Design of Blast Resistant Long-Carbon Fibre Concrete Walls

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Summary

Since the events of September 11, 2001, there has been a growing awareness of the need to design structures for resistance to terrorist attack. Many of the fatalities and injuries associated with blast on structures are due to shrapnel produced by the blast. The long carbon fibre investigated in this program is one of very few feasible alternatives for providing this resistance to spalling for concrete buildings (in addition to improving other structural properties). The material is a waste product from the Aerospace industry and can be mixed directly into concrete without significant changes to the standard casting process. The material also has potential for use in seismic regions, but the present focus is on blast resistance (explosives) and impact resistance (crash barriers, impact resistant bridge piers).

While the material can be used successfully "as is" in a straight replacement for standard concrete, the true benefits come by taking into account the material as a portion of the reinforcement. Reinforcement beyond that required results in more difficult placement of the fibre concrete, reduces spalling resistance in low cover situations, and increases cost. Specimens designed for blast resistance (by codes such as the TM5-1300) require extremely heavy reinforcement. This paper will summarize the computational modeling and large-scale blast testing program used to develop design recommendations for long-carbon fibre concrete for wall and barrier applications.

Keywords: blast; impact; fibre reinforced concrete; carbon; walls; spalling.

1. Introduction and Background

Recent terrorist events have revealed the vulnerability of many structures to large impacts and explosions. Current blast design guidelines, such as the commonly used Army document TM5-1300 [1], do not address the issue of spalling and require large amounts of reinforcement and special detailing to achieve blast resistance. Long carbon fibre concrete is a material whose behaviour is very promising for blast and impact resistant structural members. Instead of spalling on impact, the material stays bonded together, preserving its load carrying capacity and minimizing the amount of debris that is created. Carbon fibres, 75 mm in length, are added to a silica fume amended mix at volume fractions up to 2.5% (unreinforced members) or 1.5% (reinforced members). Though carbon fibres of this length have not been successfully implemented in the past, a coating developed by Ogden Technologies gives the fibres enough initial rigidity to prevent "balling" in the mixer. The increased fibre length is postulated to give the material more energy absorption capacity since the long pullout of the fibre will contribute to post peak ductility. There also exists potential to obtain the fibres from the waste stream of the aerospace industry. This would allow long carbon fibre concrete very economical.

2. Blast Testing

A preliminary blast evaluation of long carbon fibre concrete was carried out on slab specimens to obtain qualitative data on the material's blast resistance, especially how the fibres prevent spalling of the concrete. The panels (1.83 × 1.83 × 0.165 m) were designed according to the TM5-1300 [1]

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to withstand a blast of 22.7 kg TNT at a standoff distance of 1.83 m with less than 5 degrees of support rotation. Reinforcement was provided with 13 mm dia. bars in two layers spaced at 150 mm in each direction. 9 mm dia. stirrups at every other bar intersection were also provided. Two fibre concrete panels and two control panels were tested with simple supports on four sides.

The panels were all tested with a blast of 34.1 kg at 1.83 m. Only minor cracking was observed on all the panels. A new charge of 34.1 kg was detonated at 0.98 m above each panel and the results were documented. The control panel experienced large amounts of spalling on the both the top and bottom face and a maximum permanent deflection of 100 mm. The fibre concrete panels, however, exhibited only small amounts of material loss on their bottom face and only roughly 50 mm of permanent deflection. A top and side view of the control panel and a fibre concrete panel after testing is given in Figures 2 and 3 respectively.

Figure 2: Control panel after blast

Figure 3: Fibre concrete panel after blast

3. Modelling Approach

An effort was made to model long carbon fibre reinforced concrete under blast loads in the finite element code LS-DYNA [2]. The material model chosen was the continuous surface cap model, material 159 (*MAT_CSCM) [3]. Default 45 MPa concrete properties were used for the control specimens and the tensile softening parameters were modified for the fibre concrete model. A model of the panels above was created and run for generated blast loads. Little difference in displacement-time history was recorded, likely due to the high amounts of reinforcement which tended to overshadow the tensile stress of the fibre concrete. The fibre concrete model, created to match laboratory tensile test data, did not match bending test data when run in a 4-point bending model. A new model calibrated to bending test data is being developed and may exhibit more of an effect in panels under blast than the model used in this study.

4. Conclusions

Experimental testing of long carbon fibre concrete panels has shown that significantly less spalling occurs than in normal concrete during close-in blasts. This behaviour would result in improved safety to building occupants and bystanders since less material could become flying shrapnel. Testing also showed that after two blast events, the maximum permanent deflection of fibre concrete slabs was roughly one half that of a normal concrete slab.

References

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