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Performance in fire of FRP-strengthened and insulated reinforced concrete columns

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ABSTRACT

This research investigates the fire performance of one circular and one square reinforced concrete column strengthened with a fibre reinforced polymer (FRP) wrap and covered with a unique supplemental fire protection system. An experimental full-scale fire resistance test was conducted at the National Research Council of Canada. The insulated and strengthened FRP wrapped columns were exposed to the ULC-S101 standard fire and both columns obtained fire endurance ratings of over 4 h. Details of the fire endurance experiment on both columns are described in this paper. Additionally, numerical models developed specifically for circular and square columns are validated against the experimental results.

1. Introduction

A fiber reinforced polymer (FRP) is a composite material made up of longitudinal reinforcing fibers embedded in a polymer matrix material (resin). Composites combine the best properties of their constituent materials. The application of FRP composites in building and construction industries is a relatively new technology but their use is expanding quickly [1,2]. Current FRP products consist of reinforcing bars (rebar) and sheets or laminate wraps. Laminate wraps are used for strengthening, rehabilitation (renovation or repair) and retrofitting of concrete columns and beams.

FRPs are known to have excellent strength, stiffness, corrosion resistance in harsh chemical and alkaline environments and good impact properties; however their elevated temperature mechanical and combustible properties are significantly reduced at elevated temperatures due to the properties of the matrix resin. As such, concerns regarding fire resistance have slowed FRP applications in buildings. To address this concern, a new fire insulation material is applied on the surface of FRP wraps to obtain appropriate fire resistance. Innovative materials for potential use inside a building, including FRPs and insulation materials must pass certain fire exposure limits as prescribed in North America by CAN/ULC S101 [3] or ASTM E119 [4]. The objective is for the structure, protected with the new insulation material, to withstand a fire endurance test by being exposed to a standard fire for a certain amount of time, under strict conditions.

2. Background

To gain valuable fire endurance information, there has been an on-going collaborative research program in the development of various insulating materials for protecting FRP wrapped reinforced concrete columns in fire conditions. The initial tests consisted of two circular columns (Columns 1 and 2) [5], followed by three circular columns (Columns 3–5) [6]. The current study reports the work done on one circular column (Column 5) [6] and one recently tested square column (Column 6). The column fabrication, FRP strengthening, the insulation fire protection material, full-scale fire test results and thermal models are discussed.

Carbon fibres are temperature resistant and can maintain their tensile strength and stiffness up to 2000 °C [7]. However, typical polymer matrices used in FRP for strengthening, rehabilitation and retrofitting concrete columns, beams and slabs lose their mechanical/bond strength properties at much lower temperatures, being

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governed by its glass transition temperature (T_g). In general, the T_g of commercially available polymers ranges from 60 °C to 82 °C [8]. The bond properties of the FRP to the concrete column surfaces are maintained if the temperature remains below the polymer T_g.

The objective for this paper is to further the understanding of FRP strengthened concrete columns in fire. This is accomplished by conducting two full-scale fire tests and comparing the results of these fire tests to the predictions of numerical models simulating the thermal performance of the columns.

3. Experimental procedure

3.1. Column test specimens

The experimental program consisted of two fire tests: one circular and one square reinforced concrete column strengthened with carbon FRP and insulated with a spray-applied, cement-based, fire protection mortar. The columns were designated as Columns 5 and 6. Column 5 was 400 mm in diameter (D), while the square cross-section of Column 6 was 305 mm by 305 mm. Both columns had a height of 3810 mm. The dimensions and reinforcement details of Columns 5 and 6 are given in Figs. 1 and 2, respectively.

Column 5 contains eight 20 M (19.5 mm nominal diameter) longitudinal deformed steel reinforcement bars, with 40 mm clear concrete cover to the spiral reinforcement. The lateral reinforcement consisted of a 10 M (11.3 mm nominal diameter) deformed steel spiral with a centre-to-centre pitch of 50 mm. The longitudinal bars and lateral spiral reinforcement had average measured yield strengths of 456 MPa and 396 MPa, respectively. Column 6 includes four longitudinal 25 M (25.2 mm nominal diameter) deformed steel reinforcement bars fitted through drilled holes in the 38 mm thick steel end plates and fillet welded. The lateral reinforcement consisted of 10 M deformed steel bars spaced with a centre-to-centre pitch of 305 mm and a 136 mm overlap lap splice. The main reinforcing bars and ties all had average measured yield strengths of 477 MPa. The steel reinforcement had a clear cover of 40 mm from the exterior surface of the concrete to the steel ties and 50 mm clear concrete cover to the principal reinforcement. Both columns were designed for 28 MPa concrete strength using Type 10 Portland cement with crushed carbonate (limestone) aggregate having a maximum aggregate size of 14 mm and natural sand as the fine aggregate.

The columns were fabricated and cured at Queen's University and shipped to the National Research Council of Canada (NRC) for full-scale fire testing. Column 5 was part of an ongoing study following the work of Bisby [9] and was cast approximately 1 year prior to Column 6. Concrete pouring of these two columns was done separately. The concrete was supplied by Lafarge Ready-Mix. Column 5 was poured vertically into a 400 mm inside-diameter Sonotube, while Column 6 was cast vertically in plywood formwork. Once cast, the formwork of Column 5 was removed after 7 days and Column 6 after 24 h. Both columns and test cylinder specimens were cured in a humidified plastic sheet enclosure at 21–24 °C and 100% relative humidity for 28 days. The columns were allowed to cure in the laboratory, at ambient temperature and relative humidity, for at least 1 year until the columns were transported to the NRC for strengthening, insulation coating and fire endurance testing. Prior to testing, the 15 mm chamfered corners of Column 6 were rounded to a minimum radius of 25 mm using a concrete grinder as is currently recommended by most suppliers of FRP strengthening systems for reinforced concrete structures. The average of three cylinder compressive strength measurements after 28 days and 440 days for Column 5 concrete was 38.5 MPa and 40.1 MPa, respectively. Average compressive

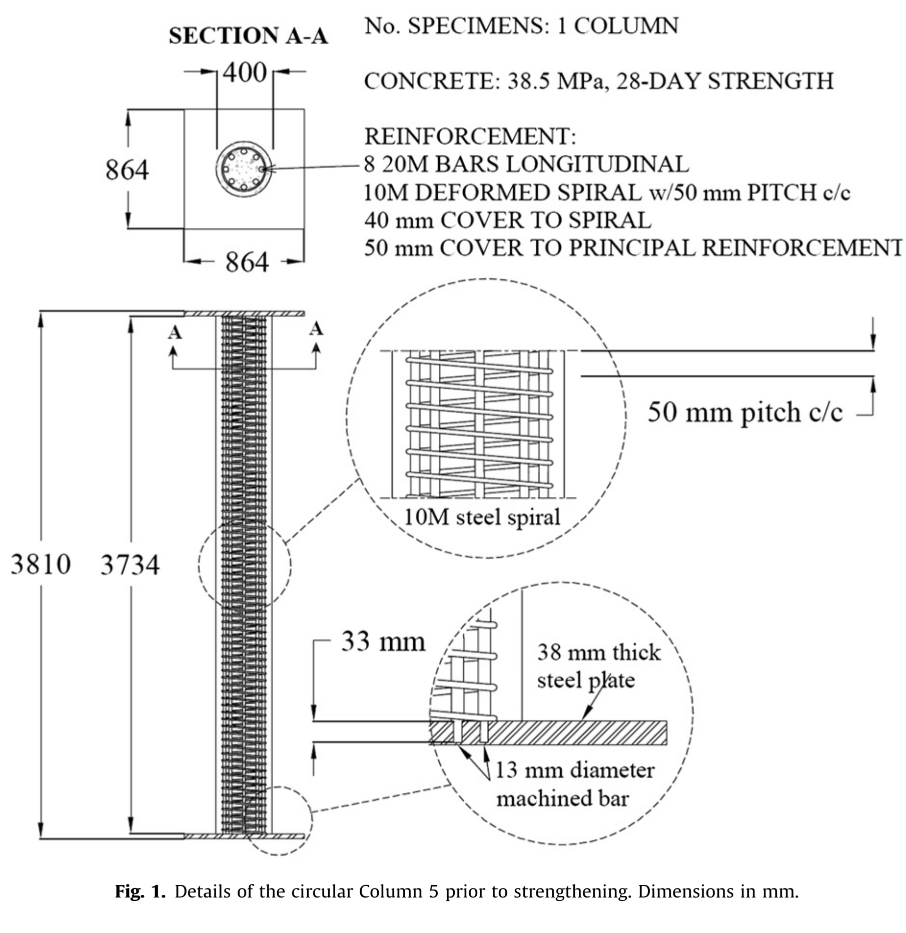

Fig. 1. Details of the circular Column 5 prior to strengthening. Dimensions in mm.