

The blast performance of real-scale reinforced concrete specimens with varying fiber types and content

M. Kovar, M. Foglar & R. Hajek

*Faculty of Civil Engineering, Czech Technical University in Prague,
Czech Republic*

Abstract

According to recent publications, from 2005 to 2008 there were more than 13,000 terrorist attacks around the world, which took more than 73,000 human lives. The attacks were targeted mainly on the technical and civic infrastructure, like governmental buildings, bridges, etc. 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. Field tests of FRC and reinforced concrete specimens were performed in cooperation with the Czech Army corps in the military training area Boletice. The test were performed using real scale reinforced concrete precast slabs (6 x 1.5 x 0.3 m) 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 were without fibers and had different concrete strength. Polypropylen fibers with length 54 mm and strength of 600 MPa and steel fibers with low ductility 25 mm long and strength 400 MPa were added in different content (0.5% and 1%) to the other nine specimens.

Keywords: blast loading, fiber reinforced concrete.

1 Introduction

Due to improved ductility, fiber-reinforced concrete (FRC) shows better performance under blast and impact loading compared to conventionally



reinforced concrete, as mentioned in Foglar and Kovar [1], Coughlin *et al.* [2] and Tabatabaei *et al.* [3].

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 and Kovar [1].

2 Specimens and material

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.

Six specimens were made in total, 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) 54 mm long synthetic fibers with strength 600 MPa were used. The fiber dosage was following: specimen No. 6 80 kg/m³ FE fibers, No. 7 40 kg/m³ FE + 4.5 kg/m³ PP fibers, No. 8 40 kg/m³ FE + 4.5 kg/m³ PP fibers, No. 9 40 kg/m³ FE fibers, No. 10 80 kg/m³ FE fibers and No. 11 40 kg/m³ 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.



Figure 1: Layout of the experiment.

The timber frame with string grid of 100mm was used to measure area and depth of concrete spalling and puncture. The method of data evaluation can be seen in Figure 2.



Figure 2: Timber frame with string grid to experiment data evaluation.

3 Results of the experiment

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

The materials of all specimens were tested for compressive strength. The results of tested cubes can be seen in Table 1.

The results of the experiment of specimen marked by “*” come from year 2010.

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

The effect of blast loading on top and bottom surfaces of the specimens can be found in Figures 3–14.

The specimen No. 11, C55/67, 40 kg/m³ FE fibers, was approximately equally damaged. The area of the puncture is 0.36 m², volume 0.11 m³, which represents 4% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.27 m³, 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.

Table 1: The results of the experiments.

Specimen No.	1*	6	7	8	9	10	11
Concrete	C30/37	C55/67	C55/67	C30/37	C30/37	C30/37	C55/67
Concrete strength (cube)	49.9 MPa	65.0 MPa	58.3 MPa	45.0 MPa	48.0 MPa	46.5 MPa	65.7 MPa
Fibers	-	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	0.31 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	1.77 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	1.45 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	0.83 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	0.77 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	0.04 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	0.04 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	0.07 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	0.05 m ²	0.05 m ²	0.30 m ²	0.17 m ²	0.14 m ²
Volume of crushed concrete	0.23 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	0.31 m	0.30 m	0.45 m	-	0.45 m	0.32 m



Figure 3: Damaged specimen No. 11 after blast – top view.



Figure 4: Damaged specimen No. 11 after blast – bottom view.

The specimen No. 10, C30/37, 80kg/m³ FE fibers, was approximately equally damaged. The area of the puncture is 0.36 m², volume 0.11 m³, which represents 4% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.24 m³, 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.



Figure 5: Damaged specimen No. 10 after blast – top view.



Figure 6: Damaged specimen No. 10 after blast – bottom view.

The specimen No. 9, C30/37, 40 kg/m³ FE fibers, was completely damaged. The specimen No. 9 after blast can be seen in Fig. 1. The area of the puncture is 1.02 m², volume 0.31 m³, which represents 11.3% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.45 m³, 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.



Figure 7: Damaged specimen No. 9 after blast – top view.



Figure 8: Damaged specimen No. 9 after blast – bottom view.

The specimen No. 8, C30/37, 40 kg/m³ FE + 4.5 kg/m³ PP fibers, was approximately equally damaged. The area of the puncture is 0.30 m², volume 0.09 m³, which represents 3.3% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.26 m³, which represents 9.6% of the total volume of the specimen. The area of 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.



Figure 9: Damaged specimen No. 8 after blast – top view.



Figure 10: Damaged specimen No. 8 after blast – bottom view.

The specimen No. 7, C55/67, 40 kg/m³ FE + 4.5 kg/m³ PP fibers was approximately equally damaged. The area of the puncture is 0.30 m², volume 0.09 m³, which represents 3.3% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.25 m³, which represents 9.3% of the total volume of the specimen. The area of 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 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.



Figure 11: Damaged specimen No. 7 after blast – top view.



Figure 12: Damaged specimen No. 7 after blast – bottom view.

The specimen No. 6, C55/67, 80 kg/m³ FE fibers was less damaged. The area of the puncture is 0.31 m², volume 0.09 m³, which represents 3.4% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.20 m³, which represents 7.4% of the total volume of the specimen. The area of puncture was reduced by 28% in comparison to specimen No. 1, the total volume of 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 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.



Figure 13: Damaged specimen No. 6 after blast – top view.



Figure 14: Damaged specimen No. 6 after blast – bottom view.

4 Conclusions

Results from the last experiments leading to determine blast performance of fiber reinforced concrete with low ductile steel fibers are described in this paper.

There is no positive effect of added FE fibers to damage of 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 increased fiber content, increased fiber strength and increased concrete strength. Combination of shear strength and fracture energy is decisive index of blast performance.

All specimens with PP fibers had better fragmentation properties – less compact fragments flew out after the blast.

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