Shaking table tests of a PRES LAM frame with and without additional energy dissipating devices: Design and testing set-up.

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ABSTRACT: Post-tensioned timber (PRES LAM) is a new form of seismic resistant construction which already has real building applications throughout New Zealand. The innovative high seismic performance system combines the use of precast concrete PRESSS technology and engineered wood products combining post-tensioning elements (providing re-centring) with large timber members. Additional steel dissipation devices are often also placed in order to provide additional strength and dissipative capacity.

The following paper describes the design, fabrication and set-up of a dynamic testing campaign to be performed in the structural laboratory of the University of Basilicata (UNIBAS) in Potenza, Italy. The test specimen is a 2/3rd scale, 3-storey post-tensioned timber frame and wall are to be studied both with and without the addition of dissipative steel angles which are designed to yield at a certain level of drift in order to provide the desirable 'flag shaped' hysteretic response. These steel angles release energy through hysteresis during movement thus increasing damping as well as providing additional strength. The ratio between post-tensioning and energy dissipation provided will be altered between tests in order to investigate their contribution to dynamic frame performance. The specimen will be subjected to an increasing level of seismic loading using a set of 7 natural earthquakes selected from the European Strong Motion database.

This paper first describes the testing set-up, the fabrication of the test specimen and testing apparatus and the selection of cases which will be tested.

1 INTRODUCTION

This paper presents the design and planned test set-up for the experimental investigation into the seismic performance of a 2/3rd scale three-storey post-tensioned timber frame building in the structural laboratory of the Di.S.G.G in Potenza, Italy. This work is part of a collaborative experimental campaign between the University of Basilicata (UNIBAS), in Potenza, Italy and the University of Canterbury, in Christchurch, New Zealand. The study will evaluate the feasibility of applying jointed ductile post-tensioning technology, originally conceived for use in concrete structures (Priestley et al. 1999), to glue laminated timber (glulam). The aim of the project is to evaluate the seismic performance of the system and further develop the system for use in multi-storey timber buildings.

The post-tensioned timber concept (under the name PRES LAM) has been developed at the University of Canterbury and extensively tested (beam-column, wall/column-foundation, 3d frame and wall structure) in the structural laboratories of the university (Newcombe et al. 2010; Palermo et al. 2005; Smith et al. 2007). In Stage One of this project a full-scale beam-column joint was designed, fabricated, constructed and tested at the Structural Laboratory of UNIBAS. This experimental programme was completed midway through 2011 providing excellent results and began to answer key questions regarding system performance. During testing the application of the post-tensioned timber concept to glulam timber was confirmed. Testing was performed both with and without dissipative elements and the system displayed the same excellent performance under static and seismic loading as when the system was employed with laminated veneer lumber (LVL) (Smith et al. 2012). The dissipative devices used were based on yielding steel angles which activate at low drift levels, both increasing the moment capacity of the system and adding energy dissipation (thus reducing seismic load through damping) without inducing plastic deformations in other elements. A new method of vertical load transfer was also designed and tested, using a hidden steel pipe to resist shear loading without hindering the rocking movement of the beam-column joint. Modelling and design procedures were also implemented and verified.

An extensive dynamic experimental testing programme is scheduled to be performed in the Structural Laboratory of the University of Basilicata.

2 TESTING STRUCTURE

As mentioned the project is based on the PRES LAM concept which uses post-tensioning technology (frequently applied to concrete structures) in order to connect structural timber elements. This technology enables the design of buildings having large bay lengths (8-12m), reduced structural sections, and lower foundation loads with respect to traditional construction methods.

2.1 The prototype structure and test model

The prototype structure is three stories in height and has a single bay in both directions. All design has been performed in accordance with the current version of the Italian design codes (NTC 2008). The interstorey height of the building is 3 m and the frame footprint is 6 m by 4.5 m. The building has been designed to represent an office structure (live loading Q = 3 kPa) with the final floor being a rooftop garden. A summary of vertical loads is described in a following section. The flooring of the building is made from solid glulam panels. The lateral resistance of the building is governed by seismic loading.

The test frame (Figure 1) is made from glulam grade GL32h (EN 1995-1-1 2004). A scale factor of 2/3 has been applied to the prototype structure resulting in an interstorey height of 2 m and a building footprint of 4 m x 3 m.

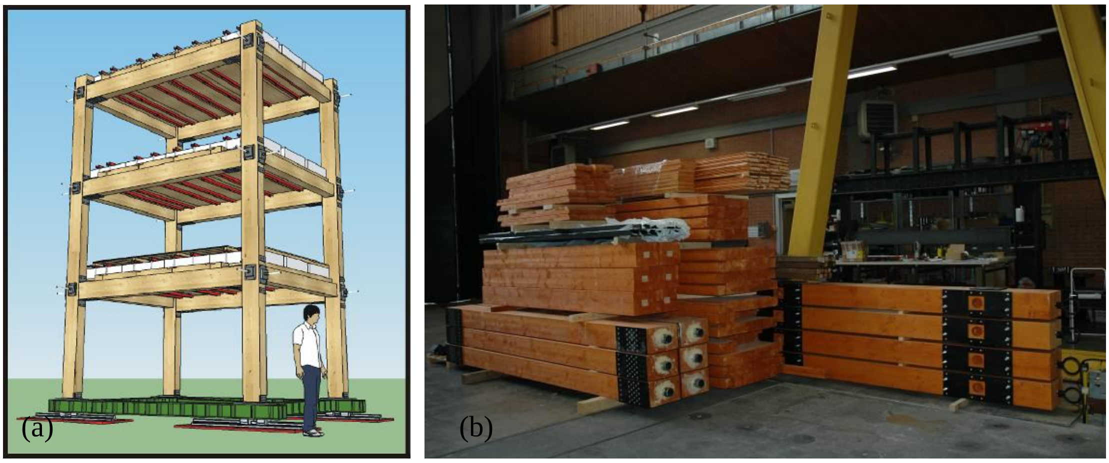


Figure 1. 2/3 scale post-tensioned glulam test frame a) design sketch and b) pieces waiting to be assembled

Seismic loading during testing will be mono-directional applied along the north-south axis of the building. The section sizes to be used in the frame are shown in Figure 2 with post-tensioning passing through the beams in both directions. The flooring spans in the east-west direction, therefore secondary beams are only required to provide torsional stability.

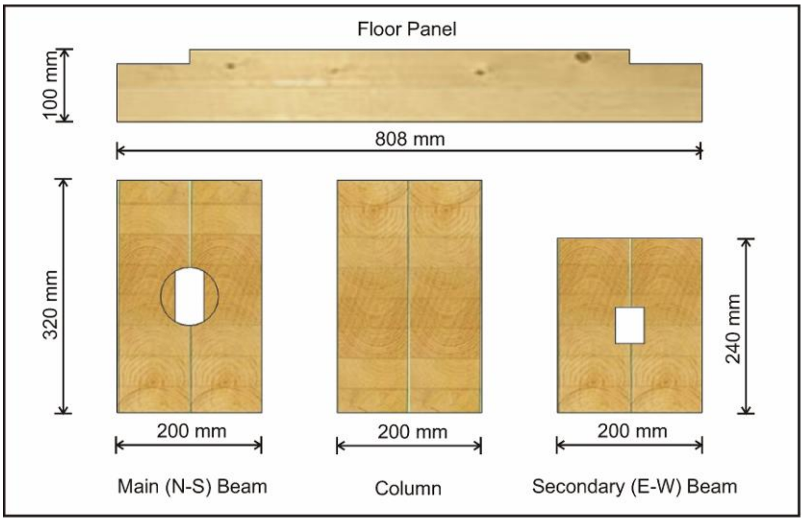


Figure 2. Section sizes used in glulam test frame

3 TEST FRAME CONNECTION DETAILING

The design of this type of structure can be complicated due to the rocking motion which occurs at the interface of the beam and column members during seismic loading. Rocking creates a concentrated displacement which must be accounted for in design and should not create damage to secondary members, flooring or non-structural elements (although the latter will not be included in test campaign).

3.1 Beam-column and column-foundation detail

The beam-column connection in the principle direction (Figure 3) is based on the connection type which was tested during Stage One. Passing through the centre of the beam is a single 26.5 mm diameter bar which will be tensioned to varying values of initial loading throughout the test programme. This is a high strength steel bar with a yield strength f_y = 1050 N/mm^2 and a Young's modulus of 170 kN/mm^2.

Screws have been used to protect the column face with 36 ϕ 8 mm, 80 mm long screws being installed in the column face adjacent to the beam and 30 screws being installed in contact with the post-tensioning back plate. 28 ϕ 8 mm 120 mm long screws have been used to attach each dissipater plate. The dissipaters are attached to the column though the use of M16 bolts which pass through the width of the column and attach to a backing plate. Where this plate is in contact with the column is also reinforced with 10 ϕ 80 mm long screws. Vertical loading will be transferred through a ϕ 76.1 mm steel tube with extends 66 mm from the beam and sits inside the column.

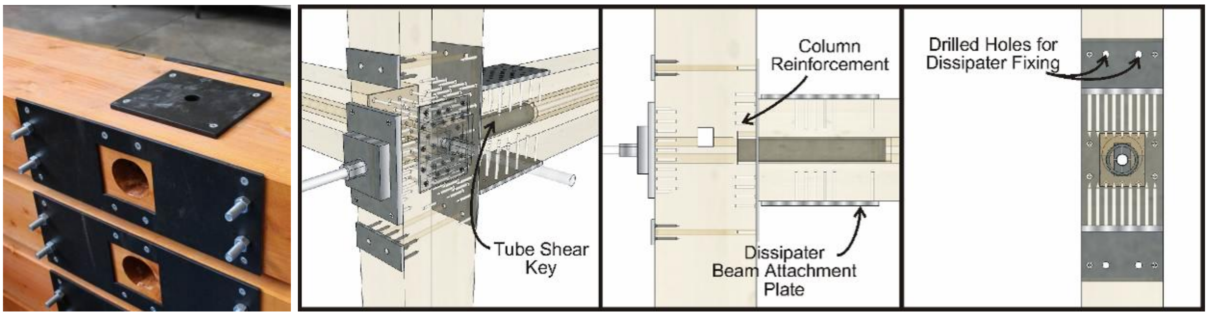


Figure 3. Post-tensioned glulam frame beam-column connection

The beam-column connection in the secondary direction is similar to that in the principle direction. A single ϕ 26.5 mm bar passes through the centre of the beam section. 22 ϕ 8 mm 80 mm long screws are used to reinforce both where the beam and the post-tensioning backing plate meet the column.

The base of the column (Figure 4) is fitted with a steel shoe which is epoxied into the base of the column and left free to rock on a base plate (which will be used to represent the building foundations in the case of the test building). Four ϕ 20 mm bars of 300 mm length are used for this connection. Shear transfer is achieved using a ϕ 76.1 mm steel tube which extends 15 mm from the steel shoe and slots into a cavity in the base plate. As shown in Figure 4 holes have been drilled and tapped in the steel shoe in order to facilitate the attachment of energy dissipation devices. In order to keep the base of the column as aesthetically pleasing as possible the steel shoe has been recessed into the column.

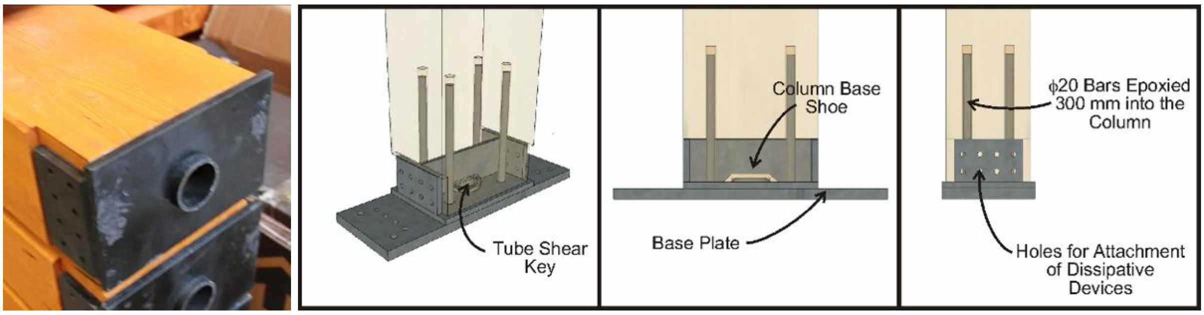


Figure 4. Post-tensioned glulam frame column-foundation connection

Dissipation in the form of a yielding steel angle based on the DIS-CAM concept of Docle et al. (2006) will be used and characterisation testing has been performed in order to define the angle forms to be used. Following the angle testing programme two different methods of creating a concentrated yield area were selected both based on the concept of creating a controlled zone of concentrated yielding. Two angle strengths were desired as will be explained in Section 5.4.

The first of these, shown in Figure 5a, involves the milling down of a certain section of a steel equal angle in order to provide a zone of concentrated yielding. The second option, shown in Figure 5b, involves the removal of two holes in order to provide a concentrated yielding zone. The second steel device is taken from a section of square hollow section. The hysteretic behaviour of the angles is shown in Figure 5b and d.

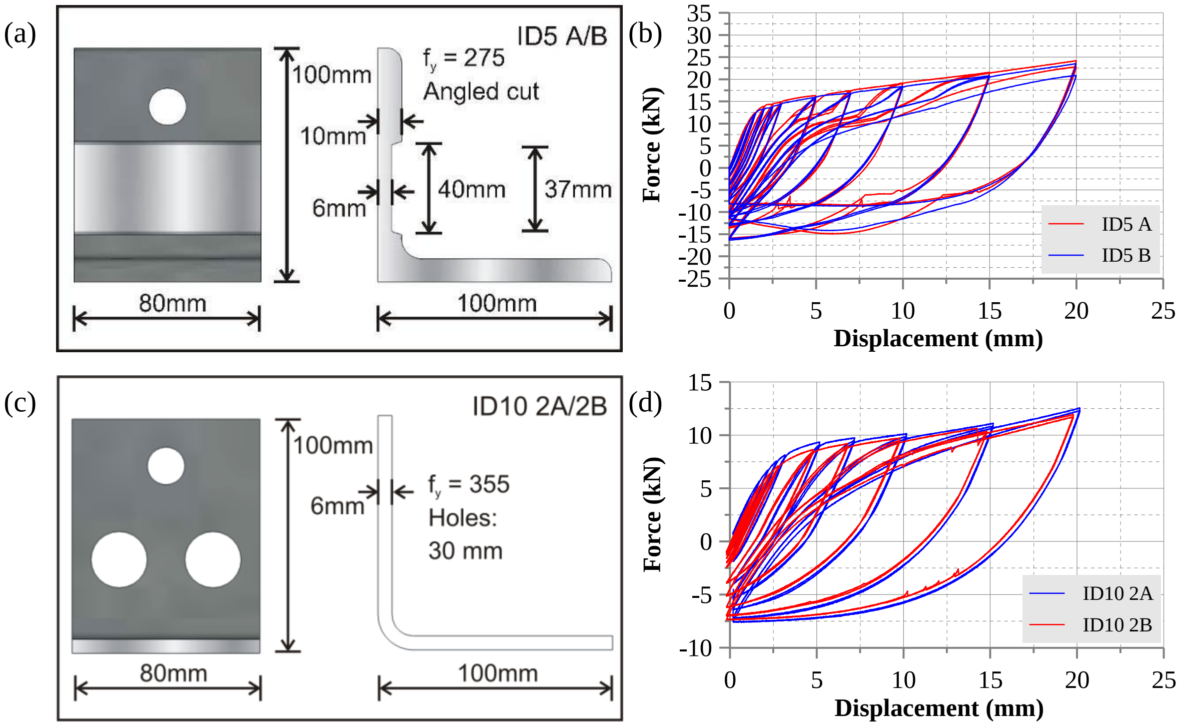


Figure 5. Yielding steel angles

4 FABRICATION OF BEAM-COLUMN JOINT

The fabrication of the frame (Figure 6) was performed by Holzbau Sud SpA in Calitri, Italy. Although the beam and column were of the same dimension slightly different methods of fabrication were used. Due to the presence of the space inside the beam section to accommodate the post-tensioning tendon two separate sections were glued together after a hollow was made in each part using a computer numerical controlled (CNC) woodworking machine. The column was made of a single piece of glulam in which a hole was made for the tendon to be placed.

Figure 6. a) First stage of glulam fabrication, b) beams being pressed together and c) reinforcing screws being placed on column face

5 TEST SET-UP AND SEISMIC INPUT

Testing will be performed under dynamic loading in real time. This will be done using a shaking foundation testing rig. Due to the fact that the frame is 2/3rd scale, mass similitude must be maintained. This means that additional mass must be added which will also represent the presence of a factored live load.

5.1 The shaking foundation

The testing apparatus consists of a shaking foundation present in the Laboratory of the University of Basilicata (Figure 7a). The foundation has a single degree of freedom in the N-S direction and consists of a steel frame made up of HEM300 sections. The foundation is driven by an MTS 244.41 dynamic actuator which has a capacity of ± 500 kN and a stroke of ± 250 mm. The actuator is fixed to a hinge at the base of the foundation and pushes against a 6 m thick strong wall. Pressure for the actuator is provided by 3 MTS SilentfloTM 505-180 hydraulic pumps.

The foundation is situated upon 4 SKF frictionless sliders (Model LLR HC 65 LA T1) with one each situated under the four columns. These sliders sit upon a series of levelling plates which have been level using grout (Figure 7b) in order to ensure that less than 1% friction is obtained.

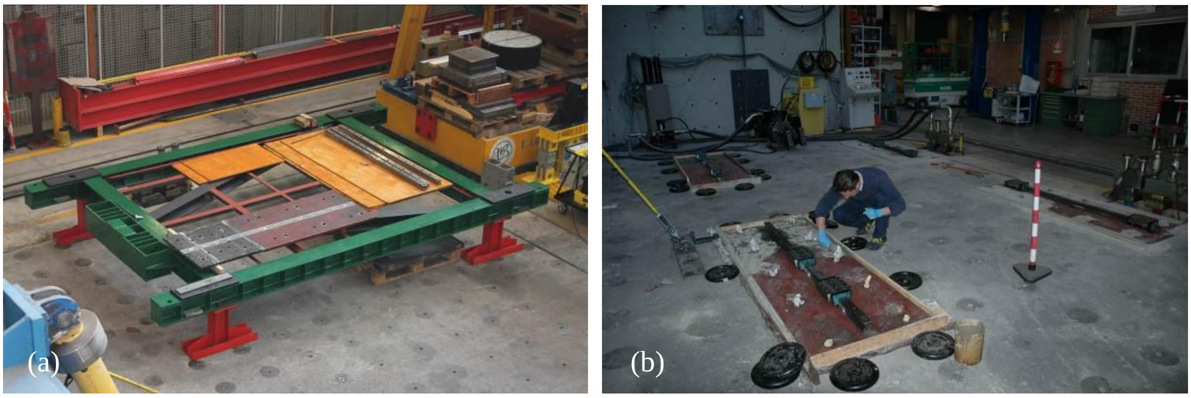


Figure 7. a) Shaking foundation and b) levelling of foundation sliders

5.2 Additional masses

Additional mass to be added to the frame comes from two sources: the mass due to the scaling of the test frame and the mass due to live loading. As mentioned above the prototype building is an office structure, which also has a rooftop garden. A glass façade (and balustrade in the case of the roof level) in considered to surround the building. The live load values for an office structure are Q = 3 kN/m^2 for the two inhabited levels and Q = 2 kN/m^2 for the open roof.

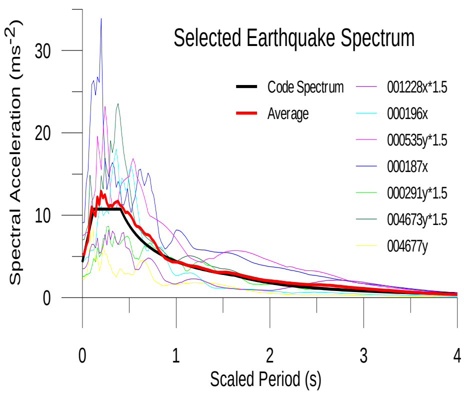
In order to calculate the required amount of mass to be added to the test frame the masses of the prototype building must be multiplied by the scale factor of $(2/3)^2$. This is related to the use of Cauchy-Froude similitude laws which are to be used in testing. Additional mass required is made up of a combination of concrete blocks and steel hold downs: 12 blocks are spread out across the flooring. For more information regarding building mass please refer to Ponzo et al. (2012).

5.3 Seismic input

The testing input will be a set of 7 spectra compatible earthquakes selected from the European strong-motion database. The characteristics of these spectra are shown in Table 1 along with the code spectrum to which they were compared when considering their suitability. The code spectrum was defined in accordance with the current Eurocode for seismic design (EN 1998-1:2003 2003) having a PGA of a_g= 0.35 and a soil factor of S = 1.25 (Soil class B – medium soil) giving a PGA for the design spectrum of 0.4375.

Table 1. Characteristics of selected earthquakes and earthquake spectrum

ID Code	Location	Date	M_W	PGA (g)
001228x	Izmit, Turkey	17/08/99	7.6	0.357
000196x	Montenegro, Serbia	15/04/79	6.9	0.454
000535y	Erzican, Turkey	13/03/92	6.6	0.769
000187x	Tabas, Iran	16/09/78	7.3	0.926
000291y	Campano Lucano, Italy	23/11/80	6.9	0.264
004673y	South Iceland	17/06/00	6.5	0.716
004677y	South Iceland	17/06/00	6.5	0.227



In order to match the above real acceleration inputs to the code spectrum it was necessary to scale earthquakes 001228x, 000535y, 000291y and 004673y. As the test structure is scaled by 2/3rd the duration of input was divided by the scale factor thus altering input period content $(2/3)^{0.5}$.

5.4 Design considerations for a post-tensioned timber system

During testing several characteristic of the post-tensioned timber concept will be investigated. The key to this type of system is made up of the ratio β , the ratio between the moment resistance provided by the post-tensioning and the moment resistance provided by the dissipation (Figure 8). Although a simple concept, this ratio provides the cornerstone in the understanding of system performance. Clearly, during design this choice affects both damping and moment capacity of the system and therefore changing this value will have a direct effect on both capacity and demand. During the experimental campaign the size of the structural members, building layout and mass will not be altered, however different values of post-tensioning and steel moment capacity contributions (thus variations in the value β) will be investigated.

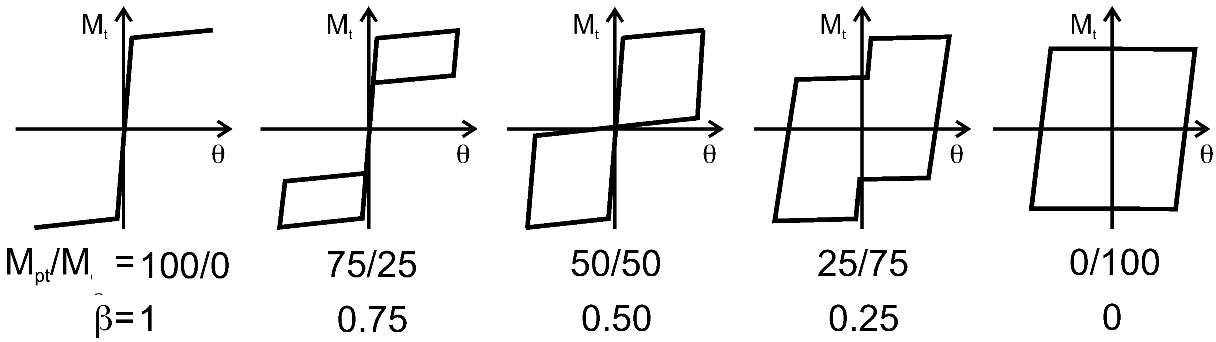


Figure 8. Moment response with varying levels of the parameter β

Following a comprehensive numerical investigation using the numerical modelling programme SAP 2000 a series of four test cases has been selected for initial testing as shown in Table 2. For more information on why these have been selected please refer to the paper mentioned above.

Table 2. Cases to be tested

Name	Initial Value of Post-tensioning	β	Moment Capacity at 2% connection rotation		
			M_{pt}	M_s	M_t
Post-tension Only Case					
PT50_1.00	50 kN	1.00	22.50	0.00	22.50
PT100_1.00	100 kN	1.00	27.21	0.00	27.21
Hybrid Cases (with the addition of steel elements)					
PT 50_0.80	50 kN	0.80	22.50	6.01	28.51
PT100_0.70	100 kN	0.70	27.06	13.07	40.13

6 CONCLUSIONS

The design and detailing of a 2/3rd scale test specimen has been presented along with the details of the testing set-up and planned testing methods.

The post-tensioned timber concept (under the name PRES LAM) is at the forefront of the resurgence of timber as a structural material in seismically resistant multi-storey buildings. Testing at the University of Basilicata in Potenza, Italy in collaboration with the University of Canterbury in Christchurch, New Zealand is furthering the development of this innovative system by considering the application to other engineered timber products, the application of steel reinforcement capable of providing additional energy dissipation and real-time dynamic testing.

The second stage of testing involves the mono-directional shaking table testing of a 3-storey single bay frame scaled to 2/3rds. Connection rocking is planned to occur at both the beam-column and column-foundation connection. Testing has been performed and two angle dissipation devices have been designed and characterized.

Elements have been fabricated off-site and arrived with all plates attached rendering the building truly modular. Preliminary predictions from the finite element programme SAP 2000 have been used in order to define four test cases. These cases will study how altering the parameter β relates the buildings structural performance.

The design and detailing of a $2/3^{rd}$ scale post-tensioned frame has been presented. Testing of this frame under real-time dynamic conditions will provide significant additional information for the design and construction of this innovative method of damage-free timber construction.

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