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ENCAPSULATED MASS TIMBER CONSTRUCTION CHAR RATE ANALYSIS

For

NATURAL RESOURCES CANADA
GREEN CONSTRUCTION THROUGH WOOD PROGRAM

Prepared for

Natural Resources Canada
580 Booth Street
Ottawa, ON
K1A 0E4

March 31, 2020

GHL File 6924.01

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APPENDICES

GHL Consultants Ltd thanks Natural Resources Canada and its Green Construction Through Wood Program for the significant financial support and Adera Group for their encouragement and support in-kind.

1.0 INTRODUCTION

GHL CONSULTANTS LTD (GHL) has prepared this report to document the testing and analysis of the char rate of Encapsulated Mass Timber Construction (EMTC) under the Green Construction through Wood program and Natural Resources Canada's requirements.

1.1 Background

The proposed National Building Code (NBC) 2020 and British Colombia Building Code (BCBC) 2018 both introduce EMTC for buildings up to 12 storeys. However, the current cost analysis of Cross Laminated Timber (CLT) structures results, based on estimates for current projects in GHL's office, is repeatedly in the range of 5% to 10% above that of concrete construction. In order to minimize construction cost and reduce cost premium, this project explores optimization of the thickness of the CLT assemblies.

Effectively, the thickness of CLT is based on the prescribed fire resistance rating of the assembly. Although the encapsulation rating is, by definition, different from the fire resistance rating, the encapsulation materials contribute to the fire resistance rating.

EMTC prescribes encapsulation of the CLT with two layers of 12mm (½in) Type X Gypsum wallboard (GWB). In practice, Type X GWB is not readily available for floor/ceiling application, but proprietary Type C GWB, which conforms to the Type X standard, is typically used in the construction industry throughout Canada wherever Type X is specified.

Further, the calculation of fire ratings for EMTC is based on methods included in Annex B of CSA O86, *"Engineering Design in Wood"* (CSA O86-19) to provide the prescribed fire resistance rating. However, it is noted that the methodology prescribed in CSA O86 2019 version remains the same as the 2014 version and was based on CLT with heat sensitive glues, subject to delamination in fire conditions per the product standard for CLT, namely ANSI/APA PRG 320 - 2012, *"Performance Standard for Cross-Laminated Timber"* (PRG-320 – 2012). PRG 320 was updated to address concerns with delamination through the introduction of heat resistant adhesives in the 2019 Edition ANSI/APA PRG-320-2019. The improved heat resistant adhesives provide increased fire resistance and are expected to result in a reduction of the effective char layer.

1.2 Scope and Objectives

For this project, GHL coordinated and witnessed three tests using two layers of 12mm (½in) Type C GWB fastened directly to the CLT in a pilot-scale fire test apparatus under CAN/ULC-S101-14 fire exposure at QAI Laboratories in Burnaby, BC.

This report is supplemental to the QAI Laboratories reports in *Appendix A* and serves the following purposes:

1. To provide the combined char rate of CLT produced to PRG-320-2019 encapsulated with two layers of 12mm Type C GWB.

2. To educate a minimum of three staff members in fire performance of encapsulated CLT through the witness of the fire tests.

3. To provide opportunity for Building and Fire Department officials at Greater Vancouver Area authorities to witness fire tests and develop confidence in EMTC.

2.0 METHODOLOGY

Three pilot scale tests exposing encapsulated CLT to the standard time-temperature curve of CAN/ULC-S101-14 were carried out for this project. The sample used in Test 1 used a patchwork layout to assess the performance among the Type C GWB from three manufacturers for determining the GWB for the char rate study. Based on the result of Test 1, Type C GWB manufactured by CGC Inc was selected as the encapsulation material for Test 2 and Test 3 where different maximum screw spacing were examined.

We have reviewed and are in general agreement with the QAI reports T1410-1A, T1410-1B and T1410-1C, copies attached in *Appendix A*. The test durations, furnace conditions, detailed thermocouple locations, and tests results are available in the test reports in *Appendix A*.

2.1 Test Specimen

For this project, the CLT panels used in all three tests were provided by Adera Group and Structuralam, and the Type C GWB was provided by National Drywall Ltd. These CLT panels were 175mm (5ply) thick and used the new heat resistant glue conforming to 2018 version of ANSI/APA PRG 320.

The CLT in each test was encapsulated with two layers of 12mm (½in) Type C GWB and mechanically fastened to the CLT using Type-W screws. The screws at the face layer and base layer were 20mm (0.75in) and 38mm (1½in) away from the edge, respectively. This follows EMTC requirements prescribed in the NBC and BCBC.

It is noted that the GWB on the outer edges were separated (cut) from the tested specimen layout and the cut filled with intumescent fire rated sealant, such that the encapsulation materials were not supported on the walls of the furnace and had a side clearance of not less than 25mm from the furnace wall. This is consistent with the specimen requirements per CAN/ULC-S146-19 *"Standard Method of Test for the Evaluation of Encapsulation Materials and Assemblies of Materials for the Protection of Structural Timber Elements"*. The detailed layouts of each test specimen are available in *Appendix B* for reference. It is noted that ULC-S146 is silent on treatment of edges, stating only that the edges be at least 25mm from the wall of the furnace; however, it is necessary to prevent flame and char getting under the encapsulation, hence this use of intumescent firestop at this cut line. In addition, Fiberfrax® insulation was placed on the perimeter of the furnace wall to further protect the edge of the test specimen and close the specimen to furnace joint.

2.2 Charring Rate Analysis

The primary objective of this study is to obtain the combined charring rate of EMTC assemblies using Type C GWB. Review of literature indicates that the degradation resulting from char can be expressed as a dimensional change of the material per unit time.

Therefore, the remaining thickness of the tested CLT panels were measured to determine the char rate per Equation 1 below.

$$\beta_0 = \frac{D-d}{120-t} \quad (1)$$

Where β_0 = one-dimensional charring rate, mm/min
D = original thickness of the tested CLT prior to fire test, 175mm
d = remaining thickness of the tested CLT after the fire test, mm
t = encapsulation time when the charring begins, min

It is noted that, due to the temperature variability in the furnace, the charring of the CLT was not consistent within the tested specimen. Therefore, we have divided the specimen both vertically and horizontally and measured the remaining thickness every ½in as shown in Figure 1 below. Due to the potential turbulent condition at the edge of the furnace, 5% of the data from each end was not included for this study.

Detailed char rate analysis for each test is available upon request.

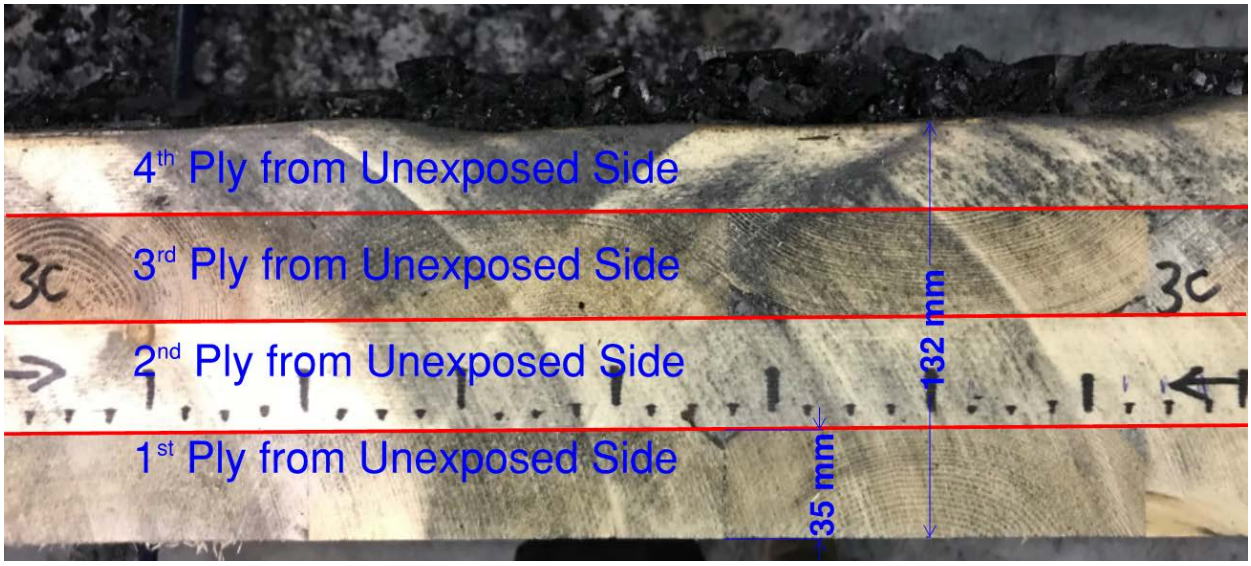

Figure 1: Photo of the Cut Section of the Tested Specimen after Test 1.

The encapsulation time, t, when encapsulating with two layers of 12mm Type X GWB, with screw spacing not less than 400mm (16in), were prescribed as 50min in both the BCBC and NBC in Article 3.1.19.2. However, in Annex B8.1 of CSA O86 standard, two layers of 12mm Type X GWB is recognized as contributing 60min to the fire resistance rating when attached with a screw spacing of maximum 300mm (12 in). This significant difference was noticed during the char rate analysis.

In addition, review of existing literature indicates the charring of the Mass Timber begins in a range of 250C to 380C. Previous research of encapsulation performance at NRC considered the temperature rise of 250C on average and a maximum single point of 270C as the assessing criteria based on the charring temperature of 300C supported by the European standards. For conservative analysis, we have determined the encapsulating time based on the 300C average temperature measured between the CLT and the base layer of the GWB.

3.0 TEST OBSERVATION AND RESULT ANALYSIS

3.1 Test 1 – February 24, 2020

Patchwork Layout

As the purpose of the first test was to study the performance between available types of Type C GWB, the selection of GWB manufacturers was made in conjunction with our industry partner based on common usage and local availability; 12mm Type C GWB manufactured by CGC Inc (CGC), Cabot Gypsum ULC (Cabot) and CertainTeed Saint-Gobain (CT) were selected. Taking the furnace temperature variability into consideration, the encapsulation was divided into 9 areas with the GWB placement as shown in Figure 2, resulting in a patchwork layout. Screws were spaced not more than 300mm (12in).

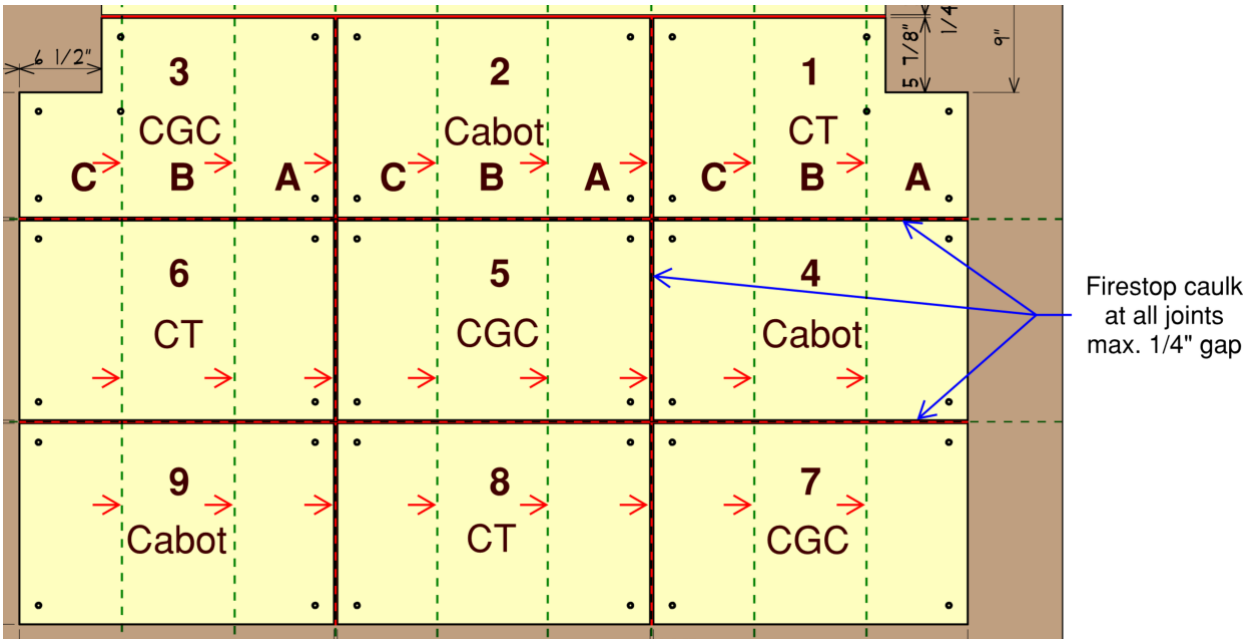

Figure 2: Schematic Section Illustration of the Patchwork Layout of 3 Different Type C GWB.

Thermocouple Locations

It was intended to place thermocouples at all interfaces between the layers of GWB and between the GWB and the CLT for all patches. However, the temperature measurement between the layers of GWB at top row of the patchwork was not available due to the equipment limitation. This was discussed with industry partners and deemed to be acceptable for the purpose of the selection. We note that some of the temperature measurement were not available due to the installation failure. This was carefully redesigned in the next two tests.

Analysis

We measured the remaining depth of the CLT panels and summarize the char rate analysis in Table 1 below. Due to the improper installation of the thermocouple, the temperature measurement of Test 1 was not reliable. However, the encapsulation time for this analysis, t, was assumed to be 60min as the purpose of Test 1 was to determine GWB for the next two tests.

It is worth noting that during Test 1, longer encapsulation time was observed. The base layers did not fall off after approximately 75min.

Table 1: Average Charring Rate with Encapsulation of Different Brands of Type C GWB in Test 1.

Brand	CertainTeed	Cabot	CGC
Average Charring Depth, mm	37.78	37.73	37.24
Encapsulation Time, min		60	
Average Charring Rate, mm/min	0.63	0.63	0.62

Based on the foregoing, we concluded that there was no significant difference in encapsulation performance among the three brands. After consulting with our industry partners on their preferences and, due to stock availability, Type C GWB manufactures by CGC Inc was selected as the material for the full extent of the encapsulation.

3.2 Test 2 – February 28, 2020

Encapsulation Layout

The layout of Test 2 followed the encapsulation layout prescribed in Article 3.1.19.2 of the NBC and BCBC with a maximum screw spacing of 400mm (16in). A joint condition was also included in the middle to study the charring performance. Please refer to *Appendix B* for detailed layout of Test 2 assembly.

Thermocouple Locations

Based on the experience from Test 1, the thermocouple installation was completed in QAI Laboratories witnessed by GHL staff. The thermocouples were located at interfaces between layers of GWB and between the base layer of GWB and the CLT.

Analysis

We measured the remaining depth of the CLT panels and summarize the char rate analysis in Table 2 below. The correspondence cut lines are shown in Figure 3 below. The measured encapsulation time was determined based on the temperature of the interface between CLT and base layer of GWB to reach 300C for conservative char rate calculation purposes, as discussed earlier. Based on the results in Table 2, the average charring rate using 400mm space was determined to be 0.63mm/min.

It is worth noting that the measured times when T= 250C and T=300C at interface between CLT and base layer of GWB do not have a significant difference (maximum 3min difference) and the average encapsulation time was 49.8min, close to the 50min encapsulation rating assumed in NBC and BCBC.

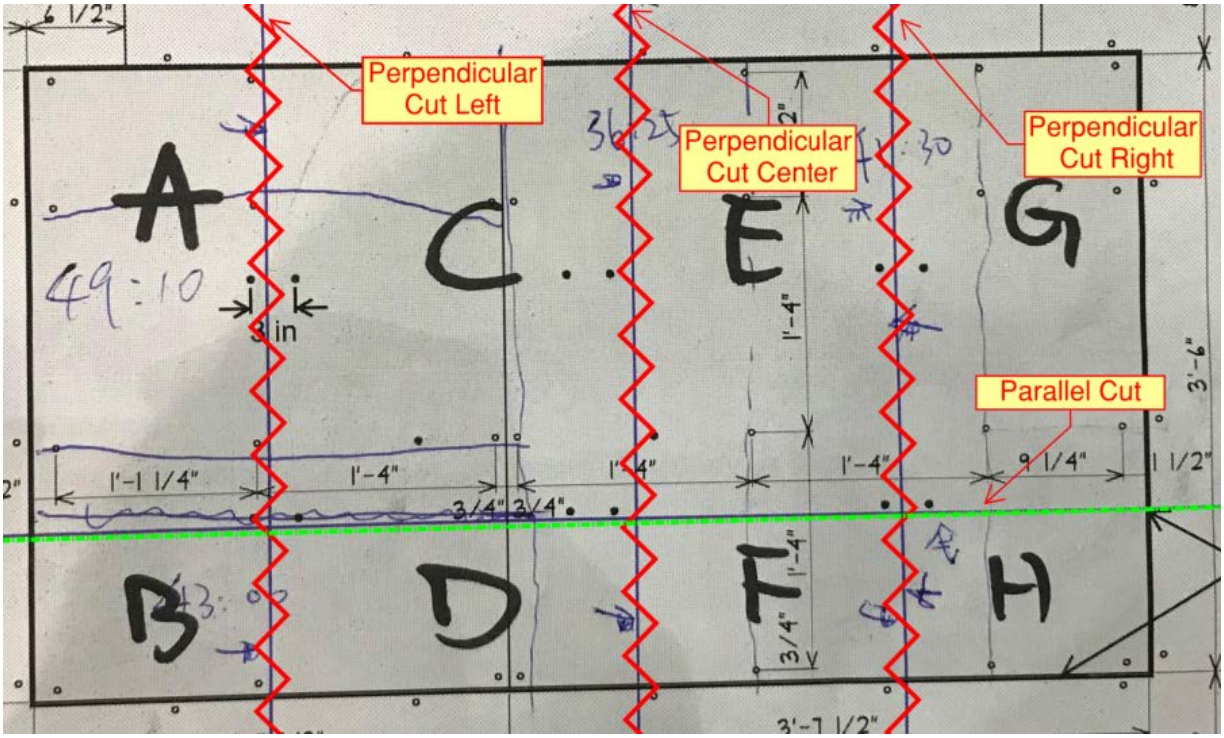

Figure 3: Cut Lines for Charring Measurement.

Table 2: Average Charring Rate with Encapsulation of Different Brands of Type C GWB in Test 2.

Cut Line Location	Perpendicular			Parallel
	Left	Centre	Right	
Average Charring Depth, mm	39.6	49.1	43	45
Measured Encapsulation Time (T=300C), min	50.5	45.5	51	52
Measured Average Charring Rate, mm/min	0.56	0.7	0.62	0.64

Additional Comments

During the test, we observed that the face layer of GWB fell off at approximately 36min, significantly earlier than Test 1, and the base layer fell off earlier than expected as well. Discussion with industry partners indicated that this may result from the large screw spacing. Review of the previous NRC fire tests indicated that the 300mm (12in) spacing may significantly increase the performance of the GWB. Therefore, it was proposed to perform Test 3 with tighter screw spacing (300mm).

3.3 Test 3 – March 6, 2020

Encapsulation Layout

As discussed in Test 2, the tighter maximum screw spacing (300mm) was proposed to fasten the 2 layers of Type C GWB to the CLT. Please refer to *Appendix B* for detailed layout of Test 3 assembly.

Thermocouple Locations

The thermocouple location remained the same as Test 2. Refer to *Appendix A* for details.

Analysis

With similar cut line shown in Figure 2 in Test 2, remaining depth of the CLT panels and the combined char rate analysis is illustrated in Table 3 below. The measured encapsulation time was determined based on the temperature of the interface between CLT and base layer of GWB to reach 300C, as discussed earlier. Based on the results in Table 3, the average charring rate using 300mm screw spacing was determined to be 0.63mm/min.

It is worth noting that the measured times when T= 250C and T=300C at interface between CLT and base layer of GWB do not have a significant difference (maximum 6min difference).

Table 3: Average Charring Rate with Encapsulation of Different Brands of Type C GWB in Test 3.

		Vertical		Horizontal
Cut Line Location	**Left**	**Centre**	**Right**	
Average Charring Depth, mm	36.1	35.3	35.2	40
Measured Encapsulation Time, min	64.6	66.3	63	65
Measured Average Charring Rate, mm/min	0.65	0.66	0.62	0.72

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Combined Char Rate and Encapsulation Time

The primary objective of this study was to evaluate the combined char rate of EMTC using two layers of 12mm (½in) Type C GWB when exposed to the standard time-temperature curve in CSA/ULC-S101 Standard. Three pilot-scale tests were performed with variable screw spacing. Following the results in Test 1, no significant difference was determined in different brands of Type C GWB and CGC Inc was selected for the remaining tests due to stock availability and industry partner consultation.

Based on the foregoing analysis, the combined char rate, despite different screw spacing, averaged at 0.61mm/min, well within the conservatively recommended 0.65mm/min in CSA O86 Annex B for solid timber and CLT without glue lines.

Moreover, during our study, a correlation between the screw spacing and the encapsulation time was found to be significant. With tighter screw spacing at Test 3, the encapsulation time (T=300C at CLT/base-layer GWB interface) increased to 65min compared with Test 2 results (49.4min).

Similar correlation was found when comparing the test results in Test 1 which had a tighter spacing compared to Tests 2 and 3 and an average encapsulation time of approximately 80min, although it is recognized the patchwork nature of Test 1 did not produce reliable results.

4.2 Outreach

This study was also intended to also help the industry in overcoming the lack of confidence in EMTC. Local Building and Fire Departments were invited to witness the test. Six members of local Fire and Building departments attended (City of North Vancouver, City of Vancouver, City of Richmond). They have provided positive feedback and expressed strong interest in witnessing future fire tests to assist in education on EMTC construction. It is noted that the lab facilities and short time frame precluded more attendees.

GHL engineers, engineer-in-trainings and technologists were involved in witnessing and organizing the tests, leading to education of our staff of fire engineers.

Adera Group, our industry partner, and their marketing partner, Talk Shop Media, also attended and noted that having marketing personnel involved would significantly assist in their efforts to promote Mass Timber construction. We note that Adera Group have completed multiple 6 storey hybrid mass timber/frame wall buildings and are actively soliciting a site and a willing municipal partner for a larger residential EMTC building. A potential pilot-scale test for media demonstration has been discussed to increase public confidence in EMTC construction.

Further, this test has highlighted the importance of screw spacing and correct calculation. This information is now proposed to be included in the upcoming Engineers Geoscientists BC Professional Practice Guidelines for Encapsulated Mass Timber Construction Up to 12 Storeys.

4.3 Future Considerations

As discussed previously, the screw spacing appears to play a significant role in calculating encapsulation time and contribution of encapsulation to fire resistance ratings. Current NBC and BCBC prescribed a general encapsulation rating of 50min for all applications with screw spacing not more than 400mm (16in). However, this study has demonstrated that the tighter spacing results in an increase in the encapsulation rating which would also contribute to the reduction of the charring calculation. Future study on the correlation between the encapsulation time and screw spacing is recommended. It is also recommended to prescribe an option of 60min encapsulation rating (recommended by CSA O86) for screw spacing not more than 300mm in EMTC provisions of NBC and BCBC.

While this study endeavoured to follow ULC S146 as much as practical, given the available facilities and funding, it would also be appropriate to confirm these effects are shown to be consistent when tested with the larger sample size and in direct conformance with ULC S146. It is also worth noting that ULC-S146 assessed the encapsulation performance based on the temperature rise of 250C on average and a maximum single point of 270C. Results from Test 2 indicated that the current prescribed EMTC with 400mm screw spacing achieves a 48.5min encapsulation rating, which is shorter than the prescribed 50min.

Based on our experience with the pilot scale test, and in discussions with QAI staff and NRC staff, the intermediate test appears a good representation of the full-scale test and would produce more uniform fire exposure. Variabilities are likely more of a factor of difference between different furnaces than related to whether intermediate scale or full scale. Further, research in analyzing the combined charring rate is recommended.

While discussing with GWB suppliers, it appears that more refined products could be designed for EMTC and one potential existing product has been identified. Future study on the combine char rating utilizing those materials is also recommended.

5.0 SUMMARY

This report has been prepared by GHL Consultants Ltd for the Natural Resources Canada to provide technical analysis on the EMTC Char Rate Study under the Natural Resources Canada's Green Construction Through Wood Program.

Three pilot-scale tests were conducted by QAI Laboratories located in Burnaby, BC with tested specimens provided by Adera Group. GHL witnessed all three tests with local municipalities and industrial partners.

GHL Consultants Ltd's study focused on the quantitative analysis of the combined char rate using Type C gypsum wallboard and concluded the test results generally agree with the recommended 0.65mm/min found in recent studies for CLT studies produced under the new edition of ANSI/APA PRG-320-2019. Further, various screw spacings were examined and our findings indicate that tighter spacing would result in a higher encapsulation rating.

The study highlighted the importance of screw spacing and the advantage of closer screw spaces.

GHL Consultants Ltd also increased awareness for Encapsulated Mass Timber Construction with local municipalities and industry partners. Recommendations for potential future studies and public presentations for promoting Encapsulated Mass Timber Construction have been proposed as well.

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Enclosures

* Limitation of Liability *

This technical report addresses only specific Building Bylaw issues under the GHL/Client agreement for this project and shall in no way be construed as exhaustive or complete. This technical report is issued only to the Authority Having Jurisdiction, the Client, Prime Consultants and Fire Suppression Designer to this project and shall not be relied upon (without prior written authorization from GHL) by any other party.

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Appendix A

QAI Laboratories Test Result T1410-1A
QAI Laboratories Test Result T1410-1B
QAI Laboratories Test Result T1410-1C

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Test Report No: T1410-1A	Revision Date: March 3, 2020

SAMPLE ID: Cross Laminated Timber (CLT) 2-hour floor/ceiling assembly with three brands of Type C gypsum board.

SAMPLING DETAIL: The GHL CLT panel was manufactured by Structurlam and the gypsum board was installed by National Drywall. The test assembly was not independently selected for testing.

DATE OF RECEIPT: Samples were received at QAI on February 24, 2020.

TESTING PERIOD: February 24, 2020.

AUTHORIZATION: QAI Test Proposal Number 20JL01281, signed and dated on February 12, 2020, by Andrew Harmsworth.

TEST PROCEDURE: Tested to the general conditions of the following test standard with the deviations found on page 5:

- CAN/ULC S101-14, *Standard Methods of Fire Endurance Tests of Building Construction and Materials* (CAN/ULC S101).

TEST RESULTS: The tested GHL CLT floor / ceiling assembly with three brands of Type C gypsum board as detailed on page 3 of this report, achieved the results found on page 5 and 6 when tested to the general conditions of CAN/ULC S101 with the deviations found on page 5.

Prepared By

Scott Leduc
Project Manager

Signed for and on behalf of QAI Laboratories, Ltd.

Matt Lansdowne
VP of Operations

Table of Contents

Introduction:

This report documents the fire testing conducted by QAI Laboratories Ltd. for GHL of a CLT floor / ceiling assembly with three brands of Type C gypsum board. The assembly was to the general conditions of CAN/ULC S101 on February 24, 2020.

Test Description:

Table 1: Test Assembly Description

COMPONENT	DESCRIPTION	
Floor/Ceiling Assembly	Overall Size:	2.29 m (90 in.) length x 1.52 m (59.85 in.) width x 176 mm (6.94 in.) thickness.
	Type:	Cross Laminated Timber (CLT) floor/ceiling assembly.
	Manufacturer:	Structurlam Mass Timber Corp.
	Grade:	PRG 320 grade V2M1.1
	Layers:	5-layers of cross laminated 1.38 in. by 5.31 in. lumber.
Gypsum Board 1	Manufacturer:	CGC
	Type:	Sheetrock Brand Firecode C Gypsum Panels.
	Thickness:	12.7 mm (1/2 in.)
	Dimensions:	Three separate tiles of 15-3/4 in. by 24-3/4 in. with two layers at each location.
	Fasteners:	No. 6 x 1-1/4 in. drywall screws were used at the corner of each tile on the base layer and nine No. 6 x 2 in. drywall screws were evenly spaced on the face layer.
Gypsum Board 2	Manufacturer:	Certainteed
	Type:	Type C Gypsum Board.
	Thickness:	12.7 mm (1/2 in.)
	Dimensions:	Three separate tiles of 15-3/4 in. by 24-3/4 in. with two layers at each location.
	Fasteners:	No. 6 x 1-1/4 in. drywall screws were used at the corner of each tile on the base layer and nine No. 6 x 2 in. drywall screws were evenly spaced on the face layer.
Gypsum Board 3	Manufacturer:	Cabot
	Type:	Type C Core Gypsum Board.
	Thickness:	12.7 mm (1/2 in.)
	Dimensions:	Three separate tiles of 15-3/4 in. by 24-3/4 in. with two layers at each location.
	Fasteners:	No. 6 x 1-1/4 in. drywall screws were used at the corner of each tile on the base layer and nine No. 6 x 2 in. drywall screws were evenly spaced on the face layer.

Test Apparatus:

The furnace used in the tests is a pilot-scale fire burning apparatus with interior dimensions of 1.78 m (70 in.) in height, 1.91 m (75 in.) in width, and 1.30 m (51 in.) in depth.

Temperatures within the furnace were monitored using four thermocouples. The temperatures are controlled by adjusting fuel to the furnace burners to conform to the time/temperature curve specified by the test standards. Temperature measurements are recorded by a Keithley 2750 data acquisition unit (ID# DMM1) which passes the readings to a computer for graphical display and storage.

16 thermocouples were placed through holes in the back of the test assembly until they hit the gypsum board layers. See Appendix A for detailed locations.

One pressure tap is installed along the longitudinal center line of the test assembly. The pressure tap is attached and monitored by Setra model 264 pressure transducers (ID# Pressure T3). The furnace pressure is controlled by adjusting a damper in the furnace exhaust stack.

Figure 1: Pilot-Scale Furnace

Test Conditions:

The GHL floor/ceiling assembly outlined on page 3 was supported by the walls of the furnace. A ceramic fiber gasket was used to maintain an air tight seal between the furnace and the floor/ceiling assembly.

The pressure of the furnace was monitored throughout the test. The pressure was continuously monitored using calibrated pressure transducers. After the first 5 minutes of the test the pressure was maintained at minimum of 0.01 in. water column 12 in. below the slab.

Prior to the fire endurance test the test assembly was placed on top of the furnace, the front panel was moved into place and the burners were ignited. The fire endurance test was initiated immediately after igniting the burners. The temperature inside the furnace was controlled to follow the standard time/temperature curve within the limits described in the test standard.

Deviation of the Test Standard:

The purpose of this test was to measure the char thickness formed on the exposed face of the CLT panel. The following requirements were not met.

1. The required sample size is 16.8 m^2.
2. The floor/ceiling assembly must be loaded.
3. The required thermocouples on the unexposed face were not used.

Test Results:

Observations

The following observations were taken over the duration of the fire test:

Table 2: Test Observations

Test Time (min)	Unexposed	Exposed
2:00		Ignition of the gypsum board paper.
2:30		Flaming has extinguished.
10:50		The gypsum board panels are beginning to sag.
29:15		The sagging at the center panel has increased.
35:20		The center panel has fallen.
40:18		Center back panel is sagging at the corner.
57:30		Center back panel is dropping more. Center right and front right corners are dropping.
61:45		Center back panel has fallen.
65:00		Front center panel has dropped. Cracks are forming in center and center back panels.
66:00		Center right and center left panels have fallen. Left front panel is sagging approx. 8 in.

Table 2: Test Observations - Continued

Test Time (min)	Unexposed	Exposed
88:00		A panel has fallen (not visible).
90:00		Another panel has fallen (not visible).
94:00		Something has fallen (not visible).
99:40		Something has fallen (not visible).
120:00	Test discontinued.	

Conclusions:

QAI performed testing to the general conditions of CAN/ULC S101 on a CLT floor/ceiling assembly with three brands of Type C gypsum board.

The assembly was exposed to the furnace conditions for 2 hours. After the fire exposure the floor/ceiling assembly was removed from the furnace, extinguished and cut in two locations at each gypsum tile location so that the char level can be measured. GHL staff measured and recorded the char depth of the assemblies.

APPENDIX A

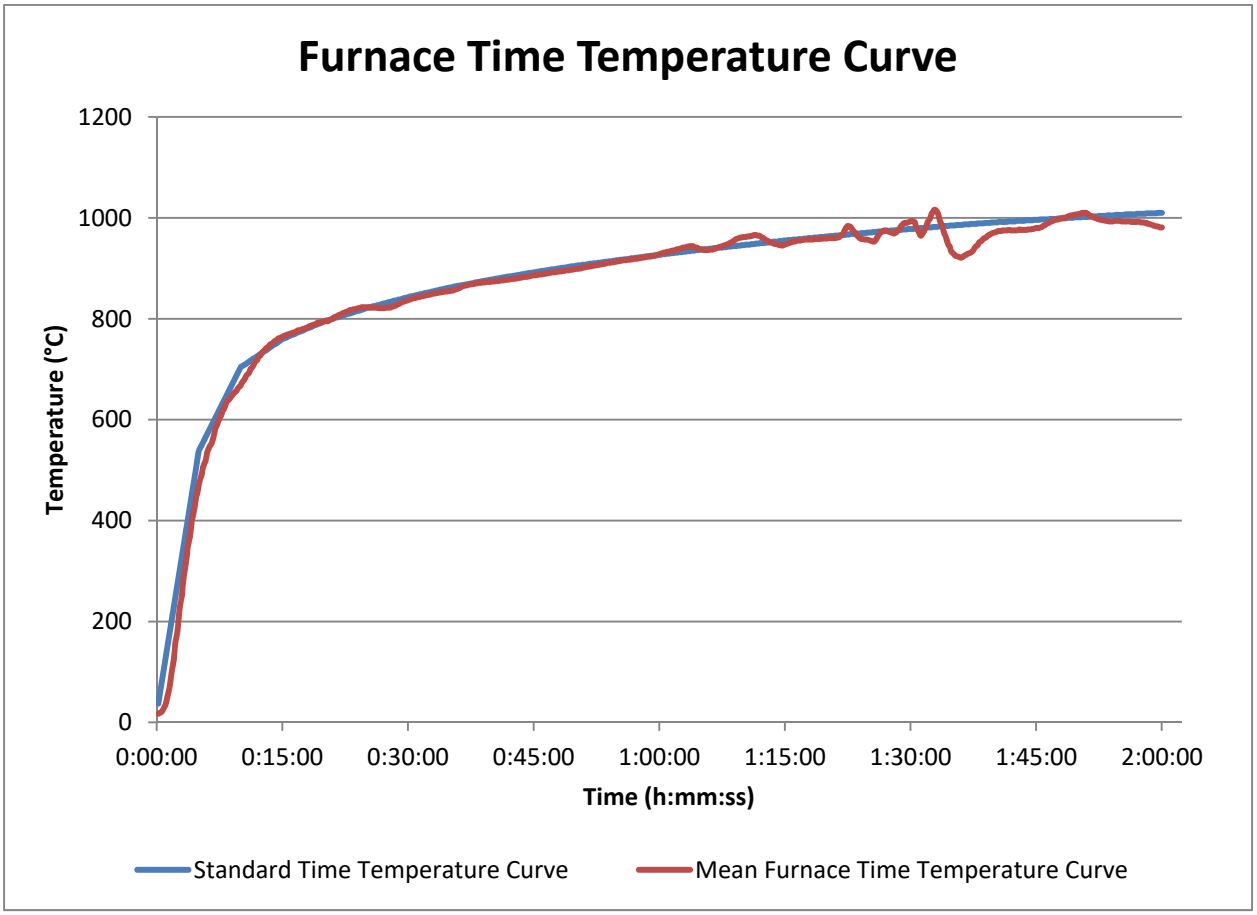

Figure 2: Time Temperature Curve

Thermocouple Locations

TC 1-9B – Located at the tile corresponding to the number placed through the hole in the back of the panel until it hit the base layer gypsum.
TC 4-9A – Located at the tile corresponding to the number placed through the hole in the back of the panel until it hit the face layer.
TC 5C – Located at the tile corresponding to the number placed through the hole in the back of the panel until it hit the base layer gypsum.

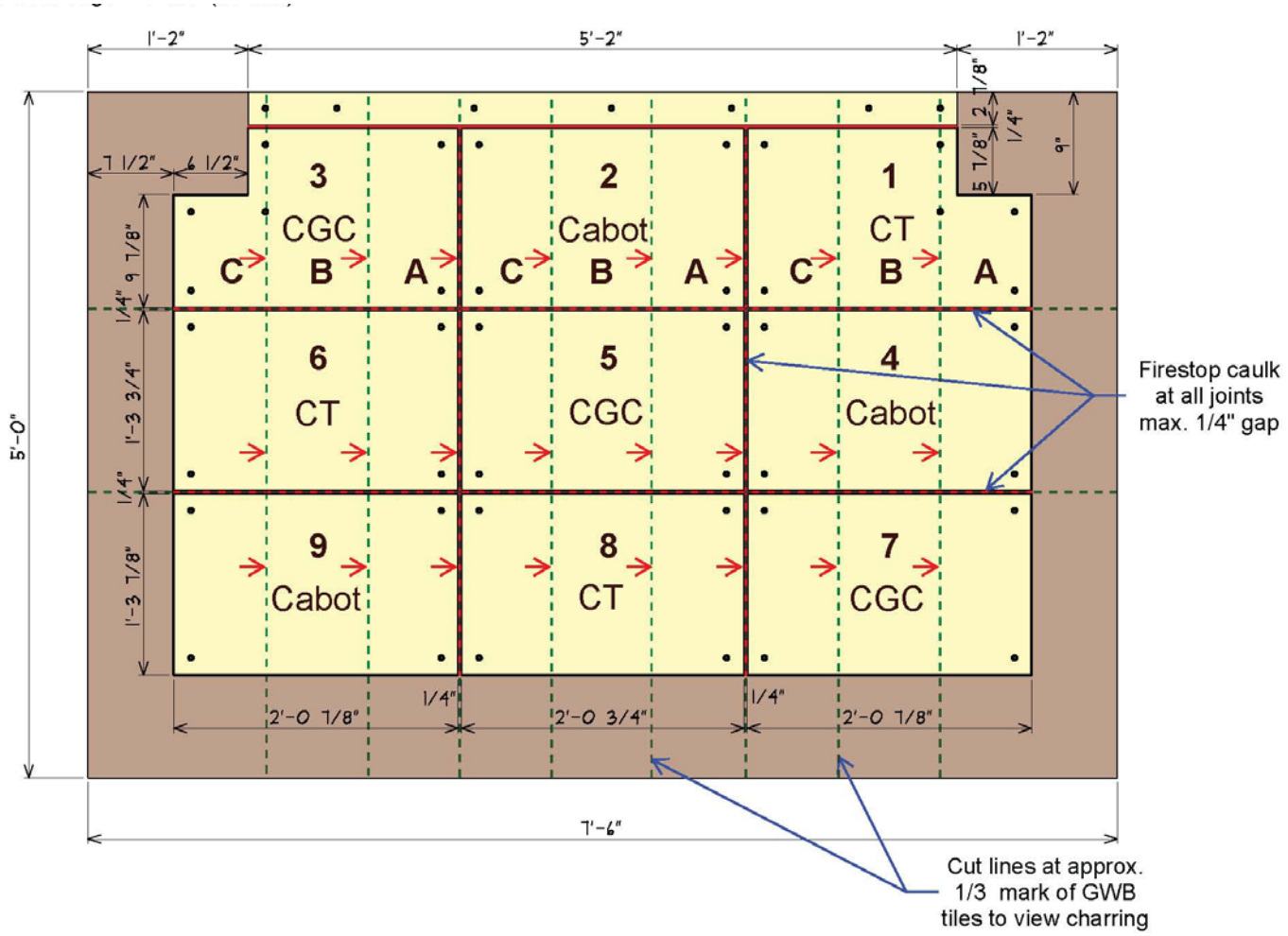

Figure 3: Gypsum board layout.

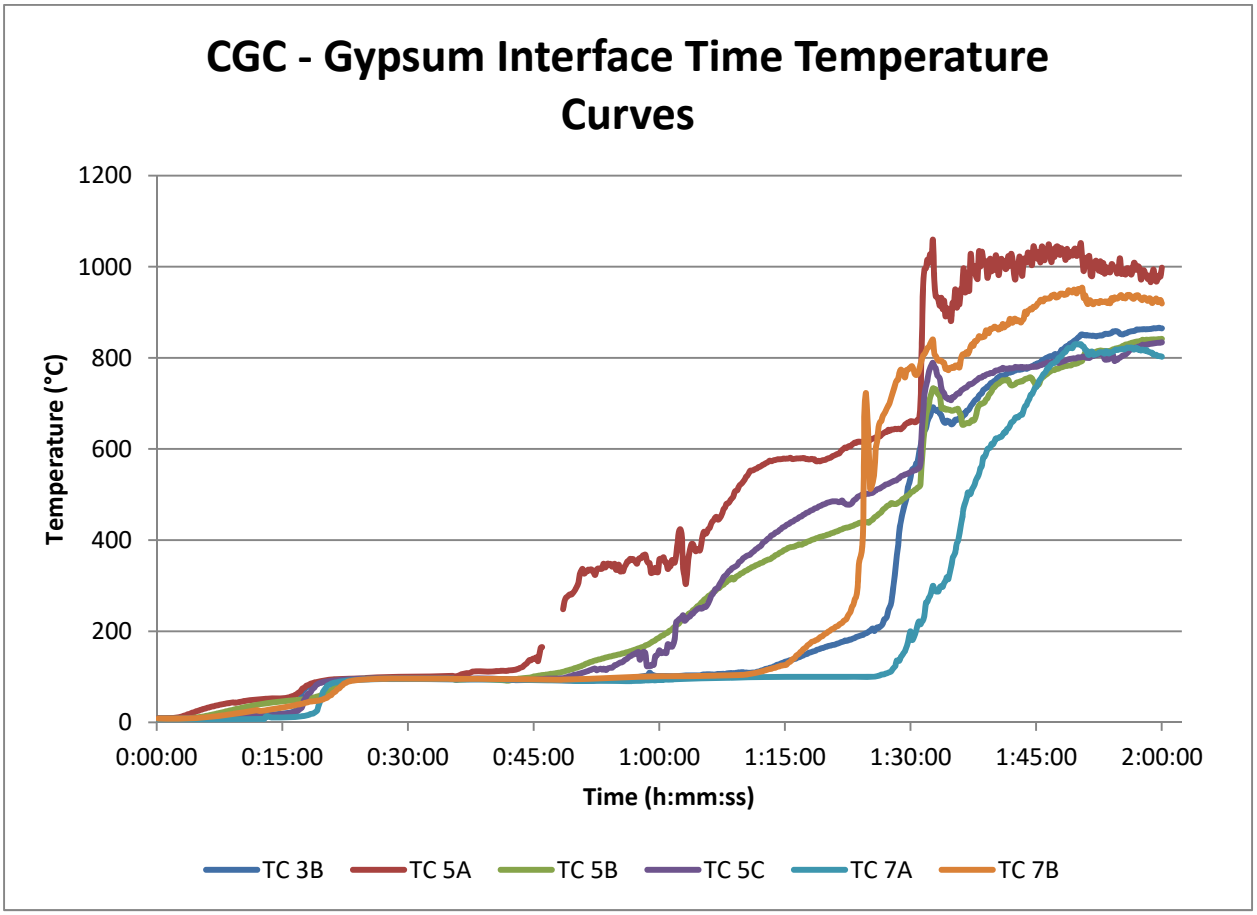

Figure 4: Interface Time Temperature Curves

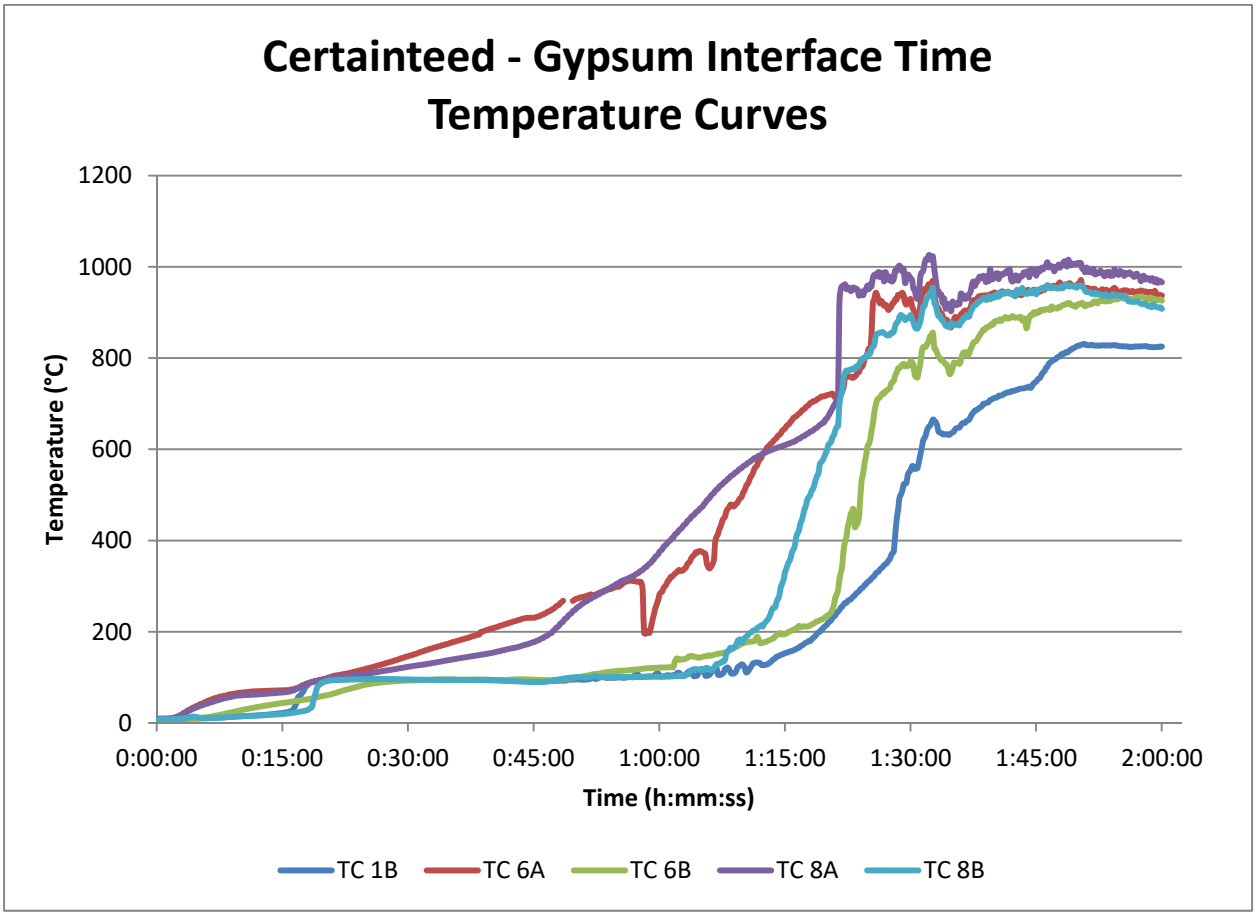

Figure 5: Interface Time Temperature Curves

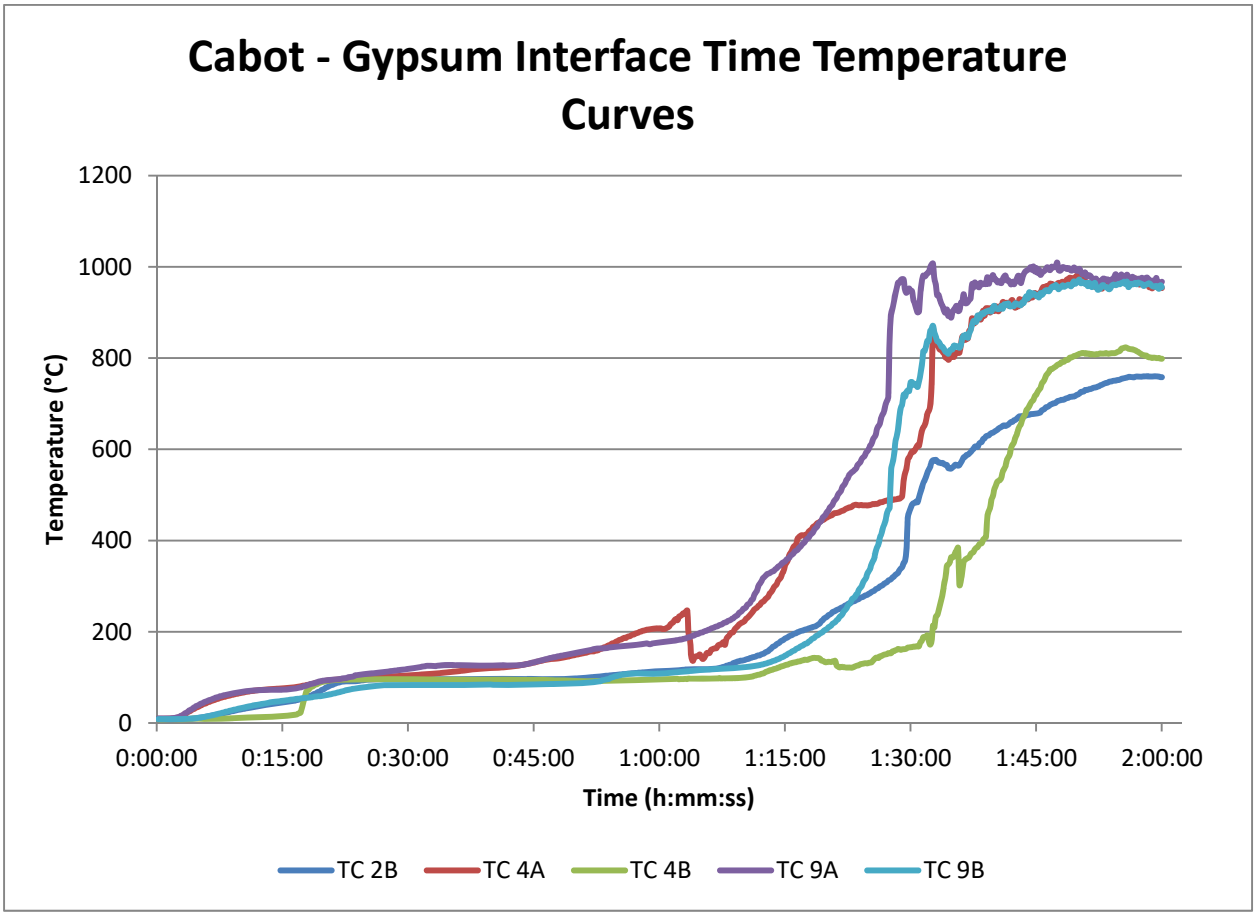

Figure 6: Interface Time Temperature Curves

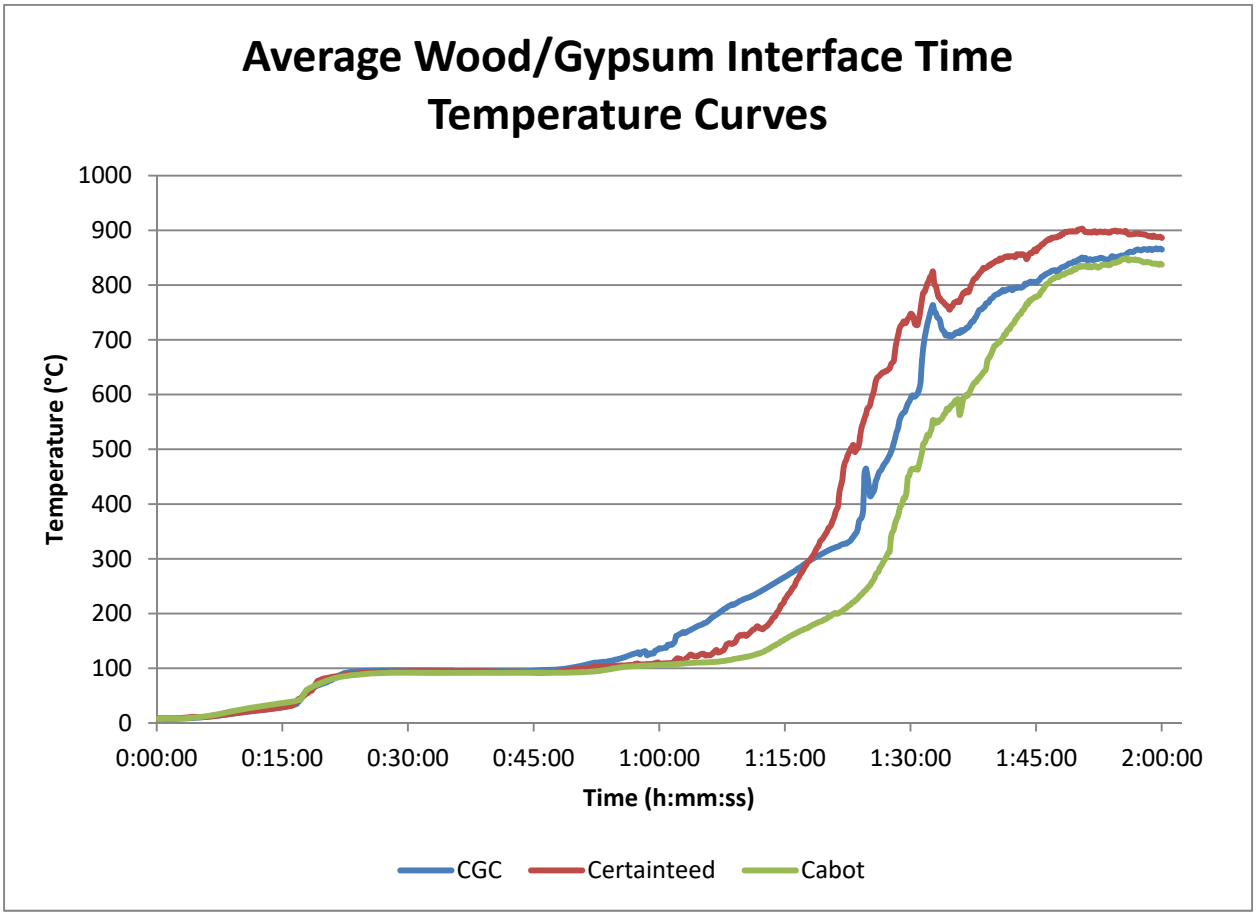

Figure 7: Interface Time Temperature Curves

APPENDIX B

Figure 8: The exposed side of the assembly prior to the fire test.

Figure 9: The unexposed side of the assembly prior to the fire test.

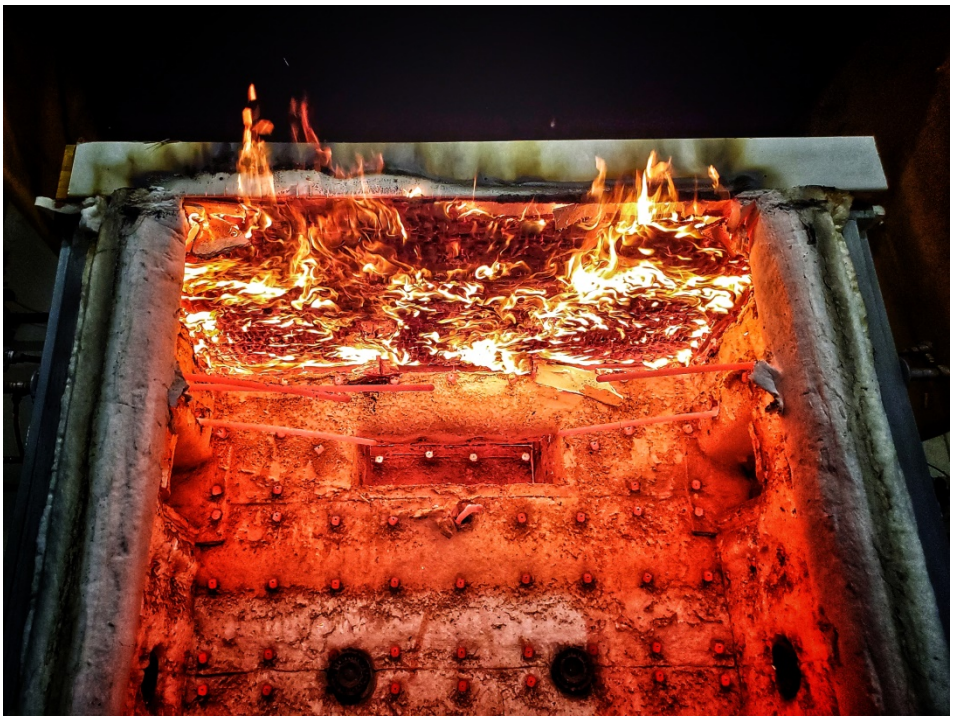

Figure 10: The exposed side of the assembly at the end of the fire test.

QAI LABORATORIES
CERTIFICATION TESTING INSPECTION

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3980 North Fraser Way
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604.527.8378 ph. | 604.527.8368 fx.

CLIENT: **GHL CONSULTANTS LTD.**
409 Granville St., Suite 950
Vancouver, BC
V6C 1T2

Test Report No: T1410-1B	Revision Date: March 4, 2020

SAMPLE ID: Cross Laminated Timber (CLT) 2-hour floor/ceiling assembly with CGC Type C gypsum board.

SAMPLING DETAIL: The GHL CLT panel was manufactured by Structurlam and the gypsum board was installed by QAI staff. The test assembly was not independently selected for testing.

DATE OF RECEIPT: Samples were received at QAI on February 27, 2020.

TESTING PERIOD: February 28, 2020.

AUTHORIZATION: QAI Test Proposal Number 20JL01281, signed and dated on February 12, 2020, by Andrew Harmsworth.

TEST PROCEDURE: Tested to the general conditions of the following test standard with the deviations found on page 5:

- CAN/ULC S101-14, *Standard Methods of Fire Endurance Tests of Building Construction and Materials* (CAN/ULC S101).

TEST RESULTS: The tested GHL CLT floor / ceiling assembly with CGC Type C gypsum board as detailed on page 3 of this report, achieved the results found on page 5 and 6 when tested to the general conditions of CAN/ULC S101 with the deviations found on page 5.

Prepared By

Scott Leduc
Project Manager

Signed for and on behalf of QAI Laboratories, Ltd.

Matt Lansdowne
VP of Operations

Table of Contents

Introduction:

This report documents the fire testing conducted by QAI Laboratories Ltd. for GHL of a CLT floor / ceiling assembly with CGC Type C gypsum board. The assembly was to the general conditions of CAN/ULC S101 on February 28, 2020.

Test Description:

Table 1: Test Assembly Description

COMPONENT	DESCRIPTION	
Floor/Ceiling Assembly	Overall Size:	2.29 m (90 in.) length x 1.52 m (59.85 in.) width x 176 mm (6.94 in.) thickness.
	Type:	Cross Laminated Timber (CLT) floor/ceiling assembly.
	Manufacturer:	Structurlam Mass Timber Corp.
	Grade:	PRG 320 grade V2M1.1
	Layers:	5-layers of cross laminated 1.38 in. by 5.31 in. lumber.
Gypsum Board 1	Manufacturer:	CGC
	Type:	Sheetrock Brand Firecode C Gypsum Panels.
	Thickness:	12.7 mm (1/2 in.)
	Dimensions:	Two layers of a 1.11 m (43-1/2 in.) by 1.02 m (40 in.) piece and a 0.80 m (31-1/2 in.) by 1.02 m (40 in.) piece. The joints are staggered.
	Fasteners:	No. 6 x 32 mm (1-1/4 in.) drywall screws were spaced 356 mm (14 in.) on center fastening the large piece and 406 mm (16 in.) on center on the small piece on the base layer. No. 6 x 51 mm (2 in.) drywall screws were spaced 406 mm (16 in.) on center on the face layer.

Test Apparatus:

The furnace used in the tests is a pilot-scale fire burning apparatus with interior dimensions of 1.78 m (70 in.) in height, 1.91 m (75 in.) in width, and 1.30 m (51 in.) in depth.

Temperatures within the furnace were monitored using four thermocouples. The temperatures are controlled by adjusting fuel to the furnace burners to conform to the time/temperature curve specified by the test standards. Temperature measurements are recorded by a Keithley 2750 data acquisition unit (ID# DMM1) which passes the readings to a computer for graphical display and storage.

14 thermocouples were placed through holes in the back of the test assembly until they hit the gypsum board layers. See Appendix A for detailed locations.

One pressure tap is installed along the longitudinal center line of the test assembly. The pressure tap is attached and monitored by Setra model 264 pressure transducers (ID# Pressure T3). The furnace pressure is controlled by adjusting a damper in the furnace exhaust stack.

Figure 1: Pilot-Scale Furnace

Test Conditions:

The GHL floor/ceiling assembly outlined on page 3 was supported by the walls of the furnace. A ceramic fiber gasket was used to maintain an air tight seal between the furnace and the floor/ceiling assembly.

The pressure of the furnace was monitored throughout the test. The pressure was continuously monitored using calibrated pressure transducers. After the first 5 minutes of the test the pressure was maintained at minimum of 0.01 in. water column 12 in. below the slab.

Prior to the fire endurance test the test assembly was placed on top of the furnace, the front panel was moved into place and the burners were ignited. The fire endurance test was initiated immediately after igniting the burners. The temperature inside the furnace was controlled to follow the standard time/temperature curve within the limits described in the test standard.

Deviation of the Test Standard:

The purpose of this test was to measure the char thickness formed on the exposed face of the CLT panel. The following requirements were not met.

1. The required sample size is 16.8 m^2.
2. The floor/ceiling assembly must be loaded.
3. The required thermocouples on the unexposed face were not used.

Test Results:

Observations

The following observations were taken over the duration of the fire test:

Table 2: Test Observations

Test Time (min)	Unexposed	Exposed
1:32		Ignition of the gypsum paper.
22:30		The back and front edges are sagging between the screws.
30:00		Back right side corner has released from the screw.
36:54		16 in. wide strip through the middle right side of the face layer has fallen.
41:11		Another 16 in. wide section has fallen.
43:16		Another 16 in. wide section has fallen on the left side.
49:09		Gypsum piece has fallen from the left side.
55:40		Flaming at the base layer gypsum joint.
58:30		Flaming from cracks in the base layer.
62:20		Right side piece of face layer has fallen.
75:00		Large section of the base layer has fallen.
120:00	Test discontinued.	

Conclusions:

QAI performed testing to the general conditions of CAN/ULC S101 on a CLT floor/ceiling assembly with CGC Type C gypsum board.

The assembly was exposed to the furnace conditions for 2 hours. After the fire exposure the floor/ceiling assembly was removed from the furnace, extinguished and cut in four locations so that the char level can be measured. GHL staff measured and recorded the char depth of the assemblies.

APPENDIX A

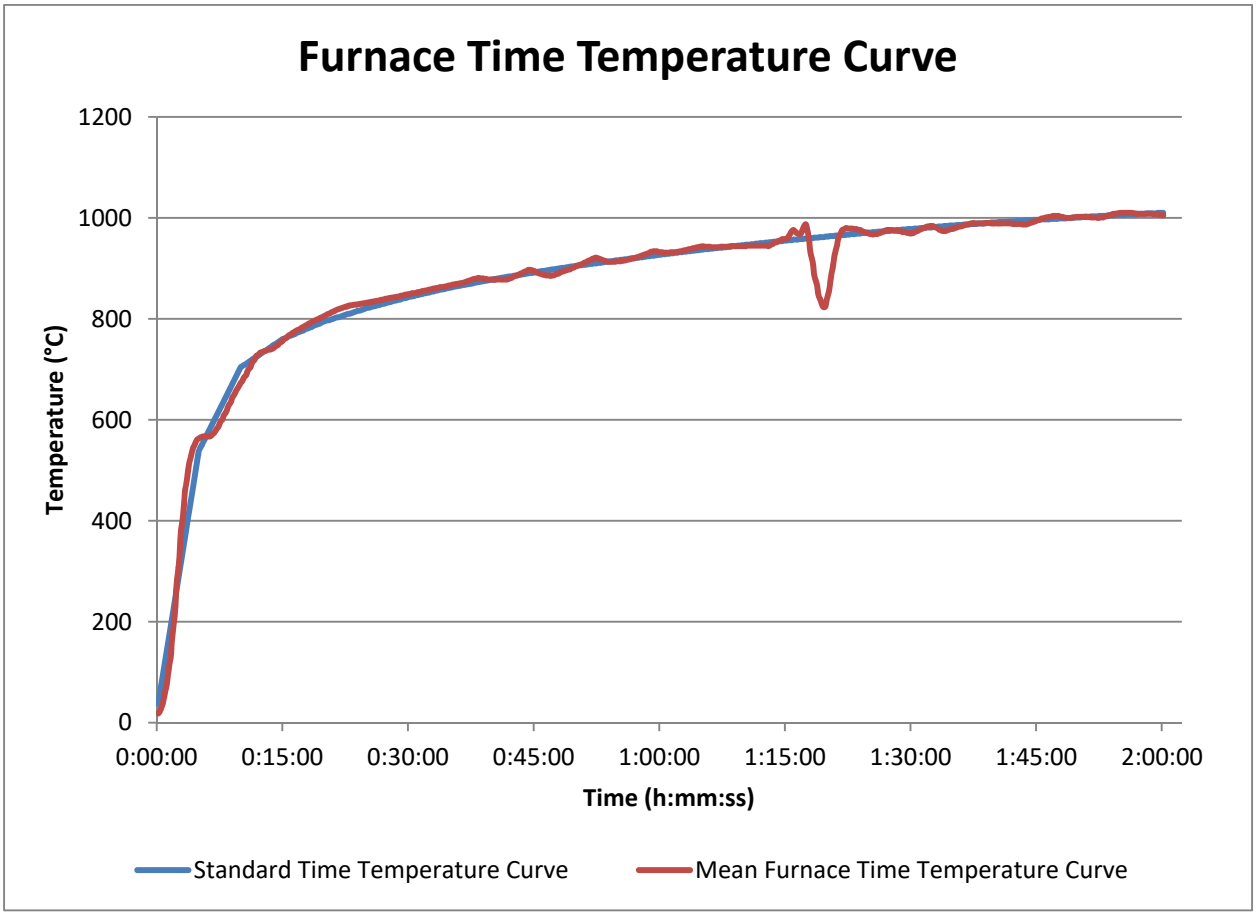

Figure 2: Time Temperature Curve

Thermocouple Locations

TC 1-6A – Located at the interface of the face layer and the base layer of the gypsum board.
TC 1-6B – Located at the interface of the base layer of the gypsum board and the wood.
TC 7A and 7B – Located at the interface of the base layer of the gypsum board and the wood at the joint locations.

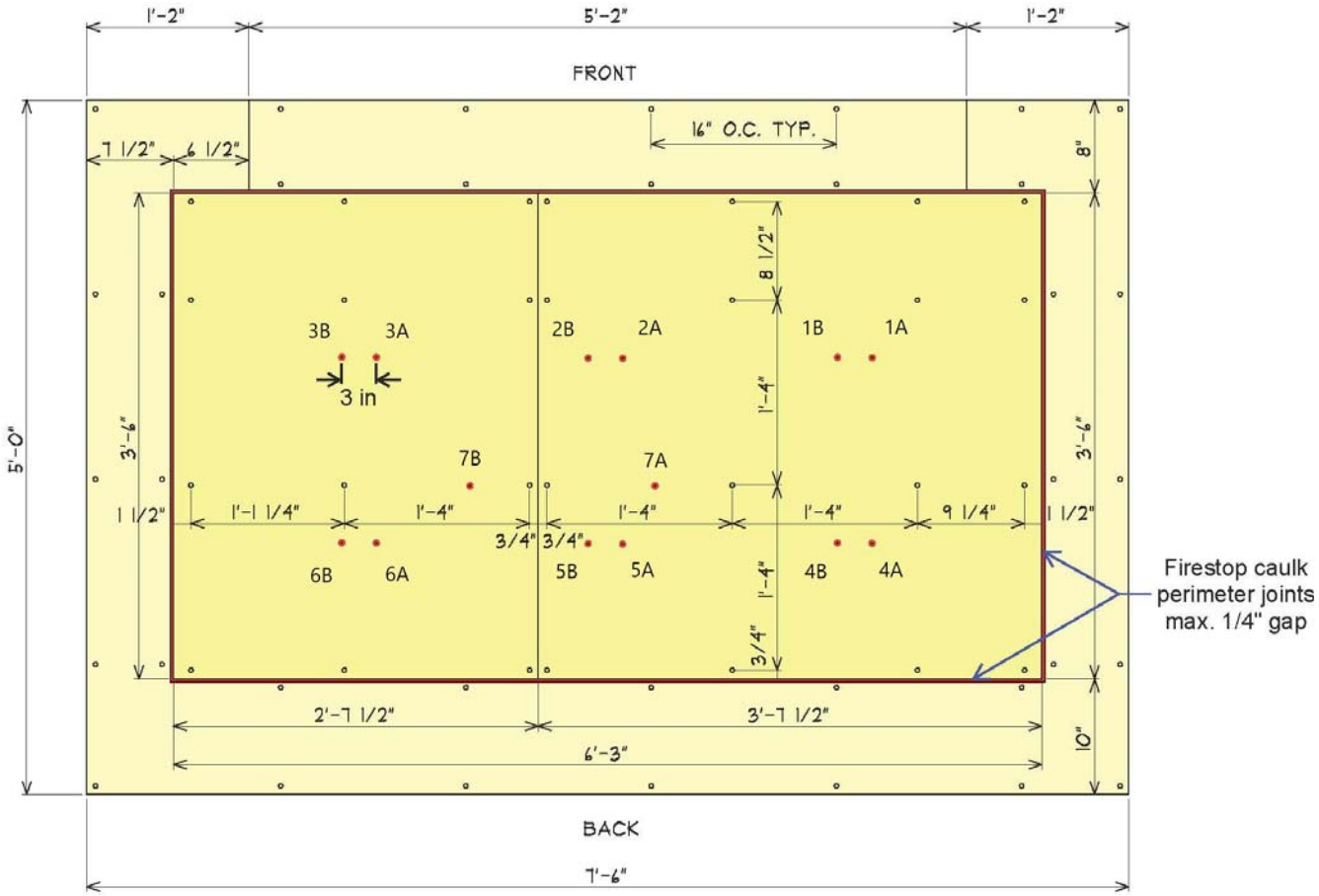

Figure 3: Gypsum board layout.

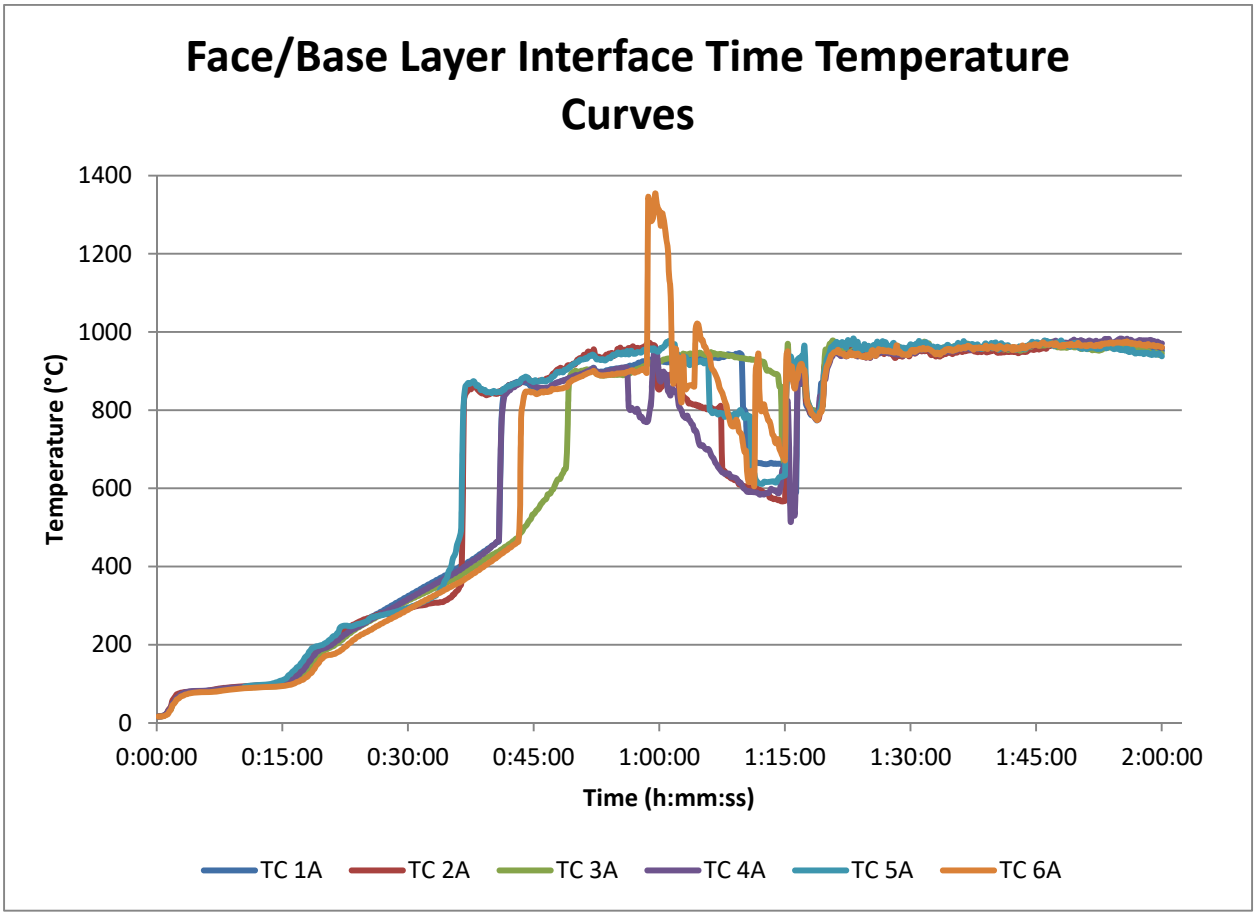

Figure 4: Interface Time Temperature Curves

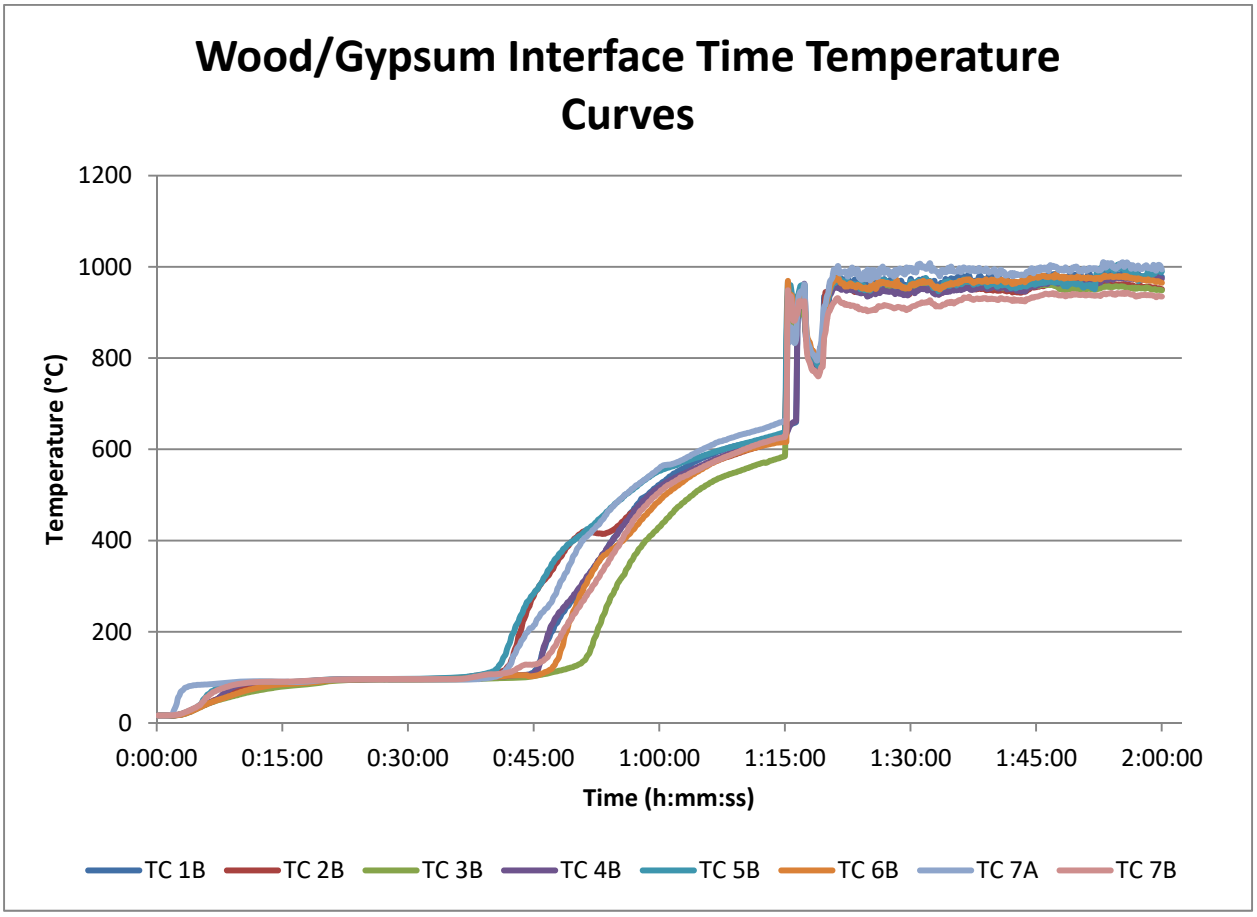

Figure 5: Interface Time Temperature Curves

APPENDIX B

Figure 6: The exposed side of the assembly after the installation of the base layer gypsum.

Figure 7: The exposed side of the assembly prior to the fire test.

Figure 8: The exposed side of the assembly at the end of the fire test.

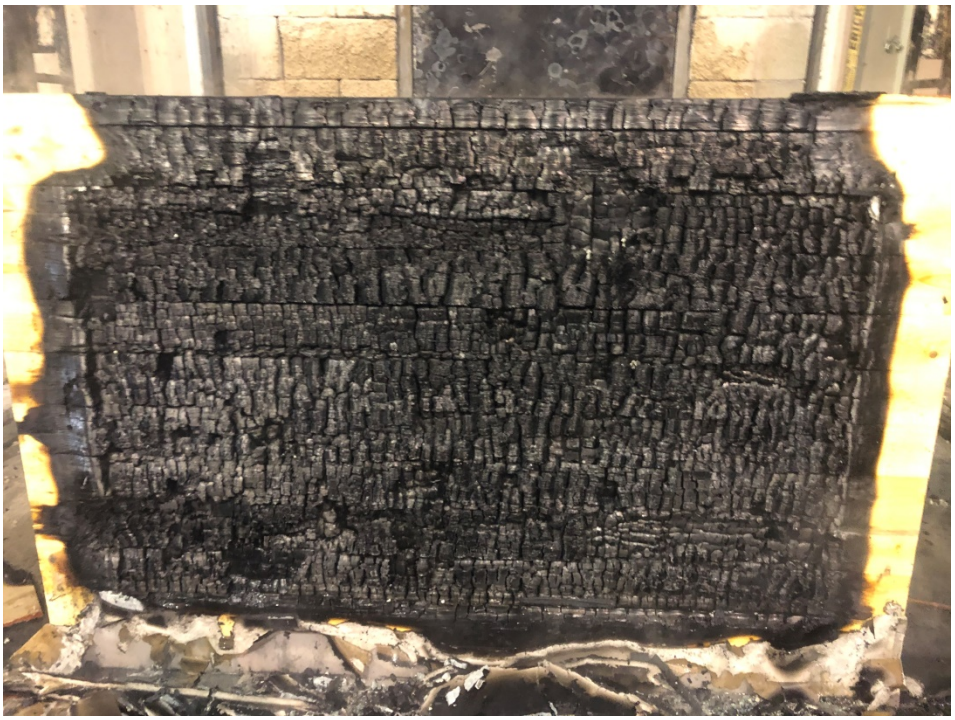

Figure 9: The exposed side of the assembly after being extinguished.

QAI LABORATORIES
CERTIFICATION TESTING INSPECTION

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Burnaby, B.C. V5J 5K5
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CLIENT: **GHL CONSULTANTS LTD.**
409 Granville St., Suite 950
Vancouver, BC
V6C 1T2

Test Report No: T1410-1C	Revision Date: March 9, 2020

SAMPLE ID: Cross Laminated Timber (CLT) 2-hour floor/ceiling assembly with CGC Type C gypsum board.

SAMPLING DETAIL: The GHL CLT panel was manufactured by Structurlam and the gypsum board was installed by QAI staff. The test assembly was not independently selected for testing.

DATE OF RECEIPT: Samples were received at QAI on March 5, 2020.

TESTING PERIOD: March 6, 2020.

AUTHORIZATION: QAI Test Proposal Number 20JL01281, signed and dated on February 12, 2020, by Andrew Harmsworth.

TEST PROCEDURE: Tested to the general conditions of the following test standard with the deviations found on page 5:

- CAN/ULC S101-14, *Standard Methods of Fire Endurance Tests of Building Construction and Materials* (CAN/ULC S101).

TEST RESULTS: The tested GHL CLT floor / ceiling assembly with CGC Type C gypsum board as detailed on page 3 of this report, achieved the results found on page 5 and 6 when tested to the general conditions of CAN/ULC S101 with the deviations found on page 5.

Prepared By

Scott Leduc
Project Manager

Signed for and on behalf of QAI Laboratories, Ltd.

Matt Lansdowne
VP of Operations

Table of Contents

Introduction:

This report documents the fire testing conducted by QAI Laboratories Ltd. for GHL of a CLT floor / ceiling assembly with CGC Type C gypsum board. The assembly was to the general conditions of CAN/ULC S101 on March 6, 2020.

Test Description:

Table 1: Test Assembly Description

COMPONENT	DESCRIPTION	
Floor/Ceiling Assembly	Overall Size:	2.29 m (90 in.) length x 1.52 m (59.85 in.) width x 176 mm (6.94 in.) thickness.
	Type:	Cross Laminated Timber (CLT) floor/ceiling assembly.
	Manufacturer:	Structurlam Mass Timber Corp.
	Grade:	PRG 320 grade V2M1.1
	Layers:	5-layers of cross laminated 1.38 in. by 5.31 in. lumber.
Gypsum Board 1	Manufacturer:	CGC
	Type:	Sheetrock Brand Firecode C Gypsum Panels.
	Thickness:	12.7 mm (1/2 in.)
	Dimensions:	Two layers of a 1.11 m (43-1/2 in.) by 1.02 m (40 in.) piece and a 0.80 m (31-1/2 in.) by 1.02 m (40 in.) piece. The joints are staggered.
	Fasteners:	No. 6 x 51 mm (2 in.) drywall screws were spaced 305 mm (12 in.) on center on the base layer. No. 6 x 51 mm (2 in.) drywall screws were spaced 305 mm (12 in.) on center on the face layer.

Test Apparatus:

The furnace used in the tests is a pilot-scale fire burning apparatus with interior dimensions of 1.78 m (70 in.) in height, 1.91 m (75 in.) in width, and 1.30 m (51 in.) in depth.

Temperatures within the furnace were monitored using four thermocouples. The temperatures are controlled by adjusting fuel to the furnace burners to conform to the time/temperature curve specified by the test standards. Temperature measurements are recorded by a Keithley 2750 data acquisition unit (ID# DMM1) which passes the readings to a computer for graphical display and storage.

14 thermocouples were placed through holes in the back of the test assembly until they hit the gypsum board layers. See Appendix A for detailed locations.

One pressure tap is installed along the longitudinal center line of the test assembly. The pressure tap is attached and monitored by Setra model 264 pressure transducers (ID# Pressure T3). The furnace pressure is controlled by adjusting a damper in the furnace exhaust stack.

Figure 1: Pilot-Scale Furnace

Test Conditions:

The GHL floor/ceiling assembly outlined on page 3 was supported by the walls of the furnace. A ceramic fiber gasket was used to maintain an air tight seal between the furnace and the floor/ceiling assembly.

The pressure of the furnace was monitored throughout the test. The pressure was continuously monitored using calibrated pressure transducers. After the first 5 minutes of the test the pressure was maintained at minimum of 0.01 in. water column 12 in. below the slab.

Prior to the fire endurance test the test assembly was placed on top of the furnace, the front panel was moved into place and the burners were ignited. The fire endurance test was initiated immediately after igniting the burners. The temperature inside the furnace was controlled to follow the standard time/temperature curve within the limits described in the test standard.

Deviation of the Test Standard:

The purpose of this test was to measure the char thickness formed on the exposed face of the CLT panel. The following requirements were not met.

1. The required sample size is 16.8 m^2.
2. The floor/ceiling assembly must be loaded.
3. The required thermocouples on the unexposed face were not used.

Test Results:

Observations

The following observations were taken over the duration of the fire test:

Table 2: Test Observations

Test Time (min)	Unexposed	Exposed
1:47		Ignition of the gypsum paper.
18:30		Gypsum board is beginning to sag at the joint.
31:37		Gypsum board corner released at the back of the joint.
55:42		Section of gypsum fell at the back left of the furnace.
59:43		Flaming at the joint near a fallen section.
63:42		A center section of the face layer has fallen.
65:45		A back right section of the face layer has fallen.
67:55		The left side section of the face layer has fallen.
68:00		The front right section of the face layer has fallen.
72:00		Heavy flaming and lots of cracks have formed.
91:00		A section of the base layer has fallen (not visible).
93:00		Another section of the base layer has fallen (not visible).
98:15		Another section of the base layer has fallen (not visible).
120:00	Test discontinued.	

Conclusions:

QAI performed testing to the general conditions of CAN/ULC S101 on a CLT floor/ceiling assembly with CGC Type C gypsum board.

The assembly was exposed to the furnace conditions for 2 hours. After the fire exposure the floor/ceiling assembly was removed from the furnace, extinguished and cut in four locations so that the char level can be measured. GHL staff measured and recorded the char depth of the assemblies.

APPENDIX A

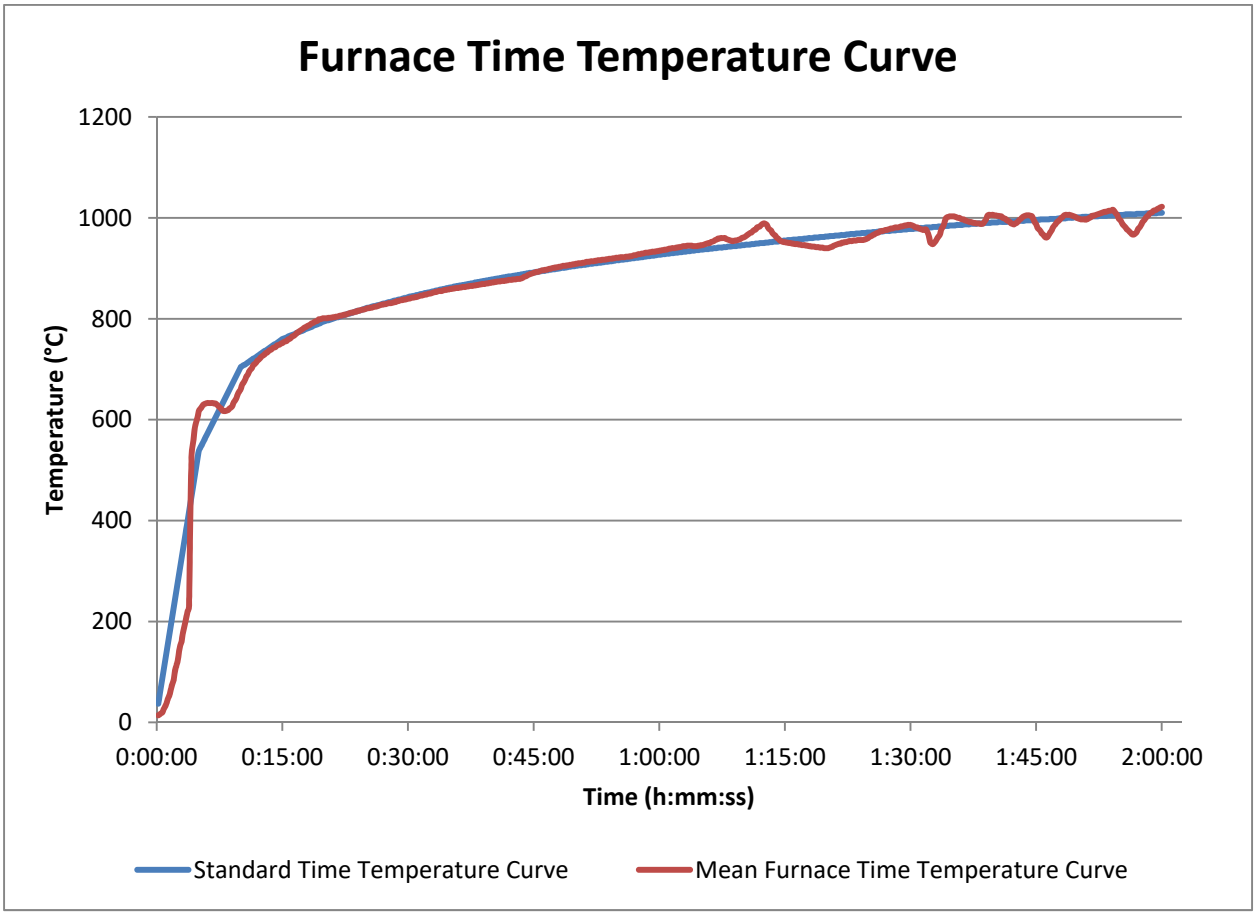


Figure 2: Time Temperature Curve

Thermocouple Locations

TC 1-6A – Located at the interface of the face layer and the base layer of the gypsum board.
TC 1-6B – Located at the interface of the base layer of the gypsum board and the wood.
TC 7A and 7B – Located at the interface of the base layer of the gypsum board and the wood at the joint locations.

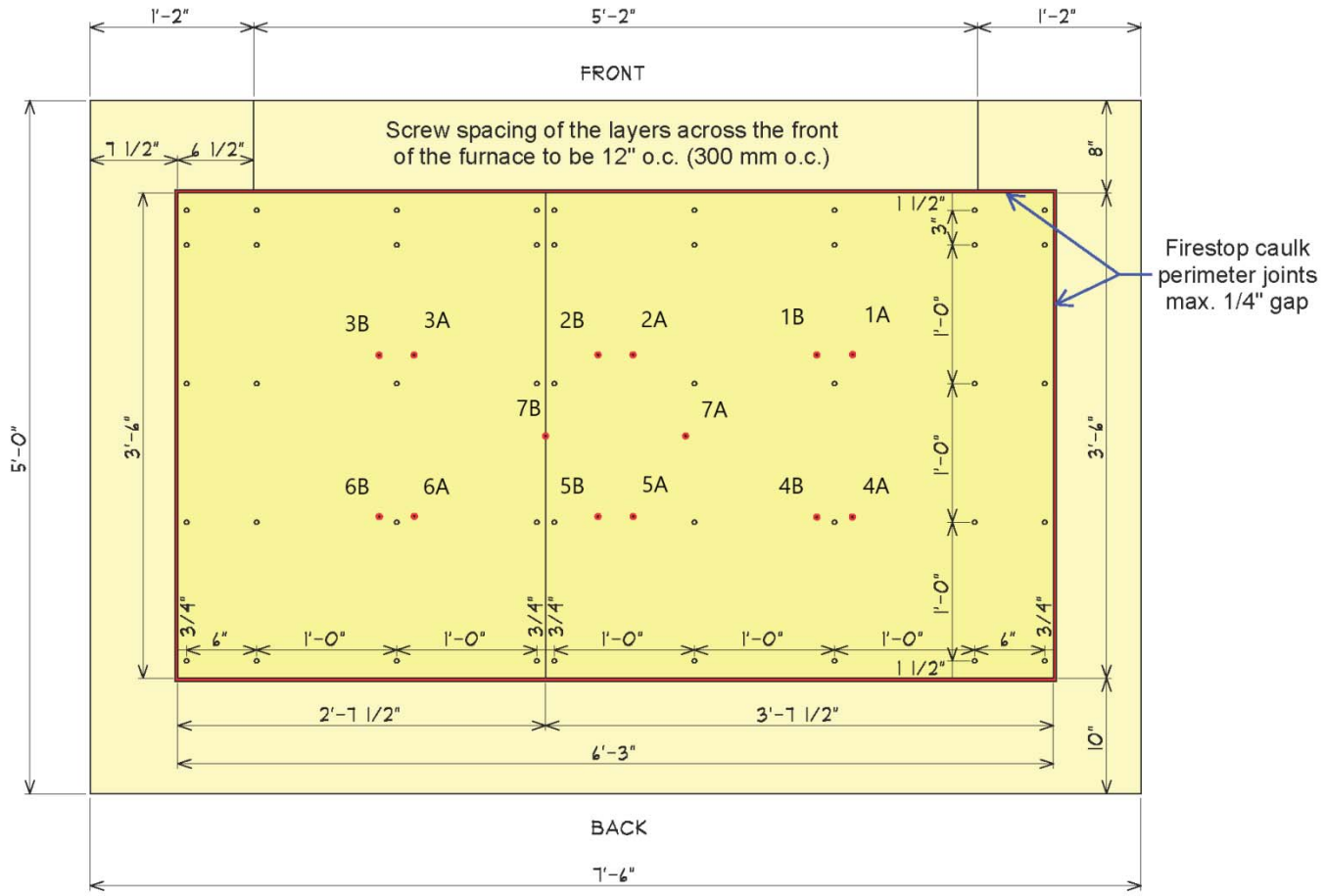


Figure 3: Gypsum board layout.

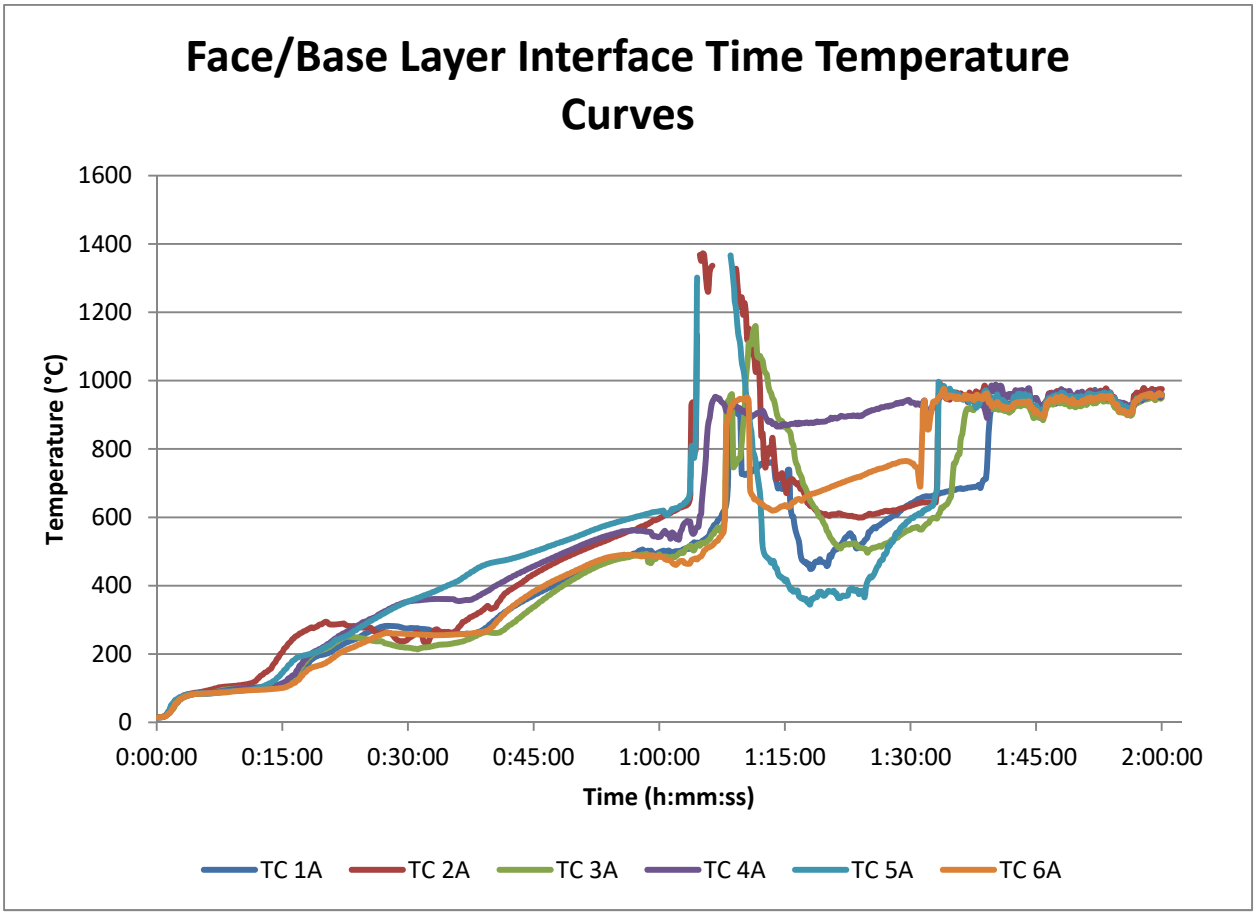


Figure 4: Interface Time Temperature Curves

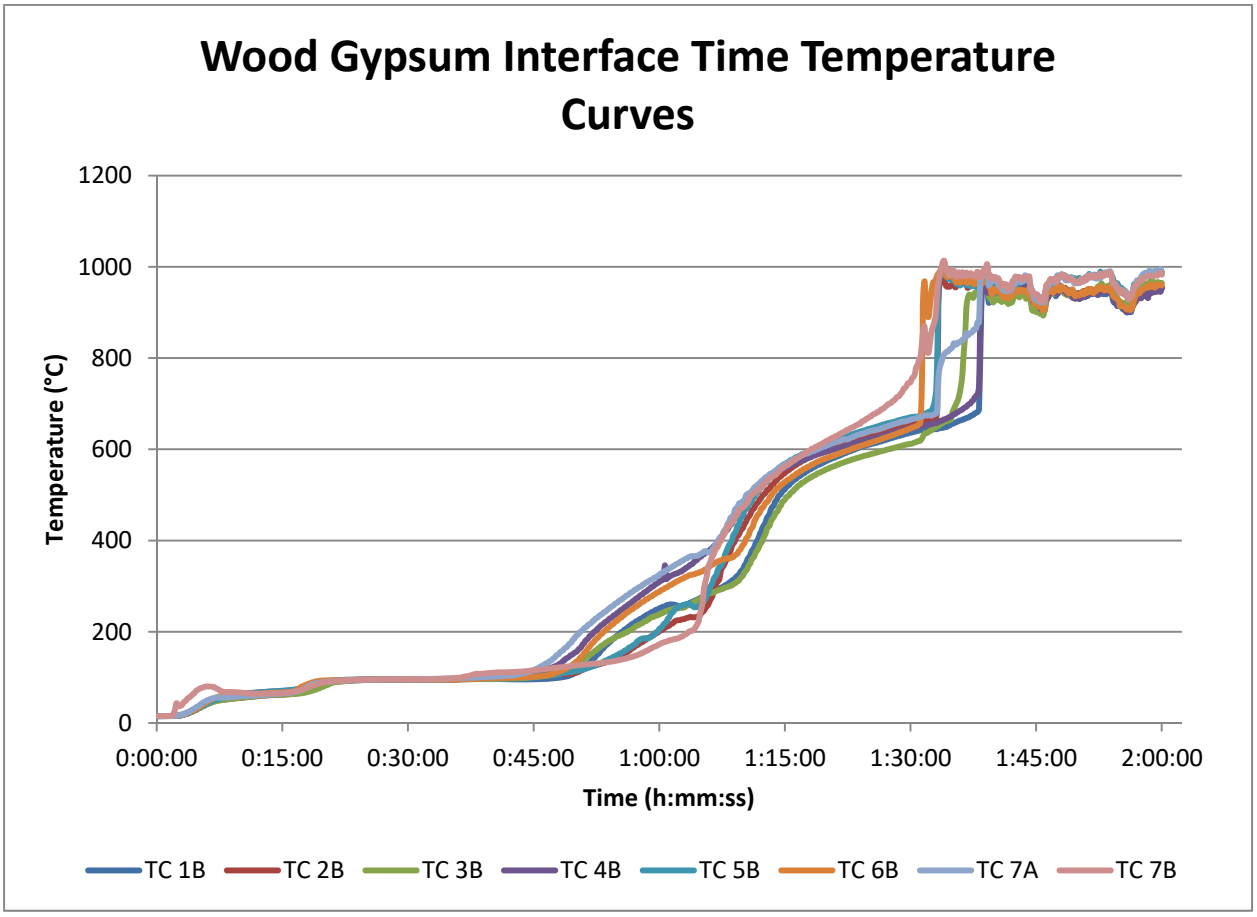


Figure 5: Interface Time Temperature Curves

APPENDIX B

Figure 6: The exposed side of the assembly prior to the installation of the base layer gypsum.

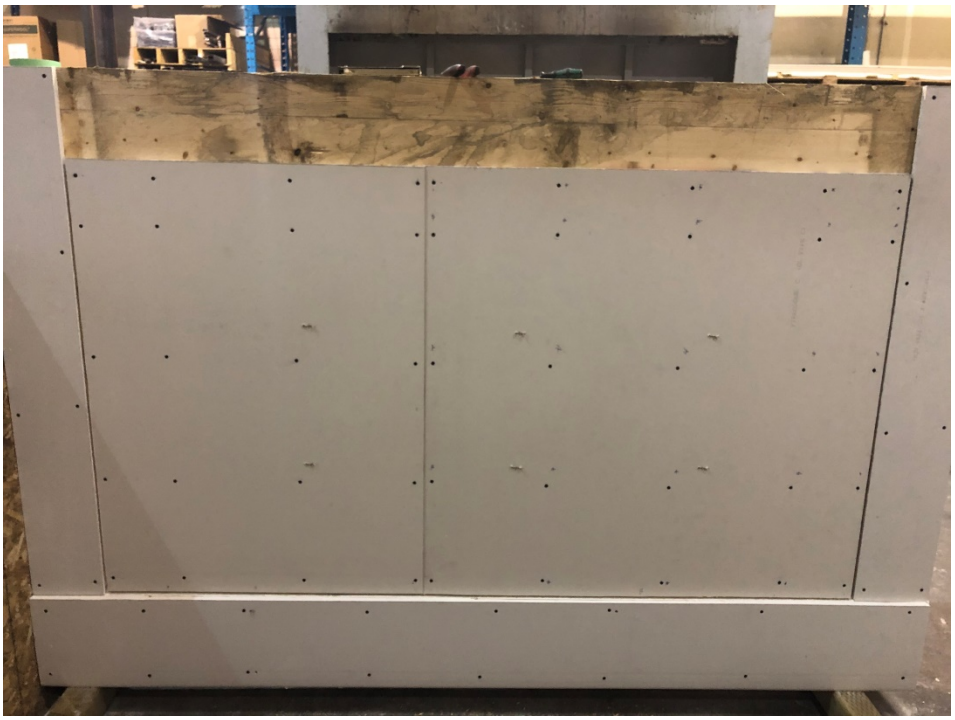


Figure 7: The exposed side of the assembly after the installation of the base layer.

Figure 8: The exposed side of the assembly prior to the fire test.

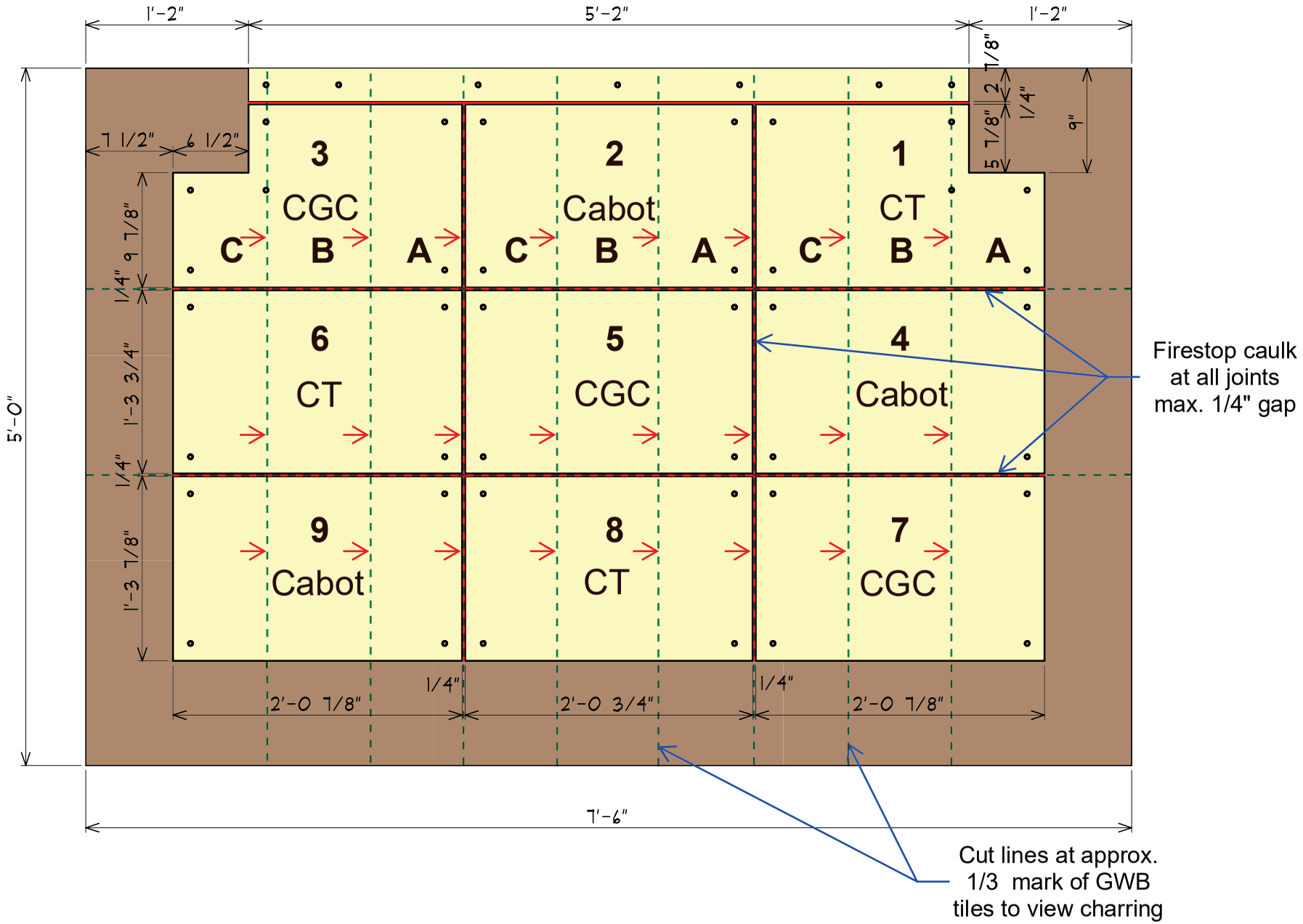
Figure 9: The exposed side of the assembly after the fire test.

Appendix B

Test Assembly Layout

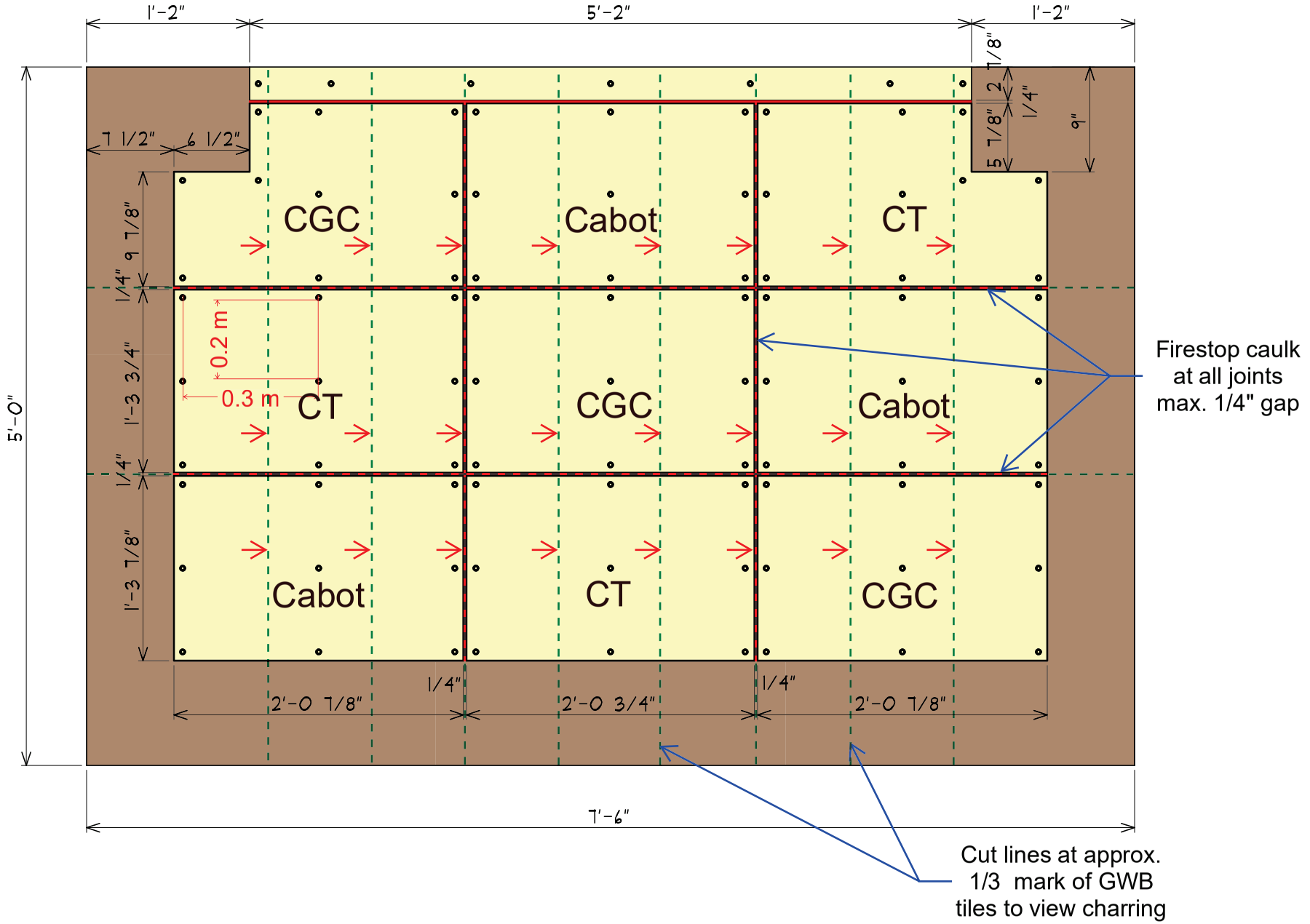
BASE LAYER GWB - Test 1

W-Type Screws
Min. Length = 1-1/4" (32 mm)
Max. Spacing = 24" o.c. (600 mm o.c.)
Distance from edge = 1-1/2" (38 mm)



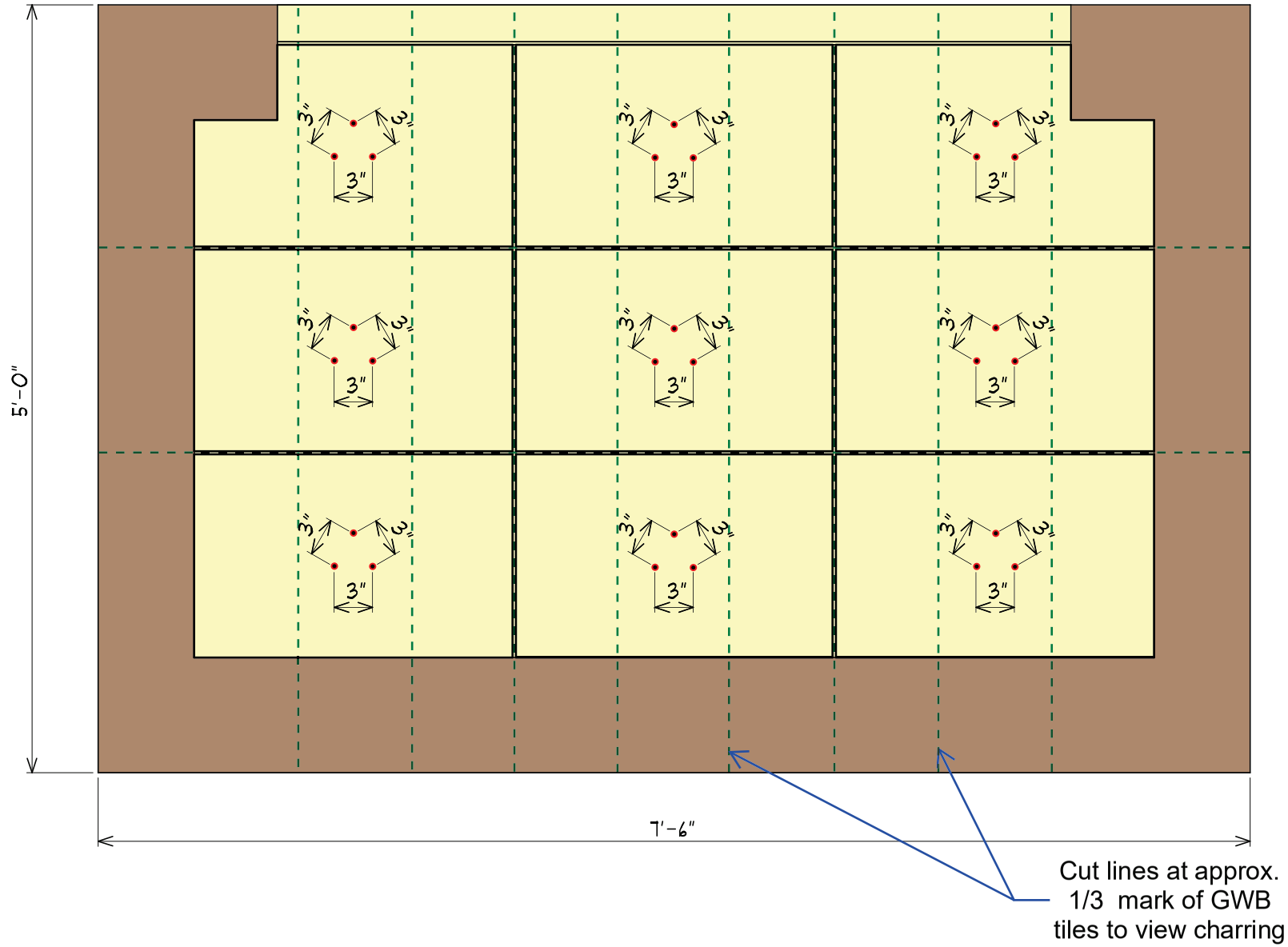
FACE LAYER GWB - Test 1

W-Type Screws
Min. Length = 1-3/4" (45 mm)
Max. Spacing = 12" o.c. (300 mm o.c.)
Distance from edge = 3/4" (20 mm)



TC HOLE LOCATIONS - Test 1

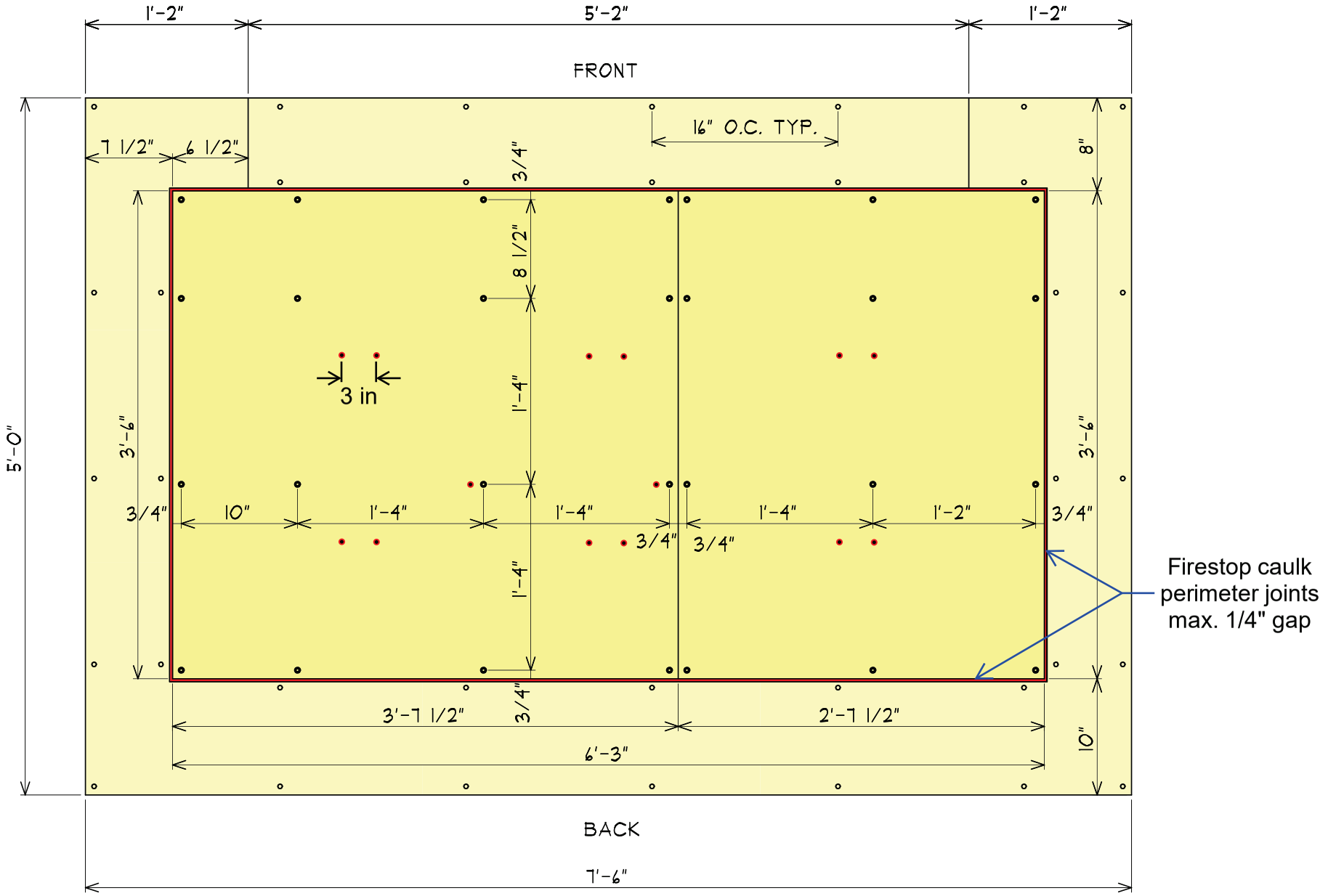
Diameter = 1/8"
Min. 3" apart, centered on GWB tile
1. Drill 2 holes through CLT,
2. Fasten GWB base layer,
3. Drill 1 hole through CLT and base GWB,
4. Fasten GWB face layer.



BASE LAYER GWB
Test 2

W-Type Screws ∘
Min. Length = 1-1/4" (32 mm)
Max. Spacing = 16" o.c. (400 mm o.c.)
Distance from edge = 3/4" (20 mm)

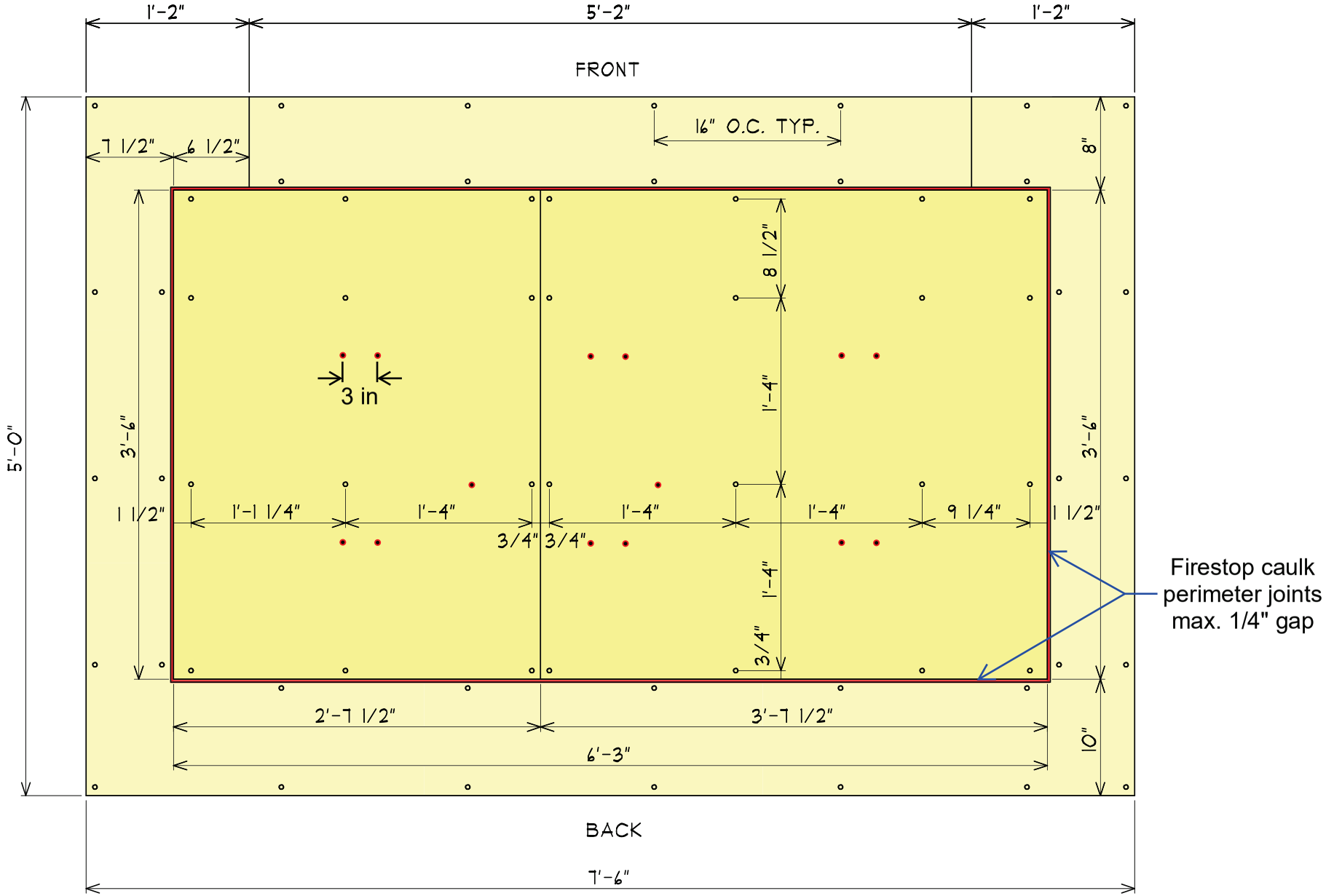
TC Holes •
Diameter = 1/8"
In pairs 3" apart at 1/3 (6 locations)
Singles near screws (2 locations)



FACE LAYER GWB
Test 2

W-Type Screws ∘
Min. Length = 1-3/4" (45 mm)
Max. Spacing = 16" o.c. (400 mm o.c.)
Distance from edge = 1-1/2" (38 mm)

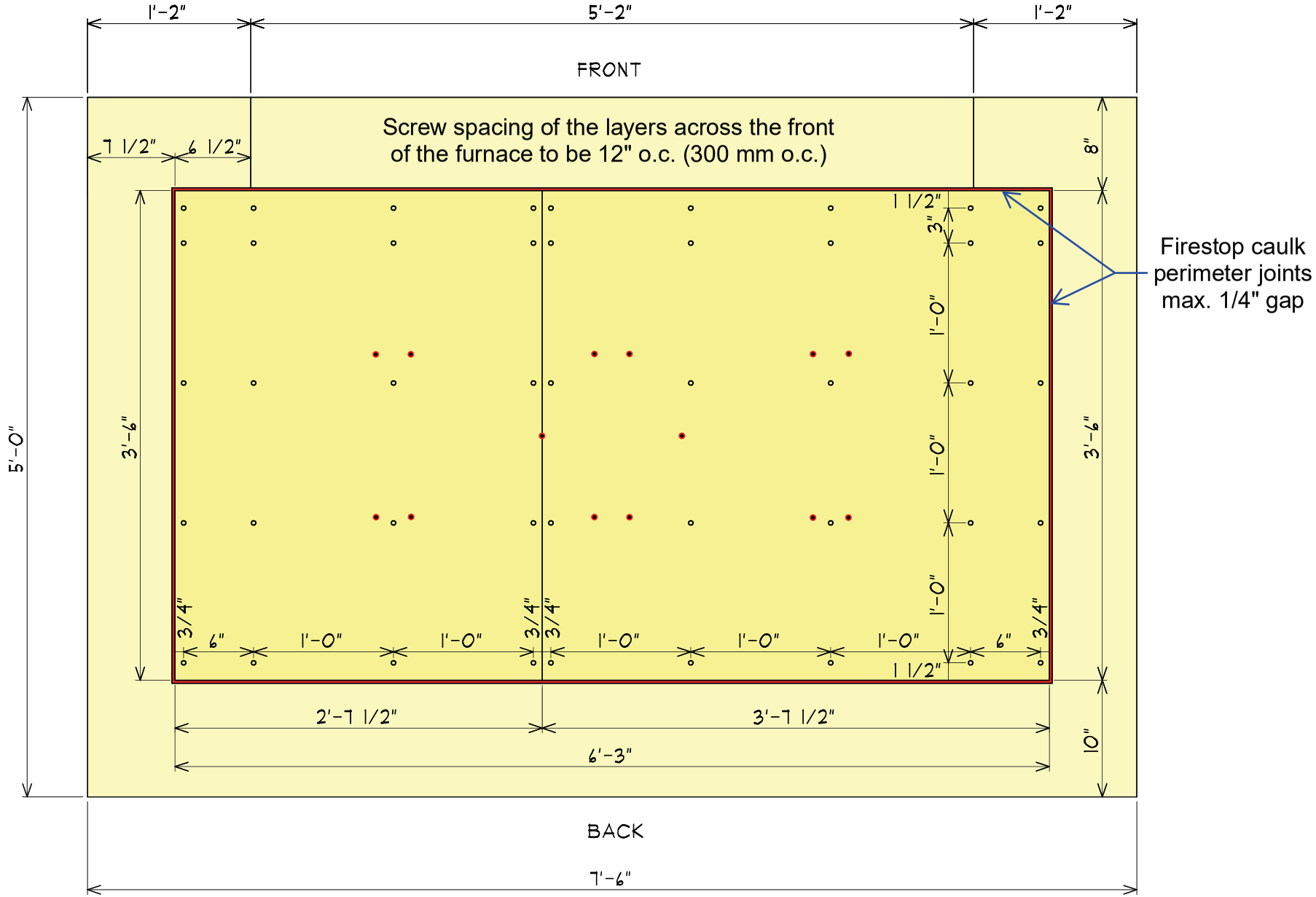
TC Holes •
Diameter = 1/8"
In pairs 3" apart at 1/3 (6 locations)
Singles near screws (2 locations)



BASE LAYER GWB
Test 3

W-Type Screws ∘
Min. Length = 2" (50 mm)
Max. Spacing = 12" o.c. (300 mm o.c.)
Distance from edge = 1-1/2" (38 mm)

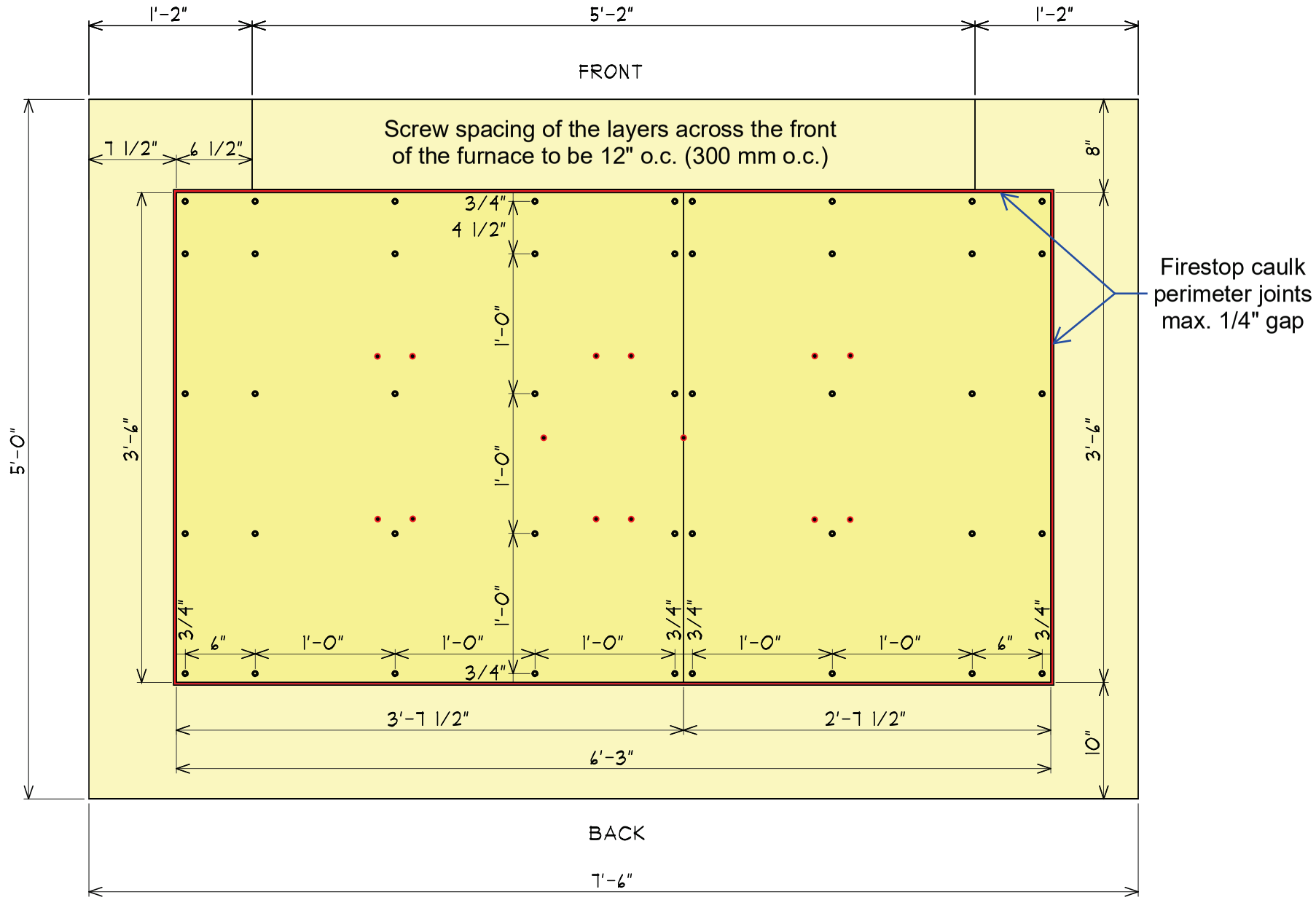
TC Holes •
Diameter = 1/8"
In pairs 3" apart at 1/3 (6 locations)
Singles centered on joints (2 locations)



FACE LAYER GWB
Test 3

W-Type Screws ∘
Min. Length = 2" (50 mm)
Max. Spacing = 12" o.c. (300 mm o.c.)
Distance from edge = 3/4" (20 mm)

TC Holes •
Diameter = 1/8"
In pairs 3" apart at 1/3 (6 locations)
Singles centered on joints (2 locations)



TC HOLES
Test 3

TC Holes •
Diameter = 1/8"
In pairs 3" apart at 1/3 short dimension & 1/4 long dimension (1A, 1B, 2A... 6B, 6B)
Singles centered on joint locations (7A and 7B)