THE RESULTS OF BLAST LOADING OF REINFORCED CONCRETE SPECIMENS WITH VARYING FIBRE TYPES AND CONTENT

РЕЗУЛТАТИ ОТ ВЗРИВНО НАТОВАРВАНЕ НА УСИЛЕНИ БЕТОНОВИ ЕЛЕМЕНТИ С РАЗЛИЧНИ ВИДОВЕ ФИБРИ И СЪСТАВ

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Abstract: *The experiment report presents the results of the field tests of fiber-reinforced concrete (FRC) and reinforced concrete specimens which were performed by research team from Faculty of Civil Engineering, Czech Technical University in Prague, Czech Republic in cooperation with the Czech Army corps in the military training area Boletice. The tests were performed using real scale reinforced concrete precast slabs (6×1.5×0.3m) with varying fibre content, fibre type, fibre strength and concrete strength class and 25 kg of TNT charges placed at a distance from the slab for better simulation of real in-situ conditions. The slabs were recorded using a high speed framing camera during the blast loading. The instrumentation enabled us to study the propagation of the blast shock wave through the material, propagation of the cracks on the soffit of the specimen and the final collapse of the middle part of the slab exposed to blast loading. The sequence of the structural behaviour is documented in detail and verified by numerical modelling using the LS-DYNA solver.*

KEYWORDS: BLAST LOAD, RC STRUCTURES, STEEL FIBRES, POLYPROPYLEN FIBRES, EXPLOSION, BLAST WAVE

1. Introduction

According to recent publications, from 2006 to 2016 there were more than 23,000 terrorist attacks around the world, which took more than 127,000 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.

Due to improved ductility, fiber-reinforced concrete (FRC) shows better performance under blast and impact loading compared to conventionally reinforced concrete, as mentioned in many sources.

The experiments from year 2016 replicate the previous test results from 2010, 2011 and 2013. They determine blast performance of FRC with low strength and low ductility steel fibers (strength 400 MPa).

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 ($f_{c,cyl}$ = 30MPa) (specimen No.8, 9 and 10), three of C55/67 grade concrete ($f_{c,cyl}$ = 55MPa) (No. 6, 7 and 11).

Steel fibers (FE) 25mm long with strength 400MPa and polypropylene (PP) 50mm long synthetic fibers with strength 600MPa were used.

The fiber dosage was following: specimen No.6 80kg/m^3 FE fibers, No.7 40kg/m^3 FE + 4.5 kg/m^3 PP fibers, No.8 40kg/m^3 FE + 4.5kg/m^3 PP fibers, No.9 40kg/m^3 FE fibers, No.10 80kg/m^3 FE fibers and No.11 40kg/m^3 FE fibers.

The dosage of the fibers was kept low as it can be achieved on-site.

The layout of the experiment is shown on fig. 1.

Fig. 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 Fig. 2.

Fig. 2 *Timber frame with string grid to experiment data evaluation*.

3. Results and discussions

The experiments were focused on the effect of fibres (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 specimen No.1 is determined as a reference specimen and is marked by “*”.

The specimen No.11, C55/67, 40kg/m^3 FE fibers, was approximately equally damaged. The area of the puncture is 0.36m^2, volume 0.11m^3, which represents 4% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.27m^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 320mm. 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 №	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), MPa	49.90	62.70	58.20	45.50	48.40	46.50	65.30
Fibers, kg/m^3	-	80	40+ 4.5	40+ 4.5	40	80	40
Puncture – top Surface, m^2	0.43	0.32	0.30	0.30	1.03	0.35	0.36
Concrete spalling (soffit) - < concrete cover, m^2	2.35	1.78	1.94	1.73	2.39	1.94	2.14
Concrete spalling (soffit) - > concrete cover, m^2	1.72	1.47	1.64	1.40	2.13	1.42	1.78
Concrete spalling (top surface) - < concrete cover, m^2	0.43	0.82	0.68	0.76	1.30	0.77	0.86
Concrete spalling (top surface) - > concrete cover, m^2	0.43	0.77	0.64	0.75	1.23	0.70	0.82
Concrete spalling (left side) - < concrete cover, m^2	0.52	0.05	0.04	0	0.24	0.06	0.06
Concrete spalling (left side) - > concrete cover, m^2	0.35	0.04	0.09	0	0.37	0	0.20
Concrete spalling (right side) - < concrete, m^2	0.34	0.07	0	0	0.24	0.11	0.06
Concrete spalling (right side) - > concrete cover, m^2	0.23	0.11	0.03	0.03	0.30	0.17	0.14
Volume of crushed concrete, m^3	0.23	0.20	0.25	0.26	0.45	0.24	0.27
Permanent Deflection, m	0.31	0.31	0.30	0.45	---	0.45	0.32

The specimen No.10, C30/37, 80kg/m^3 FE fibers, was approximately equally damaged. The area of the puncture is 0.35m^2, volume 0.11m^3, which represents 4% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.25m^3, which represents 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 450mm. 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, C30/37, 40kg/m^3 FE fibers, was completely damaged. The area of the puncture is 1.03m^2, volume 0.35m^3, which represents 11.3% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.45m^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.

The specimen No.8, C30/37, 40kg/m^3 FE + 4.5 kg/m^3 PP fibers, was approximately equally damaged. The area of the puncture is 0.30m^2, volume 0.09m^3, which represents 3.3% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.26m^3, 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 450mm. 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.7, C55/67, 40kg/m^3 FE + 4.5 kg/m^3 PP fibers, was approximately equally damaged. The area of the puncture is 0.30m^2, volume 0.09m^3, which represents 3.3% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.25m^3, 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 300mm. 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.

The specimen No. 6, C55/67, 80kg/m3 FE fibers was less damaged. The area of the puncture is 0.32m^2, volume 0.09m^3, which represents 3.5% of the total volume of the specimen. Total volume of the damaged concrete (puncture + spalling) is 0.20m^3, which represents 7.5% 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 310mm. 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.

4. Conclusion

Results from the 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.

5. Literature

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