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Fire Endurance of Exposed Cross-Laminated Timber Floor for Tall Buildings

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Fire Endurance of Exposed Cross-Laminated Timber Floor for Tall Buildings

1 Introduction

Cross-laminated timber (CLT) can be used as a structural material in tall buildings. To support the use of CLT in tall wood buildings, fire endurance data is required for its structural assemblies. This report presents the results of a standard fire endurance test performed on a full-scale floor assembly in accordance with ASTM E119-15 and CAN/ULC-S101-14. The floor assembly was constructed at NRC and subjected to a standard fire endurance test inside NRC's full-scale floor furnaces (no hose stream test was performed).

2 Test Specimen

2.1 Full-scale floor assembly

The floor assembly, which measured 4815 mm (15'-10") in length by 3607 mm (11'-10") in width, was constructed from three panels of 175 mm thick 5-ply CLT of grade E1 manufactured by Nordic. The panels were aligned such that the grain of the outer layers of timber (on both the exposed and unexposed sides) ran along the length of the floor assembly. The CLT panels were joined on the unexposed side with strips of 12.7 mm thick plywood nailed on each panel every 300 mm (starting at 150 mm from the edge of the assembly) with common 75 mm metal nails. Figure 1 and Figure 2 show drawings of the full-scale floor assembly and details of its spline joints and nailing schedule.

The exposed side of the assembly was a bare CLT surface. Figure 3 shows the exposed side of the assembly installed inside the standard floor furnace.

On the unexposed side, the CLT panels were covered with two staggered layers of 12.7 mm thick cement boards. The cement boards were manufactured from Portland cement, fly ash, expanded clay aggregate or expanded shale and a blend of proprietary mineral-based ingredients and fiber glass scrim. Expansion joints of a minimum of 3 mm (⅛") were created between the board sections. The cement boards were fastened to the CLT panels with 51 mm (2") long flat head zinc steel countersunk size 8 wood screws. Screws were spaced 610 mm apart starting 19 mm (¾") from the edge of the cement boards. Figure 4 and Figure 5 show the installation of the base layer and face layer of cement boards in a staggered pattern.

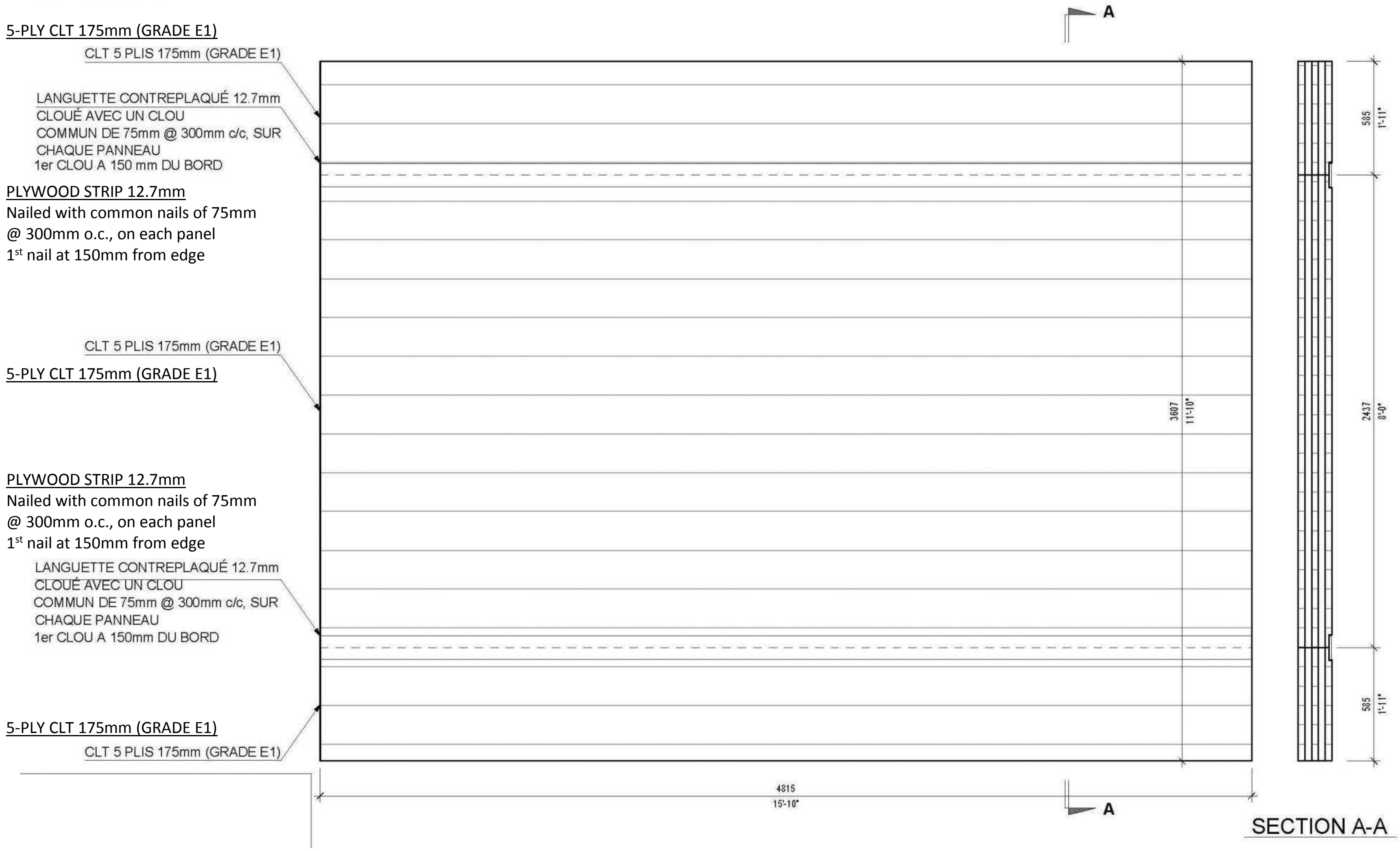
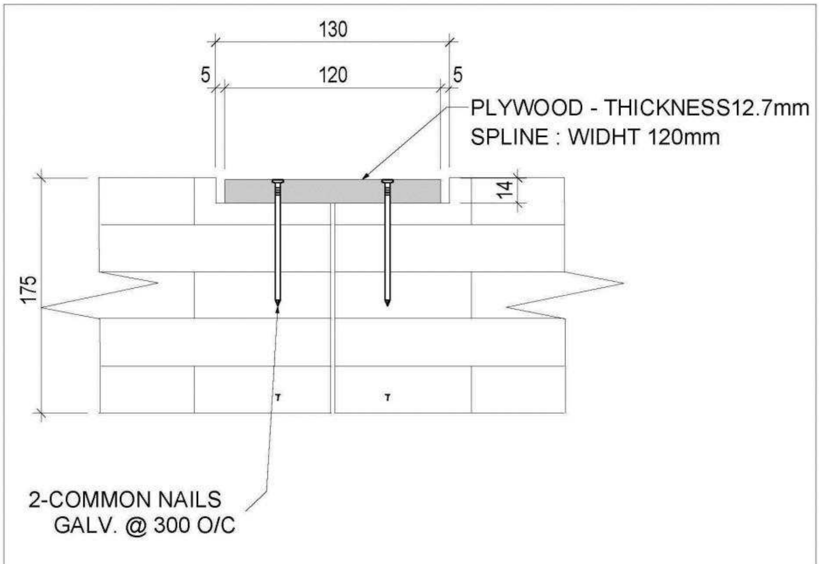


Figure 1. Full-scale floor assembly drawing.

SPLINE JOINT - XLAM



FASTENERS FOR XLAM SPLINE JOINTS				
X-LAM Panel			COMMON NAILS - GALV.	
Product X-LAM	Number of plies	Thickness (mm) "d"	Dia. (mm)	Length (mm) "L"
175-5s	5	175mm	Ø3mm	75mm

Figure 2. Spline joint and nailing for the floor assembly.

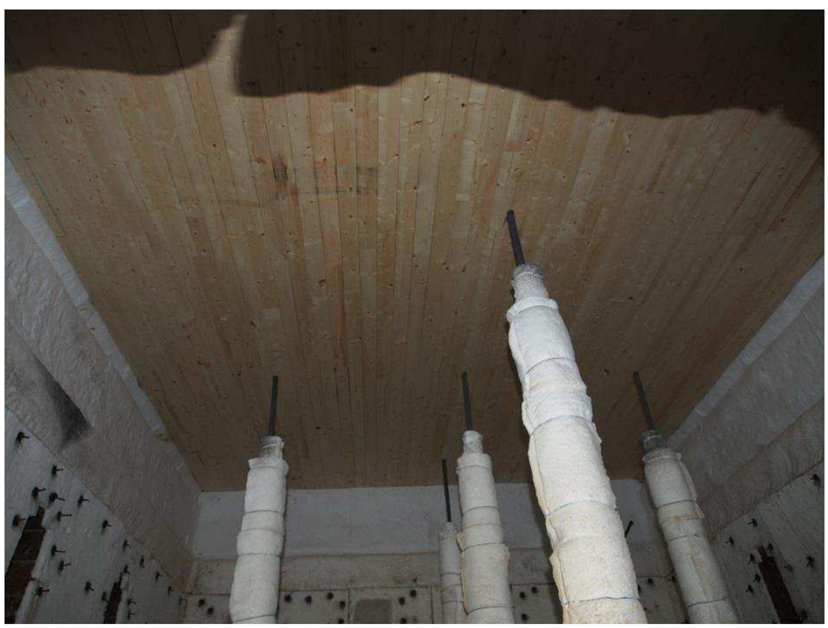


Figure 3. Exposed side of the floor assembly placed onto the standard testing furnace.

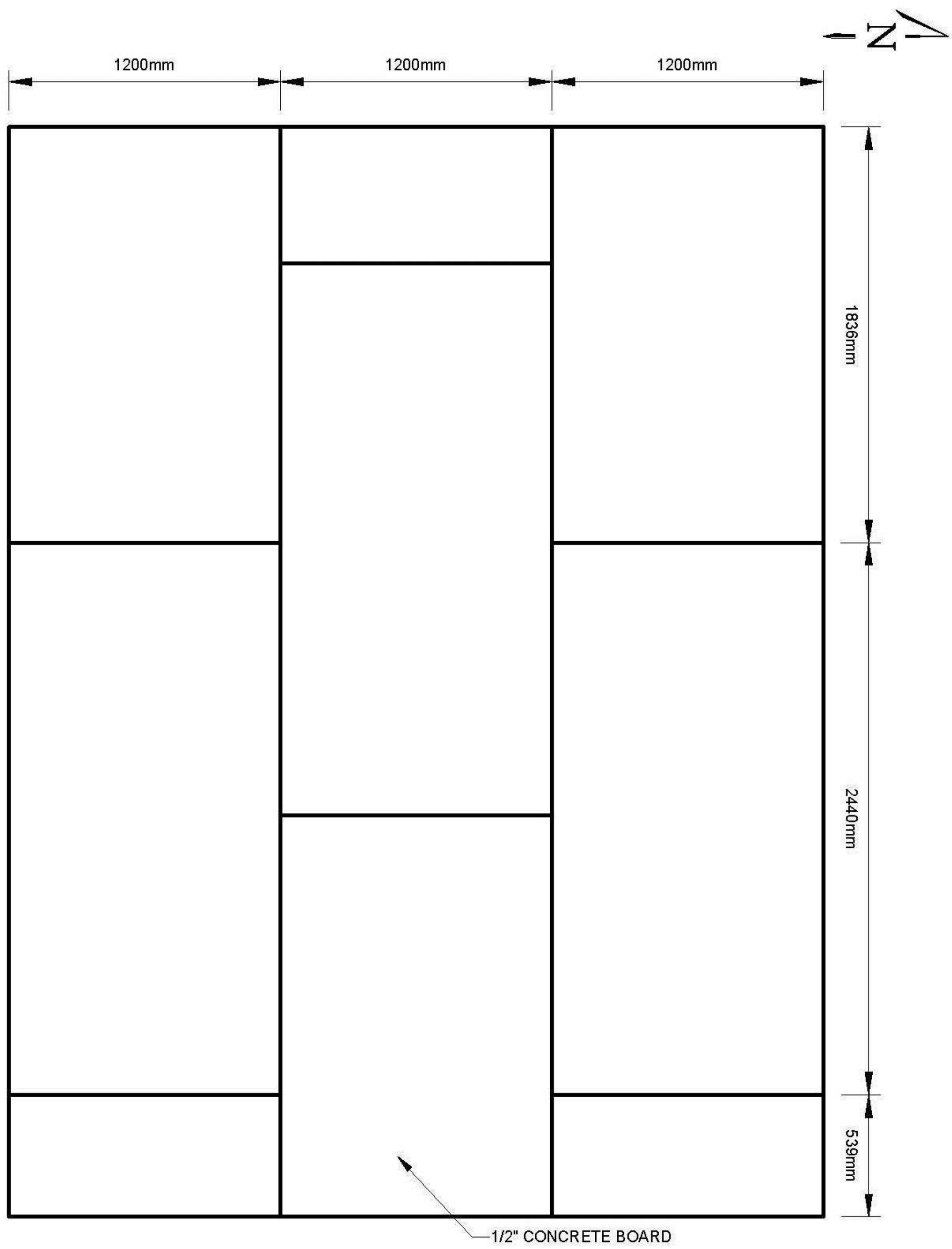


Figure 4. Base layer of cement boards on unexposed side.

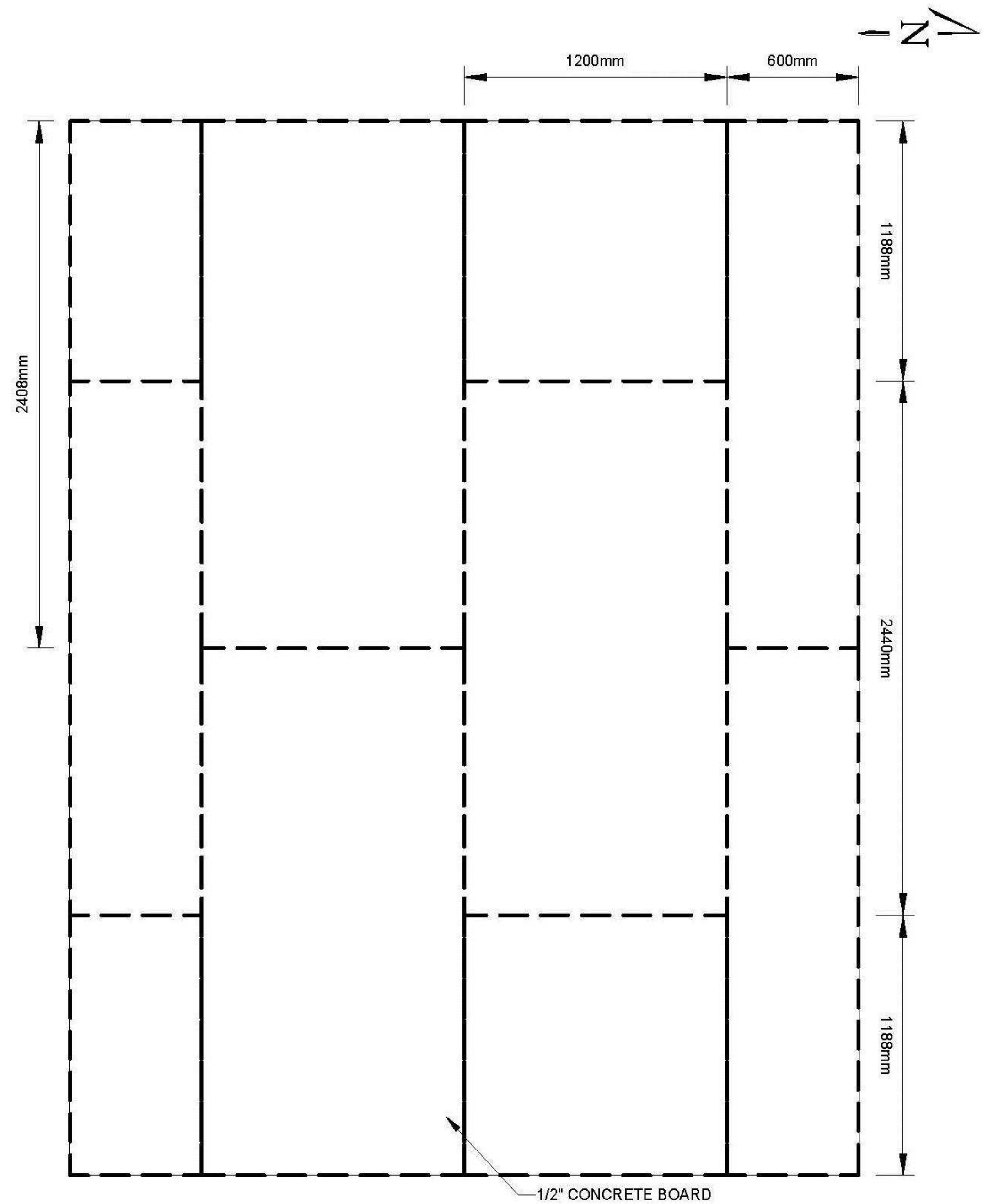


Figure 5. Face layer of cement boards on unexposed side.

2.2 Mode of restraint

The floor assembly was unrestrained. The assembly was only supported lengthwise on the furnace frame at both extremities. Three planks of 38 mm x 89 mm (2"x4") dimensional lumber were used on each end of the assembly to act as supports and lift the structural CLT panels so that the widthwise edges of the floor assembly remained unsupported. Figure 6 shows the assembly support from the exposed side.

Figure 6. View of the floor assembly support from the exposed side (underside).

3 Test Procedure

The test assembly was subjected to a fire endurance test following the requirements of ASTM E119-15 and CAN/ULC-S101-14. This section describes the instrumentation as well as the loading applied to the assembly.

3.1 Instrumentation

A total of nine type K thermocouples were installed on the unexposed face of the floor assembly to monitor temperature rise throughout the test. The unexposed side thermocouples were held against the unexposed face of the assembly with felted refractory pads. Small weights were used to maintain contact between the thermocouples and the unexposed surface of the assembly. Figure 7 shows the location of the thermocouples on the unexposed side of the assembly.

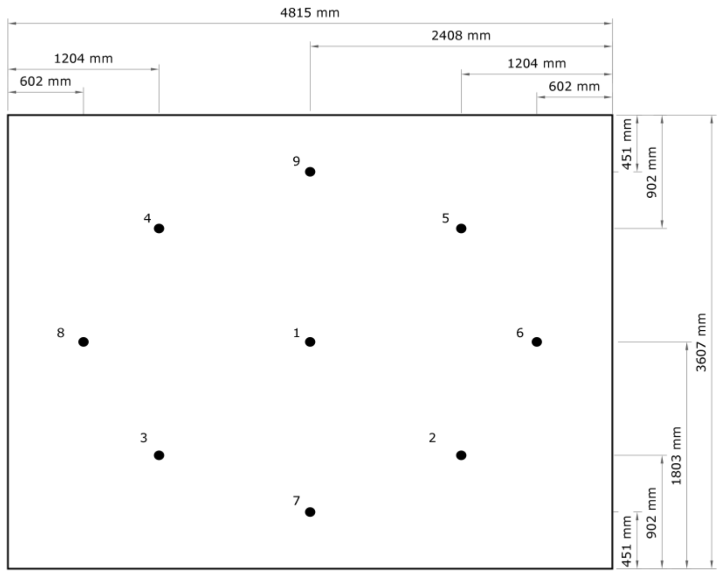


Figure 7. Location of thermocouples on the unexposed side of the floor assembly (topside).

The deflection of the floor assembly was measured throughout the test duration. A total of nine linear position transducers were installed on the unexposed side of the floor assembly to monitor displacement. The displacement gauges used in the test have a precision of 0.1 mm within an accuracy of 0.4 mm. Figure 8 shows the location of the displacement gauges on the unexposed side of the assembly.

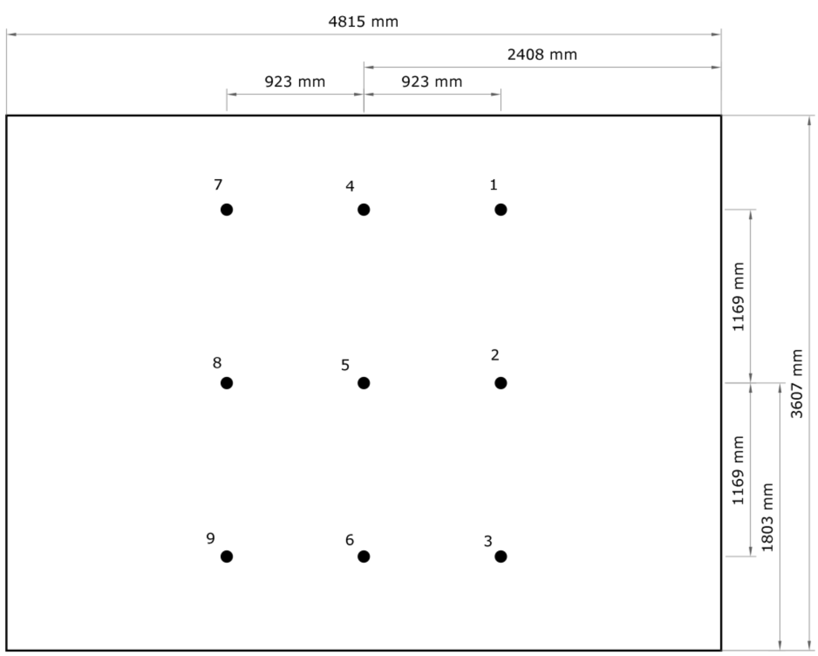


Figure 8. Location of displacement gauges on the unexposed side of the floor assembly.

Two differential pressure sensors were installed at the centre of the full-scale floor furnace to monitor the differential gas pressure throughout the test. The differential pressure sensor utilizes a variable capacitance pressure transducer combined with a glass-clad silicon chip, having an accuracy of 0.25% and a thermal coefficient of ±0.01%/°F. One pressure sensor was located at 0.75 m and the other was located at 2.55 m below the exposed specimen surface.

3.2 Loading

A superimposed load of 4.40 kN/m² (91.8 psf) was specified by the client for this test. Loading was applied to the floor assembly through a system of 30 hydraulic cylinders each distributing its load over a set of three loading pads. Figure 9 shows the system of hydraulic cylinders used to apply the superimposed floor load.

Figure 9. Floor hydraulic loading system.

In accordance with ASTM E119-15 and CAN/ULC-S101-14, preloading was applied in four increments of 25% of the total load, and deflections were allowed to stabilise between each preload increment. Figure 10 shows the load applied to the floor assembly and the deflections measured throughout the floor over the preload period. The maximum deflection under the full load was 0.7 cm at the centre of the floor assembly during preloading.

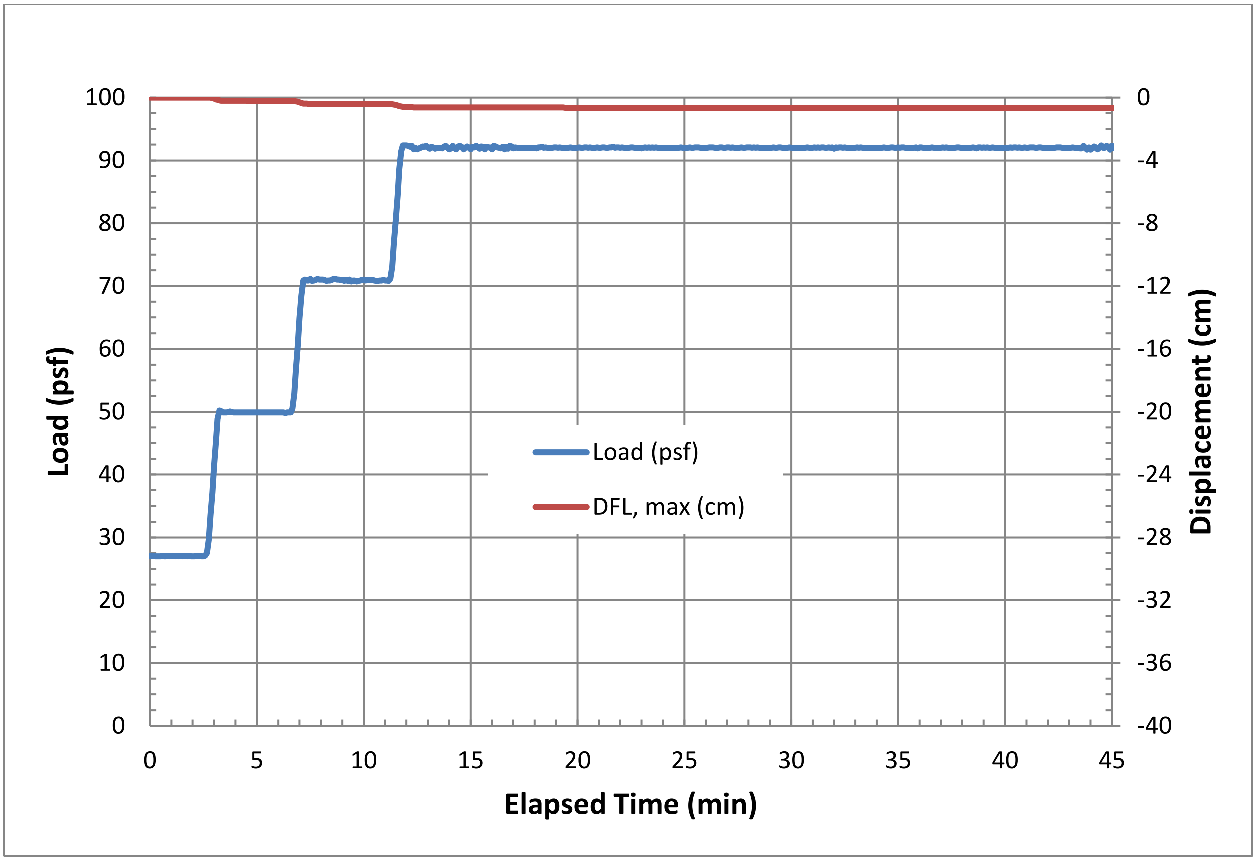


Figure 10. Load and deflection readings during floor assembly preloading period.

4 Test Results

A full-scale standard fire endurance test was performed on the floor assembly on 8 March 2016. The test was terminated after 128.5 min of elapsed test time.

4.1 Observations

Video cameras were used to record the behaviour of the exposed side and unexposed side of the floor assembly. Figure 11 shows the results of the test.

The entire exposed CLT face was engulfed in flames within 32 seconds after the start of the test. During the first 18 min, the furnace temperature oscillated near the standard temperature curve as shown in Figure 11. When the furnace temperature went beyond the standard curve due to the CLT burning, the furnace shut down to compensate and the CLT then ceased flaming during this period. When the furnace temperature returned to the standard curve, the furnace restarted and the CLT surface engulfed in flames again. This furnace on-and-off cycle continued for the first 18 minutes. Afterwards, the exposed CLT surface was fully involved in the fire till the end of the test.

Fall-off of large pieces of wood char from the exposed side was visible after 60 min and after 100 min, respectively. After 125 min, the floor deflected rapidly; heavy smoke was visible around the perimeter of the floor assembly. The structural failure of the floor assembly occurred at 128.5 min.

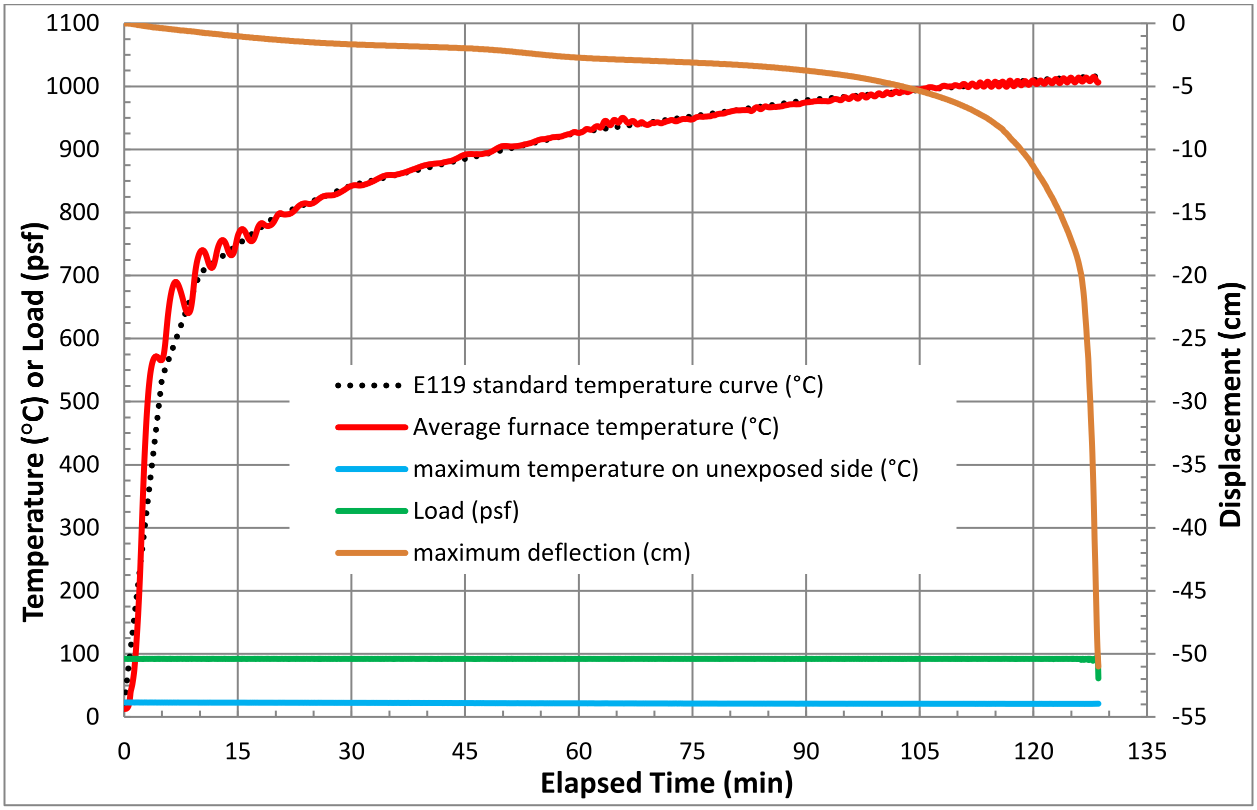


Figure 11. Temperature, load and deflection measurements during the floor test.

4.2 Temperatures

Over the duration of the test, the temperature of the furnace was measured using nine thermocouples evenly distributed inside the furnace, as required by ASTM E119-15 and CAN/ULC-S101-14. Figure 11 compares the average furnace temperature as a function of time to the standard time-temperature curve for control of fire tests defined by ASTM E119-15 and CAN/ULC-S101-14. Accurate furnace control was achieved over the entire duration of the test. The area under the average furnace temperature curve falls within 0.4% of the area of the standard time-temperature curve, meeting the 5% requirement established by the standard.

Figure 11 also shows the maximum temperature measured on the unexposed side of the floor assembly. The temperature of the unexposed side of the floor assembly remained below 23°C throughout the test duration with no temperature rise.

4.3 Deflection

Figure 11 shows the load applied to the floor assembly and the maximum deflection of the floor over the duration of the experiment. The deflection measurements have a precision accuracy of better than 1 mm. The floor began deflecting rapidly after 125 min. The floor assembly sustained the applied load of 4.40 kN/m^{-2} (91.8 psf) until 128.5 min of testing had elapsed. Figure 12 shows the deflection of the floor at 125 min and at the end (128.5 min) of the test.

Figure 12. Deflection of the floor assembly at 125 min and 128.5 min viewed from the unexposed side.

4.4 Failure

According to ASTM E119-15 and CAN/ULC-S101-14, the fire endurance period of an unrestrained floor assembly is defined by the period over which: the floor sustained the applied load without passage of flames or gases hot enough to ignite cotton pads; the average temperature measured on the unexposed side of the floor assembly did not exceed 140°C above the initial average temperature of the unexposed side; and no individual temperature measured on the unexposed side of the floor assembly exceeded 180°C above the initial temperature.

The floor assembly failed structurally as a result of excessive deflection and inability to carry the superimposed load after 128.5 min. At this time, the temperatures on the unexposed side of the floor assembly remained well below the failure criteria defined in ASTM E119-15 and CAN/ULC-S101-14. Figure 13 shows the condition of the floor assembly after testing. The deflection of the floor is evident in Figure 12 and Figure 13. The average depth of charring is 2.5 plies and the maximum depth is 3 plies out of the 5-ply CLT panels.

Figure 13. Exposed side of the floor assembly after testing showing the extent of charring and deflection.

4.5 Differential pressure

Figure 14 shows the differential pressure inside the standard fire test furnace as a function of elapsed test time. The measurements have a precision accuracy of better than 0.1 Pa.

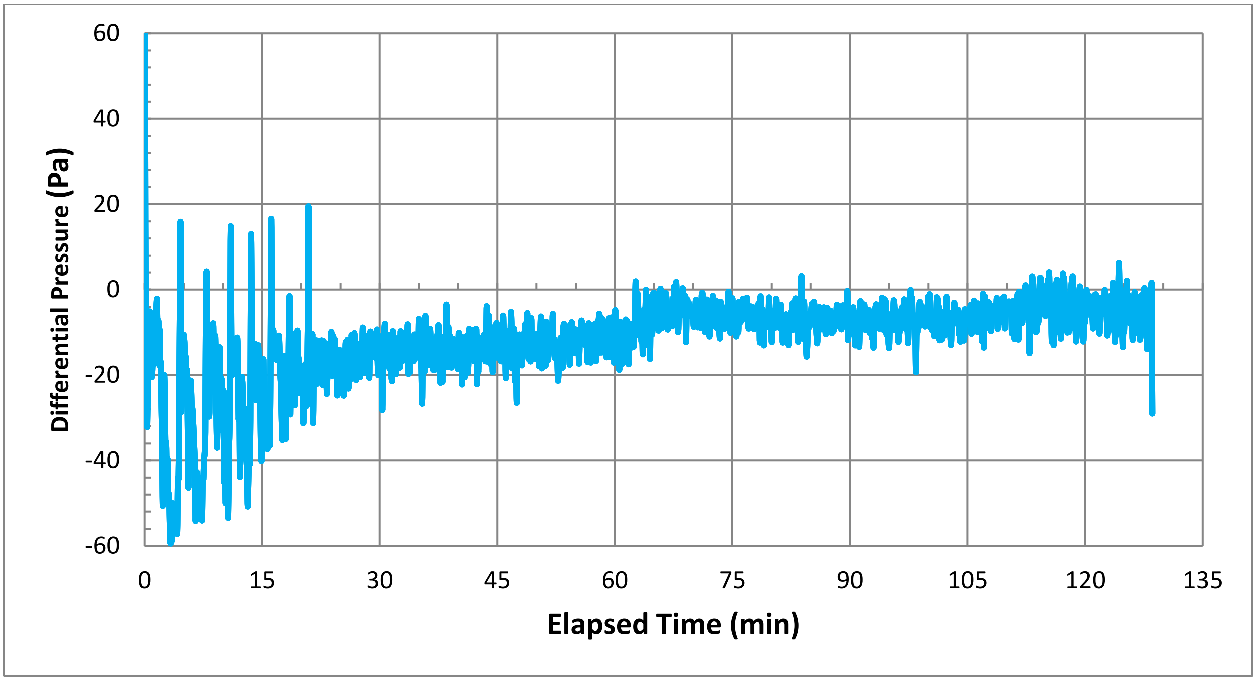


Figure 14. Average differential pressure inside the furnace as a function of time.

5 Fire Endurance Period

The fire endurance period of the exposed 175-mm thick 5-ply CLT floor assembly, tested under the superimposed load of 4.40 kN/m² (91.8 psf), was 128.5 minutes. The structural failure of the full-scale test assembly occurred as a result of a loss of load-carrying capacity. A hose stream test was not performed on the full-scale floor assembly.

Acknowledgement

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CAN/ULC-S101-14, Standard Methods of Fire Endurance Tests of Building Construction and Materials, ULC Standards, National Standard of Canada, ULC Standards, Ottawa, ON, 2014, www.ulc.ca.