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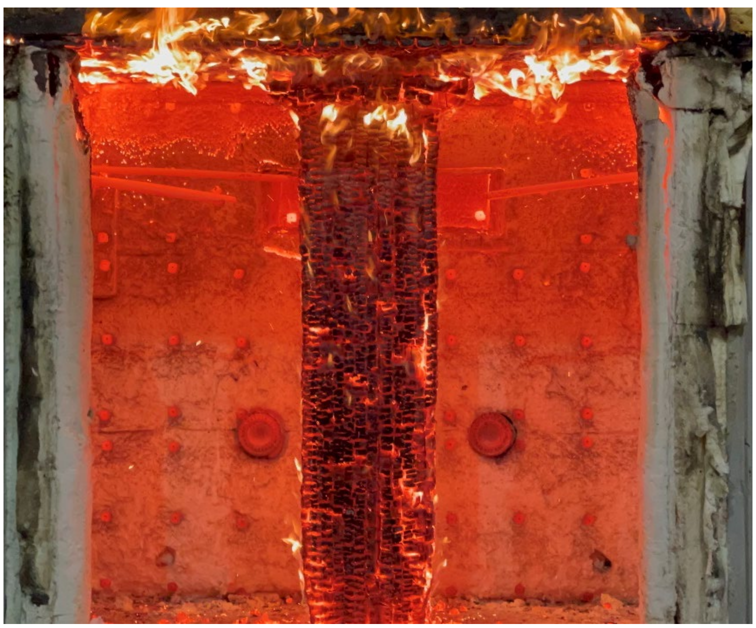
TECHNICAL ANALYSIS AND SUMMARY
PILOT SCALE DEMONSTRATIONS

For

NATURAL RESOURCES CANADA
GREEN CONSTRUCTION THROUGH WOOD PROGRAM



Prepared for

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

GHL File 8000.03

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Revision	**Date**	**Pages Revised**	**Description of the Revision**
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* Limitation of Liability *

This report reflects GHL's observations of the demonstration burns, and reasonable efforts have been made to confirm accuracy of observations. GHL is not responsible for any use or interpretation of the report by others.

TABLE OF CONTENTS

Page

APPENDICES

GHL Consultants Ltd thanks Natural Resources Canada and its Green Construction Through Wood Program for the significant financial support, Kalesnikoff for their encouragement and support in-kind, and QAI Laboratories, George Third & Son, and Fast + Epp for their assistance.

1.0 INTRODUCTION

GHL CONSULTANTS LTD (GHL) has prepared this report to document the testing and technical analysis of the fire performance in steel-timber connection under the Green Construction through Wood program and Natural Resources Canada's requirements.

1.1 Background

With the concerns around the climate change and healthy environment and economy, the Government of Canada is focusing on emission reductions to reach net zero by 2050. The building sector is an important contributor, and various levels of government in Canada have set out programming to meet the ambitious targets by 2050.

Mass timber, given recent research, has demonstrated its strong benefit in construction sustainability, as well as achieving low carbon emissions in the construction industry. With the increased national wide interest in mass timber construction, it has become significant to expand current research into the fire performance of mass timber, in order to develop appropriate and affordable mass timber design. One area that urgently requires investigation is the integrity of exposed steel connections, due to the lack of the understanding and technical data. As a result, the state-of-the-art structural connection design for mass timber construction incorporates gypsum board protection around the steel connections, resulting in increased material usage and cost. To maintain sustainability of mass timber design and to expand technical research into this unknown area, the following fire test program was proposed.

1.2 Scope and Objectives

For this project, GHL coordinated and witnessed five tests of typical steel-timber connections for CLT panel on post system in a pilot-scale fire test apparatus under CAN/ULC-S101-14, *"Standard Methods Of Fire Endurance Tests of building Construction And Materials"* 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 better understand the thermal performance and obtain fundamental thermal data of the steel-timber connection with and without protection to provide baseline for typical structural detail.

2. To assess the thermal performance and integrity of the design and explore potential optimized protection methodology to maintain the sustainability of the mass timber construction.

3. To provide technical information to assist in development of Code Change proposal to the National Building and Fire Codes for mass timber construction aiming for Net-Zero Model Code.

4. To educate relevant members in industry both fire performance and structural integrity, including engineers in training, professional members, building officials, firefighting responders and practical researchers in fire performance of mass timber through witnessing the fire tests.

5. To provide opportunity for Building and Fire Department officials in the Greater Vancouver Area authorities to witness fire tests and develop confidence in mass timber.

Fundamentally, the intent of this project is to obtain and assess the technical data steel-timber connection due to the lack of the information available. In addition, it is also to attempt to provide a baseline of steel-timber design and to inform future structural design guidelines.

It is noted that the research project was developed with a limited budget and timeline in a pilot scale furnace and, as such, it was not possible to conform directly with CAN/ULC-S101-14.

2.0 METHODOLOGY

Five assemblies consisting of typical CLT panel on post systems exposing to the standard time-temperature curve of CAN/ULC-S101-14 were carried out for this project. We have reviewed and are in general agreement with the QAI reports T1410-2a, T1410-2b, T1410-2c, T1410-2d and T1410-2f, copies attached in *Appendix A*. The durations, fire scenarios conditions, detailed thermocouple locations, and results are available in the reports in *Appendix A*.

2.1 Test Specimen

The five test specimens of this project are based on the two typical CLT panels on post systems: supported either by steel column or glulam column, with or without protection.

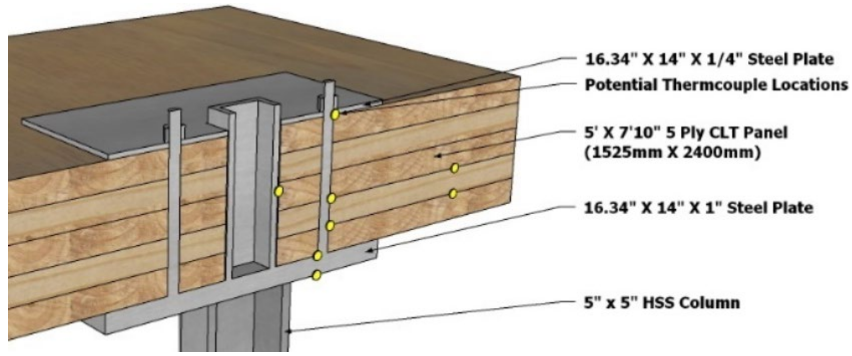
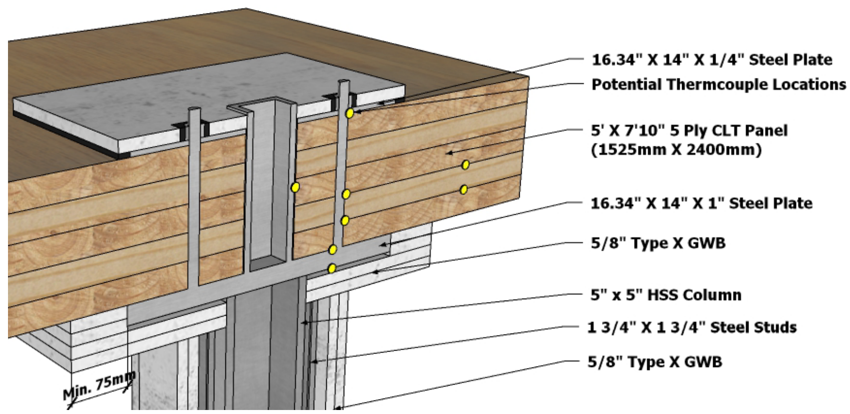
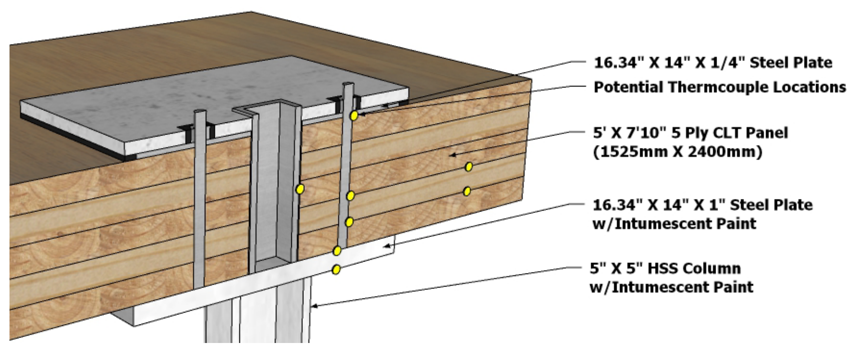
All specimens consist of a 5ply (175mm) CLT panel provided by Kalensikoff conforming to ANSI/APA PRG 320 (2019 Edition). These panels are approximately 2.2m long by 1.5m wide in size to sit on top of the test furnace. In addition, to represent the point-support condition, all panels are cut into four pieces at centre where the panel is supported by column.

CLT Supported by Steel Column

The steel column used in three of the specimens were 127mm by 127mm by 6mm thick. The columns were of hollow structural steel (HSS) with 350W in steel grade supplied by George Third & Son. A steel plate with four threaded rods was welded to the top of the steel column. Each steel plate was of 415mm by 355mm by 25mm thick in size. The threaded rods were 16mm in diameter spaced approximately 90mm from the edge of the plate. The centre of the steel plate also included a steel tube of 76mm by 76mm by 8mm in size to fit into the CLT panel. To secure the panel and the column, another 415mm by 355mm by 6mm thick steel plate was placed on the top of the panel with rods mechanically secured to tighten the panel to the column.

It is noted that one of the test specimens was fully exposed without any protection on the steel component for baseline study purposes, while the two other specimens were provided with either GWB protection or intumescent paint as noted in Table 1 below.

Table 1. Summary of the Specimen with Steel Column Support

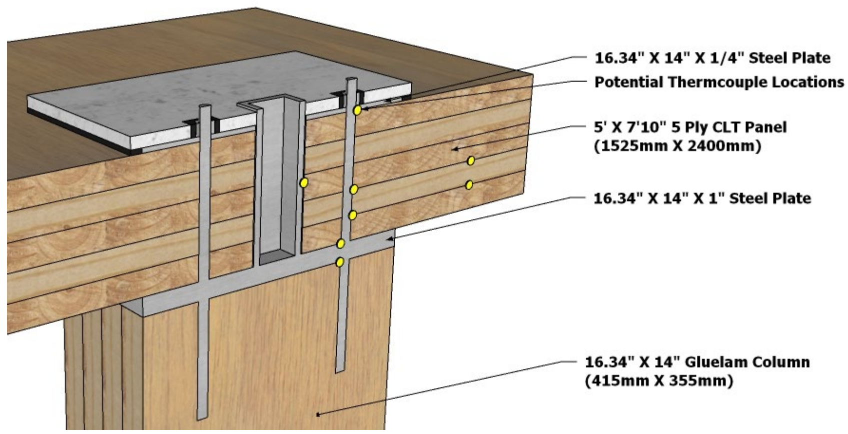
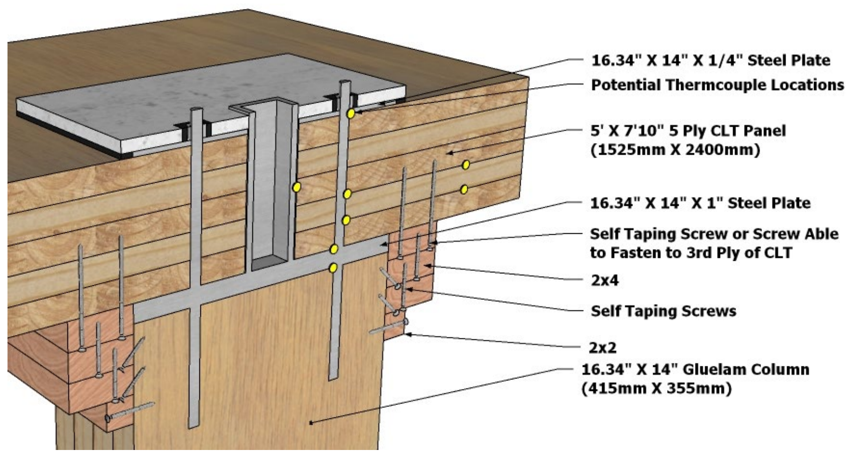
Specimen	Protection	Sketchup
Specimen 1 Exposed Steel Column	None	
Specimen 2 GWB Protected Steel Column	2 layers of 16mm Type X GWB	
Specimen 3 Intumescent Protected Steel Column	Intumescent paint conforming to ULC listed design for 2h fire separation	

CLT Supported by Glulam Column

The two specimens supported by glulam columns were using the similar set up, except the HSS column was replaced by 413mm by 355mm glulam column provided by Kaleniskoff. To connect the column to the CLT panel, the steel plate in these two specimens includes four threaded rods of same size and spacing on the bottom side and were epoxied in column with adhesive. The mechanism to fasten the plate to the panel remained same as steel column specimens.

In addition, wood cover following Technical Report No.10, "*Calculating the Fire Resistance of Wood Members and Assemblies"* was provided to Specimen 5 as comparison to explore potential optimization in protection mechanism.

Table 2. Summary of the Specimen with Steel-Glulam Column Support

Specimen	Protection	Sketchup
Specimen 4 Exposed Steel-Glulam Column	None	
Specimen 5 Wood Protected Steel - Glulam Column	Wood Cover conforming to Technical Report No.10	

2.2 Limited Loading

As noted previously, the furnace used in this project is a pilot-scale apparatus; as such, reaction frame with structural loading was not included in this fire test. However, four concrete blocks were placed on the top of the CLT panel around centre, aiming to provide some loading to study the impact of the localized crushing of CLT char at the steel interface.

Figure 1. Concrete blocks on top of panel

2.3 Data Collection and Recording

The primary objective of this project is to obtain thermal data at the steel-timber interface. In addition, it is also intended to share the testing condition for educational purposes. To serve these purposes, data collection and video recording were conducted.

Thermocouple Locations

Eight thermocouples were placed inside the test specimens as shown in Figure 2. TC 1 to TC 3, TC 5, and TC 7 to 8 measured the temperature at steel-timber interface. TC4 and TC6 were placed at the glulam of the first and second ply from the exposed side and 500mm from the edge of the panel as a baseline comparison to the temperature measurement at the steel-timber interface of TC3 and TC5, respectively. These thermocouples were installed by QAI Laboratories Inc.

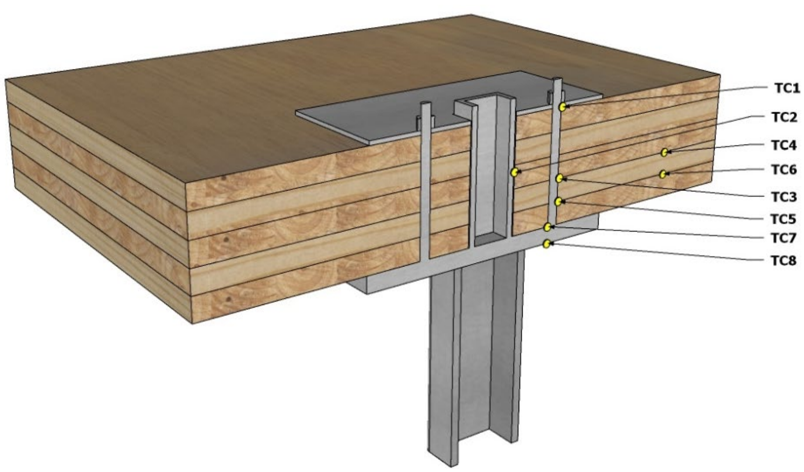


Figure 2. Thermocouple location illustration on typical set up

Video Recording and Live Streaming

As one of the purposes of the project is to provide an opportunity for appropriate stakeholders such as regulatory bodies and practical researchers to better understand the fire performance of steel-timber interface, videos of each fire scenario were recorded. Fixed cameras with live streaming were also broadcasting to appropriate stakeholders.

3.0 TEST OBSERVATION AND RESULT ANALYSIS

For this project, all test specimens were exposed to the fire endurance time/temperature curve as specified in CAN/ULC S101-14 standard. The following subsection includes the discussion on the observation and preliminary analysis of the raw data obtained.

3.1 Specific Key Test Observations

The test specimens used in this project were following a similar point-support system; that is, to have either a steel column or glulam column supporting the CLT panel with associated steel plate and threaded rod and centre tubing to secure in place. In general, after the test started, combustible materials within the furnace were ignited. Charring was observed at the surface of the mass timber elements and no flames were observed on the unexposed side of the panel except for Specimen 1. This will be discussed in the following sections.

The detailed test observations were documented by QAI Laboratories report in *Appendix A*. Key observations specific to each test was summarized in Table 3:

Table 3. Key Observations Specific to Each Test

Specimen	Protection	Key Observation
Specimen 1 Exposed Steel Column	Exposed Side: No Protection Unexposed Side: No Protection	Flame observed on the unexposed side of the CLT panel through the centre tubing area at approximately 50min.
Specimen 2 GWB Protected Steel Column	Exposed Side: 2 layers of 16mm Type X GWB Unexposed Side: 1 layer of 16mm Type X GWB	Nothing significant
Specimen 3 Intumescent Protected Steel Column	Exposed Side: Intumescent paint conforming to ULC listed design for 2h fire separation Unexposed Side: 1 layer of 16mm Type X GWB	Intumescent paint expanded at around 5min. Intumescent paint start to detach from horizontal steel component at 60min. Full exposure of the steel plate inside furnance at 75min.

Specimen	Protection	Key Observation
Specimen 4 Exposed Steel-Glulam Column	Exposed Side: No Protection Unexposed Side: 1 layer of 16mm Type X GWB	Significant radiation coming from the combustion of the mass timber elements at the beginning of the fire test. Furnance was controlled to follow ULC-S101 temperature curve. Significant turbulant flame flow observed within furnance throughout test.
Specimen 5 Wood Protected Steel -Glulam Column	Exposed Side: Wood Cover conforming to TR#10 Unexposed Side: 1 layer of 16mm Type X GWB	Significant radiation coming from the combustion of the mass timber elements at the beginning of the fire test. Furnance was controlled to follow ULC-S101 temperature curve. Significant turbulant flame flow observed within furnance throughout test.

Specimen 1

Specimen 1 was CLT panel supported by exposed steel column without any protection. It is intended to obtain thermal data of the steel-timber interface to understand the fire performance of this typical structural system and to establish the baseline in the interest of public safety and low carbon initiative.

During the test, open flame was observed on the unexposed side of the panel near the centre steel tubing area at approximately 50min after the test started, as shown in Figure 3. Review of the temperature measurement at TC 2 and TC 3 indicated that there was a temperature differential at the steel-timber interface at the centre tubing area compared with the one adjacent threaded rod. This increase may have resulted from the larger air gap between the centre tube and timber panel due to the hand fabrication of the panels by trades at field. The edges of panels could not tightly fit with the steel component as illustrated in Figure 4. After consulting with industry partners, it is noted that the panel would typically be prepared by automatic fabrication such as CNC system in factory. Therefore, the air gap on an actual construction site may not be as significant as the ones prepared for this test. It is in our opinion that the tested condition with large air gap presents a conservative scenario with respect to the charring and thermal performance.

It is noted that the perimeter of the steel components on the unexposed side was fire caulked during the test to extinguish the flame during the test and minimize further burning. Further, to minimize the potential open flame situation, the remainder of the test specimens were prepared with caulking and Type X gypsum board on the unexposed side.

Figure 3. Photo of the open flame at centre of the panel on the unexposed side

Figure 4. Photos of the panel edge after field fabrication by trades

Specimen 3

The exposed steel components in this specimen were provided with a ULC listed 2h rated intumescent paint following appropriate application. It was expected that this design would perform similar to other typical 2h listed design. The paint started to expand in the early stages of the fire test at around 5min. At approximately 20min, significant flame was observed at some of the expanded locations. Later, cracks appeared where flame was observed, and paint started to deform and lost its ability to remain in place. At approximately 70min, the bottom of the steel plate was fully exposed, as shown in Figure 5. This detachment of the intumescent paint was unexpected, as the listed design was intended for 2h application. After this test, we consulted with several industry partners on this situation; it is unknown what contributed to the detachment of the paint.

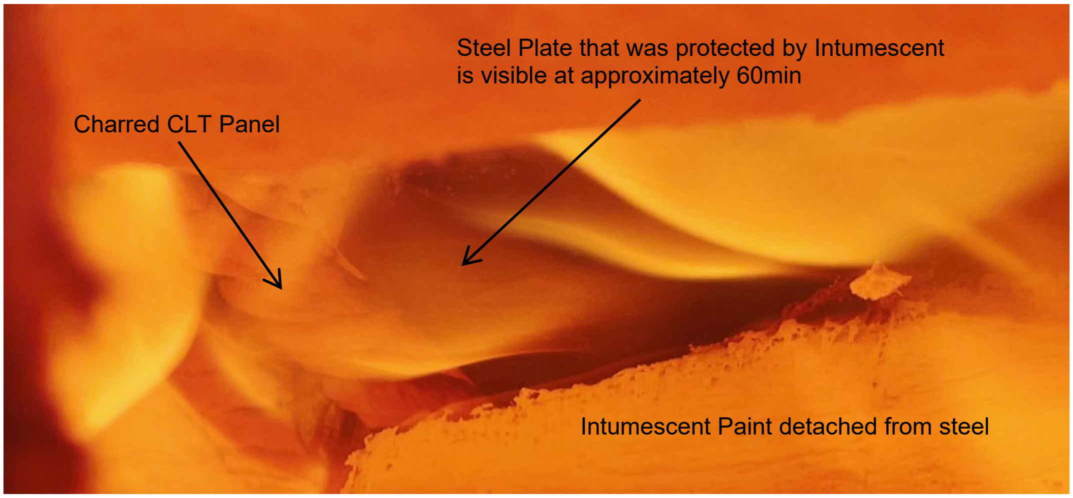


Figure 5. Screen shot of specimen 3 video illustrating the exposed steel component

Specimens 4 and 5

At the beginning of both tests with Specimens 4 and 5, significant flame and temperature rise were observed. This comes from the large mass timber surface area which contributed to the combustible fuel load available in the furnace. In both tests, significant turbulent flow of hot gasses were observed, especially at the boundary of the furnace. This turbulent flow may be as a result of the pilot scale furnace condition with significant temperature rise and continuous heat flux contributed by the combustible materials within the furnace. However, the charring at the steel-timber interfaces of measured locations were not significantly impacted as noted later in this report.

It is significant that furnace temperatures for tests 4 and 5 exceeded the standard fire test curve despite efforts to control the gas supply, likely due to the increased amount of burning exposed timber compared to the other tests and the small furnace size. These results do not necessarily represent the real fire performance of the mass timber construction.

3.2 Temperature Rise

Based on the temperature measurements obtained during this test, Table 4 summarizes the time when the critical steel failure temperature of 538C was reached. As a reference, an unexposed steel plate of similar size used in the tests would reach 538C at approximately 27min calculated using Equation 53.21 from the SFPE Handbook. Similarly char of wood is considered to begin at approximately 270C.

Table 4. Time to Reach 538C at Steel-Timber Interfaces

	TC1	TC2	TC3	TC5	TC7	TC8
Location	Threaded Rod and unexposed Timber	Steel Tube and Timber at 3rd Ply	Threaded Rod and Timber of 2nd glue line from exposed side	Threaded Rod and Timber of 1st glue line from exposed side	Steel Plate and Timber panel	Exposed Steel Plate as reference
Specimen 1	N/A	78min	79min	46min	27min	14min
Specimen 2	N/A	N/A	N/A	N/A	N/A	48min
Specimen 3	N/A	N/A	N/A	104min	80min	59min
Specimen 4	N/A	109min	N/A	N/A	83min	60min
Specimen 5	N/A	N/A	N/A	N/A	N/A	N/A

* N/A – did not reach 538C during test.

Based on the temperature measurement, Specimen 5, where the edge of the steel plate is protected by timber with a glulam column, has a similar and slightly better performance among all tests. The temperature did not exceed 538C at all steel-timber interfaces throughout the entire test period which is even better than the gypsum protected steel column system. This is significant that, although extra combustible materials (wood covers and glulam columns) were introduced, these did not contribute to the heat transfer between the steel and timber components.

However, it is significant to note that steel-timber interfaces at first glue line of Specimen 1 did not reach 538C until at least 46min after the fire started. This is also approximately 20min after the steel plate on the unexposed side reached the critical temperature. When comparing the time to reach 538C at different glue lines between the threaded rod and timber interface, it is noted that there was an approximately 33min delay at the second glue line. These delays demonstrate the performance of the mass timber in absorbing the heat which provides good fire protection to metal connections. Meanwhile, the heat conduction through the steel-timber interface did not appear to significantly impact the charring of the mass timber. TC6, which was located at the first glue line from the exposed side reached 270C, the critical timber temperature at 56min. This is equivalent to a char rate of 0.625mm/min which is slightly below the char rate of 0.65mm/min recognized by Annex B of CSA 086, *"Engineering Design in Wood"*. The char rate analysis is further assessed in the following section.

3.3 Char Rate Analysis

To quantitatively study the fire performance of the steel-timber interfaces, a char rate assessment was conducted on all specimens. Review of literature indicates that the degradation resulting from the char can be expressed as 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:

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

Where β_0 = one-dimensional charring rate, mm/min
D = original thickness of tested CLT panel prior to fire tests, 175mm
d = remaining thickness of tested CLT panel after fire tests, mm
t = time of the fire test, 120min

After the fire test, the panels were removed from the furnace and wetted by hand hose to suppress any remaining flame for additional charring. After complete cool down, CLT panels were removed from the supporting columns and disassembled back to the original four individual pieces. The remaining thickness of these panels were measured at every 100mm interval from centre line to study impact of the exposed steel component on the char rate of timber panel.

It is noted that the first measurement, which is 100mm from the centre line of the panel, was within the timber space covered by the steel plate, as shown in Figures 6 and 7. The average char rate at these steel-timber interfaces are included in Table 5.

Table 5. Average Char Rate measured at 100mm Interval from Centre, mm/min

	100mm Within Steel-Timber Interface	**200mm** Edge of Steel-Timber Interface	**300mm**	**400mm**	**500mm**
Specimen 1	0.74	0.6	0.61	0.58	0.58
Specimen 2	~0	~0	0.67	0.68	0.65
Specimen 3	0.43	0.5	0.61	0.58	0.59
Specimen 4	0.58	0.58	0.66	0.64	0.61
Specimen 5	0.2	0.54	0.75	0.72	0.7

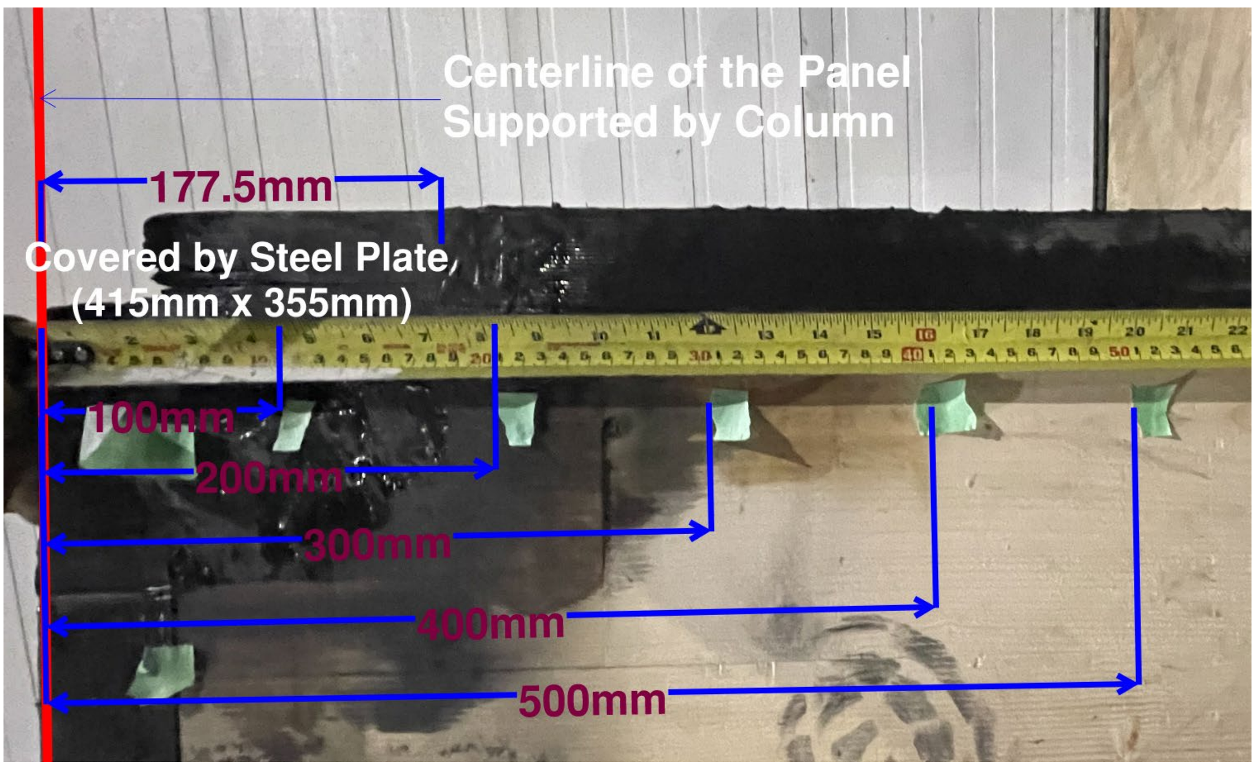


Figure 6. Photo illustrating the post-test measurement of clt panel

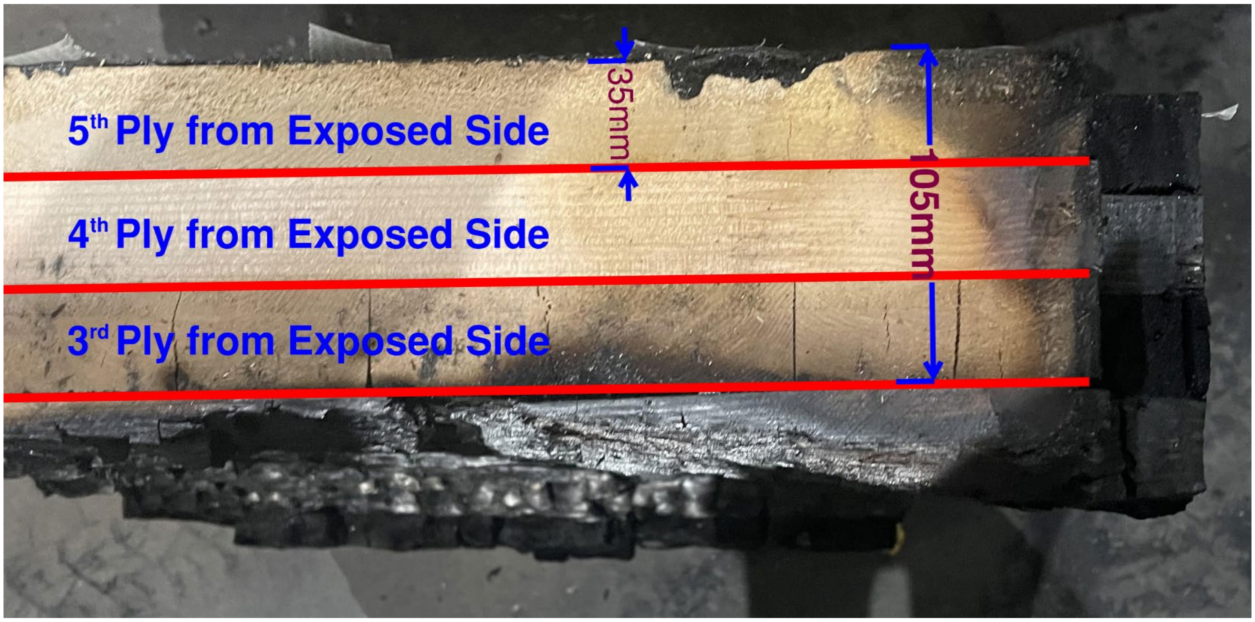


Figure 7. Photo of the cut section of test specimen 1

The exposed steel design has the fastest char rate of average 0.7mm/min. This was expected given the amount of exposed steel component presented. However, this char rate is still close to the value currently included in Annex B of CSA O86 for determining the fire resistance rating of the mass timber design and provides a level of confidence for future applications. It is noted that this is a lightly loaded condition.

The intumescent painted column had an average char rate of 0.43mm/min at the steel-timber interface. As the design was following a ULC listed 2h fire rated design and was applied in a factory, it was expected that this specimen would have a similar char rate of other listed 2h design such as the GWB protection. This increased char rate may come from the fact that the intumescent paint cracked and significant portions fell off prior to termination of the test. A future study on the performance of the intumescent painted steel design should be conducted to further investigate the appropriate design.

Specimen 4, which included the exposed steel-glulam column system with the exposed steel edge had an average char rate of 0.58mm/min, which is less than the typical 2h-exposed timber char rate of 0.65mm/min reported by recent research. In addition, the char rate further from the steel-plate area had an average char rate of 0.65mm/min despite significant flaming observed during the test. This demonstrated that the additional combustible materials introduced by the glulam column did not contribute to an increase of the char rate of timber elements.

The steel plate with wood protected edges and a glulam column system in Specimen 5 had an average char rate of 0.2mm/min at the steel-timber interface, which is significantly improved from the one obtained from Specimen 4. This demonstrated the effectiveness of the wood covering prescribed in TR10. However, it is noted that the char rate of the timber elements further away from the steel plate were measured at a maximum 0.75mm/min obtained at 300mm from the centre. This may come from the additional wood covers that are not mass timber elements, producing significant radiation to surroundings.

As Specimen 4 and 5 included glulam columns, char rates of these columns were also measured after the fire tests. Given the primary objective was to study the steel-timber interface, the char rate analysis of the glulam column was determined based on the remaining column size measured at the bottom of the column. Both Specimens had an average char rate of 0.52mm/min.

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Performance of Steel-Timber Interface

The primary objective of this study was to study the performance of steel-timber interfaces with various point-support systems of steel or glulam column when exposed to the standard time-temperature curve in the ULC/S101 Standard. The pilot scale tests were performed and based on the foregoing analysis, it can be concluded that:

- Exposed steel components did not significant increase the char rate of the timber elements at steel-timber interface. The preliminary, non-structural loaded exposed steel column system received an average char rate of 0.74mm/min at steel-timber interface.
- Two layers of 15.9mm Type X gypsum board protecting the steel components provide good protection to the steel-timber elements. No charring or ineligible charring were observed at steel-timber interfaces.
- The ULC listed 2h rated intumescent painted steel components did not perform as expected resulting in a 0.43mm/min char rate. Additional study of intumescent painted design should be considered.
- Minimal exposed steel component such as Specimen 4 with only the steel plate perimeter exposed on edges received a minimum impact on the char rate of steel-timber interface. The result of 0.58mm/min is similar to other timber locations with direct exposure to fire.
- Wood covered steel components significantly reduced the char rate at the steel-timber interface with an average rate of 0.2mm/min.

There were inherent limitations in these small scale tests. The reader may wish to review the NRC report of the Large-Scale Fire Tests of A Mass Timber Building Structure for the Mass Timber Demonstration Fire Test Program, where large scale tests of compartments with exposed timber demonstrated the ability of mass timber structures with significant exposure and in the event of sprinkler failure, to sustain complete burnout without re-ignition after 4 hours.

4.2 Outreach

This study was also intended to help industry overcome the lack of information in steel-timber design and to educate relevant stakeholders on the fire performance of point-support systems in mass timber construction. Structural engineers, fire science engineers, academic research groups as well as local building officials were invited to witness these tests in person or virtually. They have provided positive feedback and expressed strong interest in witnessing future fire demonstrations to assist in education on mass timber construction. It is noted that the very early testing schedule due to lab availability (start at 4am local time) precluded more attendees.

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

Fast + Epp, our industry partner, also attended and contributed to the design of the tested specimens. We note that both GHL and Fast + Epp offices collaborated on several projects involving mass timber projects and are actively working on practical research to improve the performance of mass timber construction.

4.3 Future Considerations

We note that due to the limited capacity of the small-scale furnace, reaction frame to provide structural loading for the tested assemblies was not possible. Therefore, the data collected in this project is not considered suitable for the specific structural system. This project is intended to provide preliminary thermal data at steel-timber interface to obtain fundamental baseline information to inform design of point-support systems with appropriate protection approach.

In addition, it would also be appropriate to confirm the char rate and fire performance of the steel-timber interface with limited loading and full-scale test apparatus. Further, research on the intumescent painted system to investigate the fire performance of the structural system is also recommended.

5.0 SUMMARY

This report has been prepared by GHL Consultants Ltd to document the summary and technical analysis of the Fire Performance of Steel-Timber Connections for point-support systems in mass timber construction under the Natural Resources Canada's Green Construction Through Wood Program.

Five pilot-scale tests were conducted by QAI Laboratories located in Burnaby, BC with tested specimens provided by Kalesnikoff and George Third & Son. GHL witnessed all five tests with local municipalities and industrial partners.

GHL's study focused on the qualitative and quantitative analysis of the fire performance of steel-timber connections in mass timber construction and obtained preliminary char rates with various structural designs.

GHL also increased awareness for mass timber construction with local municipalities and industry partners. Recommendations for potential future studies, and public presentations for promoting mass timber construction for sustainable construction design have been proposed as well.

Enclosures

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P:\PRJ\80\8000.03 - NRCan - Exposed Steel Connection Design in Mass Timber Building Fire Test\Report\2023-04-27 Final Report (GHL 8000.03).docx

Appendix A

QAI Laboratories Reports

3980 North Fraser Way
Burnaby, B.C. V5J 5K5
604.527.8378 ph. | 604.527.8368 fx.

CLIENT: **GHL CONSULTANTS LTD.**
700 West Pender Street, Suite 800
Vancouver British Columbia
V6C 1G8 Canada

Test Report No: T1410-2e	Issue Date: March 29, 2023

SAMPLE ID: 5-ply Cross-Laminated Timber (CLT) Floor / Ceiling Assembly with Exposed Glulam Column and Protected Steel Support.

SAMPLING DETAIL: CLT floor/ceiling panels were supplied by Kalesnikoff. The glulam column was supplied by Kalesnikoff. Installation of the CLT panels to the exposed steel column was completed by QAI staff. No independent sampling of components was performed on major test elements provided to QAI for evaluation.

DATE OF RECEIPT: CLT panels and glulam column from Kalensnikoff were received February 17th, 2023 in good condition.
All other components were acquired by QAI staff from local suppliers.

TESTING PERIOD: Testing was performed on March 29, 2023 by QAI Laboratories, Ltd. Burnaby, BC location.

AUTHORIZATION: QAI Test Proposal 22JL12132R1 dated December 14, 2022 signed by GHL Consultants Ltd. Associate Claire Yuan on January 6, 2023.

TEST PROCEDURE: Testing to client specified protocol with exposure following the specified time/temperature curve of the following method:

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

The above noted testing was conducted on a modified assembly as outlined in Deviations section of this report.

TEST RESULTS: The 5-ply CLT assembly with exposed glulam column and protected steel connection assembly when exposed to the specified time/temperature curve outlined in CAN/ULC S101, achieved results as outlined in the following pages of this report.

Prepared By

Signed for and on behalf of
QAI Laboratories, Ltd.

Matt Chursinoff
Fire Lab Technician

Matt Lansdowne
Vice President of Operations

Table of Contents

Introduction:

This report documents client specified fire testing program conducted by QAI Laboratories Ltd. for GHL Consultants Ltd. on a 5-ply cross-laminated timber (CLT) floor/ceiling assembly, supported on an exposed glulam column of 413 mm x 355 mm (16.25 inches x 14 inches) dimensions including protected steel connections representing a CLT floor to mass timber column connection. Testing was conducted with the glulam column and steel connection element protected with wood (lumber) during the fire endurance exposure, to evaluate thermal transmission between the CLT floor / ceiling assembly and glulam column connection. Nominal loading was induced around the glulam column connection to induce crushing of the lower compression surface of the CLT floor / ceiling to the steel plate component of the column connection. Details of the tested assembly can be found in the Assembly Description section of this report.

QAI exposed the 5-ply CLT floor / ceiling on glulam column assembly to the fire endurance time/temperature curve specified by method CAN/ULC S101 for a 2-hour duration. Temperatures were measured at different CLT floor slab and glulam column connection interface locations, and at different CLT depths at locations as outlined in Appendix A of this report. During fire endurance testing, observations were taken by QAI staff.

Following the fire endurance period, the CLT and glulam column with protected steel connection assembly were removed for the CAN/ULC S101 furnace and the test assembly extinguished. Following, final observations were then taken.

A diagram of the test assembly including thermocouple location can be found in Appendix A of this report.

Photos of the test assembly setup can be found in Appendix B.

Assembly Description:

Table 1: Test Assembly and Penetrations Description

COMPONENT	DESCRIPTION	
Floor/Ceiling Assembly	Overall Size:	2286 mm (90 in.) wide by 1524 mm (60 in.) deep by 175 mm (6.9 in.) thickness.
	Type:	5-ply Cross-Laminated Timber fabricated in accordance with ANSI/APA PRG 320 by Kalesnikoff.
	Description:	Four 5-ply CLT panels were cut by Seagate Mass Timber at QAI Burnaby location from large CLT panels delivered to QAI. Seagate Mass Timber field cut locations for the steel post, threaded rod, and column to CLT connections. The CLT panels were installed on top of the steel column as described below. After installation, the non-fire side joints between CLT panels were sealed with a butyl-based weather seal. The fire side joints between CLT panels were fire caulked with 3M IC 15 WB+ and the caulking allowed to cure overnight prior to testing.
Glulam Column	Overall Size:	413 mm x 355 mm (16.25'' x 14") column of 1765 mm (69.5 in.) in height.
	Type:	Glulam composed of laminated Douglas-fir 38 mm x 76 mm (2'' x 4'' nominal) lumber.
	Connection:	Steel plate of 415 mm x 355 mm x 25 mm thickness (16.35 inches x 14 inches x 1-inch thickness). The steel plate included four threaded rods of 16 mm (5/8-inches) diameter, spaced around a central 76 mm x 76 mm x 8 mm (3-inch x 3-inch x 0.31 inch) steel tube on the upper side. The lower surface included four threaded rods of 16 mm (5/8-inches) diameter, spaced uniformly, for embedment in the glulam column. The glulam column threaded rods were epoxied in place with Systems Three Cold Cure Epoxy Adhesive and allowed to cure a minimum 24 hours time prior to testing.
Installation	Description:	The CLT panels were each lowered onto the glulam column with steel epoxied connections, fitting the CLT panel holes over the steel column 16 mm (5/8-inch) threaded steel rod, embedding the 76 mm x 76 mm steel box element into the center of the four panel CLT assembly. After CLT placement, a 415 mm x 355 mm x 6 mm thickness (16.35 inches x 14 inches x 1/4-inch thickness) steel plate was fit over the threaded rods, and the threaded rod mechanically secured with nuts to tighten the steel plate, compressing and connecting the CLT floor / ceiling to the steel column. 4 layers of wood was installed to the fire side of the CLT panel, protecting the steel connection. The first layer consisted of 38 mm x 89 mm (2"x 4" nominal) wood around the steel plate, fastened with 2 rows of 127 mm (5 inch) wood screws located 25mm (1-inch) from edges and spaced 152 mm (6 inches) o/c into the CLT panel. The second and third layer consisted of 38 mm x 89 mm (2"x 4" nominal) wood stacked on top of the previous layer, and each layer fastened with 1 row of 76 mm (3-inch) wood screws down the middle, located 25mm (1-inch) from edges and spaced 152 mm (6 inches) o/c into the previous layer. There also was a 76 mm (3-inch) wood screw installed at a angle, through the layer into the glulam column at every screw location. The fourth layer consisted of 38 mm x 51 mm (1.5" x 2") lumber fastened with a 102 mm (4-inch) wood screw located 152 mm (6 inches) o/c. The non fire side steel plate was finished with 16 mm (5/8'') Type X gypsum board, installed flush to the protruding steel column on the non-fire side.

See Appendix A for a diagram of the noted test assembly.
See Appendix B for photos of the test assembly evaluated by QAI.

Test Apparatus:

The furnace used in the tests is a pilot-scale fire burning apparatus with interior dimensions of 1524 mm (60 in.) in height, 1524 mm (60 in.) in width, and 1321 mm (52 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.

Unexposed temperatures were monitored by thermocouples (TCs). The TC's were placed at cavity and joint locations. The temperatures were recorded continuously for the duration of the test, and the temperature rise data are provided graphically in Figure 2 and 4 in Appendix A.

The wall section is mounted in a vertical orientation, into a steel frame specimen holder. The specimen holder is then rolled up to the furnace and secured by chain and straps to the furnace opening.

One pressure tap was installed through the back wall of the test furnace. The pressure tap was attached and monitored by a Setra model 264 pressure transducer (ID# Pressure T1). The furnace pressure is controlled by adjusting a damper in the furnace exhaust stack.

Figure 1: Burners Fired in the Furnace

Test Conditions:

The 5 ply CLT floor/ceiling with glulam column with protected steel connection assembly was constructed on the floor and placed on top of the furnace once complete. The space between the furnace and the floor/ceiling assembly was filled with ceramic fiber batt to prevent air movement. Concrete masonry blocks were placed around the glulam column location on the non-fire side to induce local crushing at the CLT to glulam steel connection interface on the fire side of assembly.

The pressure of the furnace was monitored throughout the test.

Prior to the fire endurance test the test assemblies were moved into position in front of the furnace and the pilot burners were ignited. The fire endurance test was initiated 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 standards.

The testing was for Research and Development purposes. No subsequent hose stream was conducted.

Deviations from the CAN/ULC S101 Test Standard:

The following outlines deviations from the CAN/ULC S101 standard during evaluation outlined in this report:

- The test assembly did not meet the test standards required sample size of for floor / ceiling assemblies.
- The applied load was to induce compression of the char layer at and did not represent required applied loads appropriate for a floor / ceiling type assembly.
- The hose stream test was not conducted as this test was performed for R&D purposes.
- Thermocouple placement is outlined in Appendix A of this report and did not measure temperature rise on the non-fire side.

Test Requirements:

Testing outlined in this report was for research and development purposes following the client specified protocol exposing the described 5-ply CLT floor / ceiling assembly with glulam column described in this report to the fire endurance time/temperature curve of method CAN/ULC S101.

No requirements stated.

Test Results:

Observations

The following observations were taken over the duration of the fire endurance exposure:

Table 2: Test Observations

Time (min:sec)	Unexposed Side	Exposed Side
0:00	Test Initiated	
0:60		Glulam column ignition.
2:50	Temperatures exceeding CAN/ULC S101 time/temperature curve. Fuel shut off; damper closed to reduce oxygen to fire.	
30:00		Column flaming heavily.
60:00	Venting from steel plate area	
2:00:00	Test Concluded, Fuel supply cut and assembly extinguished for observations.	

Flaming and Penetration

No flaming was observed on the non-fire side during evaluation.

Temperature Rise

Temperatures were measured at eight (8) locations as outlined in test assembly diagram found in Appendix A of this report. The maximum temperatures achieved at each thermocouple location are shown in Table 3 below.

Table 3. Maximum Measured Temperatures at Thermocouple Locations

	TC1	TC2	TC3	TC4	TC5	TC6	TC7	TC8
Maximum Temp. (°C)	81	95	77	181	89	751	97	100

Times temperature data for the above thermocouples can be found in Appendix A of this report.

Hose Stream Test

The hose stream test was not conducted as the assemblies were tested until failure for research purposes.

Conclusions:

QAI performed testing for GHL on a client specified test protocol, exposing a test floor / ceiling assembly to the fire endurance time/temperature curve as specified in method CAN/ULC S101.

The 5-ply CLT assembly with exposed glulam column including a protected steel connection assembly as described in this report, when exposed to the specified time/temperature curve outlined in CAN/ULC S101, achieved results as outlined on Page 7.

APPENDIX A

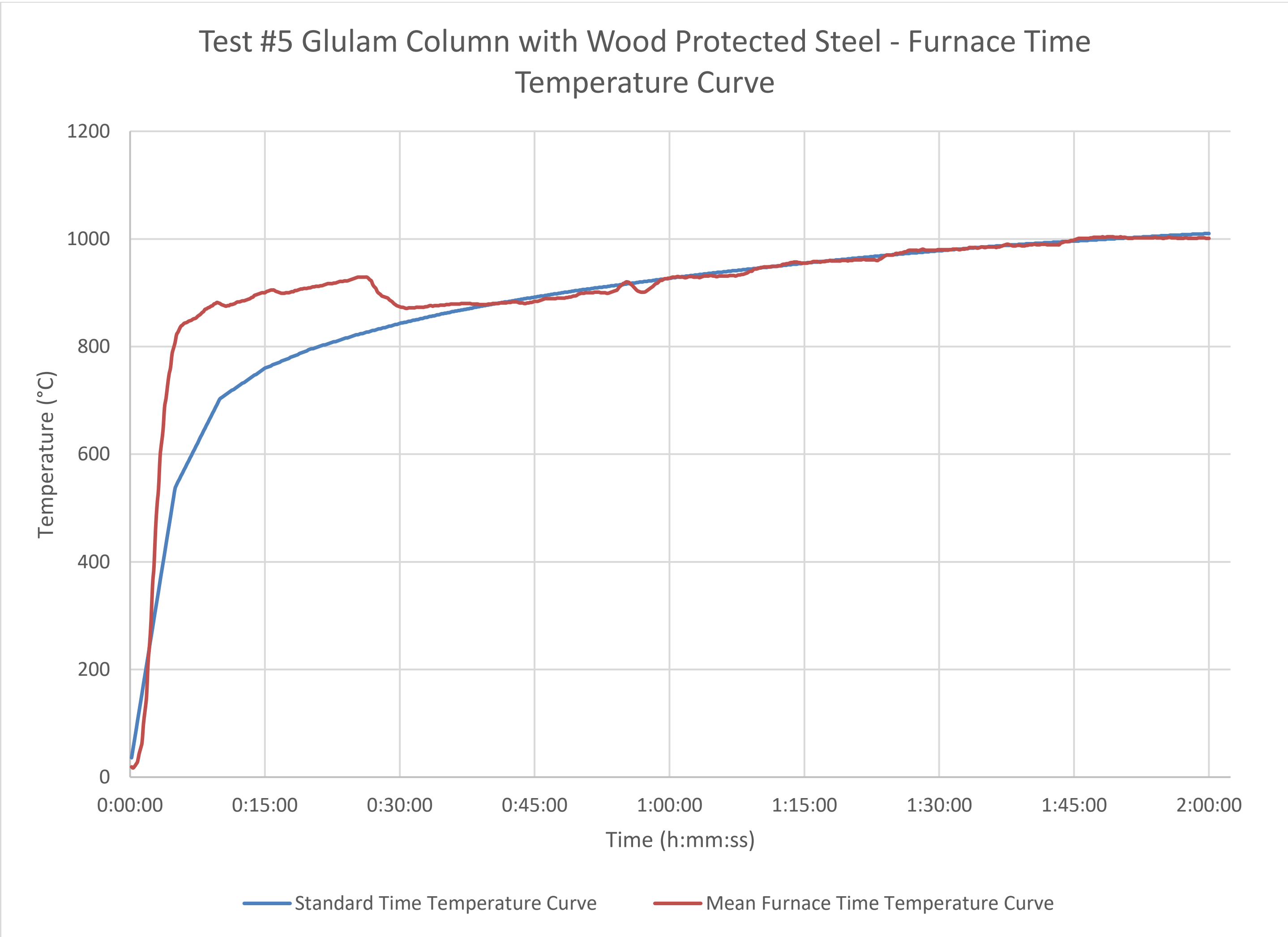

Figure 2: Time Temperature Curve

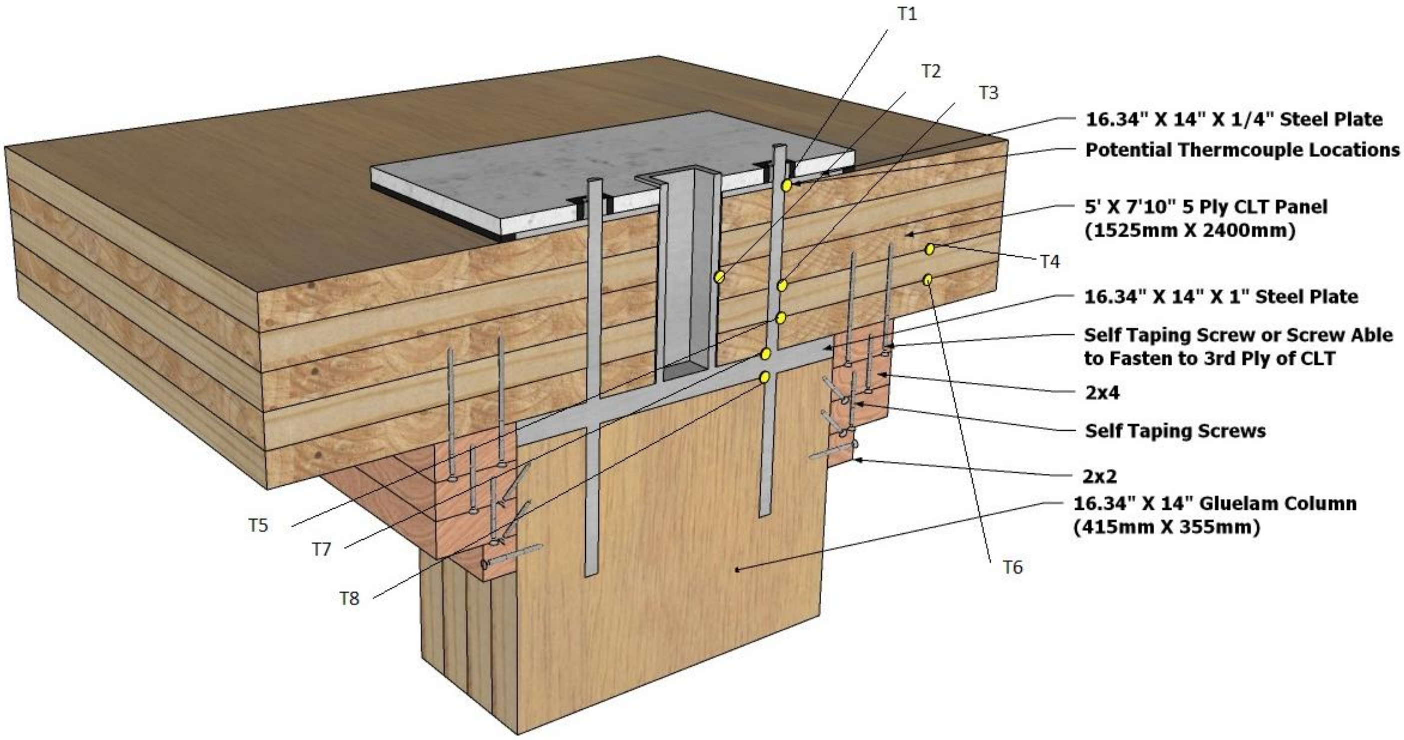

Figure 3: GHL CLT with Exposed Glulam and Wood Protected Steel Connection Assembly Including Thermocouple Placement

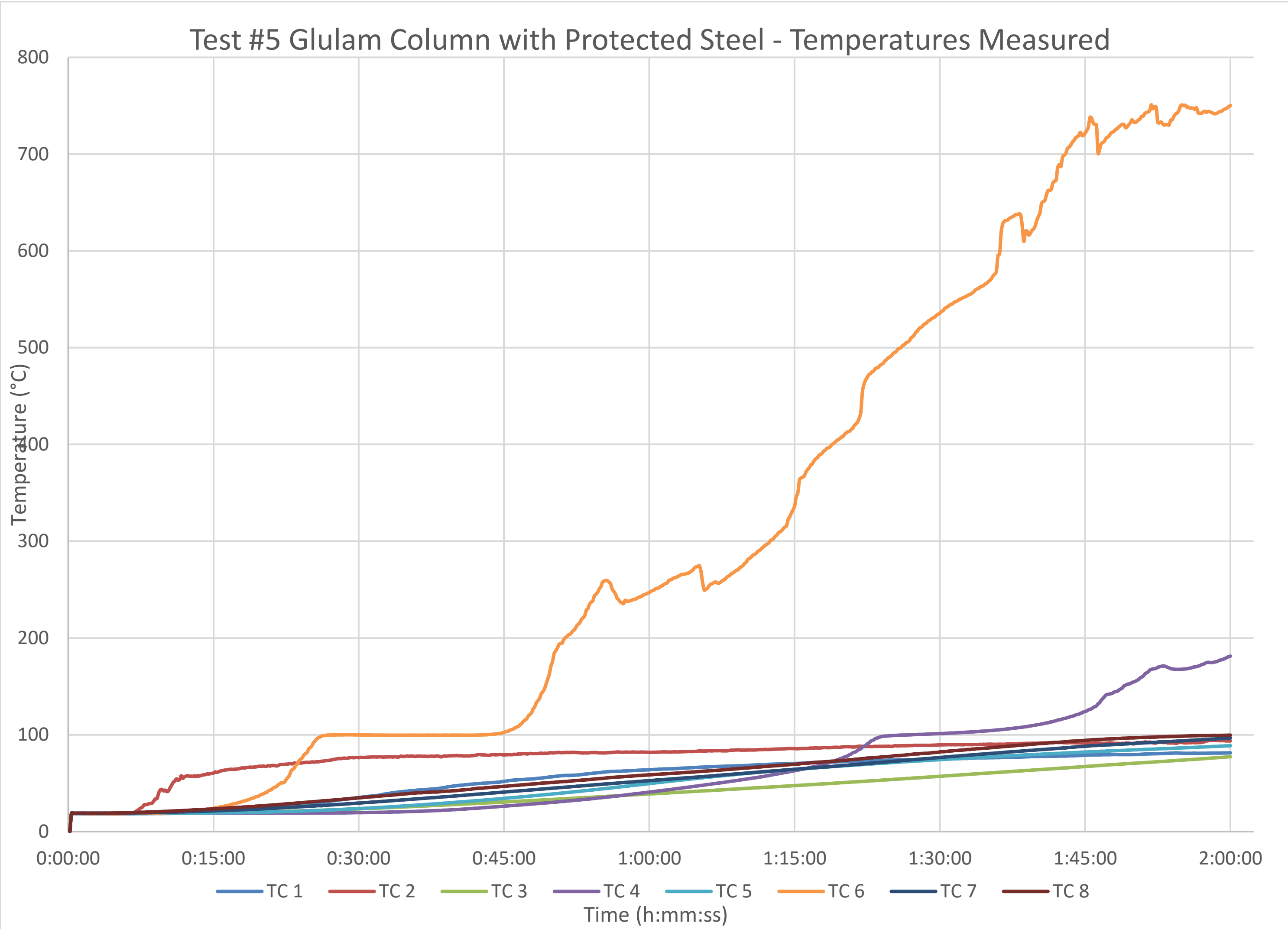

Figure 4 – Temperatures Measured Through Test Assembly.

APPENDIX B

Figure 5: Exposed side of the test assembly prior to the fire test.

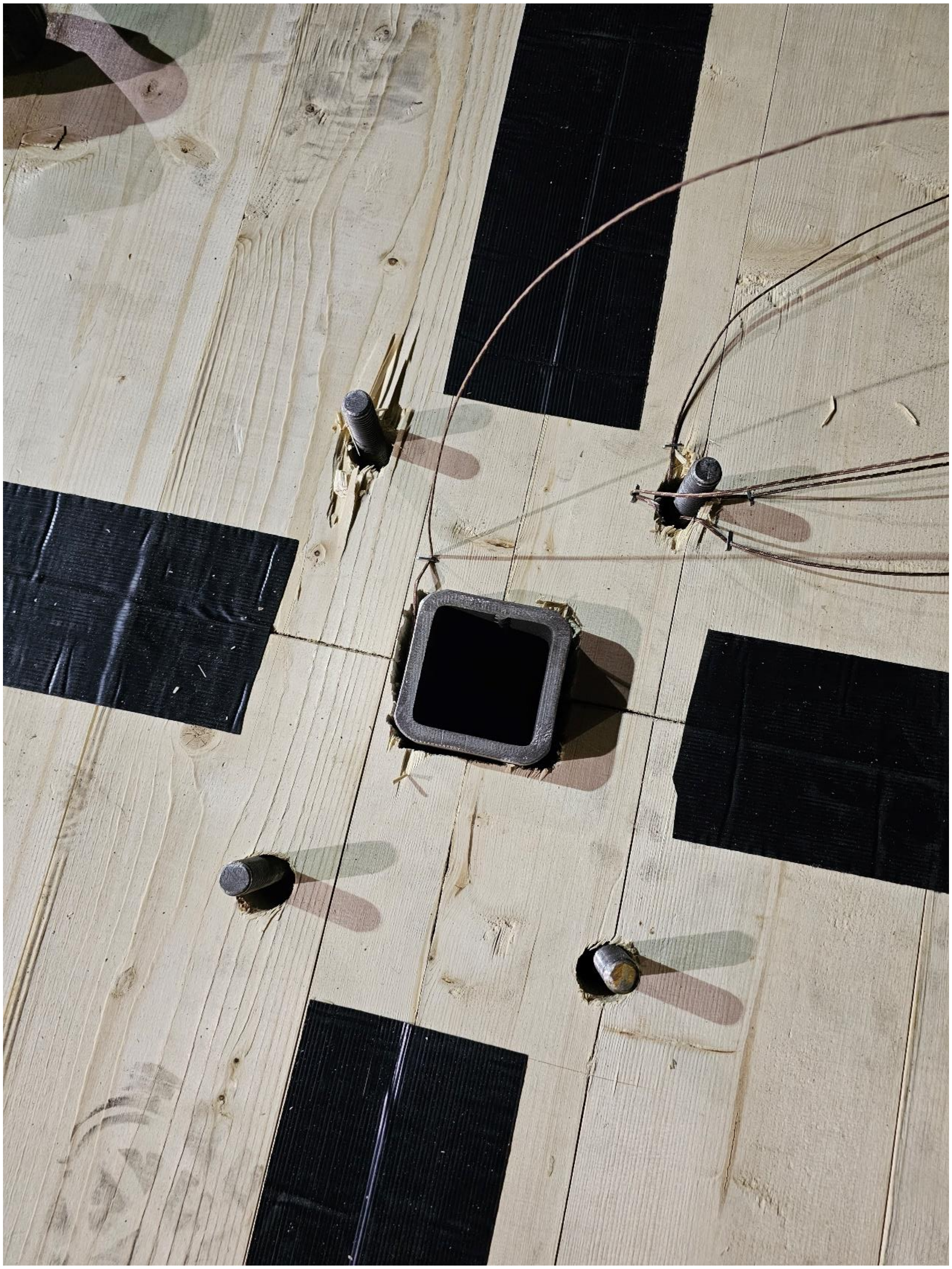

Figure 6: CLT panel joints and steel column prior to steel plate and gypsum installation.

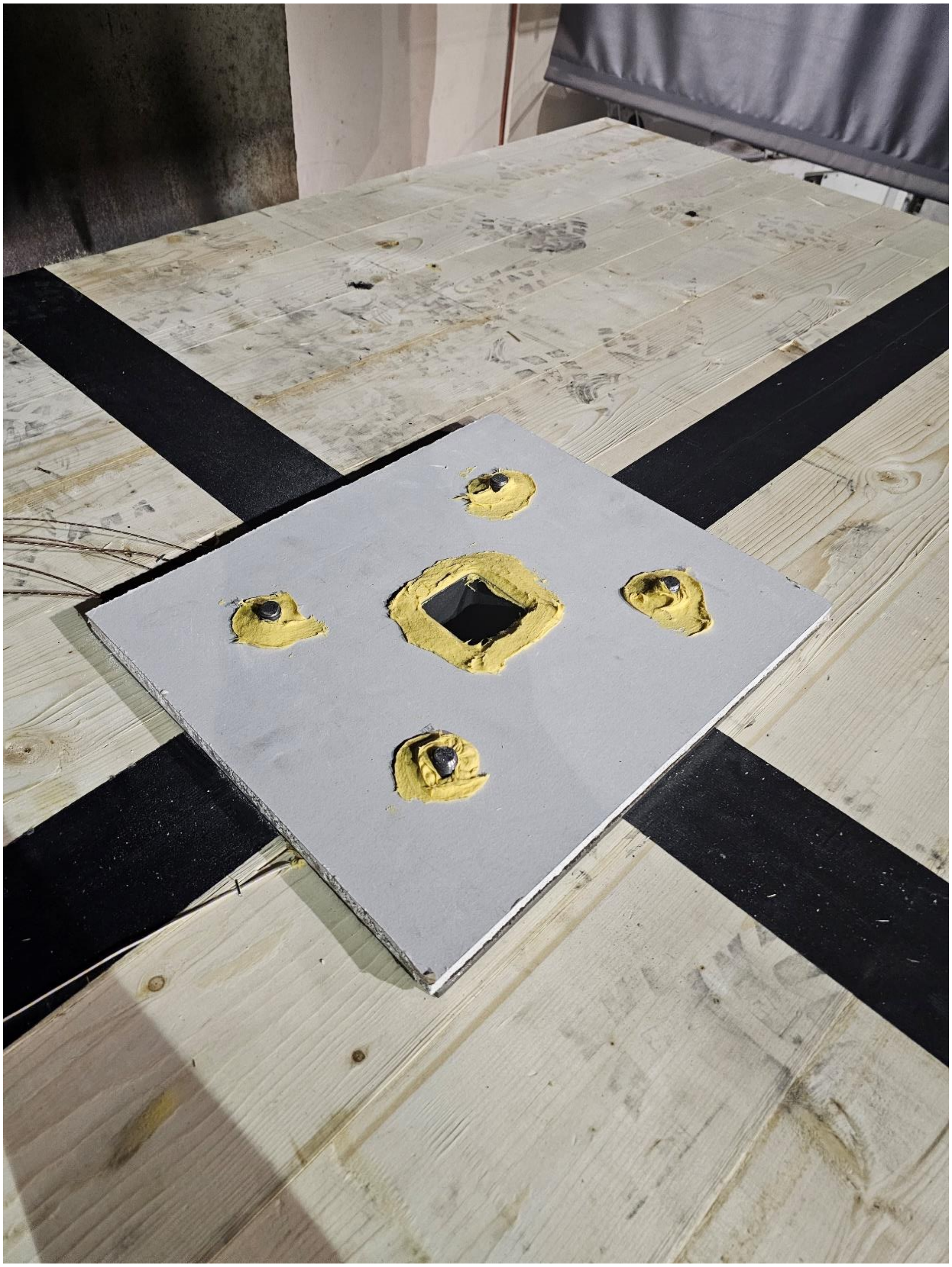

Figure 7: Unexposed CLT surface after plate installation and joint sealing.

Figure 8: First layer of wood protection around steel support

Figure 9: All layers of wood support around steel support.

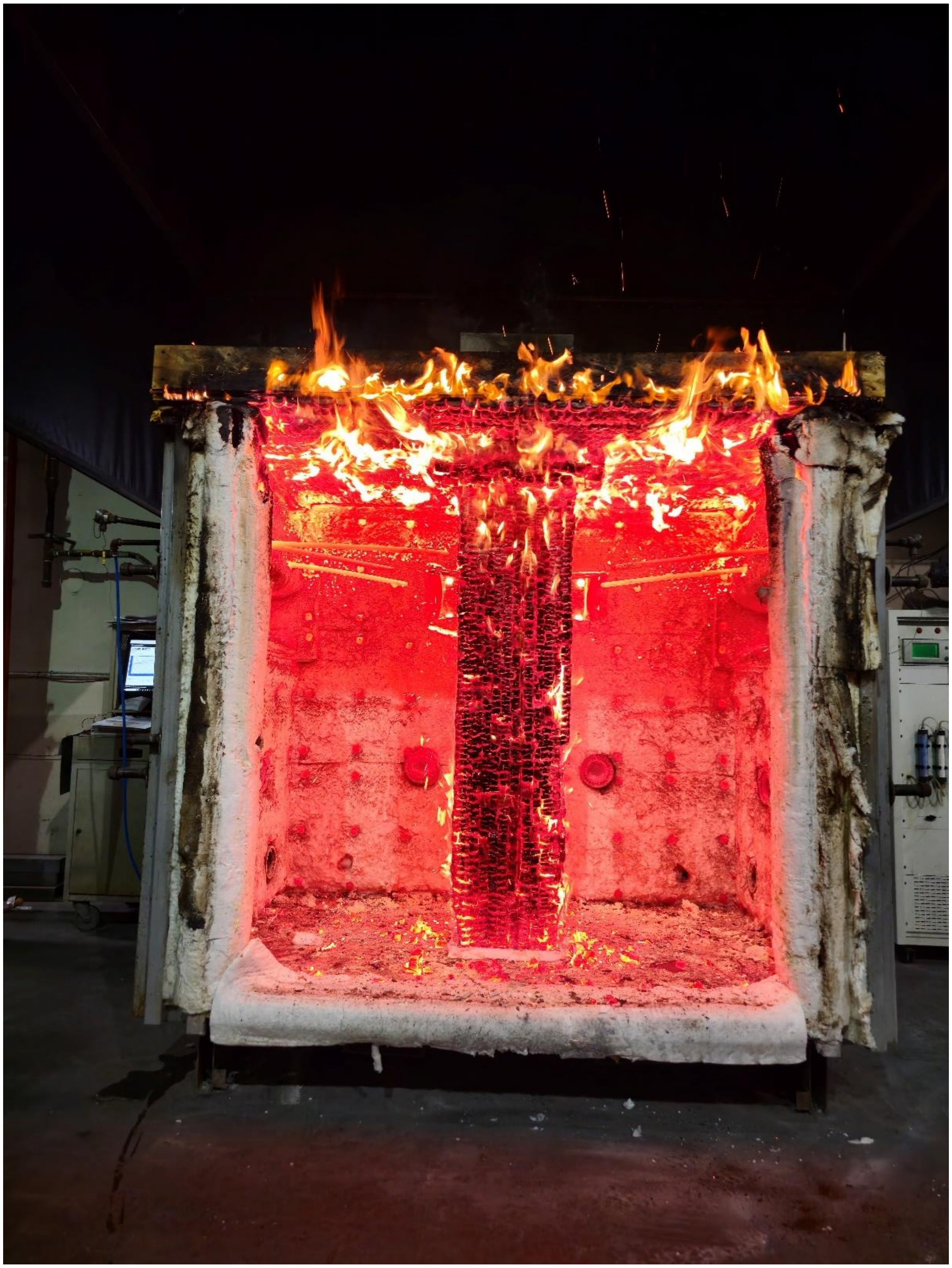

Figure 10: CLT floor / ceiling and glulam column assembly at test completion.

Figure 11: Glulam column and steel connection after fire exposure.

Figure 12: Localized damage through steel column 3 inch x 3 inch steel tube penetration through the CLT assembly.

REVISION HISTORY

Date	Revision	Issuer
March 29, 2023	Original report date.	ML

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CLIENT: **GHL CONSULTANTS LTD.**
700 West Pender Street, Suite 800
Vancouver British Columbia
V6C 1G8 Canada

Test Report No: T1410-2crev1	Revision Date: March 29, 2023

SAMPLE ID: 5-ply Cross-Laminated Timber (CLT) Floor / Ceiling Assembly with Code Prescribed Gypsum Protected Steel Column Support.

SAMPLING DETAIL: CLT floor/ceiling panels were supplied by Kalesnikoff. The steel column was supplied by George Third & Son. Installation of the CLT panels to the protected steel column was completed by QAI staff. QAI staff installed all gypsum protection as outlined in this report onsite at QAI's Burnaby, BC location. No independent sampling of components was performed on major test elements provided to QAI for evaluation.

DATE OF RECEIPT: CLT panels from Kalensnikoff were received February 17th, 2023 in good condition. The steel column was received at QAI on January 20th, 2023 in good condition. All other components were acquired by QAI staff from local suppliers.

TESTING PERIOD: Testing was performed on March 22, 2023 by QAI Laboratories, Ltd. Burnaby, BC location.

AUTHORIZATION: QAI Test Proposal 22JL12132R1 dated December 14, 2022 signed by GHL Consultants Ltd. Associate Claire Yuan on January 6, 2023.

TEST PROCEDURE: Testing to client specified protocol with exposure following the specified time/temperature curve of the following method:

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

The above noted testing was conducted on a modified assembly as outlined in Deviations section of this report.

TEST RESULTS: The 5-ply CLT assembly with prescriptive gypsum protected steel column support when exposed to the specified time/temperature curve outlined in CAN/ULC S101, achieved results as outlined in the following pages of this report.

Prepared By

Matt Chursinoff
Fire Lab Technician

Signed for and on behalf of QAI Laboratories, Ltd.

Matt Lansdowne
Vice President of Operations

Table of Contents

Introduction:

This report documents client specified fire testing program conducted by QAI Laboratories Ltd. for GHL Consultants Ltd. on a 5-ply cross-laminated timber (CLT) floor/ceiling assembly, supported on a British Columbia Building Code (BCBC) prescribed 2-layer gypsum protected steel column of 127 mm x 127 mm (5 inches x 5 inches) dimensions of 6 mm (1/4-inch) wall thickness representing a CLT floor to steel column connection. Testing was conducted with the prescribed gypsum protected steel column element exposed during the fire endurance exposure, to evaluate thermal transmission between the CLT floor / ceiling assembly and steel column connections. Nominal loading was induced around the steel column connection to induce crushing of the lower compression surface of the CLT floor / ceiling to the steel plate component of the column. Details of the tested assembly can be found in the Assembly Description section of this report.

QAI exposed the 5-ply CLT floor / ceiling on steel column assembly to the fire endurance time/temperature curve specified by method CAN/ULC S101 for a 2-hour duration. Temperatures were measured at different CLT to steel connection interface locations, and at different CLT depths at locations as outlined in Appendix A of this report. During fire endurance testing, observations were taken by QAI staff.

Following the fire endurance period, the CLT and steel column assembly were removed for the CAN/ULC S101 furnace and the test assembly extinguished. Following, final observations were then taken.

A diagram of the test assembly including thermocouple location can be found in Appendix A of this report.

Photos of the test assembly setup can be found in Appendix B.

Assembly Description:

Table 1: Test Assembly Description

COMPONENT	DESCRIPTION	
Floor/Ceiling Assembly	Overall Size:	1829 mm (72 in.) wide by 1219 mm (48 in.) deep by 175 mm (6.9 in.) thickness.
	Type:	5-ply Cross-Laminated Timber fabricated in accordance with ANSI/APA PRG 320 by Kalesnikoff.
	Description:	Four 5-ply CLT panels were cut by Seagate Mass Timber at QAI Burnaby location from large CLT panels delivered to QAI. Seagate Mass Timber field cut locations for the steel post, threaded rod and column to CLT connections. The CLT panels were installed on top of the steel column as described below. After installation, the non-fire side joints between CLT panels were sealed with a butyl-based weather seal. The fire side joints between CLT panels were fire caulked with 3M IC 15 WB+ and the caulking allowed to cure overnight prior to testing.
Steel Column	Overall Size:	127 mm x 127 mm x 6 mm thickness (5'' x 5'' x ¼'') column of 1765 mm (69.5 in.) in height.
	Type:	Hollow Structural Steel (HSS).
	Connection:	Steel plate of 415 mm x 355 mm x 25 mm thickness (16.35 inches x 14 inches x 1-inch thickness) was welded to the top of the described steel column. The steel plate included four threaded rods of 16 mm (5/8-inches) diameter, spaced around a central 76 mm x 76 mm x 8 mm (3-inch x 3-inch x ¼-inch) steel tube.
Installation	Description:	The CLT panels were each lowered onto the steel column by QAI staff, fitting the CLT panel holes over the steel column 16 mm (5/8-inch) threaded steel rods, embedding the 76 mm x 76 mm steel box element into the center of the four panel CLT assembly. After CLT placement, a 415 mm x 355 mm x 6 mm thickness (16.35 inches x 14 inches x 1/4-inch thickness) steel plate was fit over the threaded rods, and the threaded rod mechanically secured with nuts to tighten the steel plate, compressing and connecting the CLT floor / ceiling to the steel column. The non fire side steel plate was finished with 16 mm (5/8'') Type X gypsum board, installed flush to the protruding steel column on the non fire side. The bottom steel plate of the CLT to steel column connection was outlined with 2 layers of 16 mm (5/8'') x 75 mm (3 inches) wide gypsum board anchored with 102 mm (4 '') wood screws spaced at 203 mm (8'') on center approximately, fastened into the CLT as detailed in Appendix A. Two additional layers of 6 mm (5/8'') gypsum board consisting of widths,190.5 mm (7.5 inches) and 216 mm (8.5 inches), was installed covering the steel plate up against the steel column and fastened with 127 mm (5'') wood screws spaced at 203 mm (8'') on center approximately, fastened into the CLT as detailed in Appendix A Steel C channel of 41 mm width x 32 mm depth x 0.635 mm thickness (1.625 inches x 1.25 inches x 25 gauge) was tack welded to the steel column. A base layer of 16 mm (5/8'') Type X gypsum board was installed with 31.75 mm (1.25'') length self-tapping drywall screws spaced 600 mm (23.6") o/c fastening the gypsum board to the underlying steel C-channel. A second layer of 16 mm (5/8'') Type X gypsum board was installed over the base gypsum board and secured with steel flashing of 38 mm leg length x 38 mm leg length (1.5'' x 1.5'') over the gypsum corners, with the steel flashing fastened through the gypsum board with 47.6 mm (1.875'') length self-tapping drywall screws spaced at 300mm (11.8'') on center into the underlying steel C-channel.

See Appendix A for a diagram of the noted test assembly.
See Appendix A for details of the BCBC gypsum protection installation.
See Appendix B for photos of the test assembly evaluated by QAI.

Test Apparatus:

The furnace used in the tests is a pilot-scale fire burning apparatus with interior dimensions of 1524 mm (60 in.) in height, 1524 mm (60 in.) in width, and 1321 mm (52 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.

Unexposed temperatures were monitored by thermocouples (TCs). The TC's were placed at locations prescribed by the client as outlined in Appendix A. The temperatures were recorded continuously for the duration of the test, and the temperature rise data are provided graphically in Figure 2 and 5 in Appendix A.

The test assembly was mounted in a horizontal orientation. At time of testing, concrete masonry blocks were placed around the CLT to steel connections to induce loading to cause local crushing of the CLT to steel interface in the furnace.

One pressure tap was installed through the back wall of the test furnace. The pressure tap was attached and monitored by a Setra model 264 pressure transducer (ID# Pressure T1). The furnace pressure is controlled by adjusting a damper in the furnace exhaust stack.

Figure 1: Burners Fired in the Furnace

Test Conditions:

The 5 ply CLT floor/ceiling with steel column assembly was constructed on the floor and placed on top of the furnace once complete. The space between the furnace and the floor/ceiling assembly was filled with ceramic fiber batt to prevent air movement. Concrete masonry blocks were placed around the steel column location on the non-fire side to induce local crushing at the CLT steel column interface on the fire side of assembly immediately prior to testing.

The pressure of the furnace was monitored throughout the test.

Prior to the fire endurance test the test assemblies were moved into position in front of the furnace and the pilot burners were ignited. The fire endurance test was initiated 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 standards.

The testing was for Research and Development purposes. No subsequent hose stream was conducted.

Deviations from the CAN/ULC S101 Test Standard:

The following outlines deviations from the CAN/ULC S101 standard during evaluation outlined in this report:

- The test assembly did not meet the test standards required sample size of for floor / ceiling assemblies.
- The applied load was to induce compression of the char layer at and did not represent required applied loads appropriate for a floor / ceiling type assembly.
- The hose stream test was not conducted as this test was performed for R&D purposes.
- Thermocouple placement is outlined in Appendix A of this report and did not measure temperature rise on the non-fire side.

Test Requirements:

Testing outlined in this report was for research and development purposes following the client specified protocol exposing the described 5-ply CLT floor / ceiling assembly with steel column described in this report to the fire endurance time/temperature curve of method CAN/ULC S101.

No requirements stated.

Test Results:

Observations

The following observations were taken over the duration of the fire endurance exposure:

Table 2: Test Observations

Time (min:sec)	Unexposed Side	Exposed Side
0:00	Test Initiated	
1:16		Corner bead steel flashing warping
1:46		Ignition of the CLT panel.
5:08		CLT flaming to a minimum.
60:00		Continuous CLT burning, all gypsum intact. Small gaps at CLT slab to drywall on column joint.
1:29:15		Gaps at the top of column gypsum to CLT location, approximately 13 mm (1/2'').
2:00	Test Concluded, Fuel supply cut and assembly extinguished for observations.	

Flaming and Penetration

No flaming was observed on the non-fire side during evaluation.

Temperature Rise

Temperatures were measured at eight (8) locations as outlined in test assembly diagram found in Appendix A of this report. The maximum temperatures achieved at each thermocouple location are shown in Table 3 below.

Table 3. Maximum Measured Temperatures at Thermocouple Locations

	TC1	TC2	TC3	TC4	TC5	TC6	TC7	TC8
Maximum Temp. (ºC)	76	111	125	257	134	793	195	900

Time temperature data for the above thermocouples can be found in Appendix A of this report.

Hose Stream Test

The hose stream test was not conducted as the assemblies were tested until failure for research purposes.

Conclusions:

QAI performed testing for GHL on a client specified test protocol, exposing a test floor / ceiling assembly to the fire endurance time/temperature curve as specified in method CAN/ULC S101.

The 5-ply CLT assembly with 2-layer gypsum protected steel column support as described in this report, when exposed to the specified time/temperature curve outlined in CAN/ULC S101, achieved results as outlined on Page 7.

APPENDIX A

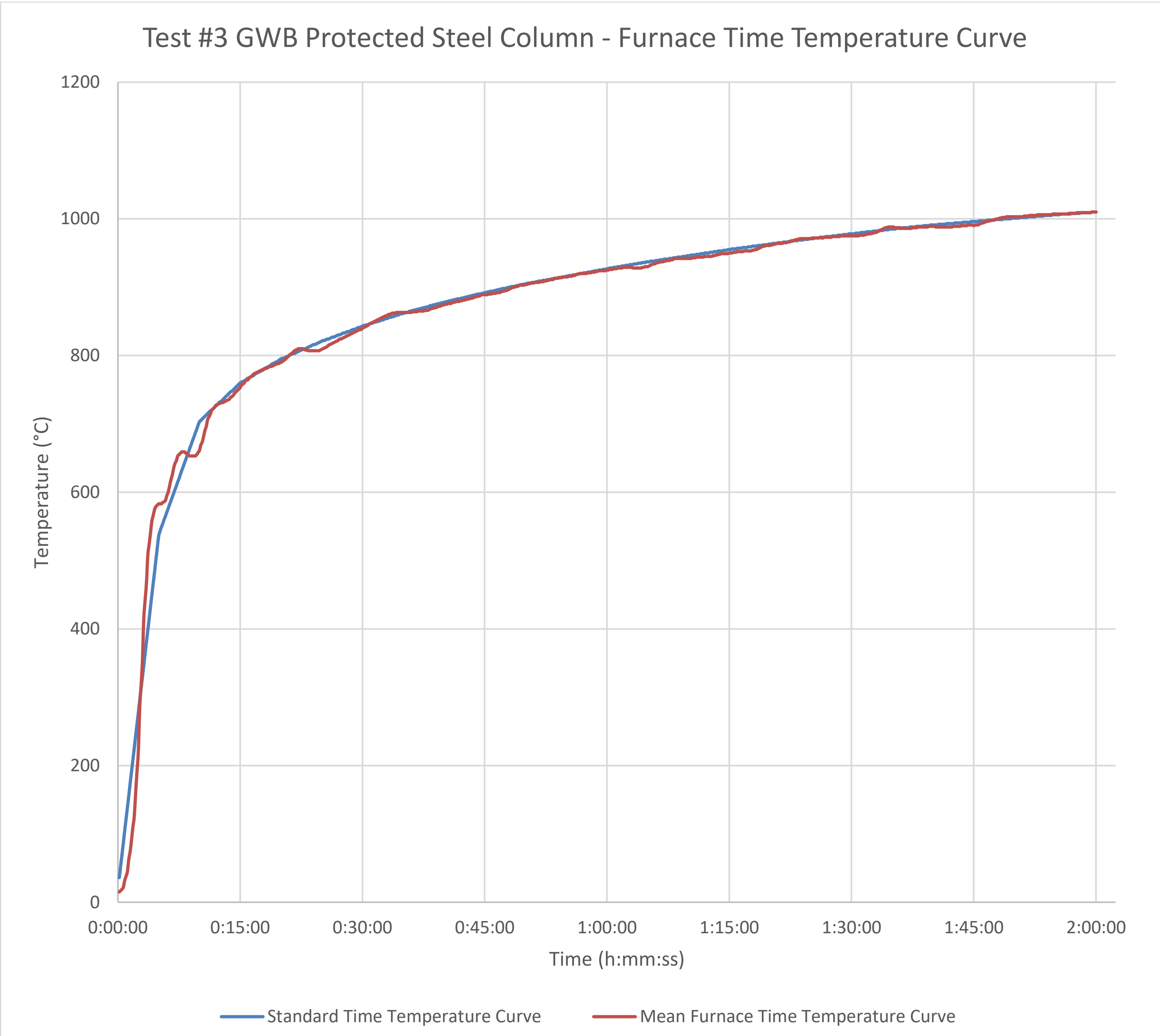

Figure 2: Time Temperature Curve

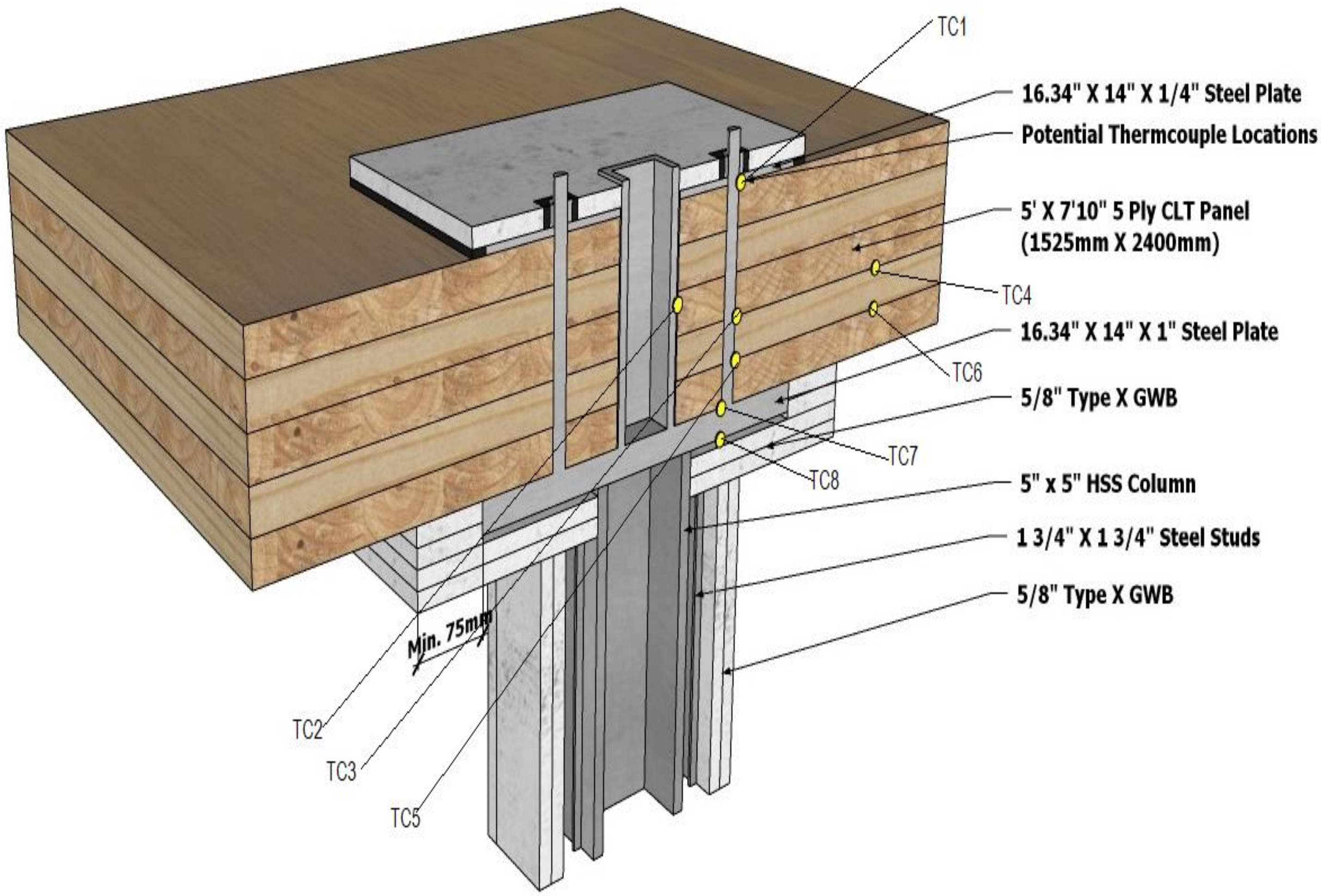

Figure 3: GHL CLT with Exposed Steel Column Assembly Including Thermocouple Placement

D-2.6.5. Attachment of Gypsum Board

1) Where Type X gypsum board is used to protect a steel column without an outside sheet-steel membrane, the method of gypsum board attachment to the column shall be as shown in Figure D-2.6.4.-B and shall meet the construction details described in Sentences (2) to (7).

2) The Type X gypsum board shall be applied vertically without horizontal joints.

3) The first layer of gypsum board shall be attached to steel studs with screws spaced not more than 600 mm o.c. and other layers of gypsum board shall be attached to steel studs and steel corner beads with screws spaced at a maximum of 300 mm o.c. Where a single layer of gypsum board is used, attachment screws shall be spaced not more than 300 mm o.c.

4) Steel tie wires spaced at a maximum of 600 mm o.c. shall be used to secure the second last layer of gypsum board in 3- and 4-layer systems.

5) Studs shall be fabricated of galvanized steel not less than 0.53 mm thick and not less than 41.3 mm wide, with legs not less than 33.3 mm long and shall be 12.7 mm less than the assembly height.

6) Corner beads shall

a) be fabricated of galvanized steel that is not less than 0.41 mm thick,

b) have legs not less than 31 mm long,

c) be attached to the gypsum board or stud with 25.4 mm screws spaced not more than 300 mm o.c., and

d) have the attaching fasteners penetrate either another corner bead in multiple layer assemblies or the steel stud member.

7) In a 4-layer system, metal angles shall be fabricated of galvanized steel and shall be not less than 0.46 mm thick with legs not less than 51 mm long.

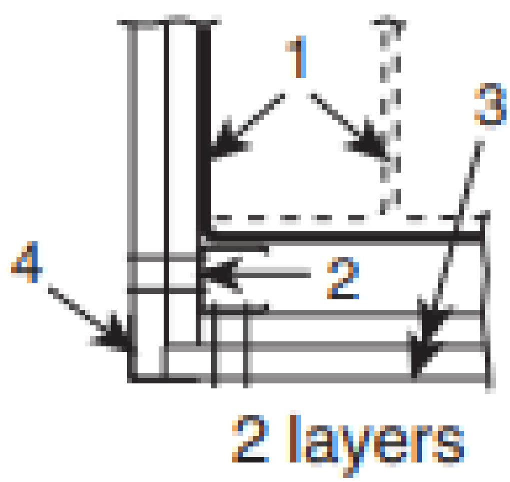

Figure 4: Gypsum Board Protection Installation to HSS Steel Column

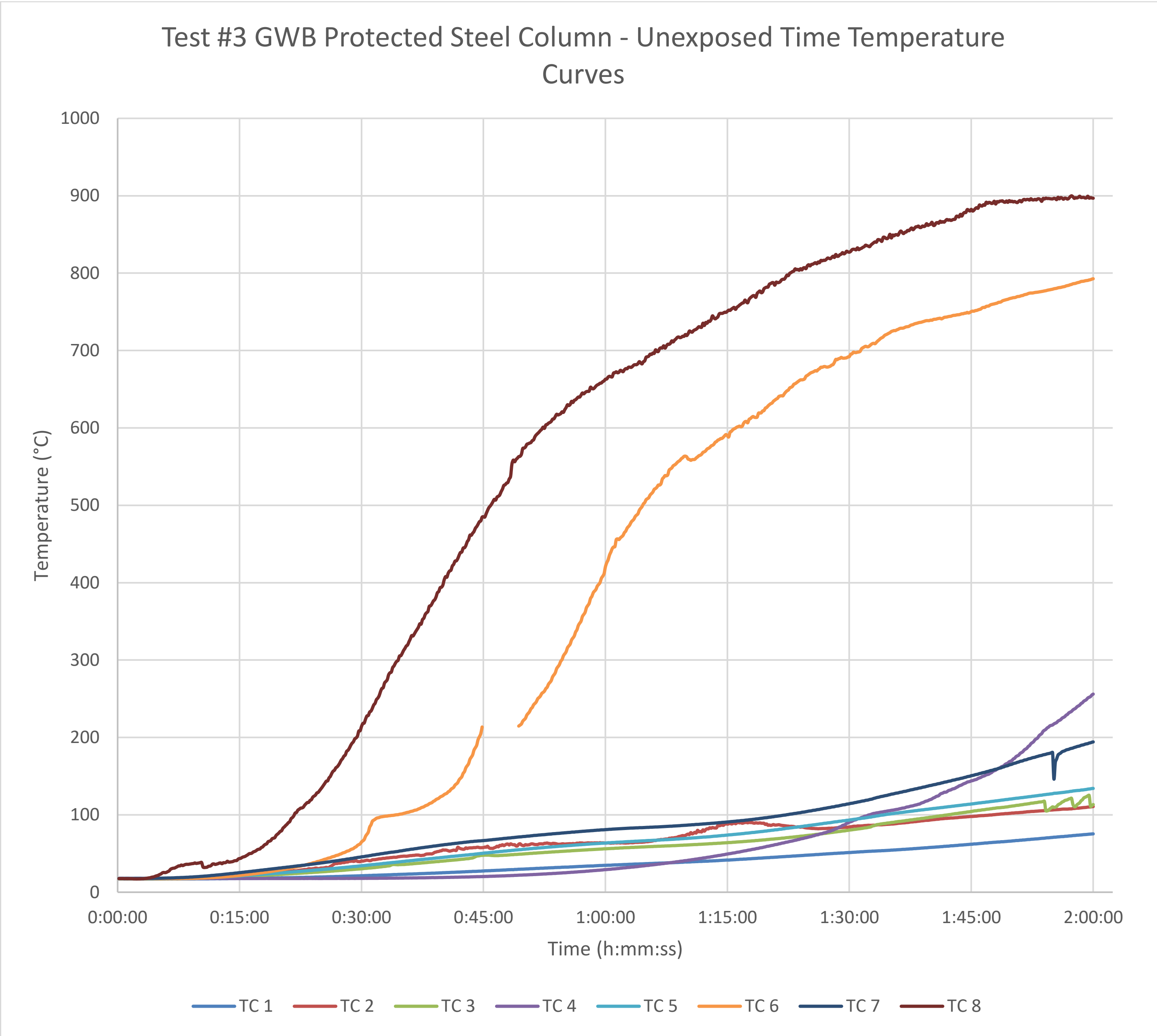

Figure 5 – Unexposed Time Temperature Curves.

APPENDIX B

Figure 6: First Layer of Gypsum Board Protection Around Steel Column Lower Plate Connection

Figure 7. Steel C-Channel Connection to HSS Column

Figure 8: CLT panel joints and steel column connection prior to steel plate installation.

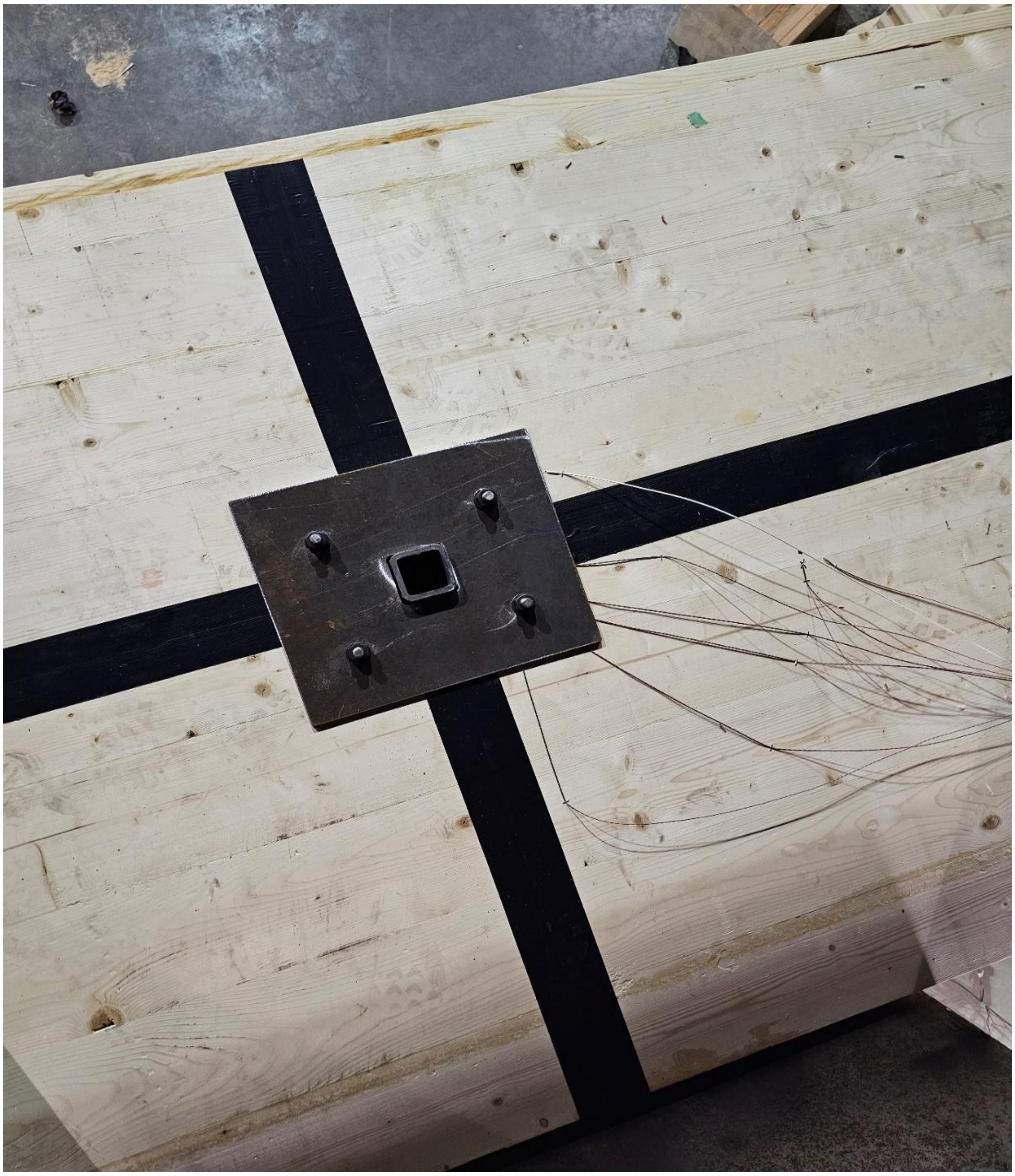

Figure 8: Unexposed CLT surface after plate installation.

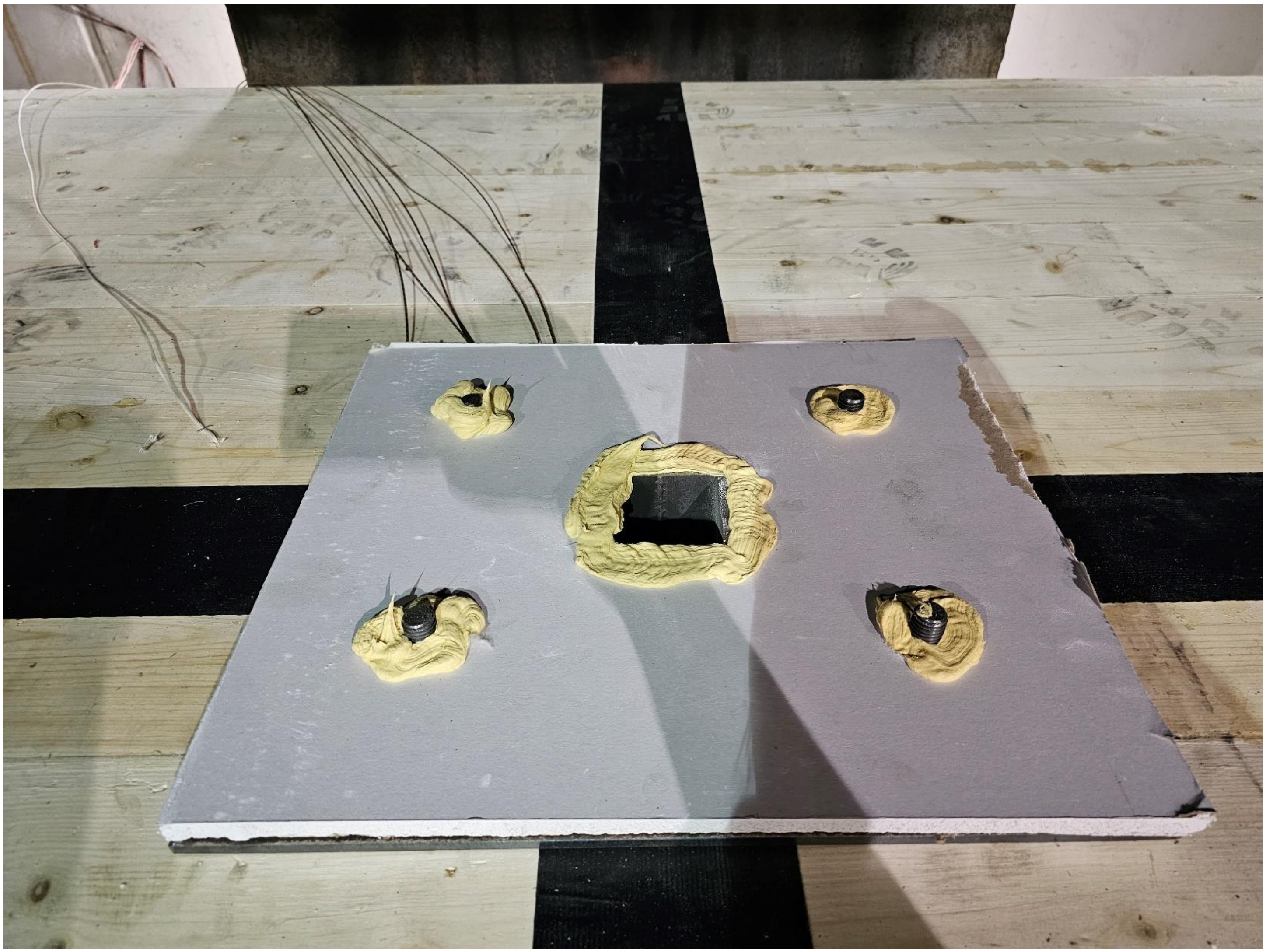

Figure 9: Unexposed Side Steel Plate Connection Finished with Gypsum Board and Fire Caulking

Figure 10. CLT with Gypsum Protected HSS Steel Column Including Corner Flashing Prior to Testing

Figure 11. CLT Assembly with Gypsum Protected HSS Steel Column During Fire Exposure

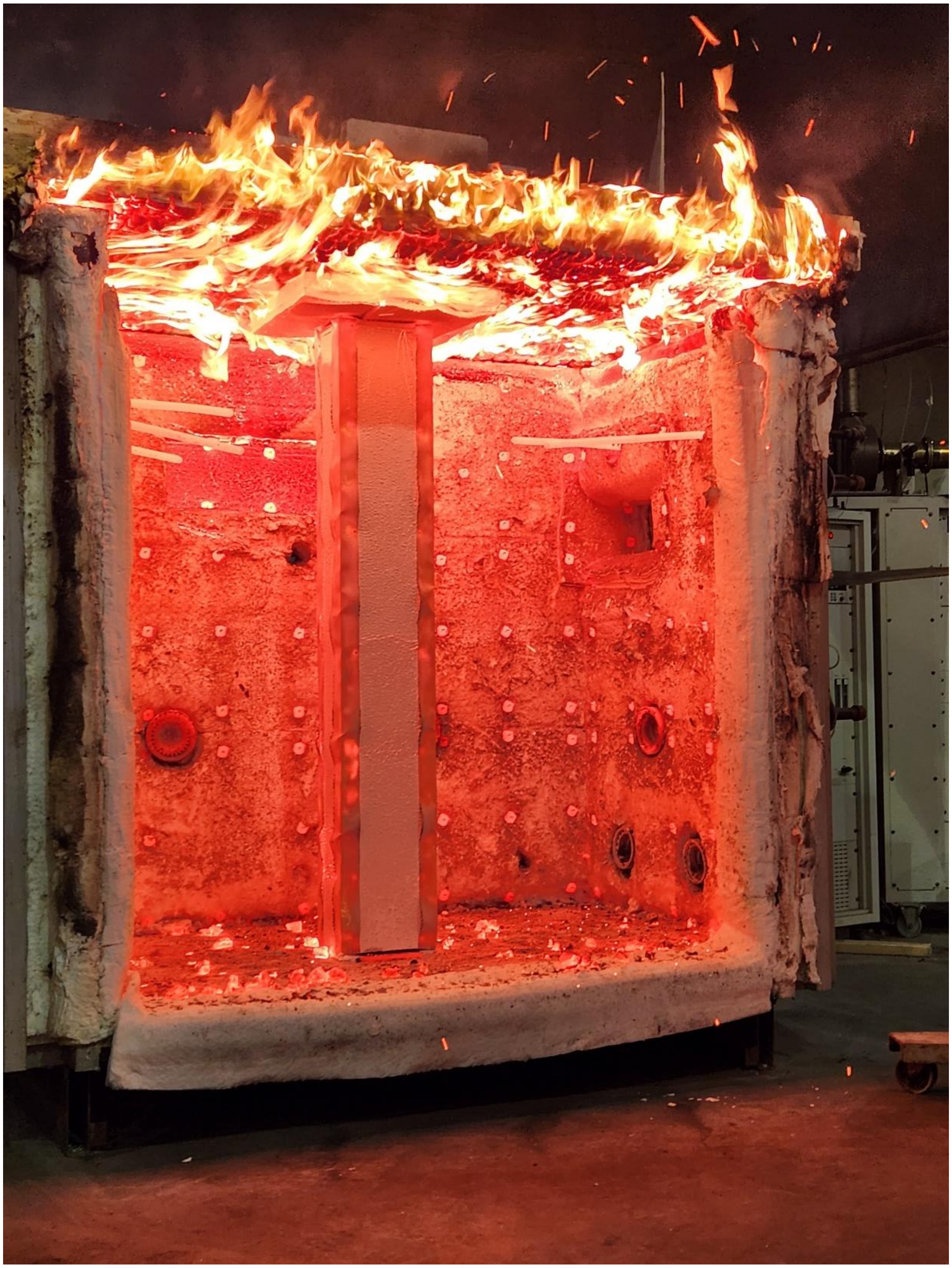

Figure 12. CLT with Gypsum Protected HSS Steel Column Including Corner Flashing After Fire Endurance Exposure

Figure 13. Fire side at HSS steel column penetration with steel plate removed.

REVISION HISTORY

Date	Revision	Issuer
March 24, 2023	Original report date.	ML
March 29, 2023	Updated Observations Table to outline fire extinguished and observations taken.	ML

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CLIENT: **GHL CONSULTANTS LTD.**
700 West Pender Street, Suite 800
Vancouver British Columbia
V6C 1G8 Canada

Test Report No: T1410-2d	Issue Date: March 27, 2023

SAMPLE ID: 5-ply Cross-Laminated Timber (CLT) Floor / Ceiling Assembly with Code Recognized Intumescent Paint Protected Steel Column Support.

SAMPLING DETAIL: CLT floor/ceiling panels were supplied by Kalesnikoff. The steel column was supplied by George Third & Son Steel Craftsmen. Intumescent paint was applied by Ener-Spray Pacific Ltd. Installation of the CLT panels to the protected steel column was completed by QAI staff. No independent sampling of components was performed on major test elements provided to QAI for evaluation.

DATE OF RECEIPT: CLT panels from Kalesnikoff were received February 17th, 2023 in good condition. The steel column with applied intumescent paint was received at QAI on March 15^{h}, 2023 in good condition. All other components were acquired by QAI staff from local suppliers.

TESTING PERIOD: Testing was performed on March 24, 2023 by QAI Laboratories, Ltd. Burnaby, BC location.

AUTHORIZATION: QAI Test Proposal 22JL12132R1 dated December 14, 2022 signed by GHL Consultants Ltd. Associate Claire Yuan on January 6, 2023.

TEST PROCEDURE: Testing to client specified protocol with exposure following the specified time/temperature curve of the following method:

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

The above noted testing was conducted on a modified assembly as outlined in Deviations section of this report.

TEST RESULTS: The 5-ply CLT assembly with 2-hour approved* intumescent paint protected steel column support when exposed to the specified time/temperature curve outlined in CAN/ULC S101, achieved results as outlined in the following pages of this report.

Prepared By

Signed for and on behalf of
QAI Laboratories, Ltd.

Matt Chursinoff
Fire Lab Technician

Matt Lansdowne
Vice President of Operations

Table of Contents

Introduction:

This report documents client specified fire testing program conducted by QAI Laboratories Ltd. for GHL Consultants Ltd. on a 5-ply cross-laminated timber (CLT) floor/ceiling assembly, supported on a 2-hour intumescent paint protected steel column of 127 mm x 127 mm (5 inches x 5 inches) dimensions of 6 mm (1/4-inch) wall thickness representing a CLT floor to steel column connection. Testing was conducted with the intumescent paint protected steel column element exposed during the fire endurance exposure, to evaluate thermal transmission between the CLT floor / ceiling assembly and steel column connections. Nominal loading was induced around the steel column connection to induce crushing of the lower compression surface of the CLT floor / ceiling to the steel plate component of the column. Details of the tested assembly can be found in the Assembly Description section of this report.

QAI exposed the 5-ply CLT floor / ceiling on steel column assembly to the fire endurance time/temperature curve specified by method CAN/ULC S101 for a 2-hour duration. Temperatures were measured at different CLT to steel connection interface locations, and at different CLT depths at locations as outlined in Appendix A of this report. During fire endurance testing, observations were taken by QAI staff.

Following the fire endurance period, the CLT and steel column assembly were removed for the CAN/ULC S101 furnace and the test assembly extinguished. Following, final observations were then taken.

A diagram of the test assembly including thermocouple location can be found in Appendix A of this report.

Photos of the test assembly setup can be found in Appendix B.

Assembly Description:

Table 1: Test Assembly Description

COMPONENT	DESCRIPTION	
Floor/Ceiling Assembly	Overall Size:	1829 mm (72 in.) wide by 1219 mm (48 in.) deep by 175 mm (6.9 in.) thickness.
	Type:	5-ply Cross-Laminated Timber fabricated in accordance with ANSI/APA PRG 320 by Kalesnikoff.
	Description:	Four 5-ply CLT panels were cut by Seagate Mass Timber at QAI Burnaby location from large CLT panels delivered to QAI. Seagate Mass Timber field cut locations for the steel post, threaded rod and column to CLT connections. The CLT panels were installed on top of the steel column as described below. After installation, the non-fire side joints between CLT panels were sealed with a butyl-based weather seal. The fire side joints between CLT panels were fire caulked with 3M IC 15 WB+ and the caulking allowed to cure overnight prior to testing.
Steel Column	Overall Size:	127 mm x 127 mm x 6 mm thickness (5'' x 5'' x ¼'') column of 1765 mm (69.5 in.) in height.
	Type:	Hollow Structural Steel (HSS).
	Connection:	Steel plate of 415 mm x 355 mm x 25 mm thickness (16.35 inches x 14 inches x 1-inch thickness) was welded to the top of the described steel column. The steel plate included four threaded rods of 16 mm (5/8-inches) diameter, spaced around a central 76 mm x 76 mm x 8 mm (3-inch x 3-inch x ¼-inch) steel tube.
Intumescent Paint	Type:	2-hour fire-resistance rated intumescing type, listed by an approved agency[1].
	Primer:	Sherwin Williams Steel Spec.
	Top Coat:	None applied.
	Installation:	Primer was applied to the steel column including the lower steel connection plate. Following, daily wet film application was applied to the column of 90-100 mils wet film thickness (WFT) manually measured. The column was allowed to cure for 24 hours. Following, another application was made of 90-100 mils WFT. The applications were repeated, with a final coat on day 5 being applied of 60 mils WFT. After curing, of approximately 15% shrinkage, the minimum estimated thickness was > 393 DFT target. This application was conducted by Ener-Spray independent of QAI. QAI did not verify application rates or accuracy related to coating coverage thickness.
Installation	Description:	The CLT panels were each lowered onto the steel column by QAI staff, fitting the CLT panel holes over the steel column 16 mm (5/8-inch) threaded steel rods, embedding the 76 mm x 76 mm steel box element into the center of the four panel CLT assembly. After CLT placement, a 415 mm x 355 mm x 6 mm thickness (16.35 inches x 14 inches x 1/4-inch thickness) steel plate was fit over the threaded rods, and the threaded rod mechanically secured with nuts to tighten the steel plate, compressing and connecting the CLT floor / ceiling to the steel column. The non fire side steel plate was finished with 16 mm (5/8'') Type X gypsum board, installed flush to the protruding steel column on the non fire side.

Note 1: Intumescent paint was noted to be a 2-hour fire-resistance rated product listed (certified) by an approved agency for the protection of steel elements.

See Appendix A for a diagram of the noted test assembly.
See Appendix B for photos of the test assembly evaluated by QAI.

Test Apparatus:

The furnace used in the tests is a pilot-scale fire burning apparatus with interior dimensions of 1524 mm (60 in.) in height, 1524 mm (60 in.) in width, and 1321 mm (52 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.

Unexposed temperatures were monitored by thermocouples (TCs). The TC's were placed at locations prescribed by the client as outlined in Appendix A. The temperatures were recorded continuously for the duration of the test, and the temperature rise data are provided graphically in Figure 2 and 5 in Appendix A.

The test assembly was mounted in a horizontal orientation. At time of testing, concrete masonry blocks were placed around the CLT to steel connections to induce loading to cause local crushing of the CLT to steel interface in the furnace.

One pressure tap was installed through the back wall of the test furnace. The pressure tap was attached and monitored by a Setra model 264 pressure transducer (ID# Pressure T1). The furnace pressure is controlled by adjusting a damper in the furnace exhaust stack.

Figure 1: Burners Fired in the Furnace

Test Conditions:

The 5 ply CLT floor/ceiling with steel column assembly was constructed on the floor and placed on top of the furnace once complete. The space between the furnace and the floor/ceiling assembly was filled with ceramic fiber batt to prevent air movement. Concrete masonry blocks were placed around the steel column location on the non-fire side to induce local crushing at the CLT steel column interface on the fire side of assembly immediately prior to testing.

The pressure of the furnace was monitored throughout the test.

Prior to the fire endurance test the test assemblies were moved into position in front of the furnace and the pilot burners were ignited. The fire endurance test was initiated 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 standards.

The testing was for Research and Development purposes. No subsequent hose stream was conducted.

Deviations from the CAN/ULC S101 Test Standard:

The following outlines deviations from the CAN/ULC S101 standard during evaluation outlined in this report:

- The test assembly did not meet the test standards required sample size of for floor / ceiling assemblies.
- The applied load was to induce compression of the char layer at and did not represent required applied loads appropriate for a floor / ceiling type assembly.
- The hose stream test was not conducted as this test was performed for R&D purposes.
- Thermocouple placement is outlined in Appendix A of this report and did not measure temperature rise on the non-fire side.
- Protection of steel elements requires thermocouples applied to steel element exterior per CAN/ULC S101 method. QAI installed a thermocouple internal to steel HSS element for information purposes. No thermocouples required for measuring of steel surface temperatures were included during evaluation.

Test Requirements:

Testing outlined in this report was for research and development purposes following the client specified protocol exposing the described 5-ply CLT floor / ceiling assembly with intumescent paint protected steel column described in this report to the fire endurance time/temperature curve of method CAN/ULC S101.

No requirements stated.

Test Results:

Observations

The following observations were taken over the duration of the fire endurance exposure:

Table 2: Test Observations

Time (min:sec)	Unexposed Side	Exposed Side
0:00	Test Initiated	
1:17		Panel ignition.
2:26		Intumescent paint darkening.
3:18		Intumescent paint flaming.
5:04		Bottom of column coating area starting to expand.
21:43		Coating continuing to flame and expand.
56:35		Heavy flaming at coating locations.
60:00		Coating on the lower steel plate connection hanging approximately 51 mm (2 inches).
1:05:00		Intumescent along plate sagging further
1:06:40	TC#8 has reached 650^{o}C	
1:18:00		Intumescent at plate continues to further sag.
1:19:00		Total separation of intumescent from steel connection plate.
1:25:00	Venting from upper plate area.	
1:31:00		Intumescent along plate hanging approximately 152 mm (6 inches) below plate, supported by column intumescent.
1:40:00		Front left column corner bare steel is visible along the edge.
1:57:00		Large chunk of intumescent along plate has fallen from corner during furnace vibration.
2:00	Test Concluded, Fuel supply cut and assembly extinguished for observations.	

During evaluation, QAI noted that CLT assembly construction included less gaps in the CLT laminations. During testing, less smoke and off-gassing through lamination layers was observed by QAI.

Flaming and Penetration

No flaming was observed on the non-fire side during evaluation.

Temperature Rise

Temperatures were measured at nine (9) locations as outlined in test assembly diagram found in Appendix A of this report. The maximum temperatures achieved at each thermocouple location are shown in Table 3 below.

Table 3. Maximum Measured Temperatures at Thermocouple Locations

	TC1	TC2	TC3	TC4	TC5	TC6	TC7	TC8	TC9
Maximum Temp. (ºC)	218	436	430	102	656	709	824	961	685

Time temperature data for the above thermocouples can be found in Appendix A of this report.

Hose Stream Test

The hose stream test was not conducted as the assemblies were tested until failure for research purposes.

Conclusions:

QAI performed testing for GHL on a client specified test protocol, exposing a test floor / ceiling assembly to the fire endurance time/temperature curve as specified in method CAN/ULC S101.

The 5-ply CLT assembly with 2-hour intumescent paint protected steel column support as described in this report, when exposed to the specified time/temperature curve outlined in CAN/ULC S101, achieved results as outlined on Page 7.

APPENDIX A

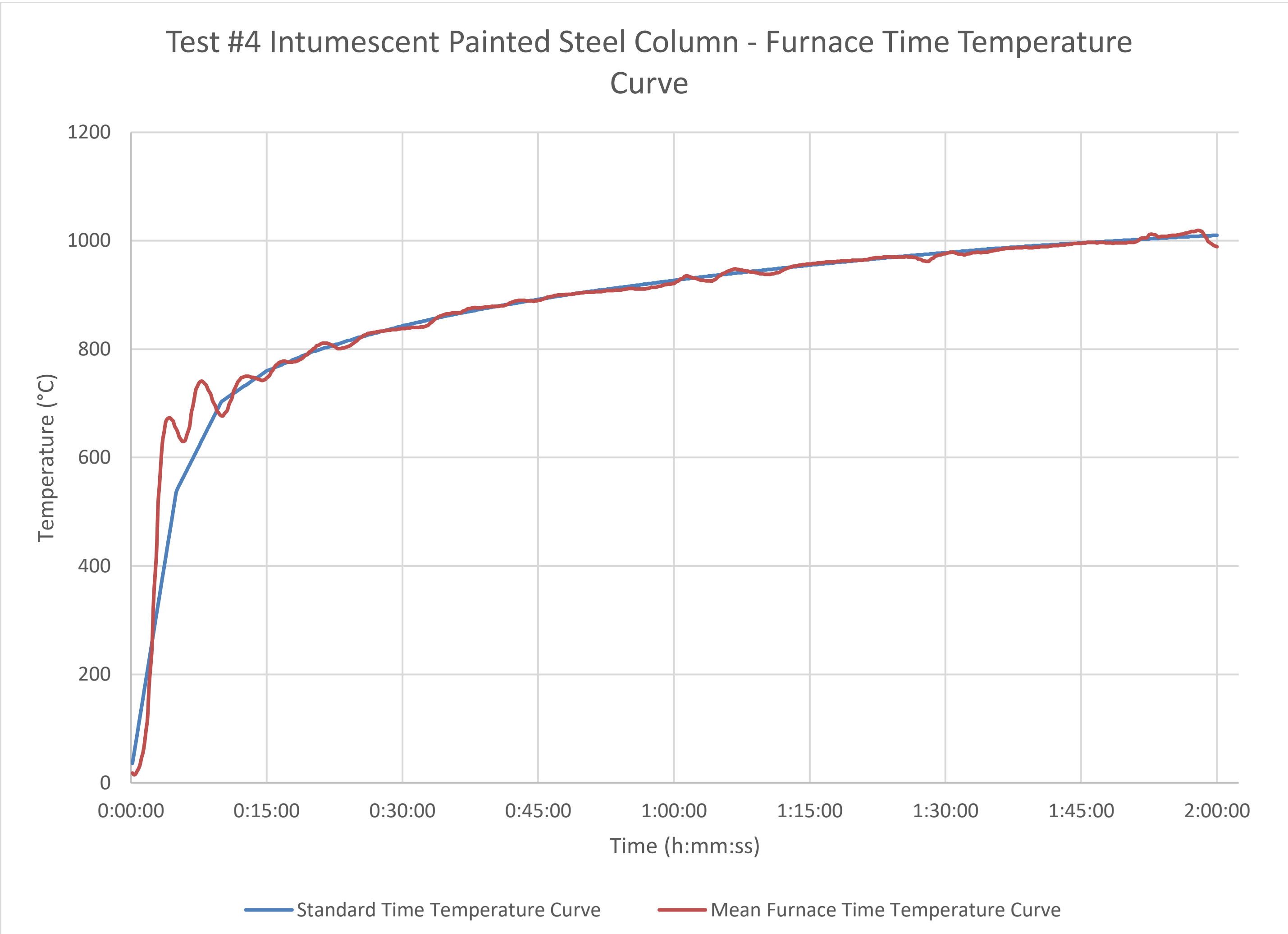

Figure 2: Time Temperature Curve

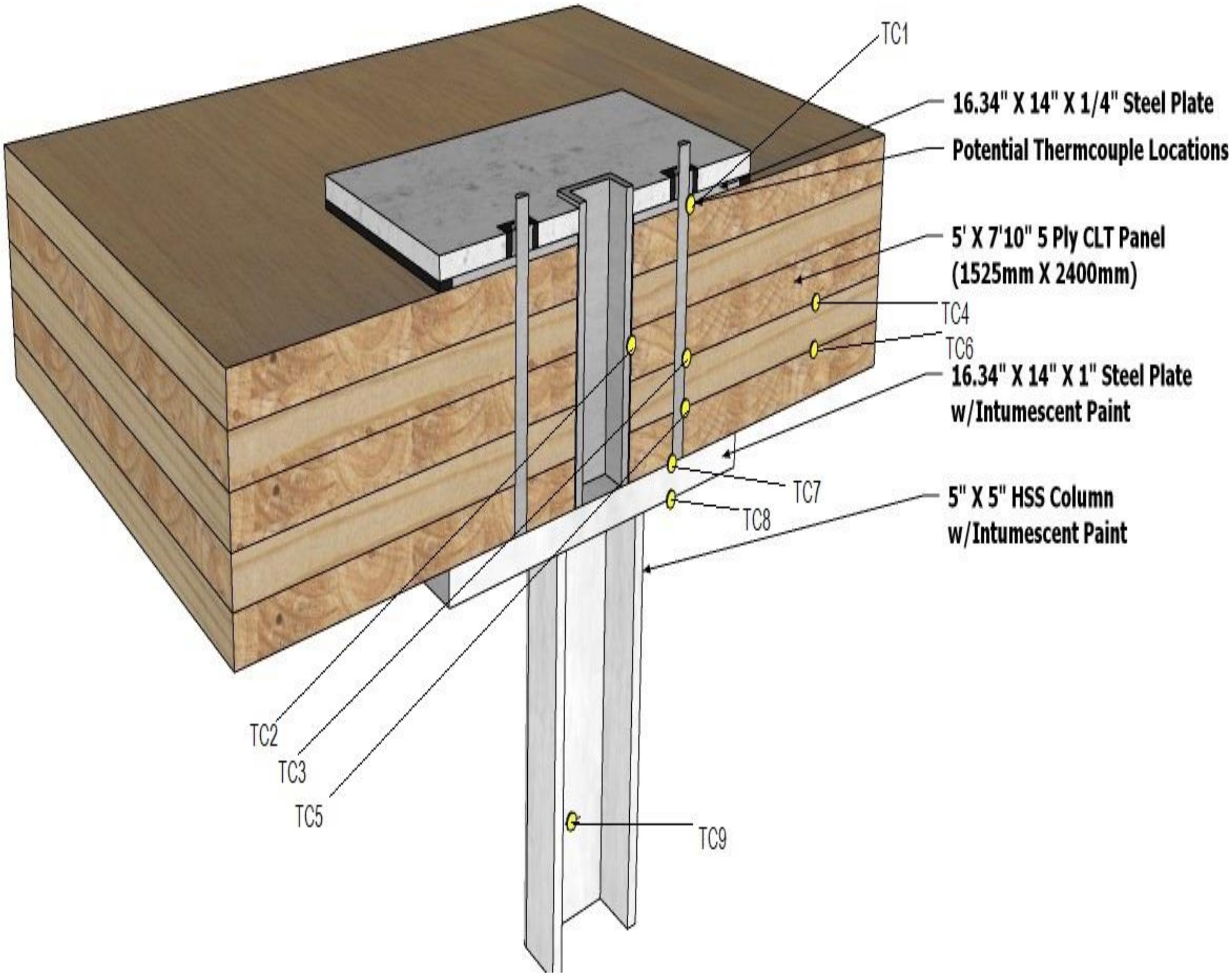

Figure 3: GHL CLT with Intumescent Paint Protected Steel Column Assembly Including Thermocouple Placement

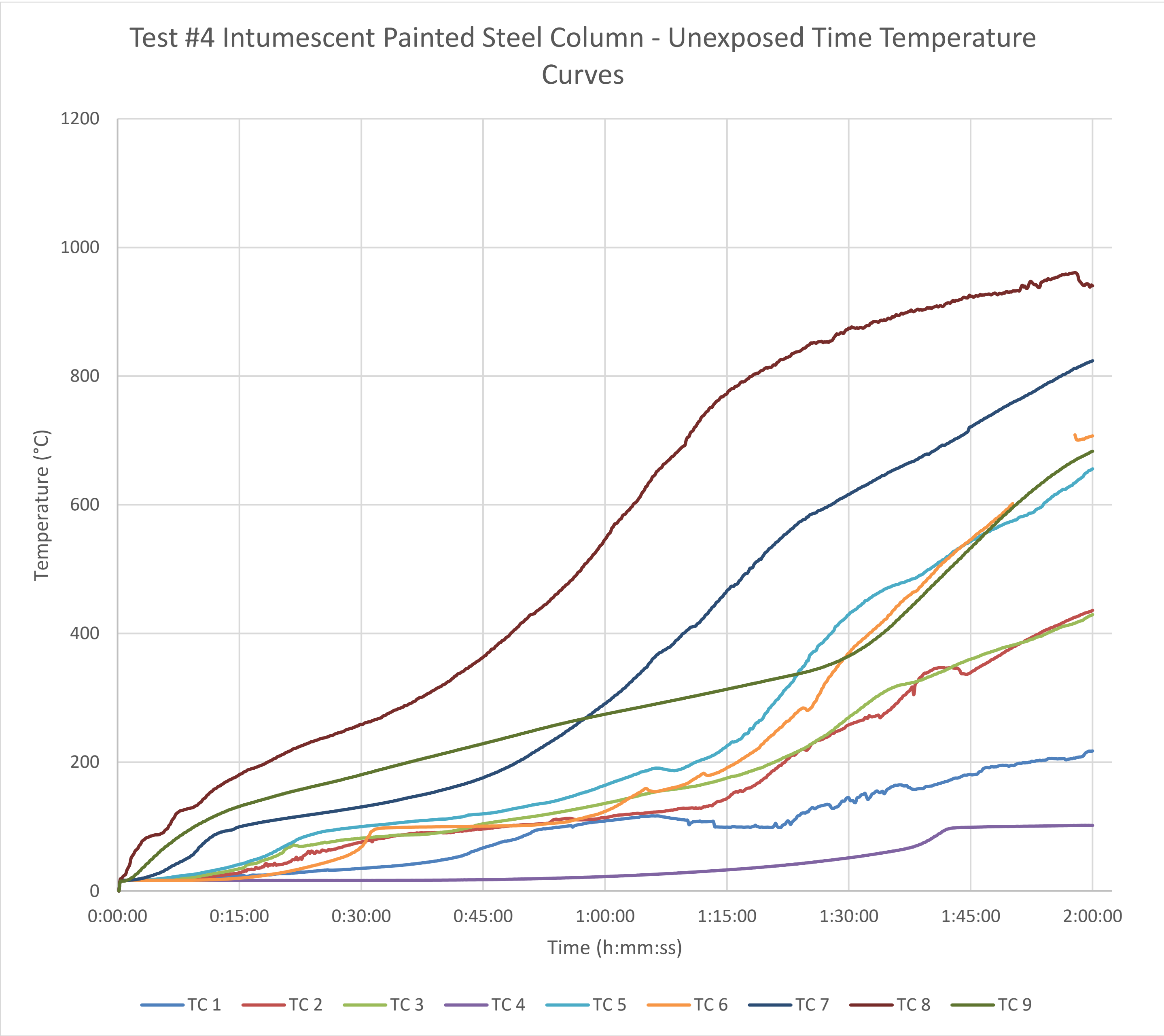

Figure 4 – Unexposed Time Temperature Curves.

APPENDIX B

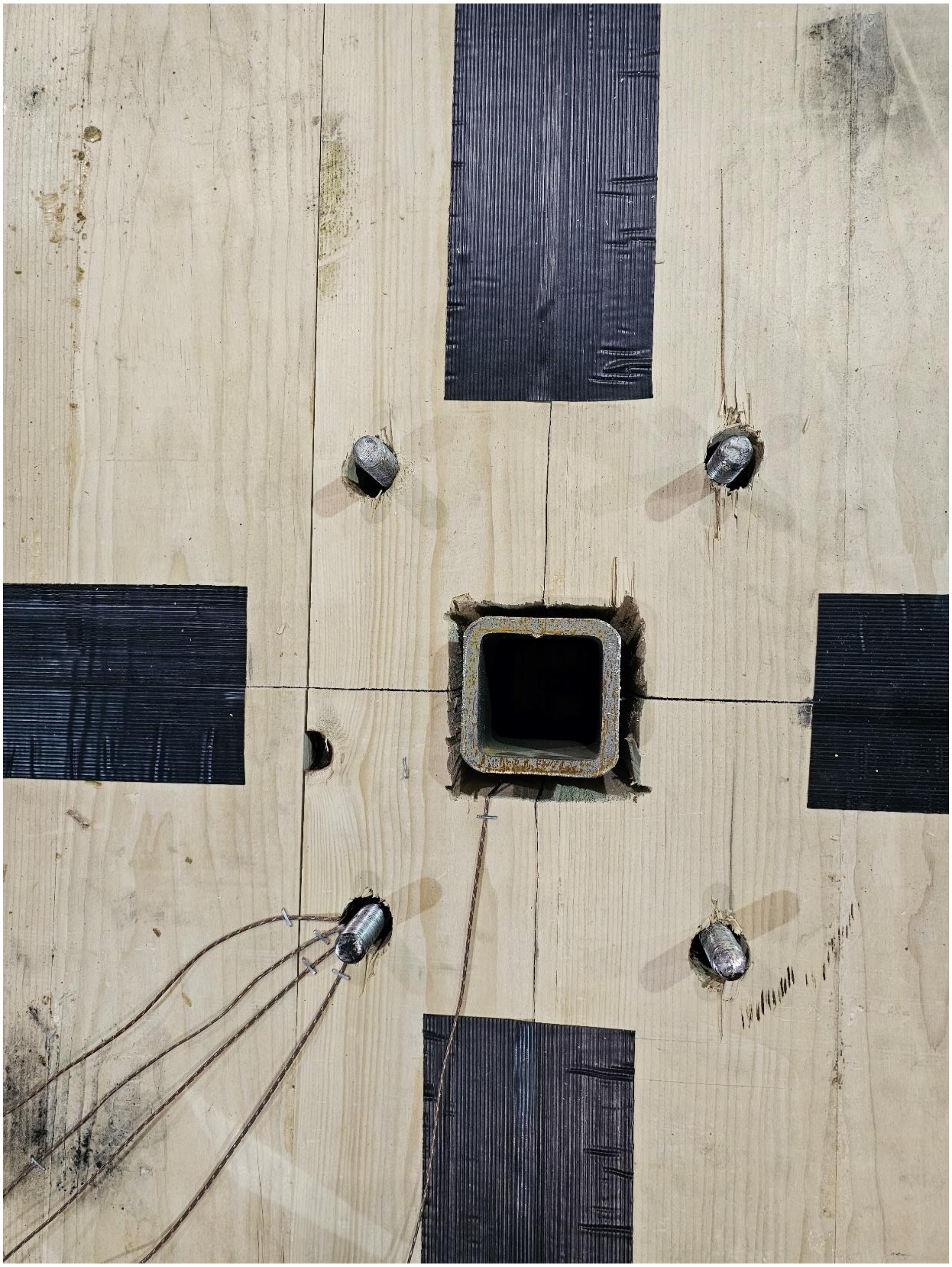

Figure 5: CLT panel joints and steel column connection prior to steel plate installation.

Figure 6: Unexposed CLT surface after plate installation.

Figure 7: Unexposed Side Steel Plate Connection Finished with Gypsum Board and Fire Caulking

Figure 8. CLT with Intumescent Painted HSS Steel Column Prior to Testing

Figure 9. CLT Assembly with Intumescent Paint Protected HSS Steel Column During Fire Exposure, Paint Flaming Shown

Figure 10. CLT with Intumescent Paint Protected HSS Steel Column After Fire Endurance Exposure, Exposed Steel Evident Along HSS Edge

Figure 11. Fire side at HSS steel column penetration with steel plate removed.

QAI LABORATORIES

REVISION HISTORY

Date	Revision	Issuer
March 27, 2023	Original report date.	ML

QAI LABORATORIES
CERTIFICATION TESTING INSPECTION

3980 North Fraser Way
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604.527.8378 ph. | 604.527.8368 fx.

CLIENT: **GHL CONSULTANTS LTD.**
700 West Pender Street, Suite 800
Vancouver British Columbia
V6C 1G8 Canada

Test Report No: T1410-2a	Issue Date: March 14, 2023

SAMPLE ID: 5-ply Cross-Laminated Timber (CLT) Floor / Ceiling Assembly with Exposed Steel Column Support.

SAMPLING DETAIL: CLT floor/ceiling panels were supplied by Kalesnikoff. The steel column was supplied by George Third & Son. Installation of the CLT panels to the exposed steel column was completed by QAI staff. No independent sampling of components was performed on major test elements provided to QAI for evaluation.

DATE OF RECEIPT: CLT panels from Kalensnikoff were received February 17th, 2023 in good condition. The steel column was received at QAI on January 20th, 2023 in good condition. All other components were acquired by QAI staff from local suppliers.

TESTING PERIOD: Testing was performed on March 10, 2023 by QAI Laboratories, Ltd. Burnaby, BC location.

AUTHORIZATION: QAI Test Proposal 22JL12132R1 dated December 14, 2022 signed by GHL Consultants Ltd. Associate Claire Yuan on January 6, 2023.

TEST PROCEDURE: Testing to client specified protocol with exposure following the specified time/temperature curve of the following method:

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

The above noted testing was conducted on a modified assembly as outlined in Deviations section of this report.

TEST RESULTS: The 5-ply CLT assembly with exposed steel column support when exposed to the specified time/temperature curve outlined in CAN/ULC S101, achieved results as outlined in the following pages of this report.

Prepared By

Matt Chursinoff
Fire Lab Technician

Signed for and on behalf of
QAI Laboratories, Ltd.

Matt Lansdowne
Vice President of Operations

Table of Contents

Introduction:

This report documents client specified fire testing program conducted by QAI Laboratories Ltd. for GHL Consultants Ltd. on a 5-ply cross-laminated timber (CLT) floor/ceiling assembly, supported on an exposed steel column of 127 mm x 127 mm (5 inches x 5 inches) dimensions of 6 mm (1/4-inch) wall thickness representing a CLT floor to steel column connection. Testing was conducted with the steel column element exposed (unprotected) during the fire endurance exposure, to evaluate thermal transmission between the CLT floor / ceiling assembly and steel column. Nominal loading was induced around the steel column to induce crushing of the lower compression surface of the CLT floor / ceiling to the steel plate component of the column. Details of the tested assembly can be found in the Assembly Description section of this report.

QAI exposed the 5-ply CLT floor / ceiling on steel column assembly to the fire endurance time/temperature curve specified by method CAN/ULC S101 for a 2-hour duration. Temperatures were measured at different CLT to steel connection interface locations, and at different CLT depths at locations as outlined in Appendix A of this report. During fire endurance testing, observations were taken by QAI staff.

Following the fire endurance period, the CLT and steel column assembly were removed for the CAN/ULC S101 furnace and the test assembly extinguished. Following, final observations were then taken.

A diagram of the test assembly including thermocouple location can be found in Appendix A of this report.

Photos of the test assembly setup can be found in Appendix B.

Assembly Description:

Table 1: Test Assembly and Penetrations Description

COMPONENT	DESCRIPTION	
Floor/Ceiling Assembly	Overall Size:	2286 mm (90 in.) wide by 1524 mm (60 in.) deep by 175 mm (6.9 in.) thickness.
	Type:	5-ply Cross-Laminated Timber fabricated in accordance with ANSI/APA PRG 320 by Kalesnikoff.
	Description:	Four 5-ply CLT panels were cut by Seagate Mass Timber at QAI Burnaby location from large CLT panels delivered to QAI. Seagate Mass Timber field cut locations for the steel post, threaded rod, and column to CLT connections. The CLT panels were installed on top of the steel column as described below. After installation, the non-fire side joints between CLT panels were sealed with a butyl-based weather seal. The fire side joints between CLT panels were fire caulked with 3M IC 15 WB+ and the caulking allowed to cure overnight prior to testing.
Steel Column	Overall Size:	127 mm x 127 mm x 6 mm thickness (5'' x 5'' x ¼'') column of 1765 mm (69.5 in.) in height.
	Type:	Hollow Structural Steel (HSS).
	Connection:	Steel plate of 415 mm x 355 mm x 25 mm thickness (16.35 inches x 14 inches x 1-inch thickness) was welded to the top of the described steel column. The steel plate included four threaded rods of 16 mm (5/8-inches) diameter, spaced around a central 76 mm x 76 mm x 8 mm (3-inch x 3-inch x 0.31 inch) steel tube.
Installation	Description:	The steel column was placed inside QAI"s mid scale furnace. The CLT panels were each lowered onto the steel column, fitting the CLT panel holes over the steel column 16 mm (5/8-inch) threaded steel rod, embedding the 76 mm x 76 mm steel box element into the center of the four panel CLT assembly. After CLT placement, a 415 mm x 355 mm x 6 mm thickness (16.35 inches x 14 inches x 1/4-inch thickness) steel plate was fit over the threaded rods, and the threaded rod mechanically secured with nuts to tighten the steel plate, compressing and connecting the CLT floor / ceiling to the steel column.

See Appendix A for a diagram of the noted test assembly.

See Appendix B for photos of the test assembly evaluated by QAI.

Test Apparatus:

The furnace used in the tests is a pilot-scale fire burning apparatus with interior dimensions of 1524 mm (60 in.) in height, 1524 mm (60 in.) in width, and 1321 mm (52 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.

Unexposed temperatures were monitored by thermocouples (TCs). The TC's were placed at cavity and joint locations. The temperatures were recorded continuously for the duration of the test, and the temperature rise data are provided graphically in Figure 2 and 4 in Appendix A.

The wall section is mounted in a vertical orientation, into a steel frame specimen holder. The specimen holder is then rolled up to the furnace and secured by chain and straps to the furnace opening.

One pressure tap was installed through the back wall of the test furnace. The pressure tap was attached and monitored by a Setra model 264 pressure transducer (ID# Pressure T1). The furnace pressure is controlled by adjusting a damper in the furnace exhaust stack.

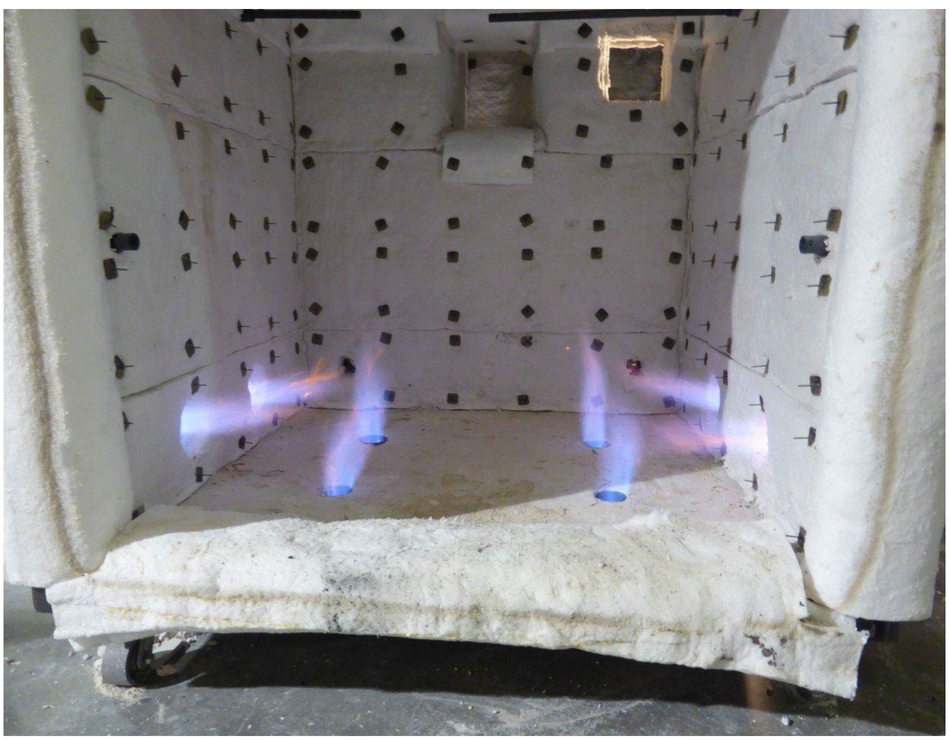

Figure 1: Burners Fired in the Furnace

Test Conditions:

The 5 ply CLT floor/ceiling with steel column assembly was constructed on the floor and placed on top of the furnace once complete. The space between the furnace and the floor/ceiling assembly was filled with ceramic fiber batt to prevent air movement. Concrete masonry blocks were placed around the steel column location on the non-fire side to induce local crushing at the CLT steel column interface on the fire side of assembly.

The pressure of the furnace was monitored throughout the test.

Prior to the fire endurance test the test assemblies were moved into position in front of the furnace and the pilot burners were ignited. The fire endurance test was initiated 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 standards.

The testing was for Research and Development purposes. No subsequent hose stream was conducted.

Deviations from the CAN/ULC S101 Test Standard:

The following outlines deviations from the CAN/ULC S101 standard during evaluation outlined in this report:

- The test assembly did not meet the test standards required sample size of for floor / ceiling assemblies.
- The applied load was to induce compression of the char layer at and did not represent required applied loads appropriate for a floor / ceiling type assembly.
- The hose stream test was not conducted as this test was performed for R&D purposes.
- Thermocouple placement is outlined in Appendix A of this report and did not measure temperature rise on the non-fire side.

Test Requirements:

Testing outlined in this report was for research and development purposes following the client specified protocol exposing the described 5-ply CLT floor / ceiling assembly with steel column described in this report to the fire endurance time/temperature curve of method CAN/ULC S101.

No requirements stated.

Test Results:

Observations

The following observations were taken over the duration of the fire endurance exposure:

Table 2: Test Observations

Time (min:sec)	Unexposed Side	Exposed Side
0:00	Test Initiated	
1:45		Ignition of CLT floor / ceiling exposed surface.
43:00	Combustion around the center steel column. Flaming is from inside the steel column air voids. Center steel 76 mm x 76 mm (3 inch x 3 inch) tube stuffed with ceramic fiber.	
50:00	Combustion of wood under center steel column perimeter. Perimeter of steel column fire caulked by QAI staff. Flames extinguished.	
1:12:45	Heavy smoke from the steel column center.	
2:00:00	Test Concluded, Fuel supply cut and assembly extinguished for observations.	

Flaming and Penetration

Flaming occurred on the non-fire side, through the 76 mm x 76 mm (3-inch x 3-inch) protruding steel column. After review, it was determined this element in field applications, would not open for venting as was present due to QAI setup. The open steel column was stuffed with ceramic fiber, reducing air flow through the steel column extinguishing flames.

Flaming occurred around the perimeter edges of the steel column. As this element would not be open for venting in field installations, the perimeter of the steel 76 mm x 76 mm steel column was fire caulked, sealing openings in the steel element extinguishing the flames.

No additional flaming was observed during the fire endurance period.

Temperature Rise

Temperatures were measured at eight (8) locations as outlined in test assembly diagram found in Appendix A of this report. The maximum temperatures achieved at each thermocouple location are shown in Table 3 below.

Table 3. Maximum Measured Temperatures at Thermocouple Locations

	TC1	TC2	TC3	TC4	TC5	TC6	TC7	TC8
Maximum Temp. (ºC)	217	673	719	239	846	827	858	955

Times temperature data for the above thermocouples can be found in Appendix A of this report.

Hose Stream Test

The hose stream test was not conducted as the assemblies were tested until failure for research purposes.

Conclusions:

QAI performed testing for GHL on a client specified test protocol, exposing a test floor / ceiling assembly to the fire endurance time/temperature curve as specified in method CAN/ULC S101.

The 5-ply CLT assembly with exposed steel column support as described in this report, when exposed to the specified time/temperature curve outlined in CAN/ULC S101, achieved results as outlined on Page 7.

APPENDIX A

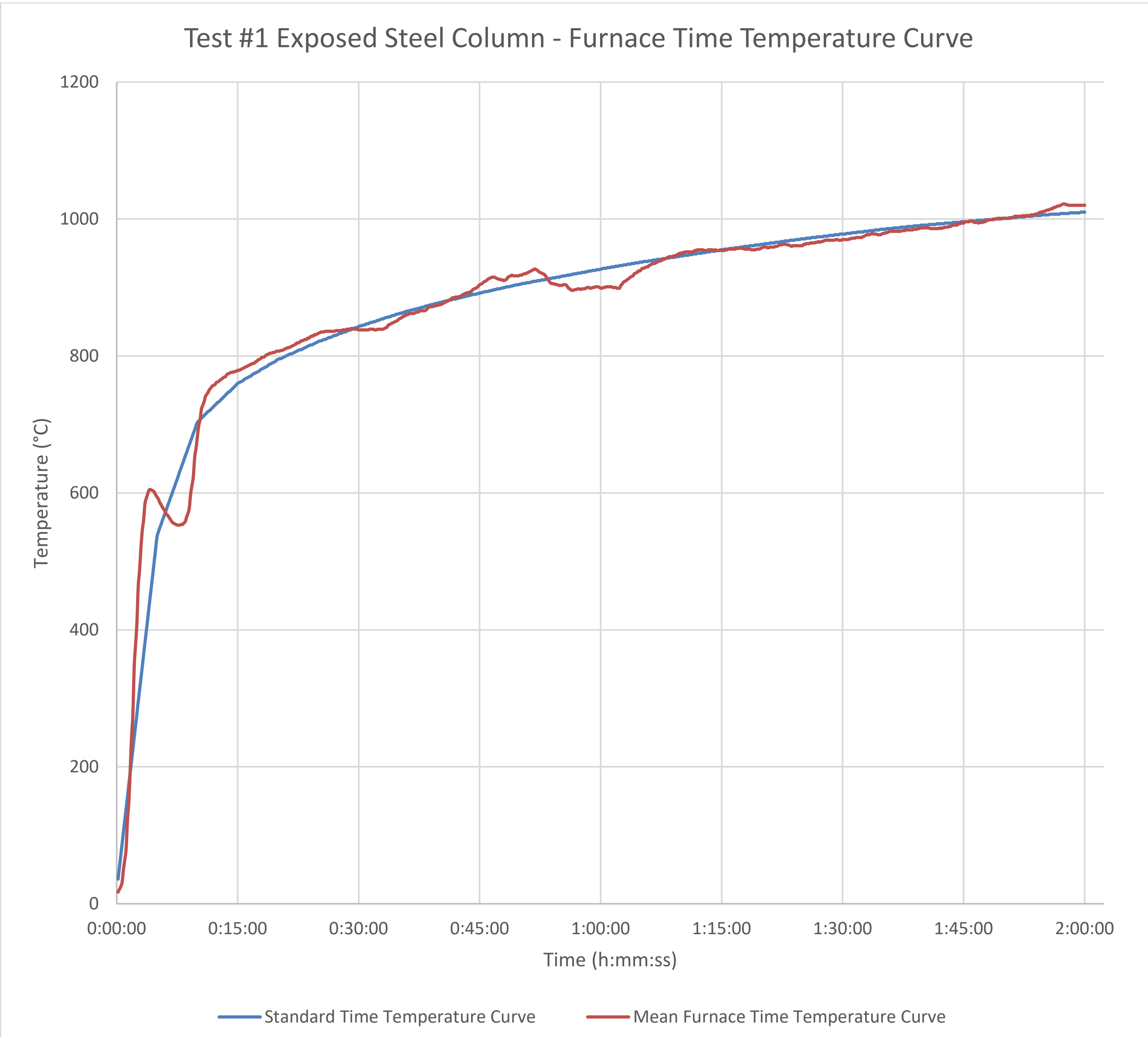

Figure 2: Time Temperature Curve

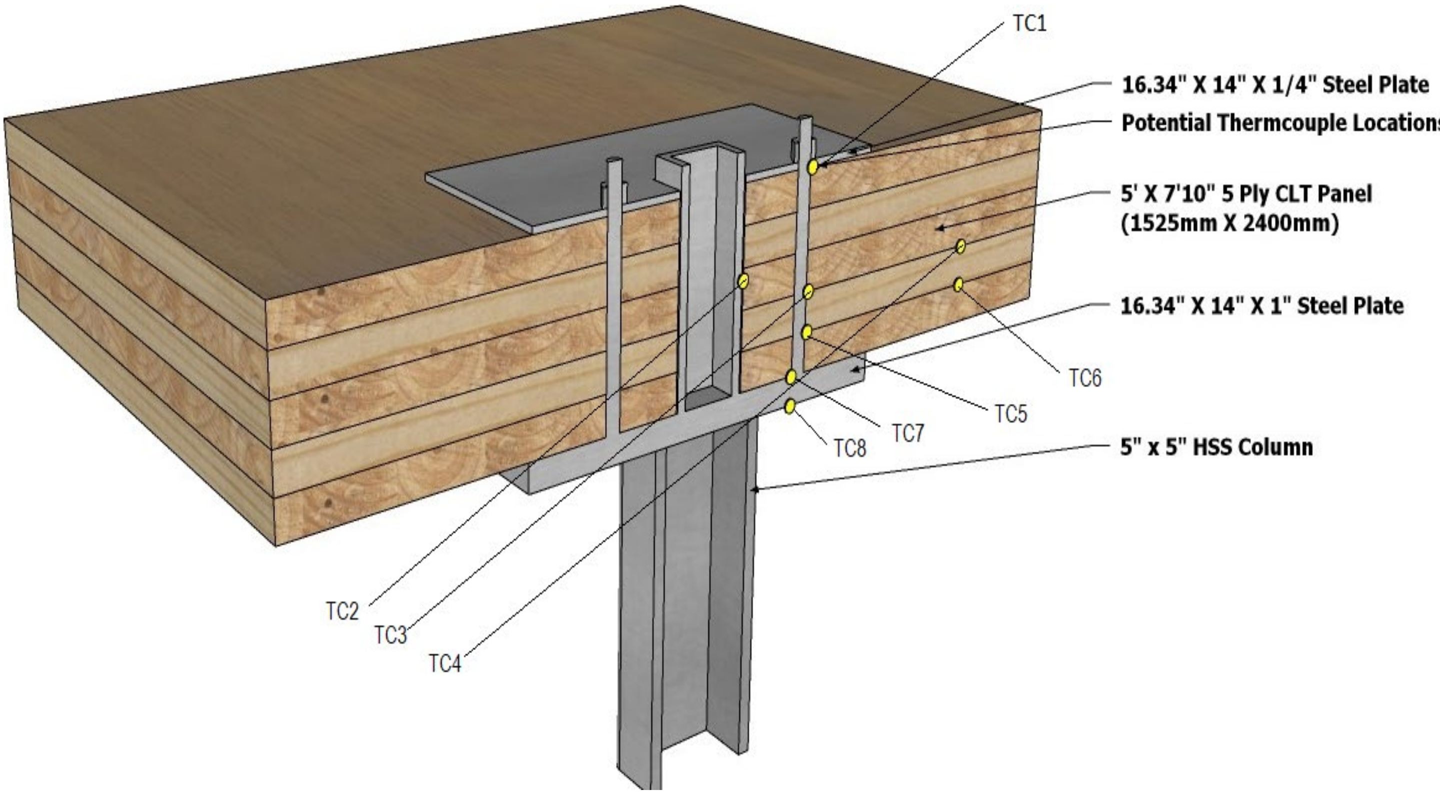

Figure 3: GHL CLT with Exposed Steel Column Assembly Including Thermocouple Placement

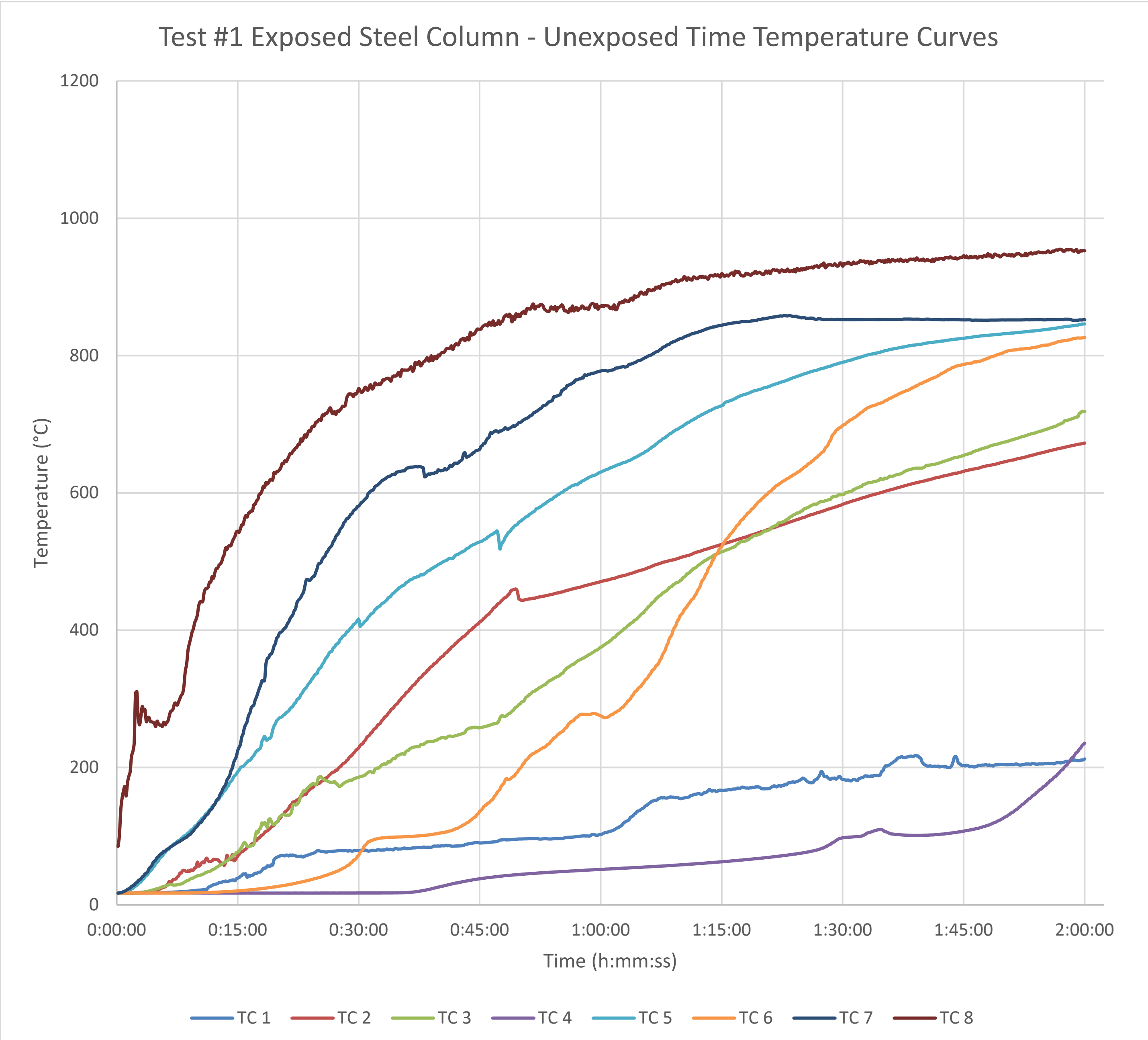

Figure 4 – Unexposed Time Temperature Curves.

APPENDIX B

Figure 5: Exposed side of the test assembly prior to the fire test.

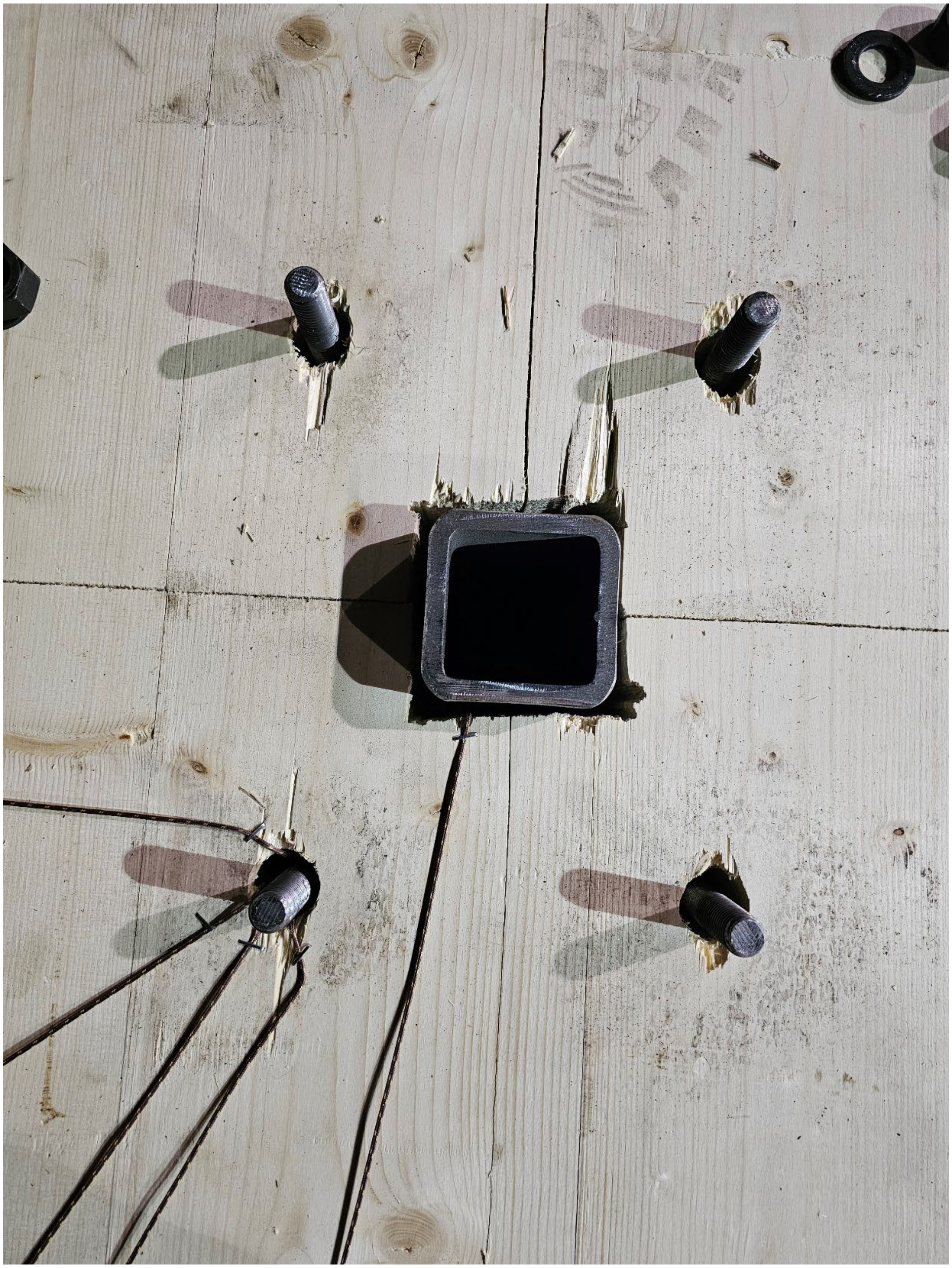

Figure 6: CLT panel joints and steel column connection prior to steel plate installation.

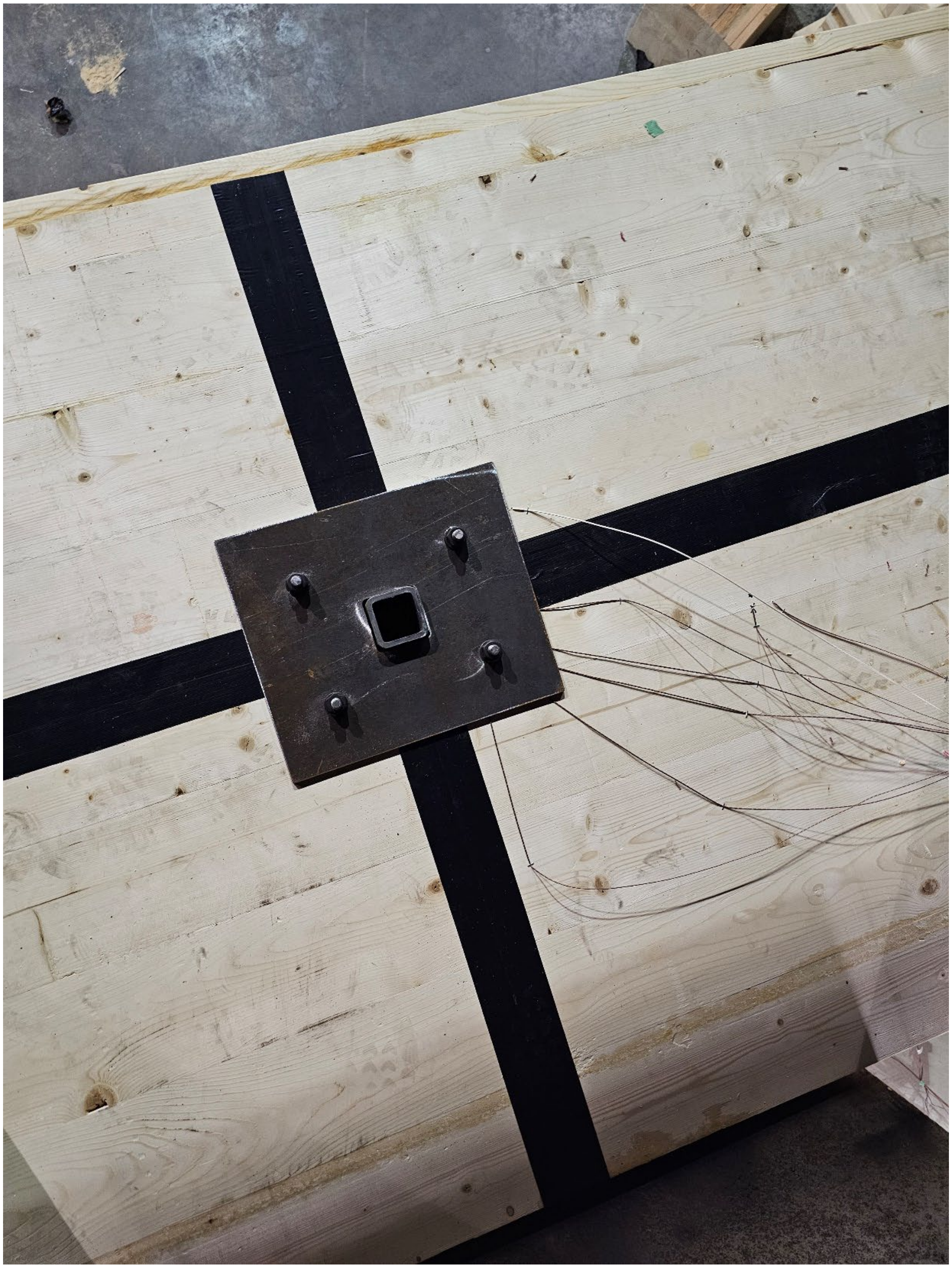

Figure 7: Unexposed CLT surface after plate installation and joint sealing.

Figure 8: Flaming non-fire side through and around 3 inch x 3 inch steel tube (including concrete masonry weight)

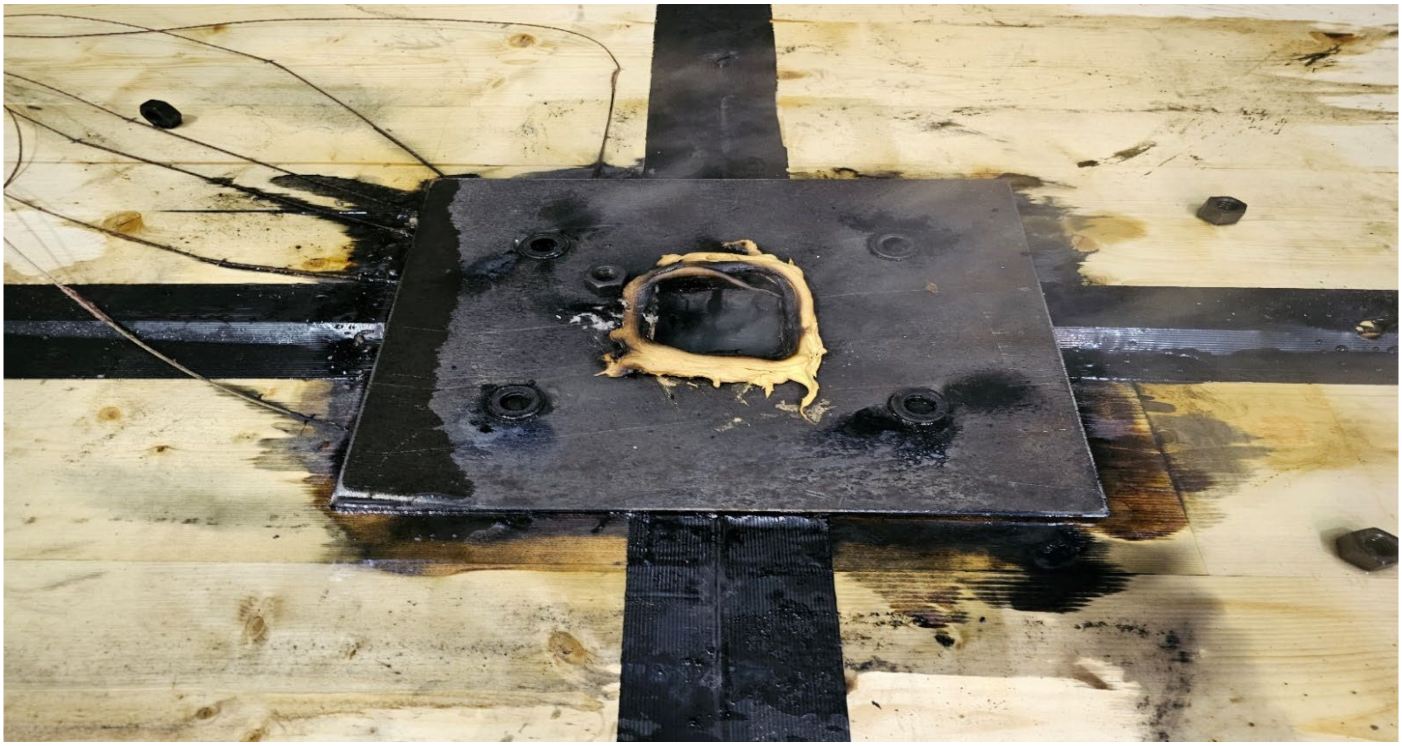

Figure 9: Steel column non-fire side after fire caulking around perimeter.

Figure 10. CLT floor / ceiling and steel column assembly at test completion.

Figure 11. CLT floor / ceiling and steel column assembly post testing.

Figure 12. Localized damage through steel column 3 inch x 3 inch steel tube penetration through the CLT assembly.

Figure 13. Non-Fire side at steel column 3 inch x 3 inch steel column penetration with steel plate removed.

REVISION HISTORY

Date	Revision	Issuer
March 14, 2023	Original report date.	ML

QAI LABORATORIES
CERTIFICATION TESTING INSPECTION

3980 North Fraser Way
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CLIENT: **GHL CONSULTANTS LTD.**
700 West Pender Street, Suite 800
Vancouver British Columbia
V6C 1G8 Canada

Test Report No: T1410-2b	Issue Date: March 22, 2023

SAMPLE ID: 5-ply Cross-Laminated Timber (CLT) Floor / Ceiling Assembly with Exposed Glulam Column and Exposed Steel Support.

SAMPLING DETAIL: CLT floor/ceiling panels were supplied by Kalesnikoff. The glulam column was supplied by Kalesnikoff. Installation of the CLT panels to the exposed steel column was completed by QAI staff. No independent sampling of components was performed on major test elements provided to QAI for evaluation.

DATE OF RECEIPT: CLT panels and glulam column from Kalensnikoff were received February 17th, 2023 in good condition.
All other components were acquired by QAI staff from local suppliers.

TESTING PERIOD: Testing was performed on March 17, 2023 by QAI Laboratories, Ltd. Burnaby, BC location.

AUTHORIZATION: QAI Test Proposal 22JL12132R1 dated December 14, 2022 signed by GHL Consultants Ltd. Associate Claire Yuan on January 6, 2023.

TEST PROCEDURE: Testing to client specified protocol with exposure following the specified time/temperature curve of the following method:

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

The above noted testing was conducted on a modified assembly as outlined in Deviations section of this report.

TEST RESULTS: The 5-ply CLT assembly with exposed glulam column and steel connection assembly when exposed to the specified time/temperature curve outlined in CAN/ULC S101, achieved results as outlined in the following pages of this report.

Prepared By

Matt Chursinoff
Fire Lab Technician

Signed for and on behalf of
QAI Laboratories, Ltd.

Matt Lansdowne
Vice President of Operations

Table of Contents

Introduction:

This report documents client specified fire testing program conducted by QAI Laboratories Ltd. for GHL Consultants Ltd. on a 5-ply cross-laminated timber (CLT) floor/ceiling assembly, supported on an exposed glulam column of 413 mm x 355 mm (16.25 inches x 14 inches) dimensions including exposed steel connections representing, a CLT floor to mass timber column connection. Testing was conducted with the glulam column and steel connection element exposed (unprotected) during the fire endurance exposure, to evaluate thermal transmission between the CLT floor / ceiling assembly and glulam column connection. Nominal loading was induced around the glulam column connection to induce crushing of the lower compression surface of the CLT floor / ceiling to the steel plate component of the column connection. Details of the tested assembly can be found in the Assembly Description section of this report.

QAI exposed the 5-ply CLT floor / ceiling on glulam column assembly to the fire endurance time/temperature curve specified by method CAN/ULC S101 for a 2-hour duration. Temperatures were measured at different CLT floor slab and glulam column connection interface locations, and at different CLT depths at locations as outlined in Appendix A of this report. During fire endurance testing, observations were taken by QAI staff.

Following the fire endurance period, the CLT and glulam column exposed steel connection assembly were removed for the CAN/ULC S101 furnace and the test assembly extinguished. Following, final observations were then taken.

A diagram of the test assembly including thermocouple location can be found in Appendix A of this report.

Photos of the test assembly setup can be found in Appendix B.

Assembly Description:

Table 1: Test Assembly and Penetrations Description

COMPONENT	DESCRIPTION	
Floor/Ceiling Assembly	Overall Size:	2286 mm (90 in.) wide by 1524 mm (60 in.) deep by 175 mm (6.9 in.) thickness.
	Type:	5-ply Cross-Laminated Timber fabricated in accordance with ANSI/APA PRG 320 by Kalesnikoff.
	Description:	Four 5-ply CLT panels were cut by Seagate Mass Timber at QAI Burnaby location from large CLT panels delivered to QAI. Seagate Mass Timber field cut locations for the steel post, threaded rod, and column to CLT connections. The CLT panels were installed on top of the steel column as described below. After installation, the non-fire side joints between CLT panels were sealed with a butyl-based weather seal. The fire side joints between CLT panels were fire caulked with 3M IC 15 WB+ and the caulking allowed to cure overnight prior to testing.
Glulam Column	Overall Size:	413 mm x 355 mm (16.25'' x 14") column of 1765 mm (69.5 in.) in height.
	Type:	Glulam composed of laminated Douglas-fir 38 mm x 76 mm (2'' x 4'' nominal) lumber.
	Connection:	Steel plate of 415 mm x 355 mm x 25 mm thickness (16.35 inches x 14 inches x 1-inch thickness). The steel plate included four threaded rods of 16 mm (5/8-inches) diameter, spaced around a central 76 mm x 76 mm x 8 mm (3-inch x 3-inch x 0.31 inch) steel tube on the upper side. The lower surface included four threaded rods of 16 mm (5/8-inches) diameter, spaced uniformly, for embedment in the glulam column. The glulam column threaded rods were epoxied in place with Systems Three Cold Cure Epoxy Adhesive and allowed to cure a minimum 24 hours time prior to testing.
Installation	Description:	The CLT panels were each lowered onto the glulam column with steel epoxied connections, fitting the CLT panel holes over the steel column 16 mm (5/8-inch) threaded steel rod, embedding the 76 mm x 76 mm steel box element into the center of the four panel CLT assembly. After CLT placement, a 415 mm x 355 mm x 6 mm thickness (16.35 inches x 14 inches x 1/4-inch thickness) steel plate was fit over the threaded rods, and the threaded rod mechanically secured with nuts to tighten the steel plate, compressing and connecting the CLT floor / ceiling to the steel column. The non fire side steel plate was finished with 16 mm (5/8'') Type X gypsum board, installed flush to the protruding steel column on the non-fire side.

See Appendix A for a diagram of the noted test assembly.

See Appendix B for photos of the test assembly evaluated by QAI.

Test Apparatus:

The furnace used in the tests is a pilot-scale fire burning apparatus with interior dimensions of 1524 mm (60 in.) in height, 1524 mm (60 in.) in width, and 1321 mm (52 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.

Unexposed temperatures were monitored by thermocouples (TCs). The TC's were placed at cavity and joint locations. The temperatures were recorded continuously for the duration of the test, and the temperature rise data are provided graphically in Figure 2 and 4 in Appendix A.

The wall section is mounted in a vertical orientation, into a steel frame specimen holder. The specimen holder is then rolled up to the furnace and secured by chain and straps to the furnace opening.

One pressure tap was installed through the back wall of the test furnace. The pressure tap was attached and monitored by a Setra model 264 pressure transducer (ID# Pressure T1). The furnace pressure is controlled by adjusting a damper in the furnace exhaust stack.

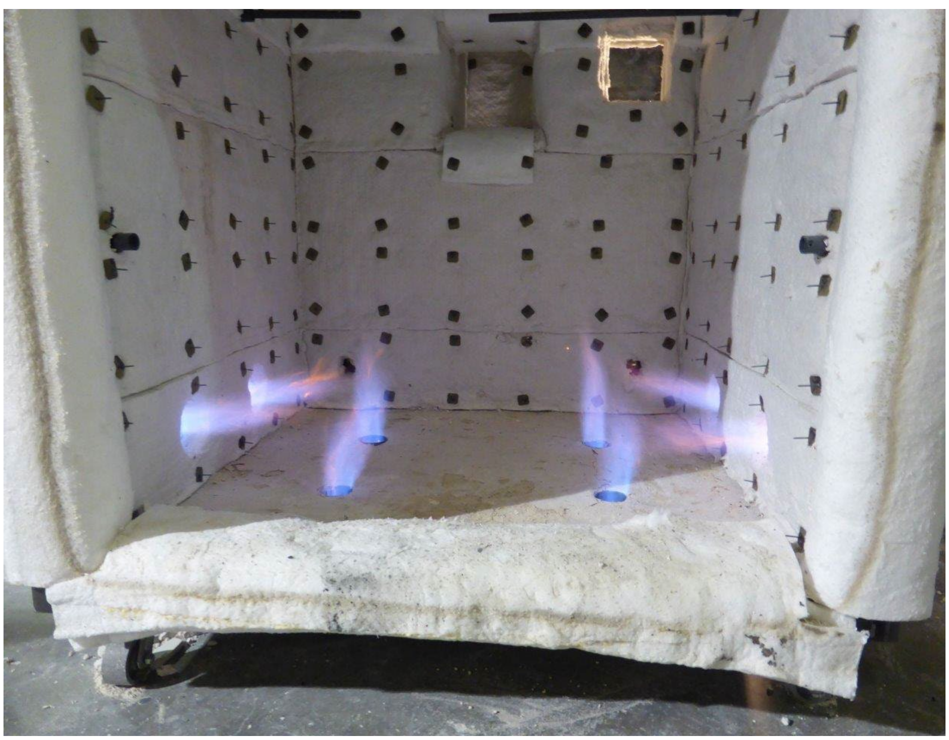

Figure 1: Burners Fired in the Furnace

Test Conditions:

The 5 ply CLT floor/ceiling with glulam column with exposed steel connection assembly was constructed on the floor and placed on top of the furnace once complete. The space between the furnace and the floor/ceiling assembly was filled with ceramic fiber batt to prevent air movement. Concrete masonry blocks were placed around the glulam column location on the non-fire side to induce local crushing at the CLT to glulam steel connection interface on the fire side of assembly.

The pressure of the furnace was monitored throughout the test.

Prior to the fire endurance test the test assemblies were moved into position in front of the furnace and the pilot burners were ignited. The fire endurance test was initiated 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 standards.

The testing was for Research and Development purposes. No subsequent hose stream was conducted.

Deviations from the CAN/ULC S101 Test Standard:

The following outlines deviations from the CAN/ULC S101 standard during evaluation outlined in this report:

- The test assembly did not meet the test standards required sample size of for floor / ceiling assemblies.
- The applied load was to induce compression of the char layer at and did not represent required applied loads appropriate for a floor / ceiling type assembly.
- The hose stream test was not conducted as this test was performed for R&D purposes.
- Thermocouple placement is outlined in Appendix A of this report and did not measure temperature rise on the non-fire side.

Test Requirements:

Testing outlined in this report was for research and development purposes following the client specified protocol exposing the described 5-ply CLT floor / ceiling assembly with glulam column described in this report to the fire endurance time/temperature curve of method CAN/ULC S101.

No requirements stated.

Test Results:

Observations

The following observations were taken over the duration of the fire endurance exposure:

Table 2: Test Observations

Time (min:sec)	Unexposed Side	Exposed Side
0:00	Test Initiated	
1:27		Glulam column ignition.
5:28	Temperatures exceeding CAN/ULC S101 time/temperature curve. Fuel shut off, damper closed to reduce oxygen to fire.	
16:56		Column flaming heavily.
20:50	Attempted furnace reignition. After short period, temperatures exceeding CAN/ULC S101 time/temperature curve. Fuel shut off.	
45:00		Continued heavy flaming in furnace. Visible char development on column.
60:00	Furnace reignition.	
1:36:15	Heavy venting from the steel plate on non-fire side.	
1:54:30		Pieces of char falling from the column.
2:00:00	Test Concluded, Fuel supply cut and assembly extinguished for observations.	

Flaming and Penetration

No flaming was observed on the non-fire side during evaluation.

Temperature Rise

Temperatures were measured at eight (8) locations as outlined in test assembly diagram found in Appendix A of this report. The maximum temperatures achieved at each thermocouple location are shown in Table 3 below.

Table 3. Maximum Measured Temperatures at Thermocouple Locations

	TC1	TC2	TC3	TC4	TC5	TC6	TC7	TC8
Maximum Temp. (°C)	212	670	710	239	845	826	851	936

Times temperature data for the above thermocouples can be found in Appendix A of this report.

Hose Stream Test

The hose stream test was not conducted as the assemblies were tested until failure for research purposes.

Conclusions:

QAI performed testing for GHL on a client specified test protocol, exposing a test floor / ceiling assembly to the fire endurance time/temperature curve as specified in method CAN/ULC S101.

The 5-ply CLT assembly with exposed glulam column including exposed steel connection assembly as described in this report, when exposed to the specified time/temperature curve outlined in CAN/ULC S101, achieved results as outlined on Page 7.

APPENDIX A

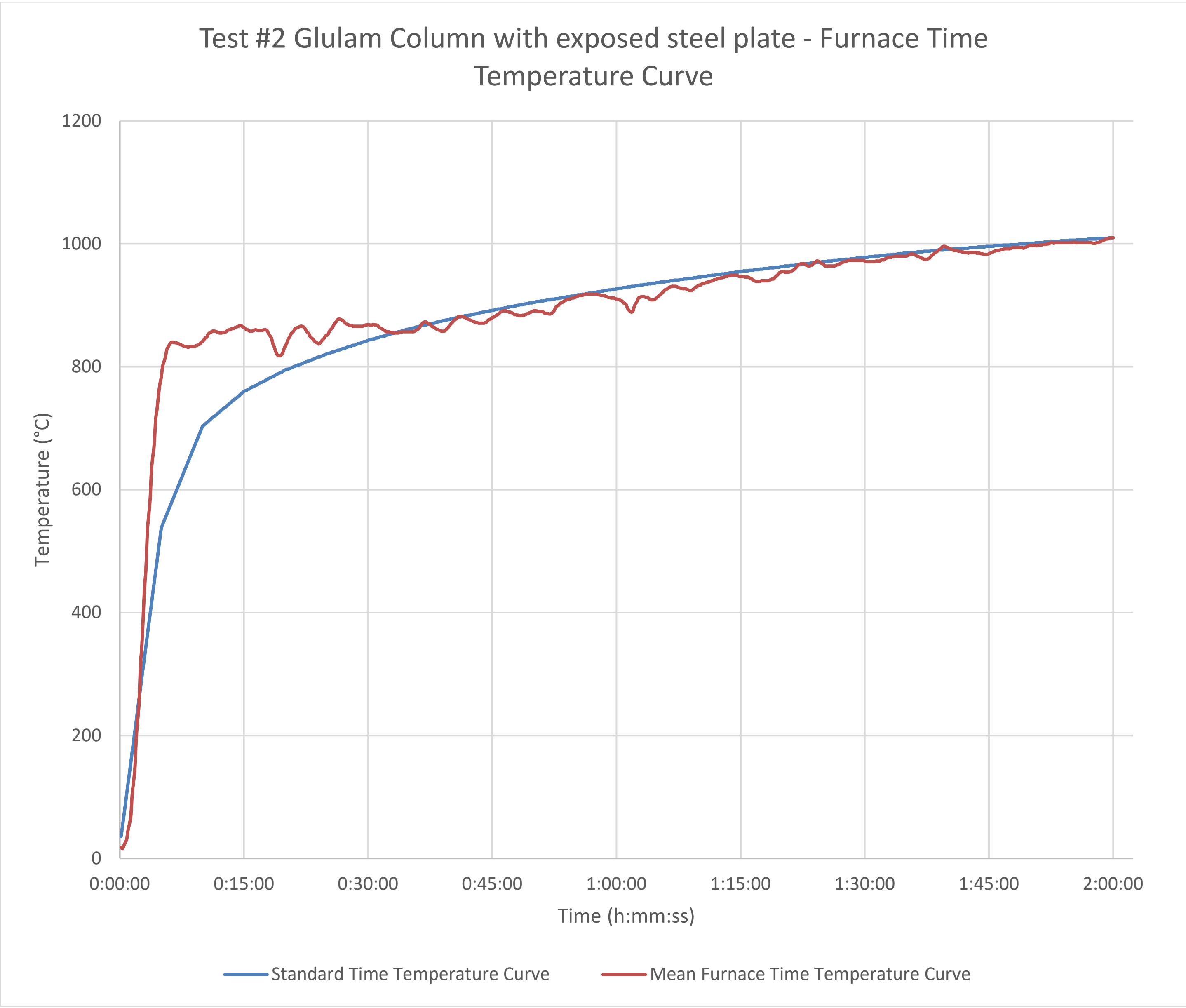

Figure 2: Time Temperature Curve

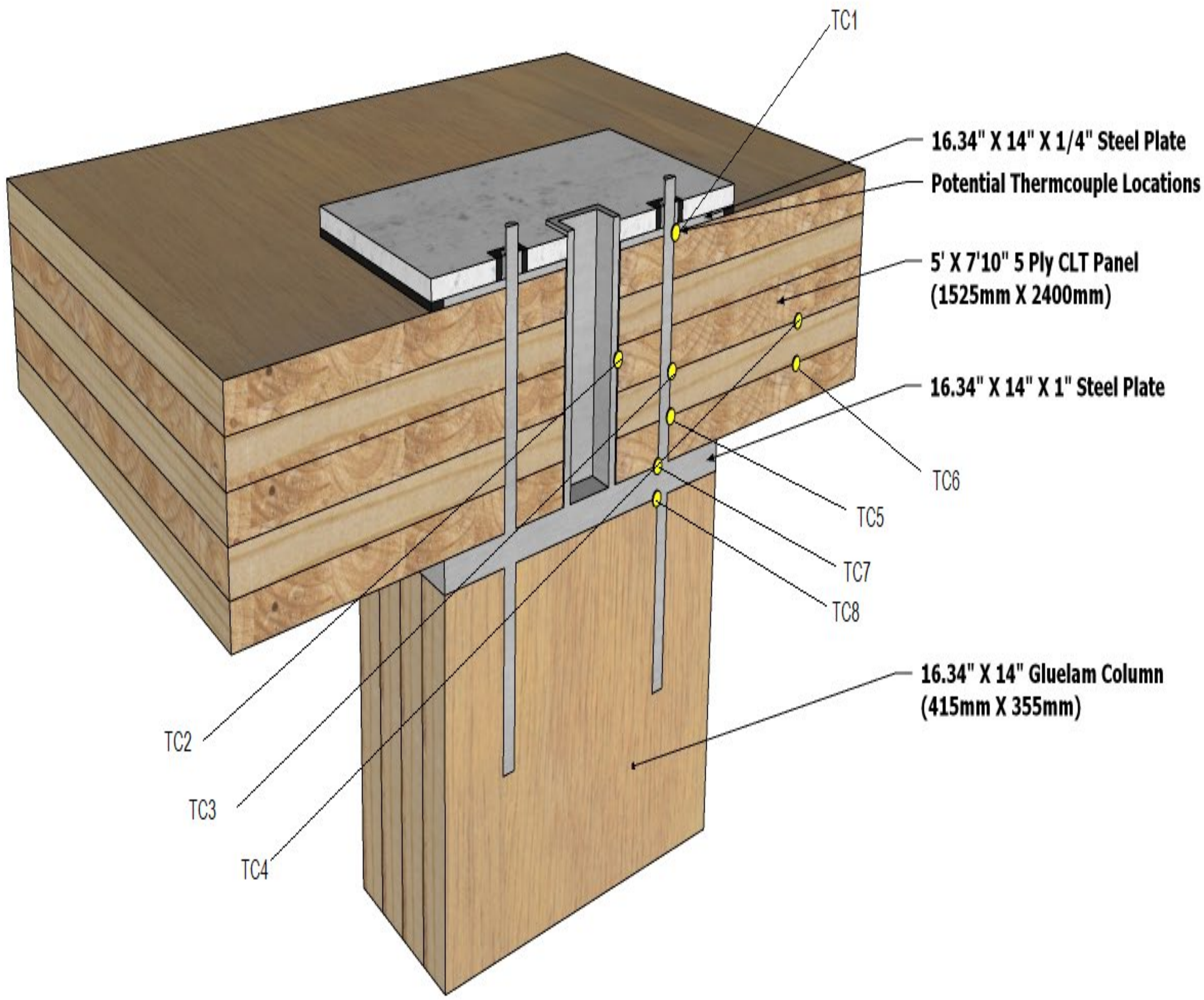

Figure 3: GHL CLT with Exposed Glulam and Steel Connection Assembly Including Thermocouple Placement

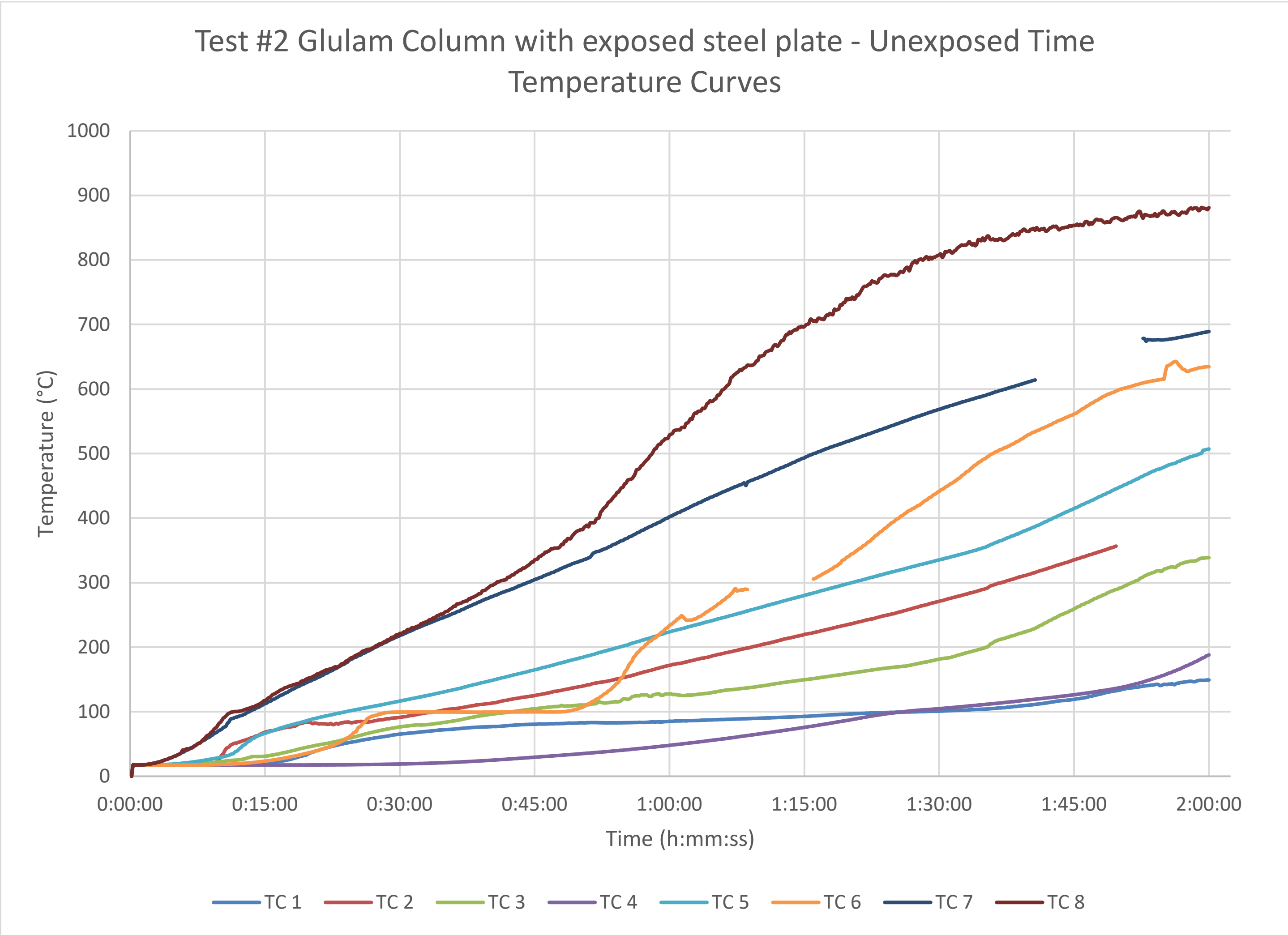

Figure 4 – Unexposed Time Temperature Curves.

APPENDIX B

Figure 5: Exposed side of the test assembly prior to the fire test.

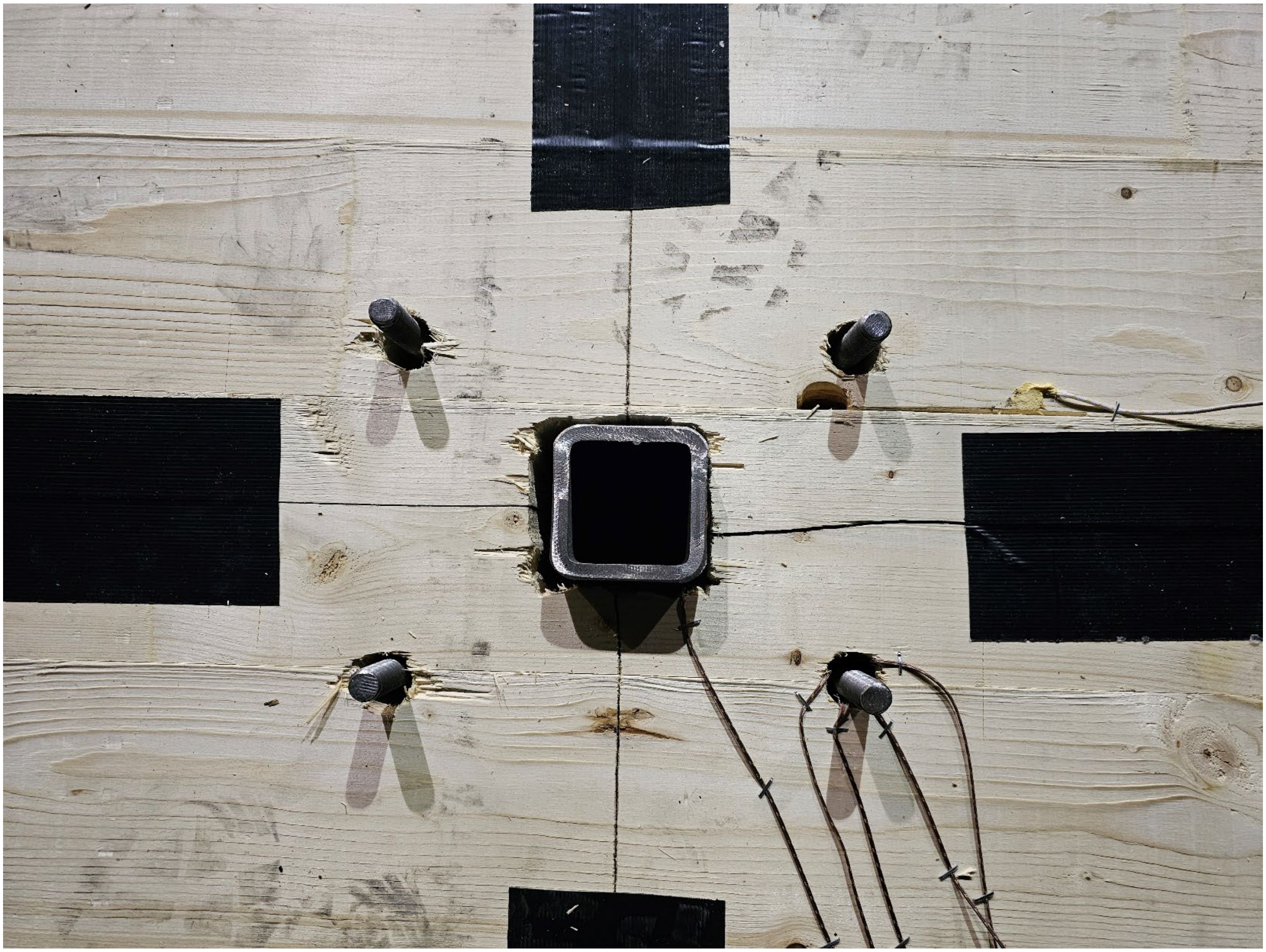

Figure 6: CLT panel joints and steel column w prior to steel plate and gypsum installation.

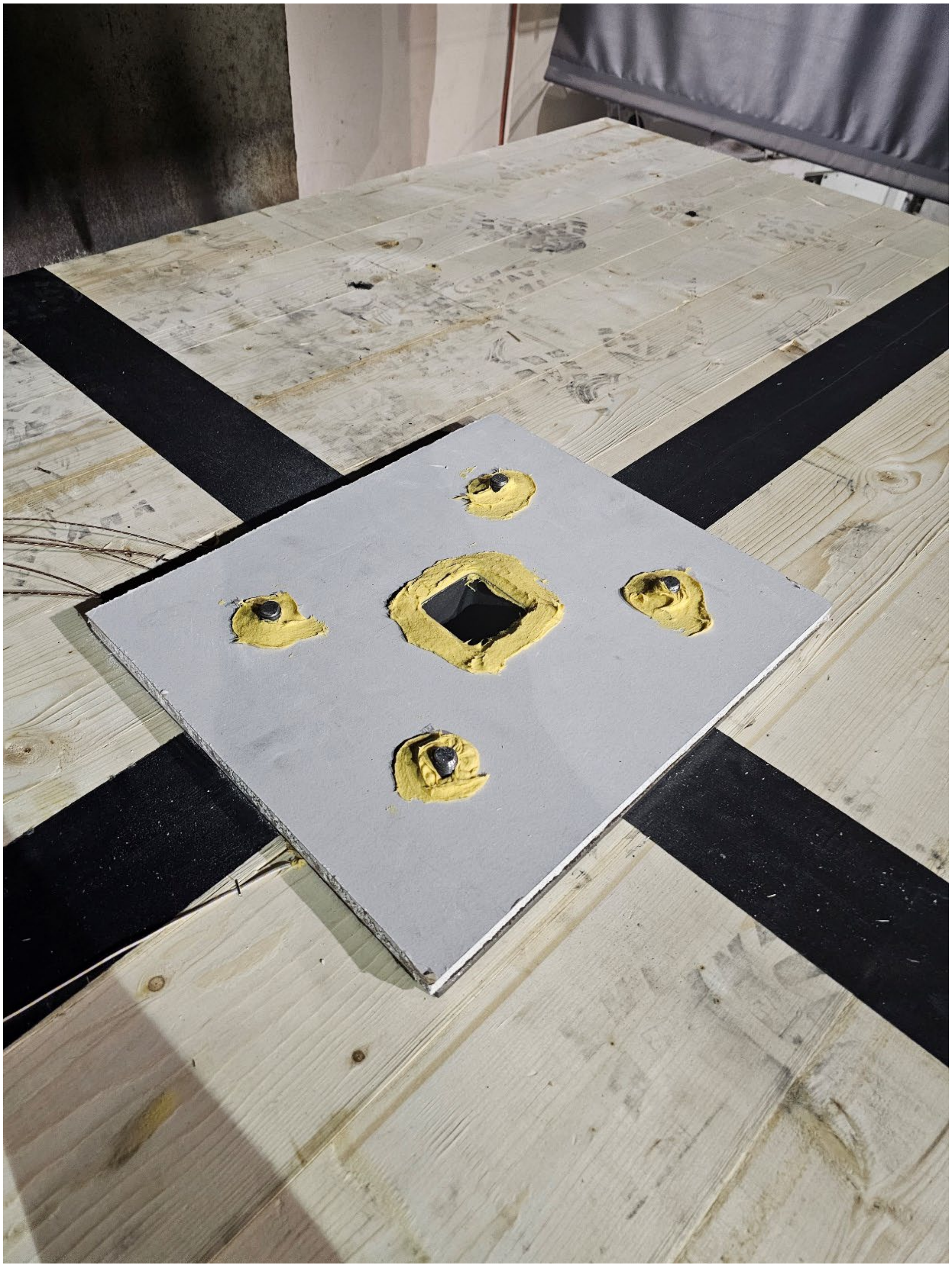

Figure 7: Unexposed CLT surface after plate installation and joint sealing.

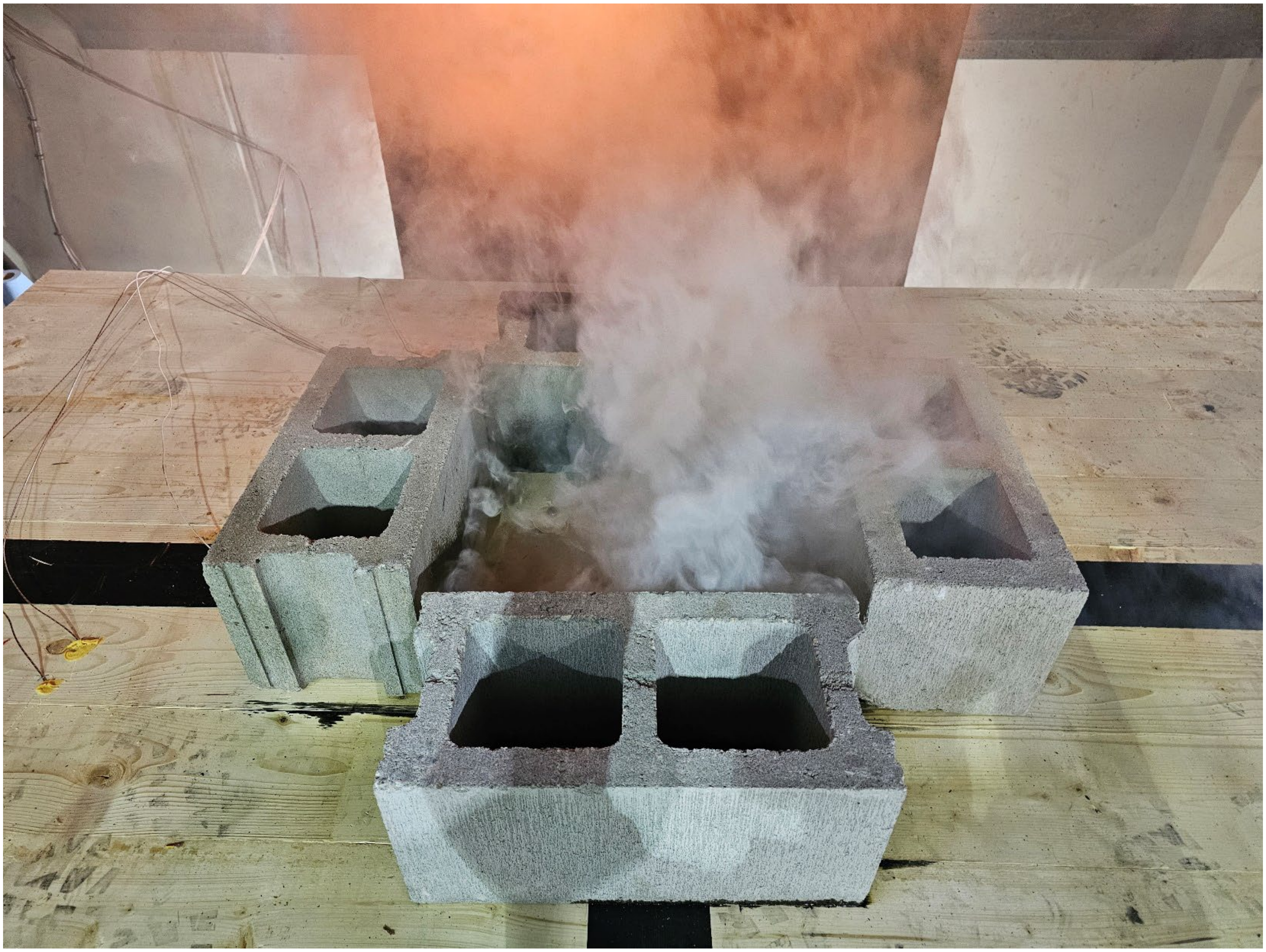

Figure 8: Observed smoking non-fire side (including concrete masonry weight)

Figure 9: Glulam column showing char development during fire endurance exposure.

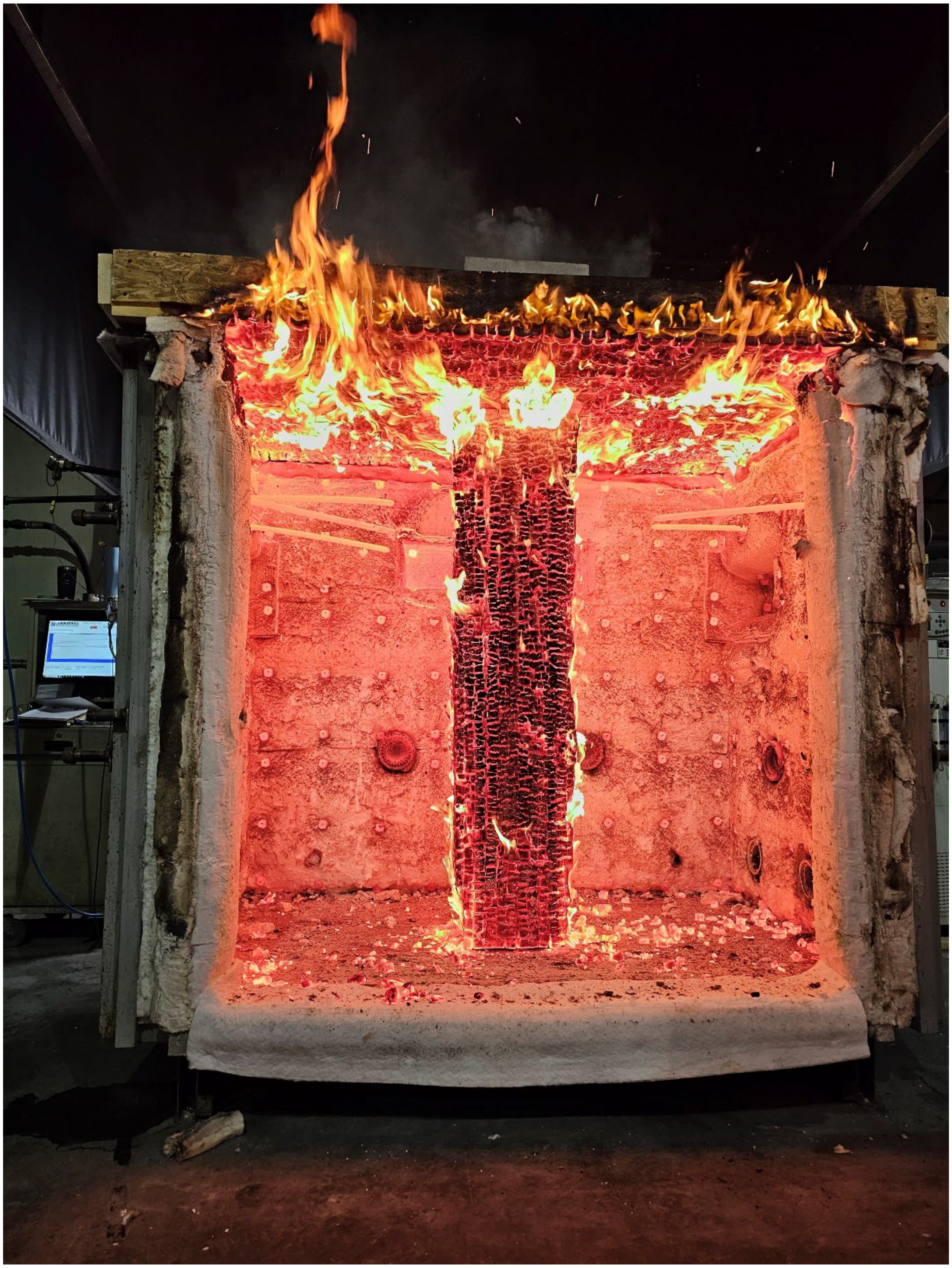

Figure 10. CLT floor / ceiling and glulam column assembly at test completion.

Figure 11.Glulam column retaining steel connection after fire exposure.

Figure 12. Localized damage through steel column 3 inch x 3 inch steel tube penetration through the CLT assembly.

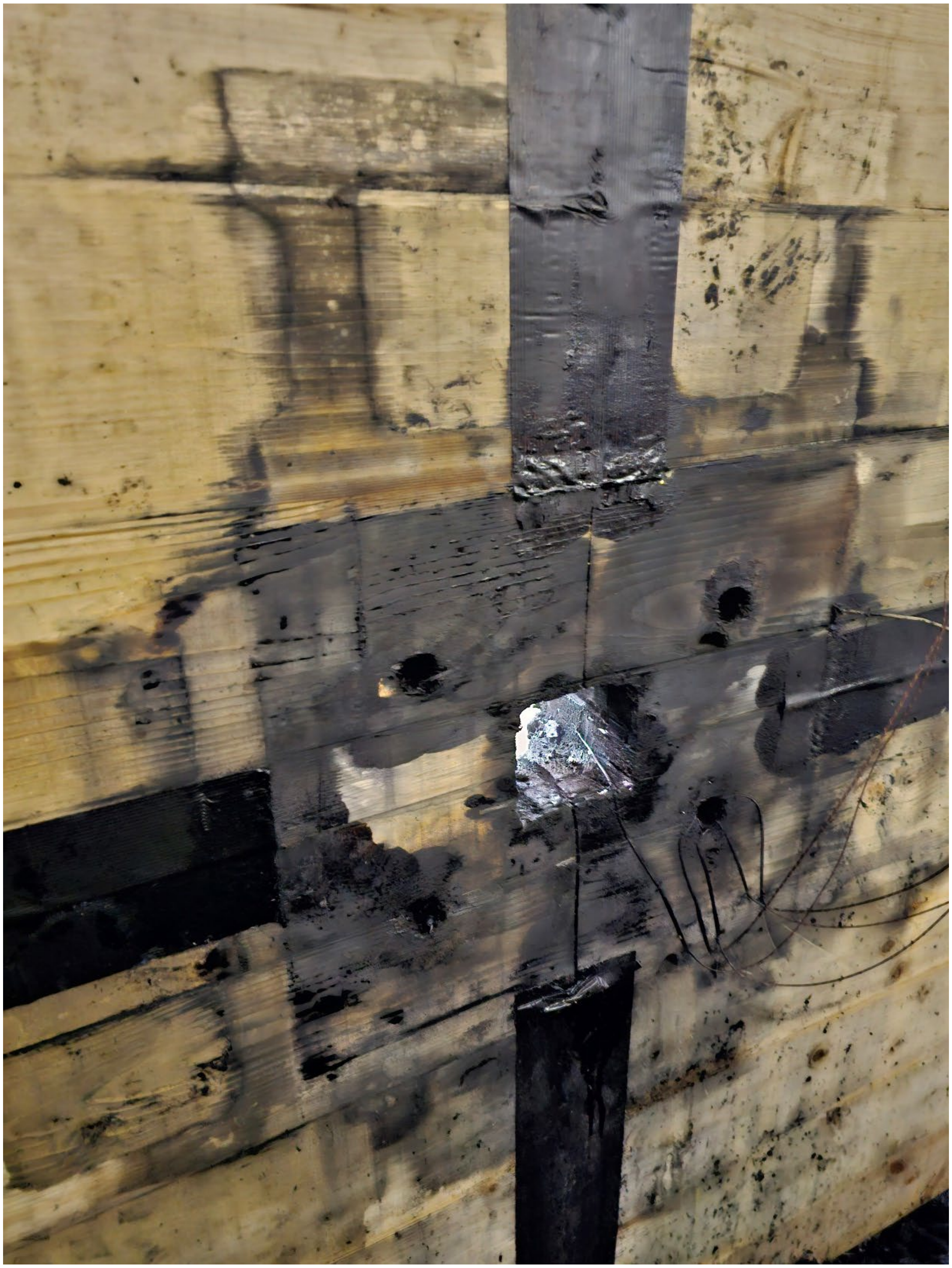

Figure 13. Non-Fire side at steel column 3-inch x 3-inch steel column penetration with steel plate removed.

REVISION HISTORY

Date	Revision	Issuer
March 22, 2023	Original report date.	ML