength of 600 MPa) and steel fibers (low ductility, 25 mm long, strength 400 MPa). This paper continues the contributions from years 2011 and 2012 and shows the results of the experiments from year 2013.*

Keywords: Blast loading, Fiber reinforced concrete, Spalling of concrete subjected to blast loading.

1. Introduction

Due to improved ductility, fibre-reinforced concrete (FRC) shows better performance under blast and impact loading compared to conventionally reinforced concrete (Foglar & Kovar, 2013).

The experiments from year 2013 determine blast performance of FRC with low strength and low ductility steel fibers (strength 400 MPa).

This paper continues results presented in (Foglar et al., 2011) and (Foglar & Kovar, 2012)

2. Specimens and Materials

Dimensions of the specimens were designed in real scale of a small span bridge as concrete slabs, 6 m long, 1.5 m wide and 0.3 m thick.

The six specimens were tested in the year 2013, where three of them were made of C30/37 grade concrete ($f_{c,cyl}$ = 30 MPa) (specimen No. 8, 9 and 10), three of C55/67 grade concrete ($f_{c,cyl}$ = 55 MPa) (No. 6, 7 and 11). Steel fibers (FE) 25 mm long with strength 400 MPa and polypropylene (PP) 54mm long synthetic fibers with strength 600 MPa were used. The fiber dosage was following: specimen No. 6 80 kg/m^3 FE fibers, No. 7 40 kg/m^3 FE + 4.5 kg/m^3 PP fibers, No.8 40 kg/m^3 FE + 4.5 kg/m^3 PP fibers, No.9 40 kg/m^3 FE fibers, No. 10 80 kg/m^3 FE fibers and No.11 40 kg/m^3 FE fibers. The dosage of the fibers was kept low as it can be achieved on-site.

The layout of the experiment was practically the same as experiments from years 2010 and 2011.

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3. Results of the Experiments

The experiments were focused on the effect of different kinds of fibers, concrete compressive strength and its combination on blast performance of concrete. By means of performance, the dimensions of puncture and spalling of concrete is understood. The differences in puncture and spalling of concrete on the soffit of the slabs can be found in Tab. 1. In this section, the findings presented in Tab. 1 are described in detail.

The concrete of all specimens were tested for compressive strength. The results of probe cubes can be seen in Tab. 1.

The specimens tested in the years 2011 and 2012 are marked by "*".

Tab. 1: The results of the experiments.

Specimen No.	**1***	**2***	**3***	**4***	**5***	**6**	**7**	**8**	**9**	**10**	**11**
Concrete	C30/37	C30/37	C55/67	C55/67	C30/37	C55/67	C55/67	C30/37	C30/37	C30/37	C55/67
Concrete strength (cube)	49.9 MPa	41.8 MPa	80.0 MPa	82.5 MPa	41.9 MPa	65.0 MPa	58.3 MPa	45.0 MPa	48.0 MPa	46.5 MPa	65.7 MPa
Fibers	-	4.5 kg/m^3	-	4.5 kg/m^3	9.0 kg/m^3	80 kg/m^3	40 + 4.5 kg/m^3	40 + 4.5 kg/m^3	40 kg/m^3	80 kg/m^3	40 kg/m^3
Puncture – top surface	0.43 m^2	0.26 m^2	0.02 m^2	-	-	0.31 m^2	0.30 m^2	0.30 m^2	1.02 m^2	0.36 m^2	0.36 m^2
Concrete spalling (soffit) - < concrete cover	2.35 m^2	1.89 m^2	1.51 m^2	0.73 m^2	0.61 m^2	1.77 m^2	1.93 m^2	1.72 m^2	2.39 m^2	1.96 m^2	2.13 m^2
Concrete spalling (soffit) - > concrete cover	1.71 m^2	1.09 m^2	1.2 m^2	0.44 m^2	0.37 m^2	1.45 m^2	1.63 m^2	1.40 m^2	2.11 m^2	1.41 m^2	1.79 m^2
Concrete spalling (top surface) - < concrete cover	0.43 m^2	0.26 m^2	0.89 m^2	0.68 m^2	0.66 m^2	0.83 m^2	0.67 m^2	0.77 m^2	1.30 m^2	0.78 m^2	0.87 m^2
Concrete spalling (top surface) - > concrete cover	0.43 m^2	0.26 m^2	0.29 m^2	0	0.08 m^2	0.77 m^2	0.63 m^2	0.75 m^2	1.21 m^2	0.70 m^2	0.81 m^2
Concrete spalling (left side) - < concrete cover	0.52 m^2	0.05 m^2	0.08 m^2	0	0	0.04 m^2	0.04 m^2	0	0.23 m^2	0.06 m^2	0.06 m^2
Concrete spalling (left side) - > concrete cover	0.35 m^2	0	0.02 m^2	0	0	0.04 m^2	0.09 m^2	0	0.37 m^2	0	0.20 m^2
Concrete spalling (right side) - < concrete cover	0.34 m^2	0.16 m^2	0.08 m^2	0	0	0.07 m^2	0	0	0.24 m^2	0.11 m^2	0.06 m^2
Concrete spalling (right side) - > concrete cover	0.23 m^2	0.11 m^2	0.02 m^2	0	0	0.11 m^2	0.05 m^2	0.05 m^2	0.30 m^2	0.17 m^2	0.14 m^2
Volume of crushed concrete	0.23m^3	0.15m^3	0.20 m^3	0.05 m^3	0.06 m^3	0.20 m^3	0.25 m^3	0.26 m^3	0.45 m^3	0.24 m^3	0.27 m^3
Permanent deflection	0.31 m	0.37 m	0.28 m	0.30 m	0.26 m	0.31 m	0.30 m	0.45 m	-	0.45 m	0.32 m

The specimen No. 1 is determined as a reference specimen.

The specimen No. 6 was the one less damaged. The area of the puncture is 0.31 m^2, volume 0.09 m^3, which represents 3.4% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.20 m^3, which represents 7.4% of the total volume of the specimen. The area of the puncture was reduced by 28% in comparison to specimen No. 1, the total volume of the damaged concrete was reduced by 13% in comparison to specimen No. 1. The damage of the left side of specimen No. 6 was reduced by more than 80%, the damage of the right side was reduced by more than 50%. The deflection was 310 mm. The shape of the deflection was similar to deflection from point loading in the mid-span of the specimen. The deflection was the same in comparison to specimen No. 1.

The specimen No. 7 was approximately equally damaged. The area of the puncture is 0.30 m^2, volume 0.09 m^3, which represents 3.3% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.25 m^3, which represents 9.3% of the total volume of the specimen. The area of the puncture was reduced by 31% in comparison to specimen No. 1, total volume of damaged concrete was increased by 9% in comparison to specimen No. 1. The damage to the sides was reduced by 85%. The deflection was 300 mm. The shape of the deflection was similar to deflection from point loading in the mid-span of the specimen. The deflection was reduced by 3% in comparison to specimen No. 1.

The specimen No. 8 was approximately equally damaged. The area of the puncture is 0.30 m^2, volume 0.09 m^3, which represents 3.3% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.26 m^3, which represents 9.6% of the total volume of the specimen. The area of the puncture was reduced by 31% in comparison to specimen No. 1, total volume of damaged concrete was increased by 10% in comparison to specimen No. 1. The damage to the sides was completely reduced by 95%. The deflection was 450 mm. The shape of deflection was similar to deflection from point loading in the mid-span of the specimen. The deflection was increased by 45% in comparison to specimen No. 1.

The specimen No. 9 did not sustain the loading and collapsed. The specimen No. 9 after blast can be seen in Fig. 1. The area of the puncture is 1.02 m^2, volume 0.31 m^3, which represents 11.3% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.45 m^3, which represents 16.7% of the total volume of the specimen. The area of puncture was increased by 131% in comparison to specimen No. 1, total volume of damaged concrete was increased by 95% in comparison to specimen No. 1. The damage to the sides was 100% because area of puncture intervened over the whole width of slab. Cross-section of slab in mid-span was represented by steel reinforcement only.

Fig. 1: The specimen No. 9 after the blast.

The specimen No. 10 was approximately equally damaged as specimen No. 6. The area of the puncture is 0.36 m^2, volume 0.11 m^3, which represents 4% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.24 m^3, which represents 8.9% of the total volume of the specimen. The area of puncture was reduced by 16% in comparison to specimen No. 1, total volume of damaged concrete was increased by 9% in comparison to specimen No. 1. The damage of the left side of specimen No. 10 was reduced by more than 85%, the damage of the right side was reduced by more than 75%. The deflection was 450 mm. The shape of deflection was similar to deflection from point loading in the mid-span of the specimen. The deflection was increased by 45% in comparison to specimen No. 1.

The specimen No. 11 was approximately equally damaged. The area of the puncture is 0.36 m^2, volume 0.11 m^3, which represents 4% of the total volume of the specimen. The total volume of the damaged concrete (puncture + spalling) is 0.27 m^3, which represents 10% of the total volume of the specimen. The area of puncture was reduced by 16% in comparison to specimen No. 1, total volume of damaged concrete was increased by 17% in comparison to specimen No. 1. The damage of the left side of specimen No. 10 was reduced by more than 80%, the damage of the right side was reduced by more than 65%. The deflection was 320 mm. The shape of deflection was similar to deflection from point loading in the mid-span of the specimen. The deflection was increased by 3% in comparison to specimen No. 1.

4. Conclusions

The results from the experiments focused on determining blast performance of fiber reinforced concrete with low ductile steel fibers are described in this paper.

There is only slight positive effect of the added FE fibers on the damage of the specimens in comparison with reference specimen No. 1.

All specimens (No. 6–11) were more damaged at top surface than reference specimen No.1.

The extent of damage of all specimens (No. 6–11) was approximately the same as reference specimen No. 1.

The extent of damage slightly decreased with the increased fiber content, increased fiber strength and increased concrete strength. The combination of shear strength and fracture energy is the decisive material characteristics for determining the blast performance.

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