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INNOVATIVE CONNECTIONS BETWEEN HYBRID FLOOR PANELS AND TIMBER COLUMNS ABLE TO REDUCE THE DEFLECTION OF THE PANEL'S BIG SPAN

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Abstract

This study experimentally investigates the mechanical response of seval new types of hybrid connections between glulam timber–concrete panels and glulam timber columns. Each panel is composed of glued laminated wood beams and/or concrete constituting the floor and wooden beams constituting the supporting framework for the façade elements. The dimensions of the hybrid panels are defined to ensure appropriate implementation and transport conditions. For these reasons, the width of the panels is fixed at 1.20 m, and the length is 7.5 m. The experiments are conducted at the Laboratory for Composite Materials and Composite Structures at the University Claude Bernard Lyon I. The experimental setup, connection configurations, and material properties are introduced, followed by a detailed analysis of the test results and observations. The obtained results reveal the overall mechanical behavior of the connections. All of the connections are designed to support the same load combination until failure. Based on the results, the new connections are able to reduce the deflection of the floor panel in the middle of the span by 45% in comparison with the common bolted connections that have been designed to support the same load combination and have the same dimensions.

Keywords: Component models, carbon FRP, glass FRP, joints, timber reinforcement, Hybrid system.

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1 INTRODUCTION

The safety of structures (existing or new; steel, reinforced concrete, or timber) is a major priority of engineering globally. The way in which constructions are strengthened depends on the main building material. For steel or reinforced concrete (RC) structures, significant effort has been focused on developing devices that can dissipate a large percentage of the seismic energy without belonging to the supporting structure of the construction [1-6]. On the other hand, timber structures are a more environmentally friendly approach in construction, and this alternative solution is governed by Eurocode 5 [7]. However, one of the major problems in using timber material is its low elastic modulus, which can only be countered by increasing the depth, thus significantly limiting the use of timber elements.

In order to achieve better timber structure performance, the main idea is to combine the wood with other materials [8-12]. The development of hybrid systems focusing on the ecology, economy, and performance of the final product is needed and represents the next step in civil engineering. According to Ferrier et al. [13] the development of ultra-high performance fibre-reinforced concrete (UHPFRC) in collaboration with timber elements has better properties than ordinary concrete (OC). As a result, the proposed hybrid solution has many advantages; the cross-section can be reduced by decreasing the height of wooden beams, and the mechanical performance is improved in terms of the load capacity and stiffness [13]. In addition, hybrid structural systems that combine materials with complementary properties have the potential to achieve significant levels of efficiency.

The main challenge in their application remains the type of connection between these panels and the façade of the building. Several studies have been carried out to investigate the connection of hybrid construction systems in which steel and timber are the main structural materials or are joined to enhance the loadbearing capacity [14-16].

This study experimentally investigates the mechanical response of seven new types of hybrid connections between glulam timber–concrete panels and glulam timber columns. We focus our study on the mechanical response of the composite panels connected with timber columns by the investigated connections. The investigated composite panels are proposed by Augeard et al. 2018 [17]. Each panel is composed of glued laminated wood beams and/or concrete constituting the floor and wooden beams constituting the supporting framework for the façade elements. The dimensions of the hybrid panels are defined to ensure appropriate implementation and transport conditions. The aim of this study is to investigate the better connection in order to reduce the deflection of the floor panel in the middle spam. The obtained results reveal the overall mechanical behavior of the connections. All of the connections are designed to support the same load combination until failure. Based on the results, the new connections are able to reduce the deflection of the floor panel in the middle of the span by 45% in comparison with the common bolted connections that have been designed to support the same load combination and have the same dimensions.

2 SHORT DESCRIPTION OF THE INVESTIGATED CONNECTIONS

This section descripts in short the seven (7) investigated connections, which are proposed by Titirla et al. [18, 19]. The design of the connections is based to a 3-floor prototype building with storey height equal to 3.00m and width of 7.5m. As well as, they are designed based to Eurocode to support the same load combination until the failure. Each hybrid panel is composed of five glued laminated wood beams and concrete constituting the floor and five wooden beams constituting the supporting framework for the façade elements. The columns are rectangular with a cross-section of 90 × 225 mm, while the beams have dimensions of 90 × 290 mm, plus 50 mm for the concrete slab (UHPFRC) connecting the beams. The connection

between the wood surfaces of the beams with the surface of the concrete slab is accomplished using sand bonded onto the wood with epoxy adhesive to enable the concrete to be cast directly on the timber [17].

The 7 connections are illustrated in Figure 1. The first connection type incorporates a dowel-type column jointed to the beam through long bolts (Figure 1a), while the second connection type consists of a steel plate slotted into the timber beam to which the timber columns are connected with transverse bolts (Figure 1b). The other five connection types are far from the bolted connections. The third connection type incorporates a steel rebar connection in UHPFRC concrete (Figure 1c), while the fourth and fifth connections are two additional connections based on the previous one in order to avoid the detachment of the concrete in the tension zone of the connections. So, the fourth connection involves the strengthening of the concrete joint with a bolt (d=16 mm) bonded in glue in the timber and concrete parts of the connection, while the fifth connection strengthens the concrete joint with a Glass FRP bar (d=16 mm) bonded in glue in the same position (Figure 1d). The sixth type utilises carbon bonded FRP rebar in glulam both in the timber and concrete parts of the beams (Figure 1e), and finally the last one uses glass bonded FRP rebar in glulam (Figure 1f).

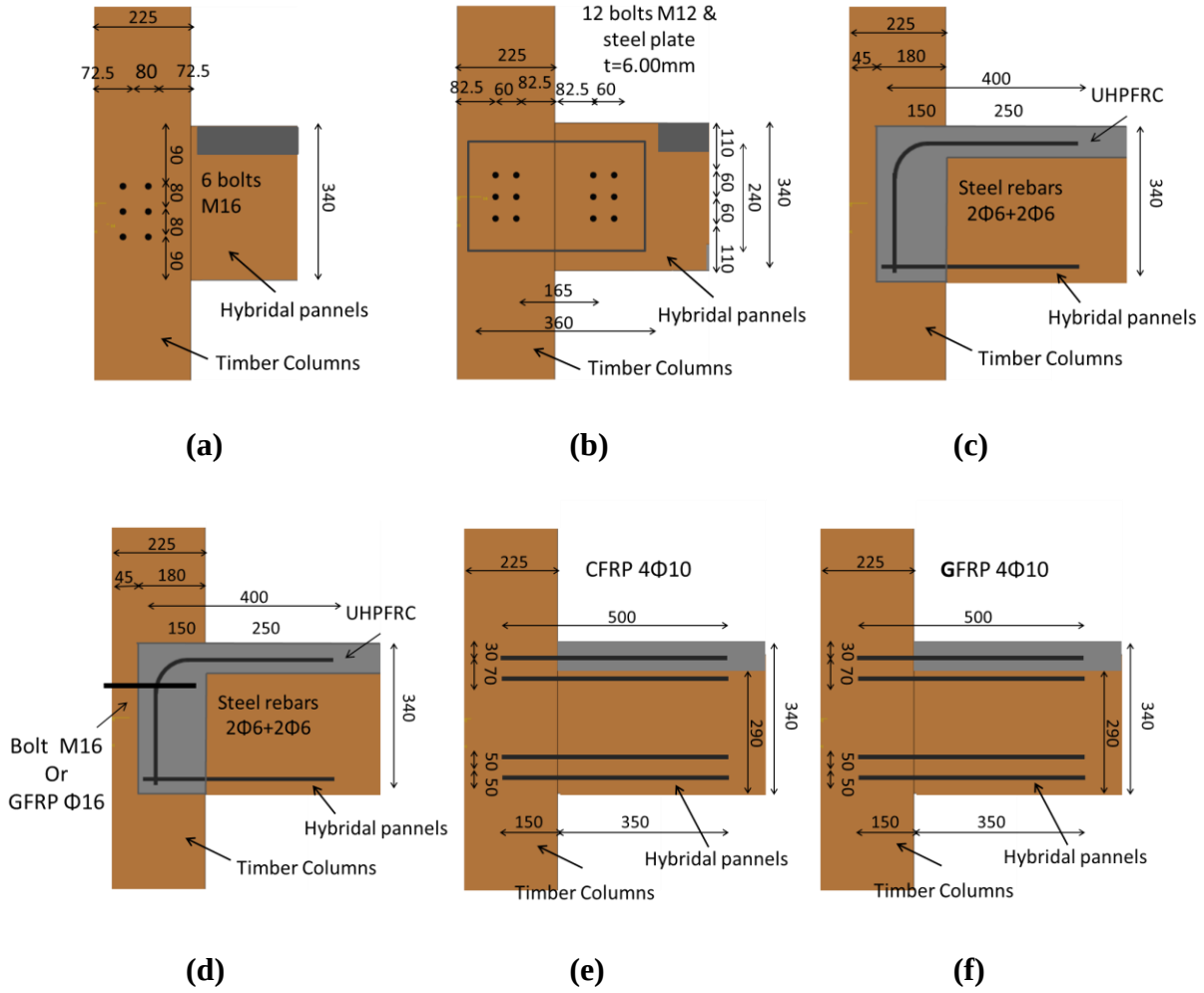

Figure 1. The seven investigated connections between composite floor panels and timber columns.

3 EXPERIMENTAL STUDY

3.1 Experimental set up

For the experimental tests, the junction specimens were first reduced to two beams and then tested at a 90° rotation. In this case, the force generating the rotation and/or the moment was applied horizontally to avoid a P-δ effect on the displacement of the column and focus attention only on the connections. Figure 2 shows the experimental setup used for testing the seven proposed moment connections between the hybrid panels and timber columns under bending. A hydraulic actuator operating in displacement control mode with a speed of 2 mm/min (fixed to a strong wall) was attached to the top of the glulam beam using a specially designed clamping device. The displacement at the top of the beam increased gradually at a rate of approximately 2 mm/min until the stroke of the actuator was reached or until clear connection failure was observed. The load cell incorporated in the actuator was used to record the applied load at the top of the beam. The column was held in a fixed position relative to the strong floor with the help of fixing blocks in both the horizontal and vertical directions. Eleven linear variable differential transformers (LVDT) and one laser were positioned on each specimen, and measured the corresponding displacement at different positions in the specimen (see Figure 4). Four LVDT (nos. 4, 5, 6, and 7) and the laser measured the horizontal displacement of the beams at three different heights, two LVDT (nos. 10 and 11) checked if there was any horizontal movement of the columns despite the existence of the horizontal fixing block, and four LVDT (nos. 1, 2, 8, and 9) checked for vertical movement of the columns despite the existence of the vertical fixing block. There was also one additional LVDT (no. 3), which measured the displacement between the UHPC and timber to check for debonding. All data was recorded and stored in a digital data system via a computer.

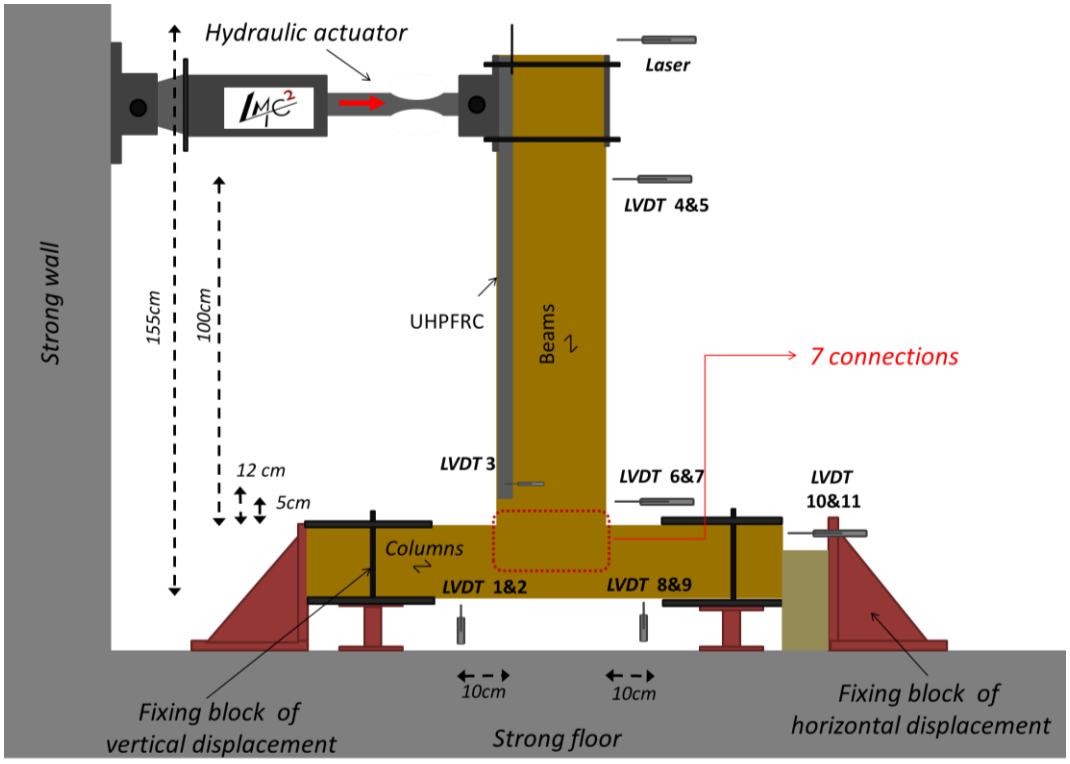

Figure 2. Details of the experimental setup.

3.2 Experimental results

The force-displacement diagram at the top of the beam (laser displacement) for the seven investigated connection types is presented in Figure 3. Two different types of response can be observed. The carbon and glass FRP connections exhibit an initial linear phase with very high stiffness (2.00 kN/mm and 1.45 kN/mm, respectively) coupled to a high tensile strength of 20.47 kN and 24.06 kN, respectively. After the failure of the first bar, the load is reduced. As carbon material is stiffer than the glass material, the connection with the carbon FRP exhibits an increase in connection rigidity of 37% that of the glass FRP connection, which resulted in a 17% reduction of the maximum load. Both of these connections experience brittle failure.

On the other hand, the other connections exhibit comparable stiffness, but cannot reach high failure loads without generating large overall displacements. In the case of the connection with bolts, the limit of the elastic behaviour is approximately 2.3 kN, after which there is a second behaviour phase with a stiffness of 0.1 kN/mm and a maximum load of 5.12 kN. Compared to the connection with carbon FRP, the maximum load of the bolted connection is four times smaller, while the stiffness is almost 10 times smaller. The connection with the bolts and steel plate exhibits a similar behaviour to the bolted connection, but with a large slippage in the junction between the wood elements and the steel plate at the beginning of the test; as a result, the limit of the elastic behaviour is approximately 0.9 kN, and a second phase of behaviour with a stiffness of 0.17 kN/mm reaches a maximum load of 2.75 kN. This suggests that for a bolted connection (with or without a steel plate), to increase the stiffness and the load, it is necessary to increase the number of bolts and the cross-section of the beams in order to satisfy the limits set by Eurocode. Finally, for the connection with steel rebars, the elastic limit load is approximately 8.25 kN, and a failure load is occurs at approximately 11 kN. In the elastic stage, this connection is reasonably stiff (1.63 kN/mm), but a relaxing of the interaction between the surface of the UHPFRC and the surface of the timber was observed at a load of 8.25 kN (which is 2.5 times smaller than the maximum load of the carbon FRP connection). The improved connections with steel rebars and a bolt or GFRP bar have effective stiffness of 0.83 kN/mm and 1.46 kN/mm, respectively, coupled to high tensile strengths of 21.9 kN and 23.5 kN (increases of 165% and 185%, respectively). Overall, we are led to conclude the stiffness of all the connections in the Table 1.

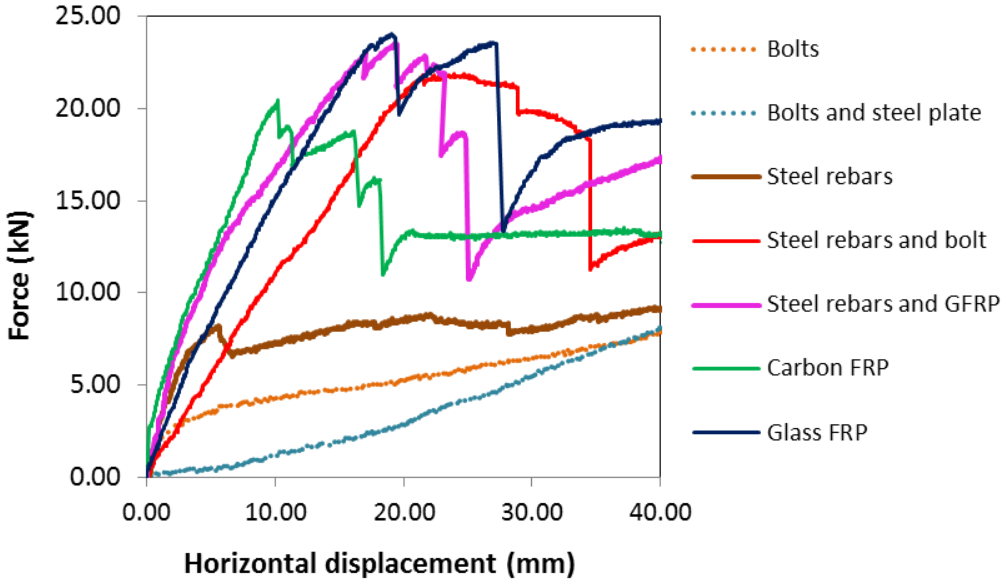

Figure 3. Load vs. horizontal displacement at the top of the beam.

Connection	Description of the connections	Effective stiffness (kN/mm)
1	Dowel-type connection with 6M16	0.45
2	Connection with 12M12 and one steel plate with thickness of 6mm	0.19
3	Steel rebars in a UHPFRC joint	1.46
4	Steel rebars in a UHPFRC joint and one bolt of M16 in the tension zone	1.45
5	Steel rebars in a UHPFRC joint and one bar of GFRP in the tension zone	1.45
6	Connection with 4 CFRP Φ10	2.02
7	Connection with 4 GFRP Φ10	1.45

Table 1: Effective stiffness of the seven connections.

4 NUMERICAL MODELING

To simulate the behavior of the investigated connections, it was selected to use the software SAP2000 [20]. Only one composite panel of the 3-floor prototype building (Figure 4) was selected to be studied, as the aim of this section is to investigate how the deflection in the middle span (composite floor panel) is change based to the type of the connection between the composite panel and the timber columns.

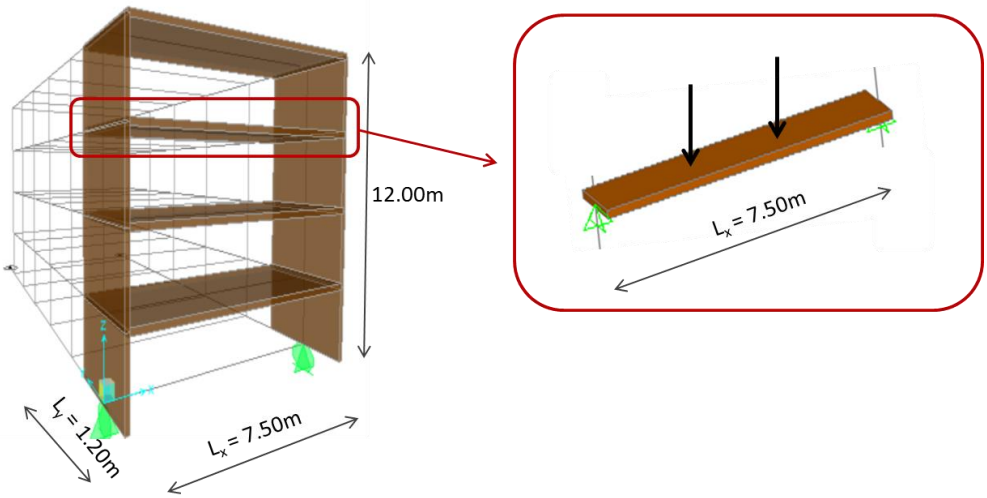

Figure 4. Study of only one panel of the 3storey prototype building.

The first step of this study was to verify the reliable modeling of the panel without taking into account the boundary conditions of the connections, but assuming that the panel is simple supported. The numerical results are compared with the experimental results that have been conducted by Augeard, 2018. After that, the stiffness of the connections is applied in the

joints and all the results are presented in Table 2. The load that is applied is based to the combination 1.35G+1.5Q, where a gravity load (dead load: G = 2.5 kN/m2, live loads: Q = 3 kN/m2) are assumed to act on the beams based on European Standard [21].

Connection	Description of the connections	Deflection in the middle span [mm]
Simple support	The panel is isostatic	17.12
1	Dowel-type connection with 6M16	13.38
2	Connection with 12M12 and one steel plate with thickness of 6mm	14.31
3	Steel rebars in a UHPFRC joint	10.63
4	Steel rebars in a UHPFRC joint and one bolt of M16 in the tension zone	10.63
5	Steel rebars in a UHPFRC joint and one bar of GFRP in the tension zone	10.63
6	Connection with 4 CFRP Φ10	8.27
7	Connection with 4 GFRP Φ10	10.63

Table 2: Deflection of the panel in the middle span.

Based on the numerical results, the following conclusions are drawn:

i. Bolted connections (Dowel-type connection with 6M16 *(see connection 1)* and/or connection with 12M12 and one steel plate with thickness of 6mm (see connection 2)) seem to behave like a simple supports.
ii. All the other types of connections are stiffer in the elastic part as a result the deflection in the middle span is reduced at least 25% compared with the bolted connections.
iii. The connection with the FRP bars in Carbon is the best one as it can reduce the deflection of the big span to 45%.

5 CONCLUSIONS

This paper experimentally investigates the mechanical response of seven new types of hybrid connections between glulam timber–concrete panels and glulam timber columns. We focus our study on the mechanical response of the composite panels connected with timber columns by the investigated connections. The investigated composite panels are proposed by Augeard et al. 2018 [17]. The aim of this study is to investigate the better connection in order to reduce the deflection of the floor panel in the middle spam. The obtained results reveal the overall mechanical behavior of the connections. All of the connections are designed to support the same load combination until failure. These results confirm the outcomes of previous theoretical and experimental studies about the innovative moment connections between composite floor panels and timber columns [18, 19].The present study represents that:

i. For the bolted connections (with or without a steel plate), the breaking load is reached at a large displacement. As a result, these connections cannot guarantee the recovery of the moments in the junctions without involving strong rotation. Furthermore, to increase the stiffness and the load in this type of connection, it is necessary the increase of the number of bolts and the cross-section of the beams in order to satisfy the limits provided by Eurocode. Finally, in terms of the deflection, these types of connections behave like a simple support.

ii. The connection with the steel rebars is fairly stiff (1.63 kN/mm) in the elastic part, but a slackening of the interaction between the surface of the UHPFRC and the surface of the timber is observed at a load of 8.25 kN. To increase the load capacity of the connection with steel rebar, as well as to prevent detachment of the concrete in the tension zone, two additional connections based on the initial connection with steel rebar are proposed and investigated: the connection with steel rebars and bolt, and the connection with steel rebars and GFRP bar. The connection with steel rebars and bolt and the connection with steel rebars and GFRP bar exhibit effective stiffness of 0.83 kN/mm and 1.46 kN/mm, respectively, coupled to high tensile strengths of 21.88 kN and 23.5 kN (an increase of 165% and 185%, respectively). Finally, in terms of the deflection, these types of connections can reduce the deflection in the middle span at least 25% compared with the bolted connections.

iii. The two connections utilizing FRP bars provide similar but not identical results due to the different Young's modulus of the two materials (carbon and glass). As carbon is stiffer than the glass material, in the connection with the carbon FRP, an increase in the rigidity of the connection equal to 37% that of the connection with the glass FRP can be observed, resulting in a 17% reduction of the maximum load. In addition, the connection with the FRP bars in Carbon are able to reduce the deflection of the floor panel in the middle of the span by 45% in comparison with the common bolted connections that have been designed to support the same load combination and have the same dimensions.

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