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Determination of fire resistance ratings for glulam connectors within US high rise timber buildings

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ABSTRACT

Multi-storey mass timber buildings constructed with cross laminated timber and glulam are being developed globally. Where engineered timber such as glulam is utilized, the column to beam connections need to be constructed with a fire resistance rating equal to that of the connecting members. The preferred glulam connectors are either a concealed steel plate with bolts and dowels; or a concealed proprietary screw-in sleeve type connector. The fire resistance of connectors for glulam members is an unresolved design issue, as there is no clear methodology to assess their capacity under fire, when the timber is exposed and not clad behind fire protective plasterboard. There is limited fire test data on concealed connectors under shear forces, which is the normal loading condition within a constructed building. Fire test data is also limited on full-size specimens. Correlations developed to date to calculate concealed connector fire resistance have only limited application.

A methodology for the design of glulam beam to column connections has been developed based on an extensive literature review, examining the key issues for connection failure. It has been determined that char rate for the timber at the connection needs to be increased above the normally accepted design values, due to the influence of the steel connectors. Secondly, the reduction in timber strength behind the char layer needs to be accounted for, by including a greater depth of reduced strength and stiffness timber, such that the connection can effectively transfer the applied forces through the timber to the steel connector. The methodology detailed within this paper provides a simple approach to evaluate the timber cover to the concealed steel connector, where the timber strength and stiffness are effective.

1. Introduction

There is a resurgence in timber construction globally due to the availability of innovative materials like cross-laminated timber (CLT), but also based on the need for green and sustainable architecture. High-rise timber buildings are also being planned and constructed in many countries, including the US. To encourage developers to look at timber as a high-rise construction material, the United States Department of Agriculture (USDA) has sponsored a Tall Wood Building Competition [1], which awarded two winners, a ten storey residential building in New York (475 West 18th Street [2]) and a twelve floor mixed office and residential building in Portland (Framework [3]). Both the Portland and New York buildings will be using a combination of glulam as the primary structural gravity frame, with CLT floors. The Portland building is progressing towards construction, whereas the New York building has faced development difficulties. These buildings and others being planned introduce a significant step-change in the design and construction of high-rise timber buildings in the US. The USDA competition has encouraged other developers and architects to plan tall timber buildings and more are expected within the US in the near future.

One of the significant technical challenges faced by both medium and high-rise `buildings is the fire safe design of connections, where glulam members are used as part of the primary structural frame and the architect, building owner or developer wants to have some or all of the timber exposed. If the timber structure includes glulam members as part of the structural frame then these members need to have a proven fire resistance rating (FRR) at connections.

This paper provides an overview of the methodology that has been developed to address the fire safe design for glulam member to member connections, where those glulam members are exposed to a possible fire. The methodology developed provides the basis for a fire safety alternative engineering solution, to prove compliance to the International Code Councils International Building Code [4] (IBC). The methodology will be proven with full scale fire testing being undertaken in early 2017.

2. Engineered timber connection design and construction

Where glulam or other engineered timbers are used in mid or high-rise construction, the connectors will require a fire resistance of 60–120 min, depending on the height of the building. Connectors must be designed to have at least a strength and a fire resistance rating equal to that of the connecting members. For large timber structures, where the

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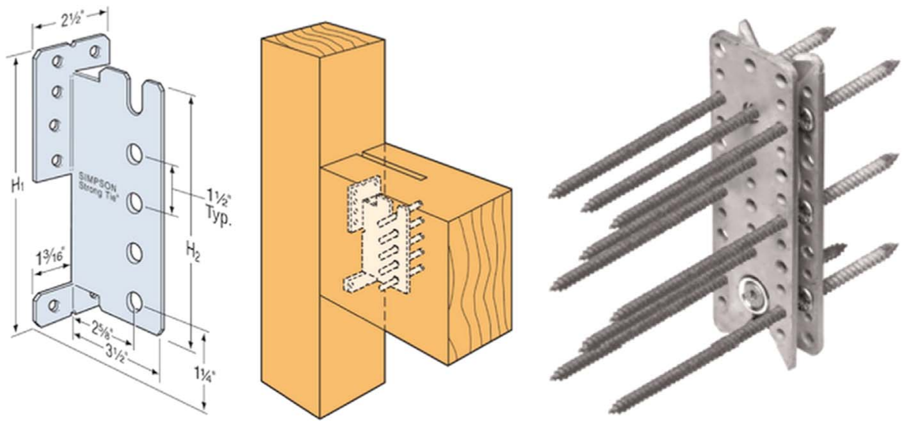

Fig. 1. Typical mechanical connector types. A knife plate with bolts or dowels (from Simpson Strong Tie); a proprietary sleeve type connector for a beam to column joint (from My-Ti-Con).

connectors are carrying significant gravity or lateral forces, mechanical fasteners are used that may consist of dowels, bolts, screws or nails or a proprietary sleeve connector (as shown in Fig. 1). All these types of mechanical connectors are preferred as they typically fail in a ductile manner.

Connectors in engineered timber, such as glulam, are an unresolved design issue, as there is no clear methodology to assess their capacity under fire, when the timber is exposed and not clad behind fire protective plasterboard, for an FRR of 60 min or more.

3. Code compliance requirements

Within the US, each state and some cities adopt one or more model building codes. All 50 states adopt the IBC, with some states also adopting NFPA 101 'Life Safety Code' [5]. Each State adapts and amends the model codes to provide the basis for construction compliance.

The load-bearing structure (i.e., columns, beams, floors and any load-bearing walls) for mid-rise and high-rise buildings are required to have a fire resistance rating (FRR). Buildings that are four floors or more in height are required to have a 60 min FRR and once the building is a high-rise structure, bearing more than 75 feet (22.9 m) in height, the building requires a 120–180 min FRR. A high-rise building is required to have load-bearing elements that survive full burn out of a fire, where the sprinklers have failed and the fire department has limited intervention. The building is to remain structurally sound even in this highly unlikely fire scenario. There is a significant difference in expected structural performance for a high-rise building, when compared to a medium-rise building and is considered very conservative for buildings of 8–12 floors where external fire-fighting can still occur.

The IBC requires high-rise buildings to have an increased level of fire protection and structural performance and hence timber has been traditionally limited to low and medium rise buildings only. Approval for high-rise timber buildings is only permitted through the "Alternative materials, design and methods of construction and equipment" clause. Undertaking an alternative engineering approach (or a performance based design) is subject to approval by the authority having jurisdiction (AHJ). The use of timber as a high-rise construction material is difficult in many jurisdictions in the US, given the code limitations coupled with the unfamiliarity of mass timber as part of the primary structural frame. A tall timber building is a very new form of construction and hence undergoes intense approval scrutiny as it progresses through to the approvals stage.

3.1. Guidance on fire rated connections in glulam

To provide compliant fire rated construction for mass timber, the IBC references the American Wood Council's (AWC) "National Design Specification for Wood Construction" (NDS) [6]. The NDS details the methods for determining an FRR for mass timber construction, including CLT, up to 120 min. The NDS references "Calculating the Fire Resistance of Exposed Wood Members, Technical Report No. 10″ (TR-10) [7], which provides significant detail on how an FRR can be determined for mass timber products. TR-10 provides some information on connections in mass timber, with recommendations to encapsulate the connection, provide additional member size (char depth) to protect a connection or provide some form of coating to a connection.

Of the three approaches to glulam connection protection from fire, the method of providing additional timber, as char to protect a connection, is discussed in detail within this paper. The method of encapsulation through fire rated gypsum plasterboard is not discussed further, as this approach is not desired by architects. Using a coating to protect a connection is also discussed.

For CLT panels, these are normally fire tested with spline or splice connections as part of the fire test set-up and hence, when the CLT panel achieves an FRR of up to 120 min, the connection is also tested and proven.

4. Recommended calculation methods

As shown in Fig. 1 (above), the preferred glulam connector is a concealed wood-steel-wood (WSW) assembly, with either a centrally located and fully concealed steel plate with bolts or dowels; or a fully concealed proprietary sleeve connector. These connectors are also relatively easy for a structural engineer to design for gravity and potentially lateral forces.

The methods available to a fire safety engineer to analyze the FRR for a glulam connector are from AWC's TR-10 and EN 1995-1-2 Eurocode 5 (EC5) [8]. TR-10 has an approach of limited validity up to 60 min, using the reduced cross-section method. EC5 has methods validated up to 30 min, using simplified rules or a reduced load method. Both methods are based on determining a char layer for the timber that surrounds the connection and this char layer provides the "cover" to protect the concealed connector from the heat of the fire.

The TR-10 approach is based on the nominal char rate. For design purposes, the nominal char rate is increased by 20% to account for corner rounding, fissures and a reduction in strength and stiffness for the zero strength layer. The zero strength layer is located directly behind the char. TR-10 requires that the depth of char ("a_{char}") to a bolt or dowel or steel connector is determined through assessing a char rate of 1.5 in/h (0.64 mm/min), for 60 min FRR (based on an a_{char} of 1.8in/h, reduced to 1.5 in/h, as per Figs. 3–8 of TR-10). Hence the minimum timber cover required is calculated as 38.1 mm. The distance from the