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NRCC-51253

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May 2009

A version of this document is published in / Une version de ce document se trouve dans:
Conference and Workshops of the ISIS Canada Network Association, Toronto, ON., May 7-8, 2009, pp. 2

**Towards Safe and Durable Infrastructure**
Conference and Workshops of the ISIS Canada Network Association
*May 7 and 8, 2009 - Toronto, Ontario*

# Fire Resistance of FRP Strengthened Concrete Columns

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## ABSTRACT

Fire resistance of buildings is extremely important as evidenced by recent dramatic collapses of buildings in fire, such as occurred in the World Trade Center disaster, or in the Windsor Tower fire, in Madrid, in 2005. Although these examples highlight the extreme situation for fire in buildings, they serve to demonstrate the need to consider fire in structural design. Thus, when fibre reinforced polymer (FRP) materials are applied to strengthen concrete members in buildings, an understanding of the performance of the strengthened members in fire is paramount. In some situations, designers may be reluctant to apply FRP materials in buildings because of concerns relating to the loss of strength of FRPs at high temperature. To address these concerns, ISIS has sponsored research into the fire resistance of concrete structures strengthened with FRPs, and has shown that such structures can be designed to perform adequately in fire if appropriate measures are incorporated into design and construction.

The results of an extensive experimental and numerical study into the fire resistance of FRP strengthened concrete columns will be presented and discussed. The work is a collaboration between Queen's University, ISIS Canada, the National Research Council of Canada, and several industry partners. As part of this research effort, six full-scale column tests have been conducted on FRP strengthened columns with external insulation applied to enhance fire resistance. Fire endurance ratings greater than 4 hours have been achieved (Table 1 and Figure 1). Numerical models have also been developed to compare against the results observed in the fire tests. The basic approach has been finite difference models for predicting the thermal response combined sequentially with structural models incorporating temperature dependent material properties. These models have been verified against full-scale tests, and results from the models will be presented and discussed.

To improve and extend the numerical models, better knowledge of the material properties of different types of FRP at high temperatures is required. To address this knowledge gap, testing of FRP materials at high temperature is ongoing at Queen's University. These tests include tension tests and lap-splice bond tests under both steady-state high temperature conditions and transient (increasing temperature) conditions. Initial results from this testing program will be presented, and the implications of the observed material behaviour for understanding and predicting structural performance in fire will be discussed.

To summarize and conclude the presentation, ongoing and future work will be outlined. In addition, the implications of the research work for the design of concrete columns strengthened with FRP will be discussed. Research needs, including the development of FRP materials with better high temperature properties, will be critically discussed.

**Table 1: Summary of results from fire tests on columns**

| Member | Dimensions (mm) | FRP | Insulation | Test load ratio | Fire Endurance (min) | Failure Load (kN) | Predicted Room Temperature Strength (kN) |
|---|---|---|---|---|---|---|---|
| Circular column 1 | ϕ 400 × 3810 | 1 layer CFRP-A | VG 30 mm | 0.73 | > 300 | 4437 | 5094 |
| Circular column 2 | ϕ 400 × 3810 | 1 layer CFRP-A | VG 60 mm | 0.73 | > 300 | 4680 | 5094 |
| Circular column 3 | ϕ 400 × 3810 | 2 layers CFRP-B | None | 0.82 | 210 | 2635 | 4720 |
| Circular column 4 | ϕ 400 × 3810 | 2 layers CFRP-B | Cem | 0.82 | > 300 | 4583 | 4720 |
| Square column | 400 × 400 × 3810 | 1 layer GFRP | VG 40 mm | 0.81 | > 240 | 3093 | 6115 |

Notes: CFRP-A - $t_f$ = 1.0 mm per layer, $f_f$ = 745 MPa, $\varepsilon_f$ = 0.012, $E_f$ = 62 GPa, $T_g$ = 93°C

CFRP-B - $t_f$ = 0.165 mm per layer, $f_f$ = 3800 MPa, $\varepsilon_f$ = 0.0167, $E_f$ = 227 GPa, $T_g$ = 71°C

VG - gypsum-based insulation, Cem - cementitious insulation.

Test load ratio = test load divided by the design strength of the strengthened member calculated using ISIS design guidelines.

Predicted strength calculated using ISIS design guidelines with material resistance factors equal to 1.0.

$t_f$ = thickness of one layer of FRP, $f_f$ = strength of FRP, $\varepsilon_f$ = maximum strain at failure for FRP

$E_f$ = modulus of elasticity of FRP, $T_g$ = glass transition temperature of FRP

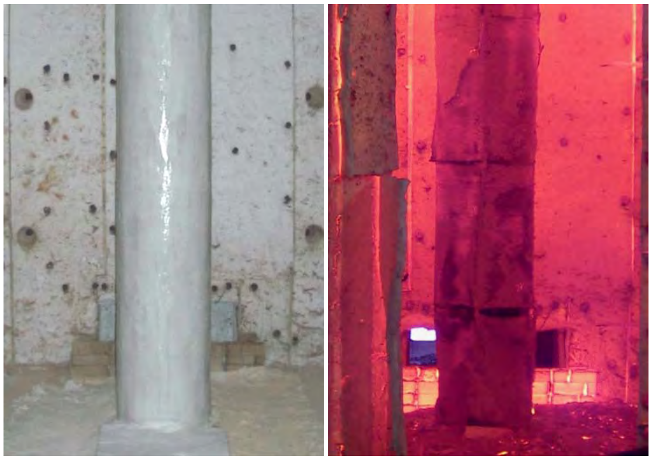

**Figure 1: Typical circular column before and after fire testing**