FIRE SAFETY / SÉCURITÉ INCENDIE

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Re/Objet Progress Report A1-002190.1

Message

FIRE RESISTANCE BEHAVIOUR OF FRP REINFORCED CONCRETE SLABS: RESULTS OF THE FIRST FIRE TEST (PROGRESS REPORT-I)

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INTRODUCTION

Applications of fibre-reinforced polymer (FRP) materials and products for the construction and rehabilitation of new, durable concrete structures are rapidly becoming a viable option for North American critical concrete infrastructure. For new construction, FRP bars can be used as either non-pre-stressed or pre-stressed concrete reinforcement. As an alternative to traditional steel reinforcement bars, the interest in the use of FRP reinforcement in concrete structures has increased significantly in recent years. For a wide use of FRP as internal reinforcement in structural members of buildings, the ability of these materials to meet fire resistance requirements must be established as prescribed in building codes.

One of the major concerns with applications of FRP bars for reinforcing concrete buildings is fire resistance. Currently, CSA S806 (CSA 2012) allows a simplified method to design concrete slabs with FRP reinforcement bars. This design approach is based on establishing a critical temperature for FRP bars based on their strength at high temperature. For currently available FRP bars, this approach results in a requirement for concrete cover of approximately 60 mm to achieve a 2 hour fire resistance rating (a typical concrete cover is 25 mm).

To verify the appropriateness of the 60 mm cover requirement, the National Research Council of Canada (NRC) in partnership with industry clients (Pultrall Inc. and BP Composites Ltd.) and collaborators from Queen's University designed a research project to study the fire resistance behaviour of FRP-reinforced concrete slabs. The proposed study will produce experimental data from two tests, calibrated numerical models for predicting the fire resistance of FRP-reinforced concrete slabs, and design guidance suitable for use in building codes and standards. The results of the first fire test are presented in this report.

TEST SPECIMENS

The experimental program consisted of two fire tests on glass fibre-reinforced polymer (GFRP) reinforced concrete slabs. The first fire test comprised of two slabs tested at the same time: one reinforced with TUF-Bar high modulus bars produced by BP Composites Ltd. (designated as Slab-A) and the other with V-Rod high modulus straight bars manufactured by Pultrall Inc. (designated as Slab-B). The two slabs were not structurally connected. Rather, steel beam spacers protected with fiber frax to seal any opening were put between the two slabs. The second fire test will be decided based on the results of the first fire test. Details of the reinforced concrete slabs for the first fire test are shown in Figure 1.

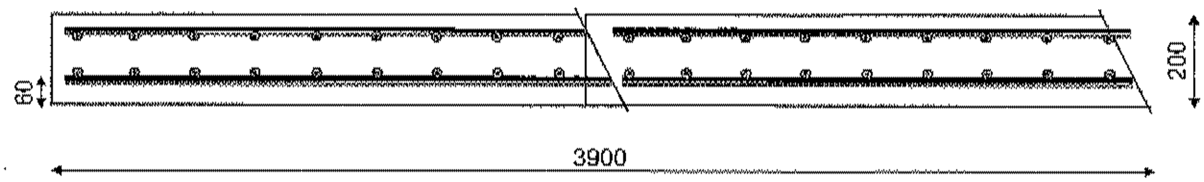


Figure 1. Longitudinal section of the slabs.

The slabs were cuboids, 3900 mm long, 1200 mm wide and 200 mm thick. They had a span of 3800 mm. The FRP reinforcement was distributed in two orthogonal directions in both the top and bottom of the slabs.

The slabs had a clear concrete cover of 60 mm, in accordance with CSA S806 (CSA 2012), to represent the common parking garage construction.

INSTRUMENTATION OF THE SLABS

The slabs were instrumented thoroughly with thermocouples. Some sets of thermocouples were particularly placed near the centre of the slabs where the strength of the bars is most important and the other sets were placed near the supports of the slabs where bond issues were expected to be critical. Thermocouples were also installed at different depths of the concrete slabs. Strain gauges were installed at the reinforcing bars and on the unexposed side of the slabs. In addition, deflection measurements were taken on the unexposed side of the specimens during the fire test.

SUPPORT CONDITIONS

The slabs were tested in simply supported conditions without axial restraint. Although axially restrained slabs are representative of some structural elements, the simply supported flexural test provides results that are more conservative.

REQUIRED SUPERIMPOSED LOAD

During the fire test, the slabs were loaded to their expected service loads as specified by CAN/ULC S101 (2014). The recommended test load level corresponded to a total applied moment of 45 kN-m. This moment was achieved by superimposing a 19.1 kN/m load during the fire test.

As per CAN/ULC S101, the superimposed load was applied gradually in four increments, each of 25% of the full superimposed load, to allow stable deflection. The full superimposed load was applied for at least 30 min before the start of the fire test and was maintained throughout the test.

The superimposed load was applied by means of a loading system comprised of several jacks uniformly located on each slab. After the desired fire endurance rating was obtained, the superimposed load was increased until the slabs reached failure.

FIRE TEST PROCEDURE

The fire test for the slabs was conducted in accordance with the CAN/ULC S101. The furnace temperature followed the standard time-temperature curve given by ULC S101. According to CAN/ULC S101, the following criteria shall be met in order to obtain the fire endurance rating:

- The test specimen shall be subjected to sustained load throughout the fire endurance period without passage of flames or gases hot enough to ignite cotton pads.
- The average temperature of the unexposed surface of slabs throughout the fire test shall not rise by more than 140°C above its initial average temperature before the test; Moreover, temperature rise at any individual point has to remain below 180°C including a temperature measured by a roving thermocouple.
- The slabs must be able to support the applied loads without structural failure.

TEST RESULTS

Results

As mentioned previously, both slabs were instrumented with thermocouples to measure the temperature of concrete and GFRP reinforcement and displacement gauges to measure deflection throughout the tests. A summary of results are given in Table 1.

Table 1. Summary of test results.

	Relative Humidity (%)	Ambient Temp. (°C)	Ultimate Load Capacity (kN/m)	Applied Load (kN/m)	Failure Load (kN/m)	Fire Endurance (min.)	Failure Mode
Slab-A*	69	21	28.1	19.1	Unknown	> 180	Unknown
Slab-B*	70	21	28.1	19.1	22.9	>180	Structural

* Slab-B reached failure when the load was increased. However, the test was stopped without failing Slab-A to avoid damage to the furnace.

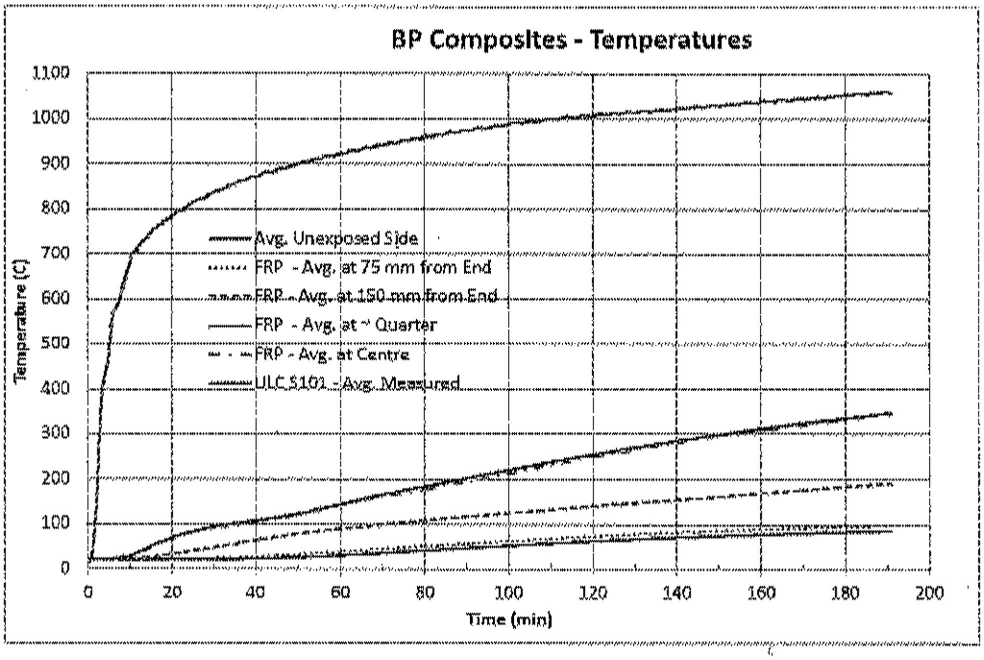
Temperatures

Results of the thermocouple temperature readings for the two slabs are given in Figure 2. These figures show the measured average temperature of the furnace (ULC S101 standard fire), the average temperature on the unexposed side of the slabs and the average temperatures at the FRP reinforcement (at the central core and the ends) during the fire tests.

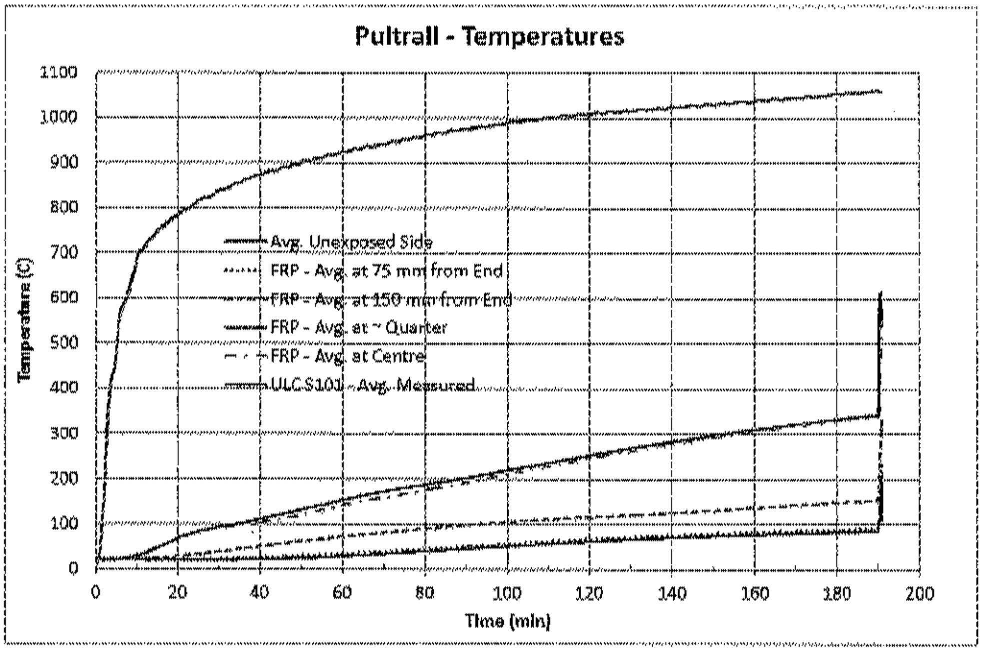
The average unexposed surface temperature after 3 hours of fire exposure reached 82°C and 81°C in Slab-A and Slab-B, respectively. A sudden increase in temperature for Slab-B at the end of the test as shown in Figure 2 (b) is an indication of flames reaching the unexposed side after failure. The temperatures on the unexposed side for Slab-A and Slab-B were below the temperature of 100°C for the duration of the test.

The temperatures at the FRP reinforcement were observed to depend on the location measured. For the centre and quarter locations, the average temperatures recorded were approximately 250°C for both Slab-A and Slab-B after 2 hours. After 3 hours, the average temperatures were more than 350°C at the centre and quarter locations for both slabs.

For the end zones, the average temperatures were 73°C at 75 mm and 140°C at 150 mm for Slab-A, and 67°C at 75 mm and 115°C at 150 mm for Slab-B. After 3 hours, the average temperatures were 94°C at 75 mm and 183°C at 150 mm for Slab-A and 88°C at 75 mm and 148°C at 150 mm for Slab-B. These readings are an indication that while bond failure at the centre has occurred before the hour mark, the less exposed ends were able to hold the temperatures of the FRP reinforcement below the bond failure temperature for more than 3 hours.



(a) Slab-A



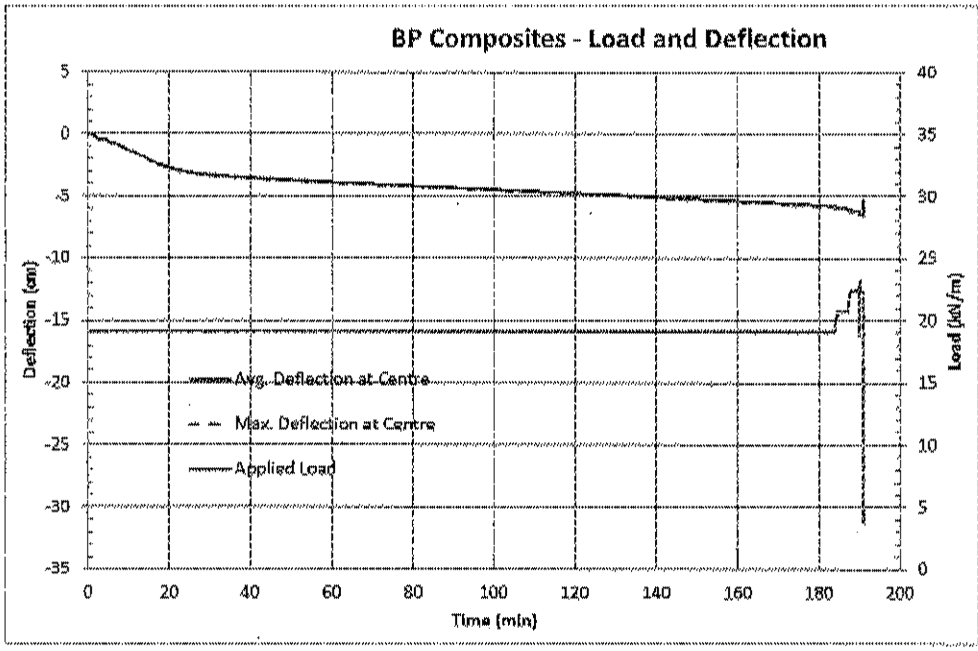
(b) Slab-B

Figure 2. Measured temperatures during the fire test.

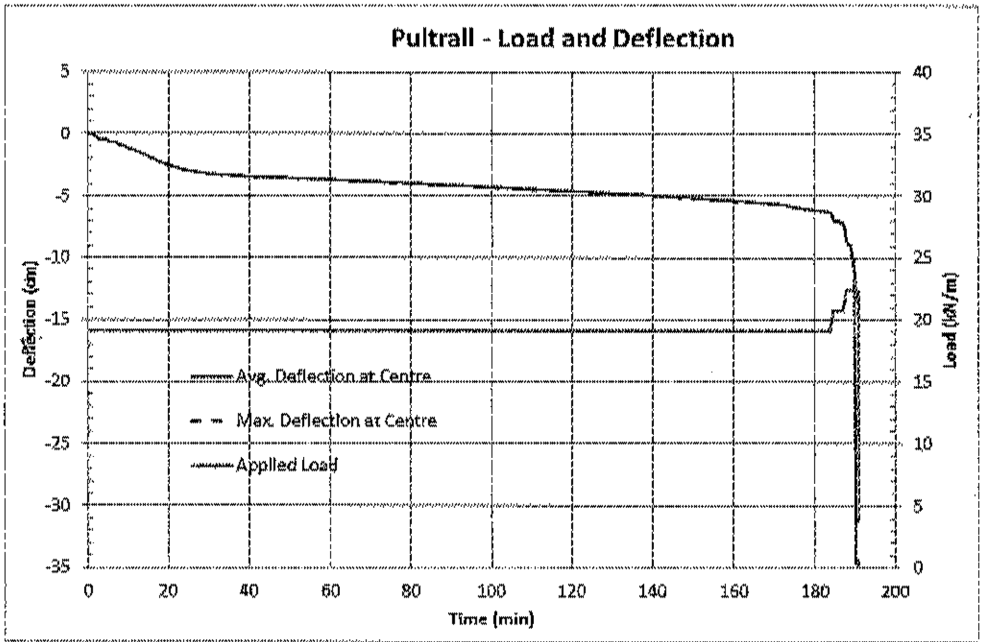
Load and Deflection

The deformations and load applied as a function of time for both slabs during the fire test are given in Figure 3. As can be seen, both slabs sustained the full superimposed load (19.1 kN/m) for over 3 hours. After the 3 hours, the load was steadily increased (1.66 kN/m/min) until failure. The test was terminated when Slab-B failed at a load of 22.9 kN/m.

The maximum preload deflection was 1.81 cm for Slab-A and 1.63 cm for Slab-B. These were set to zero at the start of the fire test and therefore, the deflection readings in Figure 3 do not include the preload deflection. As shown in Figure 3, the deflections for both slabs showed an initial increase in the first 25 min to about 3 cm. The rate of deflection reduced after that point and the maximum deflection recorded at 3 hours was about 6 cm for both slabs. A few minutes after the 3 hours, the load was increased gradually to induce failure of the slabs. After 185 min Slab-B started showing a fast rate of deflection. Slab-B then failed structurally at about 190 min. The deflection of Slab-A remained at about 6.5 cm during the increase of load. Figure 4 shows photos of the slabs before and after the fire test with a clear indication of the large crack of Slab-B at failure.

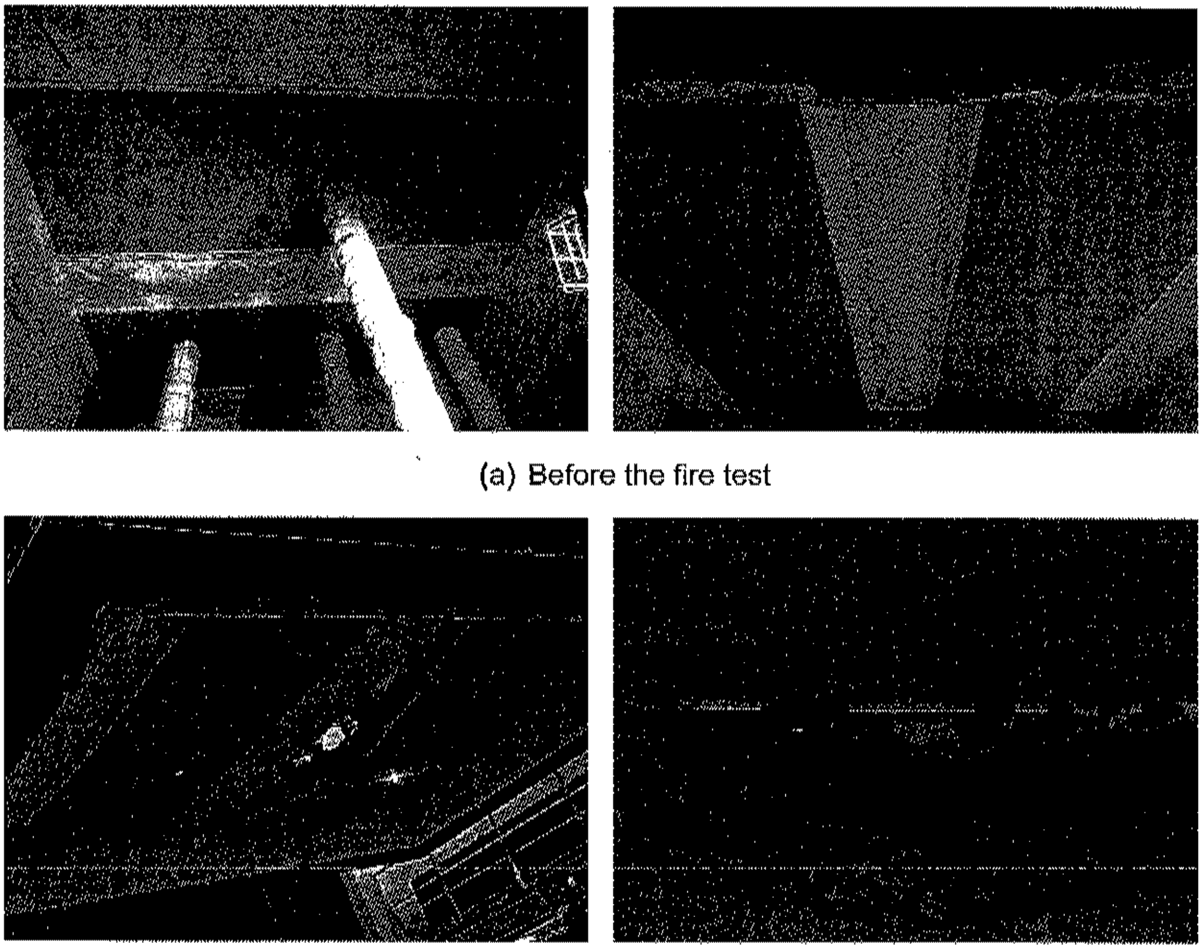


(a) Slab-A



(b) Slab-B

Figure 3. Measured deflection and applied load during the fire test.



(a) Before the fire test

(b) After the fire test

Figure 4. Photographs taken before and after the fire test.

Conclusion
Structural members used in the buildings should assure two major roles: (1) load bearing and (2) fire separating. Both slabs successfully resisted the sustained applied load of 19.1 kN/m for more than three hours of fire exposure without structural failure. In addition, the criteria for passage of flames or hot gases and temperatures on the unexposed side were satisfied during the 3 hour exposure and beyond. A few minutes after the three hours mark, the applied load was increased gradually to fail the slabs. At about 190 min, Slab-B failed structurally (the FRP bars ruptured at mid-span with a large crack in the concrete) and the test was terminated to prevent damage to the floor furnace and the loading system.

The slabs resisted the applied mechanical and thermal loading during the tests for more than 3 hours and therefore Slab-A and Slab-B archived a 3 hour fire resistance rating.

SUMMARY

To determine the fire performance of FRP reinforced concrete slabs, an experimental full-scale fire resistance testing was designed. The results of the first fire resistance experiment were described in this interim report. The fire resistance test was conducted on two FRP-reinforced concrete slabs. Both slabs were loaded to their expected service loads and exposed to the standard fire curve. The two slabs achieved a fire resistance rating of 3 hours while satisfying the criteria stated in the ULC-S101 standard. After the 3 hours, the load was increased to reach failure, at which time the test was terminated.

REFERENCES

1. CSA S806 CSA 2012. S806-12, Design and Construction of Building Structures with Fibre-Reinforced Polymers, Canadian Standards Association, Mississauga, Ontario.
2. CAN/ULC-S101, Standard Methods of Fire Endurance Tests of Building Construction and Materials, Underwriters Laboratories of Canada, Ottawa, Ontario, 2014.

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