Influence of internal composition of fiber reinforced cement composites on resistance to near field blast

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Abstract. This paper describes the influence of internal composition of fiber reinforced cement composites on resistance to near field blast. The influence of multiple basalt meshes and dispersed fibers on a damage induced by a near-field blast is studied and numerically evaluated. Experimental measurements performed in the Boletice military area in 2014, 2015 and 2016 are evaluated by numerical simulations. The evaluation of the results is mainly focused on the stress in the cement composite, propagation of the overpressure caused by the blast and velocity of the ejected parts from the specimen. The influence of velocity of ejected parts coming out of the specimen, originally caused by the impact of a steel plate which bears TNT charges, is examined. And last, but not least, the influence of presence and position of basalt meshes in the specimen on its damage induced by delamination is also examined.

1. Introduction to the experimental program
The main objective of this article is to describe the experimental program and to present the numerical simulations that evaluate it. However, numerical simulations are closely related to the experimental program (or experimental measurements). Composition of the concrete mixtures and heterogeneity level included in the numerical material model is given by experimental measurements. And therefore it is necessary to provide a reader with some basic and important information.

Experimental program focused on resistance of concrete structures subjected to blast loading (blast resistance of concrete structure) has been taking place continuously for many years. In the last three years (2014, 2015 and 2016) the basalt mesh has been put into the concrete specimens. The mesh increases heterogeneity of the cross section. High heterogeneity of the concrete elements (or concrete cross section) is important for improving the blast resistance of these elements.

The experiments were performed in the Boletice military training area, in cooperation with the Armed Forces of the Czech Republic. The location and layout of the experiment was very similar to the authors’ previous experiments [1, 2, 3]. The shape and size of the specimens were the same as the specimens used in the previous (and next) tests. Specimens were concrete slabs 6 m long, 1.5 m wide and 0.3 m thick. Each specimen had the same amount of steel reinforcement, i.e. 11 pcs \( \varnothing \) 16 mm reinforcing bars every 140 mm on both sides, \( \varnothing \) 10 mm every 150 mm as an outer transverse reinforcement, while the shear reinforcement was provided by \( \varnothing \) 8 mm links (9 pcs/m^2). Concrete cover of 50 mm was taken to the surface of the transverse reinforcement. The scheme of the experiment is shown in Fig. 1. The ground beneath the slabs was excavated to the depth of 2 m in order to avoid the results being influenced by a shock wave bouncing off the ground. The 25 kg TNT charges were placed
on the steel chairs (steel plate which is used for placing the charges is shown in Fig. 1 too) in the middle of each slab. The steel chairs provided 450 mm standoff from the slab. The other research has found that the steel chairs (steel plate) which bear the TNT charges behave like a projectile. It will be introduced as a projectile in next parts of the article. Information on the instrumentation used during the experiment can be found in [4,5,6].

**Figure 1.** Scheme of the experiment – specimen P19 with basalt mesh in five layers

Used specimens were made of ultra-high performance fiber-reinforced concrete (UHPFRC). Two types of high-strength steel (HSS) fibers were used: 35 mm and 13 mm in length. The yield strength of the fiber material to be higher than 2200 MPa is guaranteed by the manufacturer.

The specimens contained basalt meshes in multiple layers along the depth of the specimen in distances about 50 mm (Fig. 2). Mesh size of basalt mesh was 30 x 30 mm. The melting point of the basalt mesh is 1350 °C and the tensile strength is about 4200 MPa with tensile modulus of elasticity of about 85 GPa. The unit weight of the mesh is 250 g/m² with weight density of 2.67 g/cm³.

**Figure 2.** Concrete details drawing of a Specimen No. 18 – specimen with basalt mesh in five layers
2. Numerical evaluation

Numerical simulations were performed in the LS-DYNA software – the explicit finite elements method was used. Numerical models were created for the evaluation of a shock wave propagation, velocity of flying elements (ejected parts) and influence of heterogeneity on delamination of the specimen. During the evaluation of these main effects, other values were checked in order to verify the correctness of the numerical models. Numerical models are used to understand and describe the phenomenon inside the specimen which includes different cross-sectional heterogeneities [7,8].

2.1. Description of the model

Exact specification of the material models was taken from [1, 2, 7]. Heterogeneity of specimen is included in each material model.

Concrete was defined by the material model *MAT_CSCM. Reinforcement and basalt mesh were defined by the material model *MAT_PLASTIC_KINEMATIC which is a standard material model of the LS-DYNA [7, 8]. All material models were assigned with the appropriate parameters based on real material properties.

Using axis symmetry of the experiment, one quarter of a specimen is considered for a shorter calculation time. This simplified model is also easier and more friendly to interpret the results.

Three types of numerical models were created (with different concrete mixtures):

- Model with reinforced concrete and dispersed fibers (Fig. 3)
- Model with reinforced concrete, dispersed fibers and one layer of basalt mesh at the soffit of the specimen in the half of the reinforcement cover (Fig. 4)
- Model with reinforced concrete, dispersed fibers and five layers of basalt meshes (Fig. 5)

![Figure 3. Specimen without basalt meshes layer](image1)

![basalt meshes](image2)

![Figure 4. Layout of basalt meshes, 1 layer at the soffit of the specimen in the half of the reinforcement cover](image3)
Near-field blast was simulated by the function *LOAD_BLAST_ENHANCED (LBE) which converts the blast loading into pressure impulse. Input data of this function are the distance between charges and specimen, weight and type of charges. This method was selected on the basis of [7] where compliance with other load method is verified.

2.2. Velocity of ejected parts
For the velocity evaluation of ejected parts of the specimen, there were points determined on the lower surface of the specimen. During the experimental measurement, the velocity was measured in the middle of the specimen span, 150, 300 and 450 millimetres from the center. Coordinates consider the coordinate system of a quarter of a specimen. The velocity of the ejected parts in the middle of the span only was measured during the experimental measurement (Fig. 6 and 7).

- Channel position CH1, Node 332, Coordinate [3000; 0; 0]
- Channel position CH2, Node 317, Coordinate [2850; 0; 0]
- Channel position CH3, Node 302, Coordinate [2700; 0; 0]
- Channel position CH4, Node 289, Coordinate [2550; 0; 0]
Velocity of ejected parts of specimen at the bottom surface is slower for ultra-high performance fiber-reinforced concrete (UHPFRC). Elements (ejected parts) start to move earlier than if common concrete is used. Energy consumed by the shock wave of the specimen is higher for the UHPFRC and velocity of the elements is lower. It is obvious from the experiment that the velocity of the ejected parts decreases away from the centre of the specimen for each concrete mixture used. Also, in the figures below there can be seen that using the basalt mesh in one or five layers can reduce the velocity. By using the basalt mesh in the specimen (along the depth of the specimen) appropriately, the velocity can be reduced up to 15%.

In the following figure 8, the influence of the basalt mesh layers in the specimen can be observed with respect to the velocity of the ejected parts.

![Velocity, node 340](image)

**Figure 8.** Velocity of the ejected parts, in the middle of the span

2.3. **Shock wave propagation**

According to the numerical model, there was found that the shock wave propagation is faster than commonly used concrete if the UHPFRC concrete is used. The high strength concrete has higher bulk density. Also, it is more homogeneous than common concrete. Fine aggregate fraction, more cement and steel fibers make faster passage of the shock wave. The time difference of the shock wave propagation depends on used material is about 0.01ms.

During the passage of the shock wave, there is a concentration of stress around the reinforcement and reflections of the shock wave at the interface between the concrete and reinforcement. The stress in the reinforcement is redistributed from the centre (away from the epicentre of explosion) to the edge of
specimen. By the concentrating the stress the cohesion between the concrete and the reinforcement is reduced.

For the specimen with basalt mesh, it is possible to observe stress concentration near this reinforcement. At the same time, it is possible to observe the redistribution of generated stress after reflection of the shock wave from the lower surface of the specimen. The stress is then redistributed in the concrete cover from the centre to the edge of the specimen.

2.4. Shock wave propagation
In Figures 9 to 12, delamination of the specimen due to use of basalt meshes can be observed. When passing a shock wave of a specimen piece, the energy is absorbed by basalt mesh and reflects a part of the shock wave. In the specimen without basalt mesh, the section is delaminated only at the steel reinforcement where stress is concentrated. In the specimen with one layer basalt mesh, a delamination occurs in the area of the steel reinforcement at the top surface and at the basalt mesh. At the specimen with five layers of basalt meshes, there is a clear delamination near all the basalt meshes.

Figure 9. Specimen without basalt meshes – delamination at steel reinforcement

Figure 10. Specimen with basalt mesh in the middle of the concrete cover, delamination of the specimen due to the placement of basalt meshed and at the steel reinforcement

Figure 11. Specimen with five basalt meshes, delamination of the specimen due to the basalt meshes and steel reinforcement
3. Conclusion

Numerical models were made by the LS DYNA software. Blast loading was made by the Load Blast Enhanced function. Models served primary to evaluate shock wave propagation and determination of velocity of ejected parts of specimen taking into the material properties of the specimens.

Appropriate increase of heterogeneity of the element - using some basalt meshes at along the depth of the specimen, can reduce the velocity of ejected parts up to 15% against the specimen without these non-steel reinforcements in this case. From the models it is also evident that passage of the shock wave is faster for ultra-high performance concrete (with steel fibers in this case) than concrete which is commonly used. However, the velocity of ejected parts is lower for the UHPFRC. Using these findings, the protection of civilian population against the effects of ejected parts of structures exposed to extreme loads due to near-field blast can be successfully increased.

From numerical models it is also clear that there is a concentration of stress around the steel reinforcement. Stress concentrated in the reinforcement is redistributed from the center to the edge of specimen (away from the centre of explosion). In place of the stress concentration, the cohesion between concrete and steel reinforcement is disrupted. This phenomenon is also verified by the numerical model with basalt meshes. Around the basalt meshes, there is a concentration of stress, reflection of the shock wave and thereby delamination of the specimen.

Commonly available literature does not mention concrete elements with basalt meshes and their influence on its resistance under near-field blast. The same problem is with describing the behaviour of a projectile (steel chairs which bears TNT charges). This topic is very specific and unique. Therefore, this article and whole work is not easy to compare with another measurement or results of other experimental programs.

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