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FIRE TESTING EXTERIOR CROSS-LAMINATED TIMBER WALLS TO NFPA 285

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ABSTRACT

Mass timber buildings are utilizing CLT for floors, walls and if permitted by regulations and codes, as exterior wall elements. In the United States, the IBC allows an exterior (external) wall to be load-bearing and constructed from Cross-Laminated Timber, provided the exterior surface is protected with fire rated gypsum board and if located above 12.2m, passes an NFPA 285 fire test. Supported by a US Forest Service grant, two CLT based exterior wall assemblies have been fire tested to NFPA 285, a global first. This paper presents the design of the exterior walls, summarizes the required code path and provides the results of the fire tests. The fire test assembly includes a 3 ply CLT panel, fire rated gypsum board, a commonly used water resistive barrier and mineral wool. Both of the CLT based exterior wall assemblies successfully passed the NFPA 285 test and will enable greater use of mass timber in future buildings. All data, drawings and test reports will be made public to progress the acceptance of CLT for fire safe use in exterior walls.

KEYWORDS: Mass Timber, Cross-Laminated Timber, Exterior walls, NFPA 285, Tall timber buildings, Fire testing

1 INTRODUCTION

Mass timber construction utilizing glulam and Cross-Laminated Timber (CLT) continues to be popular globally due to the carbon storage it offers, the efficiency in construction and as a differentiator in a competitive leasing market. Within the US, the nationally adopted model code is the International Building Code (IBC) [1] and the 2021 edition includes new provisions that increase the use of mass timber in multi-story office and residential buildings, up to 18 floors in height. As part of this change there are new requirements for exterior (external) walls that allow construction to be based on CLT panels. This change allows building designers to consider differing structural typologies for mass timber high-rise buildings.

1.1 EXTERIOR WALLS UTILIZING CLT – MOTIVATION FOR FIRE TESTING

The 2021 IBC provides a significant step-change for mass timber construction and CLT is permitted to be used as part of an exterior wall assembly for buildings of the new IBC mass timber Construction Types IV-A, B and C. Type IV-A construction allows mass timber up to 18 floors and 82m (270ft) in height. CLT can also continue to be used as an exterior wall in the mid-rise Construction Types IV-HT, V-A and V-B, being limited to a height of 25.9m (85ft) or less. The prescriptive IBC language says CLT can be utilized in a load bearing or non-load bearing exterior wall, provided the CLT is clad on the exterior side with a single layer of fire rated gypsum board of 16mm (5/8in). An exterior wall is made up of a number of different layers and components from the interior to the exterior face, with these components referred to as an assembly. The CLT forms the supporting panel for the exterior wall components (see Figures 1 and 2).

Figure 1: *CLT exterior wall assembly prefabricated off-site being lifted at site. CLT forms the support for the thermal and water barriers to the exterior face (image credit: Blomgren)*

Due to CLT combustibility, the IBC contains multiple conditions for exterior walls that trigger a requirement that the exterior wall assembly pass a fire test to NFPA 285 "*Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Wall Assemblies Containing Combustible Components*" [2]. The NPFA 285 testing requirement is most commonly triggered for wall heights greater than 12.2m (40ft).

NFPA 285 is the nationally adopted fire test standard to determine vertical flame spread acceptance for exterior walls. It is the author's understanding that no CLT based exterior wall has ever successfully passed an NFPA 285 fire test. Due to the compliance cost and timing barriers of completing an NFPA 285 test, building designs in the

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US typically avoid using CLT as part of an exterior wall, even though a CLT exterior wall can provide efficiencies in construction, especially for residential buildings. A building project wanting to use CLT as a load bearing, or non-load bearing exterior wall over 12.2m (40 ft) in height will face a technical justification barrier and will need to invest in an NFPA 285 fire test specific to the proposed wall assembly, adding significant project expense and risk.

Figure 2: *Five story building constructed in the US with CLT exterior wall approved without NFPA 285 fire testing (image credit: Blomgren)*

With the lack of substantive fire testing available globally on CLT as part of an exterior wall and given the issues of interpretation and application by building authorities of the IBC requirements, and further, to remove a degree of project risk, a project supported by a 2021 US Forest Service Wood Innovation Grant has been undertaken. The project aims were to determine: 1) The IBC code language requirements for exterior walls; 2) If the IBC approved solution for CLT use in exterior walls above 12.2m (40ft) will pass an NFPA 285 test; and 3) The minimum encapsulation required for the CLT exterior wall to pass an NFPA 285 test. The background to the IBC requirements, exterior wall test set up and results are described in this paper.

1.2 GLOBAL IMPLICATIONS

The use of combustible construction within exterior walls of buildings is of global concern given the number of catastrophic fires that have occurred when highly combustible composite panels have been used. Building Regulations in England have been changed to severely limit the use of timber as part of exterior walls due to fire safety concerns [3]. No fire testing has occurred on mass timber based external / exterior walls to prove or disprove if this change in regulations is appropriate. With few fire tests to any national standards on CLT exterior walls available for designers and regulators to assess, these fire tests to NFPA 285, an internationally recognized standard, will be of significant interest and can assist with decision making regarding the fire-safe implementation of CLT as part of a building's exterior wall.

2 IBC REQUIREMENTS

Where CLT is used as part of an exterior wall above 12.2m (40ft), the exterior wall assembly must be checked for compliance based on a range of code sections. The IBC requirements for exterior walls are included within Chapters 6, 7 and 14 and are open to interpretation, as compliance is based on building construction type, height of the exterior wall, separation to neighbouring buildings, the combustibility of the water resistive barrier (WRB) and the inclusion of CLT or other timber in the assembly.

The IBC requires that where CLT is used for an exterior wall assembly that it be protected from fire by direct fixing a layer of 16mm (5/8in) fire resistant gypsum board to the exterior face, so no timber is exposed and is deemed to protect the timber by 40 minutes. These requirements apply up to 82m (270ft) or 18 floors. The interior face of the CLT may be exposed or covered by non-combustible protection, required by separate IBC requirements not related to exterior walls. The WRB in use has strict flammability limits and when a WRB is combustible, which the majority are for use in modern construction, the IBC then requires an NFPA 285 fire test when used above 12.2m (40ft).

For a non-load bearing CLT based exterior wall assembly within Construction Type IV-A, IV-B, IV-C or IV-HT construction, the code requirements are summarized below and introduce one possible code compliance path. It should be noted that each building situation will differ and may result in outcomes that change the path to code compliance. The type of exterior wall arrangement is also important as to whether the exterior wall is part of a "balloon framing" solution (also referred to as a by-pass or curtain wall); or part of a platform framed solution (also referred to as an in-fill or window wall). The code references below are based on the unmodified 2021 IBC.

Chapter 6

Table 601:	Sets a fire resistance rating requirement for exterior load bearing walls from no requirement for Type V-B to a 3-hour FRR for Type IV-A.
Section 602.4:	Allows mass timber to be used in exterior walls in Type IV construction provided the requirements are met including the following:
Section 602.4.1.1: IV-A **Section 602.4.2.1: IV-B** **Section 602.4.3.1: IV-C**	Requires 40 minutes of non-combustible protection for the exterior face of the CLT determined per section 722.7 and flammability requirements for the WRB. The 40 mins can be provided with one layer of 16mm (5/8in) Type X fire rated gypsum board. Requires all components of the exterior wall covering be non-combustible except WRBs meeting the flammability requirements.

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Section 602.4.4.2: IV-HT	Requires exterior protection of CLT in exterior walls in IV-HT of either 11.9mm (15/32in) fire retardant treated sheathing, 12mm (½in) gypsum board, or any non-combustible material.
Chapter 7	
Section 705.5:	Sets a fire resistance rating required of an exterior wall based on fire separation distance if the building is located near a boundary lot line or another building. Also determines if the fire resistance rating is required for fire exposure from the exterior only or both the interior and exterior.
Section 705.6:	Sets the requirements for the supporting construction of the exterior wall with different requirements for interior elements and exterior elements or within the exterior wall. Requires elements that brace the exterior wall but are not located within the plane of the exterior wall, to achieve a fire resistance meeting Table 601. This is relevant where the CLT wall is balloon framed or platform framed.
Section 715.4:	If the CLT is balloon framed (by-pass or curtain wall), the exterior wall intersection to the floor requires an approved fire seal that meets with ASTM E2307, to provide an "F" rating consistent with the floor (for Type IV-B this is 2hrs).
Section 722.7	Where required in Type IV construction, determines the required protection from non-combustible coverings on the exterior of the CLT. Recognizes that 40 mins can be provided with one layer of 16mm (5/8in) Type X fire rated gypsum board.
Chapter 14	
Section 1402.5:	For an exterior wall over 12.2m (40ft) in height in all but Type V construction, if the water-resistive barrier (WRB) is combustible then the exterior wall is required to undergo a fire test to NFPA 285 "*Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Wall Assemblies Containing Combustible Components*". There are two exceptions. Both Exceptions are not applicable to CLT framed exterior walls as the exceptions apply when the WRB is the ***only*** combustible component in the exterior wall assembly. Most, if not all, commercially viable WRBs are combustible. The combination of the combustible WRB and with mass timber framing in the exterior wall results in this Section requiring the exterior wall assembly comply with the NFPA 285 acceptance criteria when used above 12.2m (40ft).
Section 1405.1.1:	In all but Type V construction, exterior wall coverings are not permitted to be constructed of fire-retardant-treated wood above 18.3m (60 ft) above the grade plane nor constructed of other combustible materials above 12.2m (40 ft) above grade plane.

2.1 Summary

Where CLT is to be used within an exterior wall assembly, once the wall is above 12.2m (40ft) an NFPA 285 fire test is required, as the WRB will normally always be combustible. This is further clarified within the document "*Mass Timber Buildings and the IBC 2021 Edition*" [4] by the International Code Council and American Wood Council under "Change Significance 602.4.1.1 Exterior Protection" as follows:

> Buildings of Type IV-A, IV-B and IV-C construction will be subject to testing prescribed for exterior walls. Section 1402.5 of the IBC requires these walls to be tested according to NFPA 285. Nothing in this section is intended to preclude that test being applicable to these new types of construction. Even for wall assemblies passing the NFPA 285 test, all construction materials exterior to a mass timber wall, except the water-resistive barrier, must be noncombustible.

The CLT based exterior wall in Type IV-A, B, and C construction differ in required protection to the exterior face compared with Type IV-HT. Type IV-HT has more flexibility in the required non-combustible covering to the exterior face. A higher level of protection by non-combustible materials may also be needed if the exterior wall is load bearing or has a close fire separation distance.

3 DESCRIPTION OF THE NFPA 285 FIRE TEST

NFPA 285 "*Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Wall Assemblies Containing Combustible Components"* specifies a fire test for an exterior wall assembly to determine the potential for flame spread vertically up the wall, laterally across the wall and within the wall assembly. The fire test requires a two-story wall, including a window opening, to be constructed. A successful test demonstrates the exterior wall assembly, as a whole, passes the test, not any individual element.

The NFPA fire test uses two separate gas burners, one located within the lower story room that ignites from time zero. This burner provides a simulated fire that replicates the ASTM E119 *Standard Test Methods for Fire Tests of Building Construction and Materials* [5] fire curve which is used to determine fire resistance. After 5 mins of testing, a second gas burner is moved into position in front

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of the window to simulate large external flames for a fire, replicating a fire that starts internally, then breaches a window or wall and then grows on the exterior face of the building (See Figure 3). This method of fire testing was developed from testing in the 1980's to assess combustible exterior cladding materials.

There are several different pass or fail criteria for the wall, with temperatures checked at various heights above the window and laterally away from the window. Temperatures are also checked within the wall. Flame spread height above the window is also visually observed and measured (see Figure 3). A wall needs to meet all test criteria to have been deemed to have passed.

Figure 3: *NFPA 285 test showing window burner in position for testing (image credit: Barber)*

4 EXTERIOR WALL ASSEMBLY DESIGN AND FIRE TEST SET-UP

Two CLT based exterior wall assemblies were designed, constructed and tested. The assemblies were selected based on a typical wall that would be constructed for locations with a mild temperature and humidity range in the U.S. The aim of the design was to make the exterior wall applicable and extendible to a broad range of mass timber projects (see Figures 4 to 12).

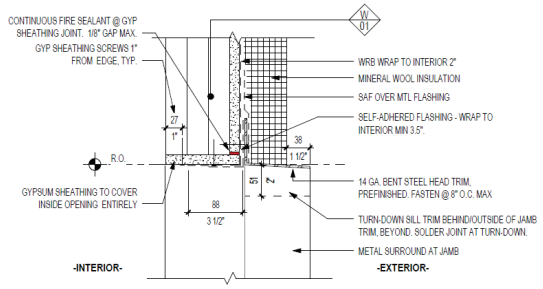

Figure 4: *Details at window head (image credit: Mithun Architects)*

The exterior wall assemblies included:

- A 3 ply 105mm (4.1in) CLT panel manufactured to ANSI/APA PRG 320-2019. Given this is the minimal CLT thickness expected for any exterior wall.
- The WRB was specified to have a reasonable performance for moisture control. The WRB did not meet the flammability classification criteria within IBC Sections 602.4.1.1, 602.4.2.1, 602.4.3.1 or 1402.5 Exception 2, being more flammable. This was based on understanding how limited the supply is for a very low flammability WRB and their high cost. A WRB typically used for mid and high-rise construction was chosen.
- The mineral wool batts were non-combustible and of a high-density given their better insulative performance with a minimal thickness included. A typical building in most USA climate regions will have a thicker depth of mineral wool.
- The window opening jambs, sill, and header were highly detailed given this is an area of likely failure. A window frame product was not included in the tests. For actual projects the expectation is the window will positively fasten to the CLT edges at the opening.
- The interior face of the CLT was left exposed given this may be the architectural solution desired. In having the interior face of the CLT exposed, there was additional combustible fuel added to the test as the CLT interior face combusted and charred.
- The CLT based exterior wall assemblies were tested with no exterior facing rain screen or wall covering. This allows additional non-combustible coverings to be directly fixed on the exterior face of the assembly. By not including a rainscreen, the exterior face of wall was exposed to worst-credible fire conditions, as a rainscreen would beneficially shield the wall.
- For Test 1 the exterior side of the CLT is clad with 16mm (5/8in) fire rated gypsum board, a combustible water resistive barrier and 50mm (2in) of mineral wool insulation.
- For Test 2 the wall assembly is similar to Test 1, but the fire rated gypsum board was removed, with only the WRB and 50mm (2in) of rockwool in place.
- All details are provided within drawings that will be available for download from www.woodworks.org.

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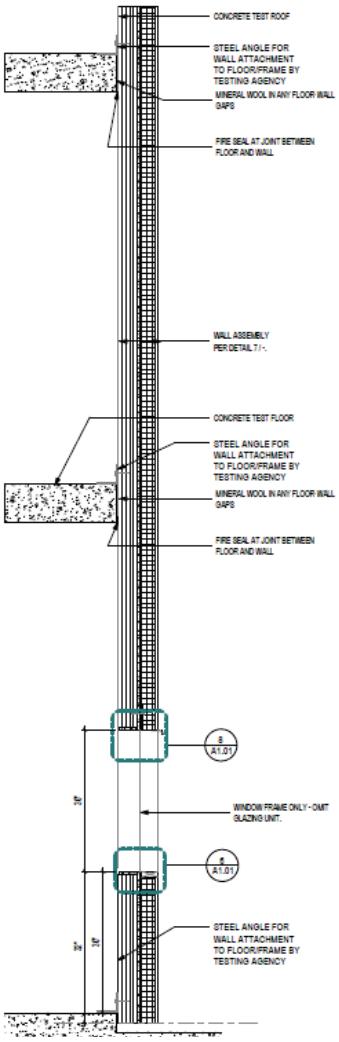

Figure 5: *Section through CLT wall specimen for testing (image credit: Mithun Architects)*

Two fire tests were carried out at Southwest Research Institute in San Antonio, in April and May 2022.

Figure 6: *Detail of C Test 1 set up, showing CLT wall completed in frame (image credit: Barber)*

Figure 7: *Test 1 set up, showing installation of fire rated gypsum board (image credit: Barber)*

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Figure 8: *Test 1 set up, showing (left) installation of WRB (image credit: Barber)*

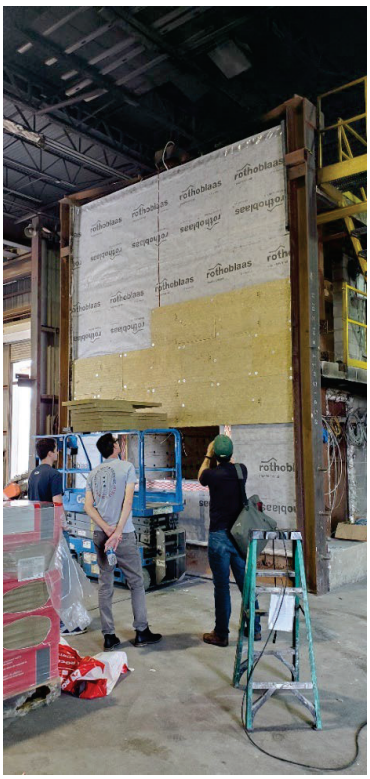

Figure 9: *Test 1 set up, showing installation of mineral wool (image credit: Barber)*

Figure 10: *Test 1 set up, close up of gypsum board to window edge and WRB wrap-around (image credit: Barber)*

Figure 11: *Test 1 set up, showing installation of window frame surround and sealing tape, prior to mineral wool overlay (image credit: Blomgren)*

Figure 12: *Completed wall set up prior to testing (image credit: Barber)*

5 FIRE TEST RESULTS

A brief description of the two fire tests undertaken to NFPA 285 are provided below.

5.1 Test 1 Summary

Test 1 was designed to be near compliant with the 2021 IBC, with a single layer of 5/8in (16mm) Type X fire rated gypsum board located on the exterior side of the CLT face, meeting section 602.4.2.1. As noted above, the WRB did not meet section 602.4.2.1 or section 1402.5 for limited flammability.

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The CLT based exterior wall assembly passed the NFPA 285 test with no temperatures exceeding the failure criteria of the standard and the flame extension was limited in height and lateral spread. During the test and on completion of the test and disassembly of the panel, the following was observed:

- Interior face of the CLT was visibly flaming through the whole test, as expected and was charred.
- The mineral wool above the opening was heavily scorched yet still provided protection to the underlying CLT, preventing flame spread.
- The WRB had significant heat damage directly above the window, but this was limited in height to about 600mm (24in)
- The window surround suffered damage and remained in place throughout the test.

The interior face of the CLT based exterior wall assembly was exposed to the gas burner was significantly charred. The combustion of the CLT and resultant charring negatively impacted the performance of the exterior wall by increasing the extent of flames above that prescribed by the NFPA 285 test. By exposing the CLT on the internal face, the worse-case conditions for the CLT exterior wall assembly were tested (see Figures 13 to 18).

Figure 13: *Test 1 underway (image credit: Barber)*

Figure 14: *Test 1 flames impinging on mineral wool above window (image credit: Barber)*

Figure 15: *Test 1 completed, showing window burner extinguished with on-going flaming within test room (image credit: Barber)*

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Figure 16: *Test 1 completed, showing damage to assembly layers with mineral wool manually removed (image credit: Barber)*

Figure 17: *Test 1 completed, showing interior side of CLT and extent of charring (image credit: Barber)*

Figure 18: *Close-up of Test 1 charring at top side of window opening. Charring extends into the first lamella only (image credit: Barber)*

5.2 Test 2 Summary

Given the results of Test 1, the CLT based exterior wall assembly was modified and the single layer of 16mm (5/8in) Type X fire rated gypsum board was not included on the exterior face of the panel. The exterior face of the CLT panel relied on the mineral wool to provide the protection against fire spread. This exterior wall assembly also passed the NFPA 285 test. The following was observed:

- Similar charring to the panel as for Test 1.
- Similar damage to the mineral wool and window surrounds as for Test 1.
- More heat damage to the WRB was observed, with damage extending up the face behind the mineral wool approximately 900mm (36in) and across the width of the window opening (see Figure 18).
- Overall temperatures and flame heights were similar to Test 1.

Figure 19: *Test 2 completed, showing extent of damage, with mineral wool manually removed. Damage can be compared with that of Test 1, shown in Figure 16 (image credit: Blomgren)*

5.3 Discussion

Two successful NFPA 285 fire tests were completed for a CLT based exterior wall. Test 1 was closely compliant with the requirements of the IBC as a CLT based exterior wall, with only the WRB being of a higher flammability classification. Test 2 did not include the non-combustible protection of gypsum board to provide 40 minutes of protection to the exterior face, utilizing mineral wool only to provide the non-combustible protection. The WRB was the same as for Test 1. Hence the CLT based exterior wall assembly for Test 2 had two variances with the requirements of IBC Section 602.4.

The test set-up for both walls was based on a design that replicates a typical project, acknowledging that there are many different types of exterior walls that could be designed and constructed. While the tests demonstrated the assembly as tested will pass the NFPA 285 test, an assembly with any of the following changes is also expected to pass the NFPA 285 criteria:

- CLT as a load bearing wall: Using the CLT as a load bearing wall is determined via ASTM E119 testing or similar approved method.
- Change in CLT depth: A thicker CLT panel can be used and would have no detrimental impact on the outcomes of the fire test.
- Addition of an exterior wall covering: A non-combustible wall covering can be included to the exterior face. This exterior covering would need to be direct fixed to the mineral wool insulation and could not include a vertical void or airspace as this could result in accelerated vertical flame spread between the mineral wool and the exterior wall covering.
- Addition of an interior covering to the CLT: The NFPA 285 tests had the CLT exposed on the interior side (facing into the interior or occupied building area). The results would not be changed if the CLT was covered with a non-combustible covering.

Test 2 was successful without the inclusion of a single layer of 16mm (5/8in) Type X fire rated gypsum board, which IBC Table 722.7.1(2) recognizes to provide the required 40 mins of non-combustible protection. For Test 2 the mineral wool insulation provided the CLT the non-combustible protection. For Test 2 to be used in a Type IV A, B or C building, an application to the authority having jurisdiction would be required, such as applying for a code variance or alternative material, design, or method of construction, given the wall assembly did not include the IBC required single layer of Type X fire rated gypsum board.

5.4 Applicability of NFPA 285 Testing to Mass Timber Buildings

NFPA 285 is a standard for assessing fire spread on exterior walls. Like all international fire tests for exterior / external walls and facades, the test methodology may need to be revisited where a building includes a large area of exposed mass timber structure (internal to the building), given that the exterior flaming is extended in length and temperatures are increased, due to the exposed timber structure [6]. NFPA 285 is a referenced standard for the IBC and would be used where an exterior wall is of a height over 12.2m (40ft), hence applicable for mid and high-rise mass timber buildings.

Fire testing of CLT based exterior walls with similar design set-ups is encouraged to occur in other countries to national standards, especially to test standards such as BS 8414 [7] and the proposed harmonised European test [8].

6 CONCLUSIONS

This project has demonstrated that a CLT based exterior wall assembly can pass the NFPA 285 fire test. In doing so, the results provide guidance to building officials, architects, engineers, and contractors as to how they can design and construct a CLT based exterior wall assembly that satisfy IBC requirements. The wall assemblies were designed so that the exterior face of the CLT was not directly exposed to flames and the detailing was well-thought through to prevent vertical flame spread.

With funding from a USFS Wood Innovation Grant, a current market barrier to mass timber construction has been removed by successfully demonstrating that a CLT based exterior wall assembly can pass NFPA 285. By publishing the details of the exterior wall designs and the fire test results, these CLT based exterior wall assemblies can be replicated for future multi-story mass

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timber building projects and can be used by building authorities, architects, engineers and contractors, acknowledging the exterior wall design and limitations of the test method.

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