Short Term Scientific Mission

REPORT

COST action: FP 1004: “Enhance performance of connections and structural timber in weak zones“.

STSM title: Investigation on self-tapping screw capability to induce internal stress in timber elements

STSM period: 25.11.2013 - 07.12.2013

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***Background**:*

Self-tapping screws have the capability to induce an internal stress state in timber elements during the drilling procedure. This aspect can be exploited in different fields. For example it can prove useful in the production and reinforcement of new timber elements as well as in the refurbishment of existing wood structures. In the following lines some examples are described.

<u>Production of glued timber elements</u>

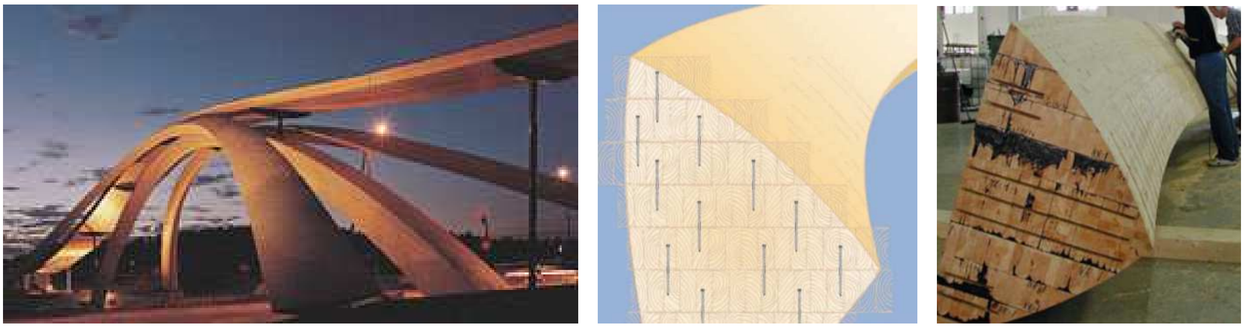

Figure 1 - Bridge Leonardo da Vinci, Norway

Conventional gluing methods require that the individual wooden planks are pressed together mechanically. The pressure generated by the driving of self-tapping screw fasteners binds the planks safely, without having to wait for the glue of every fresh layer to take hold. For an efficient and well controlled production of glued timber elements with self-tapping screw, it is fundamental to know exactly the stress level generated by the screws.

<u>Cambering procedure to “lift” a beam in composite structures</u>

A procedure which enables to “lift” a beam by just superposing a “dry reinforcement element” onto a timber beam was investigated, and a patent is currently pending for it. This method consists in inserting screws inclined at 45° to the beam axis with a specific operational procedure which results in a camber of compound beam thank to the screw capability to induce internal stress.

The effectiveness of this method is based on the capability of self-tapping screws to induce internal stress in timber elements during the driving procedure: the horizontal component of the resultant pressure produced by the inclined screws is directly related to the possibility of cambering the composite system.

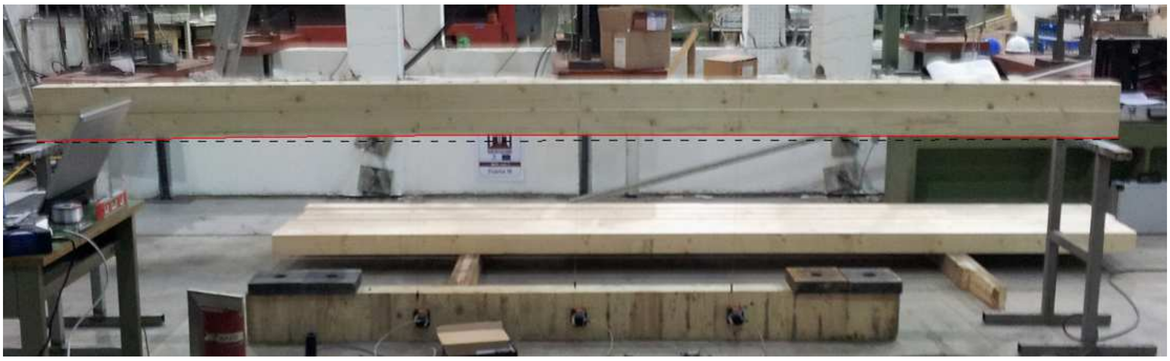

Figure 2 Example of a cambered timber composite beam

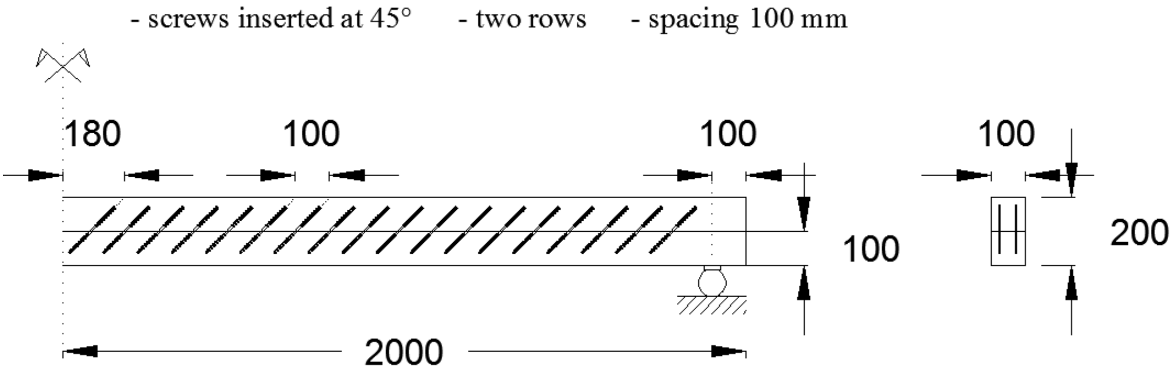

Figure 3

Reinforcement of timber elements in weak zones

Self-tapping screws are also employed to reinforce local areas where the wood fibers are stressed perpendicularly to their direction. Wood fibers are in fact characterized by negligible mechanical performance when loaded in such way.

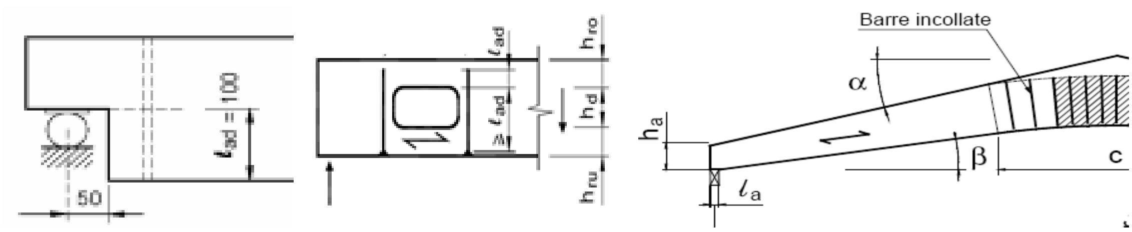

Figure 4 - Weak zone with wood in tension

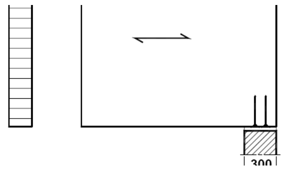

Figure 5 - Weak zone with wood in compression

In all these applications it is very important to investigate the levels of the internal stress induced by different types of fasteners. This means studying the influence of different parameters such as screw angle with respect to the grain direction, initial pressure, head penetration length, threaded part length, connector typology, wood density, and time-dependence.

A preliminary campaign was conducted at University of Trento with a simple setup described in the following pictures:

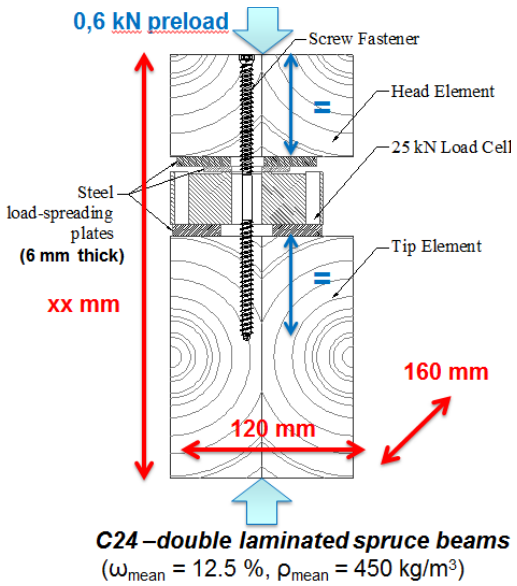

Figure 6 *Test setup adopted at the University of Trento*

The pressure level was registered by four 25 kN load cells with a 20 mm central hole which allowed the passage of the fasteners. The dimensions of the steel load-spreading rings were chosen so as not to exceed the design compressive strength perpendicular to the grain. The stress level on the head-element surface, was determined considering the equivalent T-stub in compression approach.

Timber elements were made out of C24 double laminated (duo-beams) spruce. The moisture content ($\omega mean$ = 12.5 %, CoV = 7 %) and material density ($\rho mean$ = 450 kg/m3, CoV = 4 %) were measured for each wood specimen right before its use. The specimen width and depth were 160 mm and 220 mm respectively, while the specimen height was dependent on screw length.

From the analysis of the test results it appeared that screw fasteners can exert a considerable compression force on the timber elements that they are connecting. The observed pressure values ranged from nearly 1 kN to about 9 kN, accordingly to the connector size and typology. By showing the highest resultant pressure values and the smallest losses, double thread screws proved to be the most effective fasteners. Single thread screw performance, on the other hand can be improved by the employment of washers. The inclination to the grain direction did not show a significant influence on the results. It should be kept in mind that, despite an elevated number of tests, the "population" on which such considerations are based, is relatively small (considered the result variability), owing to the several parameters investigated.

Further study need to be carried out. Particular attention should be paid to the determination of the "load diffusion area" at the interface between the two timber elements. Considering the cambering method above mentioned, additional tests should be performed to deepen the understanding of pressure evolution at really long term. The aim of the STSM here under discussion, was to address such issues.

Purpose of the STSM:

The goal of the Short Term Scientific Mission to the University of Bristol was:

- to broaden the experimental campaign for the evaluation of timber prestress state generated by the most promising type of self-tapping screws adopted in the first campaign at University of Trento.

- to try different experimental setups, in order to investigate the possible influence of the adopted setup on the experimental results. In particular, the presence of a rigid element between the two wooden elements (like the load cell employed in the original setup), may introduce a modification to the prestress effect that could be quantified by means of an alternative setup (a possible alternative to the load cell could be to instrument directly the screw with strain gauges).

- to start a long term testing phase to quantify the creep effect.

Work carried out during the STSM:

As already mentioned, one of the main objectives of the STSM was to investigate the effects that the use of a load cell (to measure the screw pressure) produces on the resultant pressure. To do this, a *pressure sensitive film* (*PSF*, Figure 7) was employed instead of the load cell described in the "background" paragraph. The *PSF* was inserted between two timber specimens cut from a GL24 beam. The screw connectors selected for the testing campaign were both single thread screws (diameter = 10 mm, length = 180 mm) and double thread screws (diameter = 8.2 mm, length = 190 mm). For the *PSF* tests, the length of timber specimens was 500 mm, so as to be able to detect the contact zone between the two timber elements around the screw over which the load was spread. Some test results are given in Figure 8. It can be noted how, despite the fact that the timber specimens showed quite good finishing surfaces, the pressure distribution was not uniform (test 1, test 3), reflecting local undulations in the timber surfaces. In order to evaluate the average colour/pressure range, test 2 was performed with a cork mat (approximately 3 mm thick) inserted between the timber elements. As expected, this led to development of a uniform pressure distribution away from the local area affected by the screw.

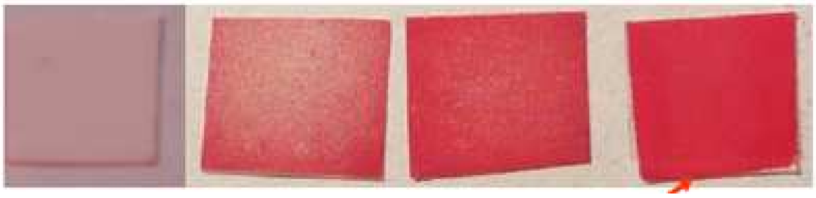

Figure 7 Samples of *pressure sensitive film* at different pressure level

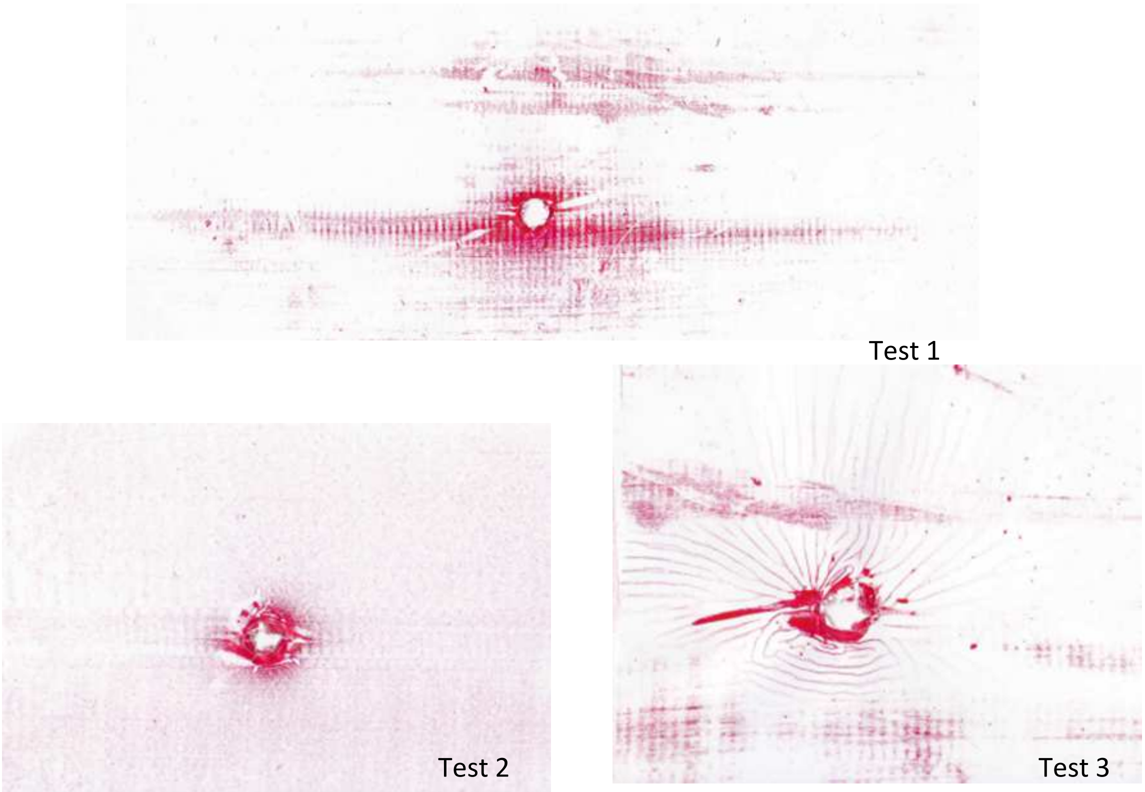

Figure 8 PSF test results

Since the process of pigment transfer within the PSF is not reversible, the approach based on the PSF is not suitable for investigating the long-term behavior. For this reason, an alternative test setup was adopted. The screw-induced variation of pressure over the timber contact surfaces was measured through two strain gauges placed on the smooth part of the shank of the screw, which crossed the interfaces between the two timber specimens in the final layout. As regards the single thread screws, the strain gauges were positioned on the shank close to the head, to facilitate the wire exit. A thin groove was also cut on the top surface of the top timber element. A hole of approximately 3.5 cm deep and with a slightly bigger diameter than the screw shank, was pre-drilled into the timber element receiving the head to prevent the strain gauges from being damaged by the rotation of the screw. To minimise the risk of breaking the fragile strain gauge leads, the screw was driven very slowly.

For insight into any heating effects on the screw (due to screw-timber friction) during rotation, the temperature variation during a “normal installation” was measured. From this it was found that single thread screws reached a temperature of approximately 65 °C (measured at the screw tip), while double thread screws reached almost 100°C. The thermal expansion coefficient and the strain gauge response to temperature variations were evaluated (as a first approach) by performing some “heating tests” (Figure 10). The pressure tests with double-thread screws were more complicated, since the only part of the screw suitable for the application of the strain gauges was in the middle of the screw. In this case the lead wires were brought out through a groove cut into the contact surface between the two timber elements. To allow the double-thread screws to be inserted with a 45° inclination to the grain, the timber specimens were cut as shown in (Figure 12). The process of placing the strain gauges on the screw, connecting the wires and driving the connector into the timber specimen proved challenging and required several attempts before finally being successful.

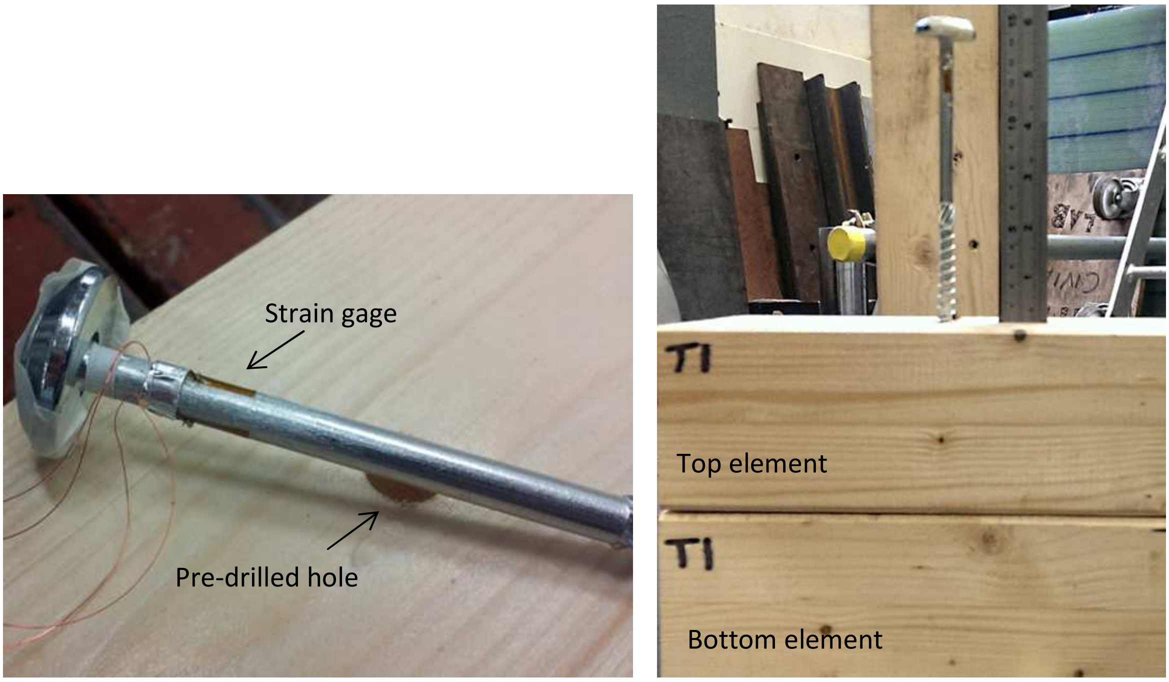

Figure 9 Single thread screw ready to be inserted

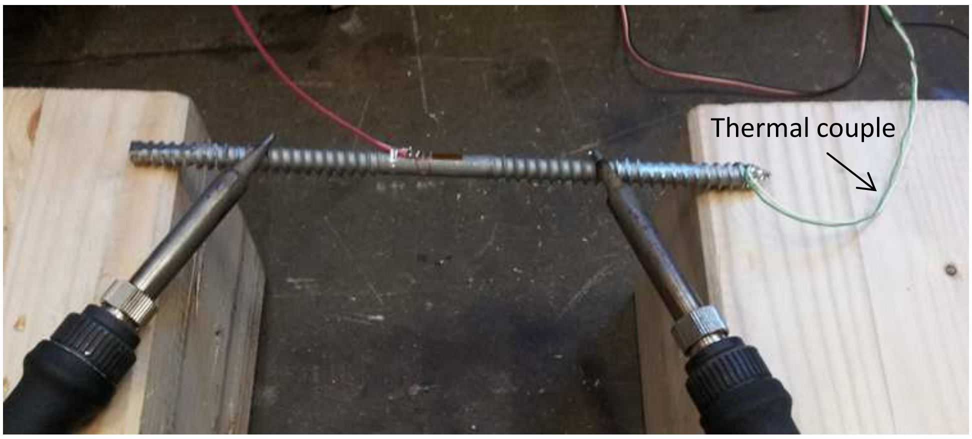

Figure 10 Determination of the thermal expansion coefficient and the temperature effects on the strain gauges

The modulus of elasticity of the screws was determined through tensile tests carried out as represented in Figure 11. To avoid the occurrence of bending stresses, the screw ends were machined to match the connecting system of the testing machine.

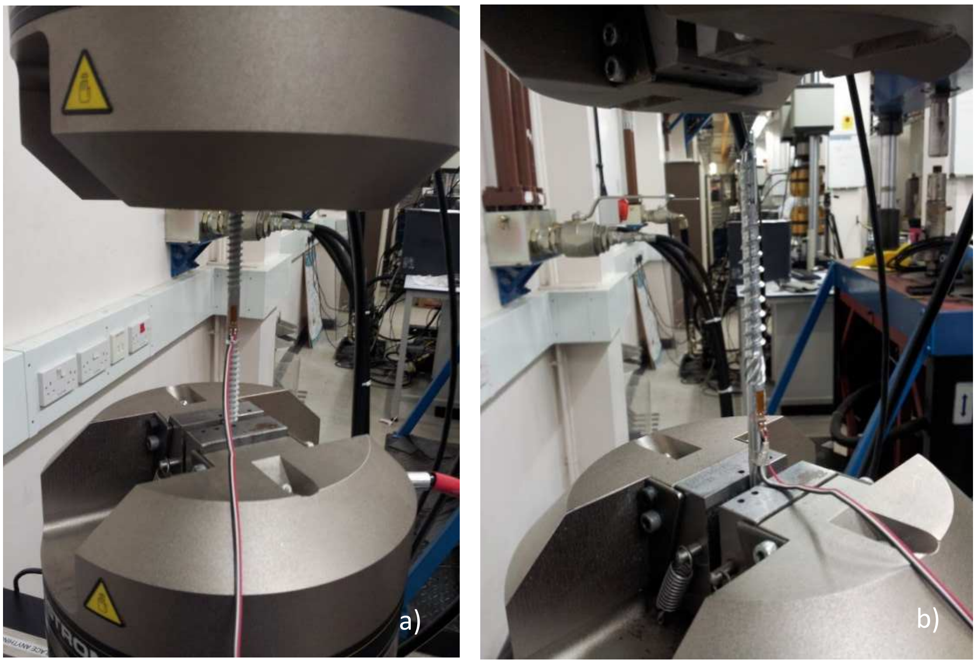

Figure 11 Tensile tests on the connectors – a) double thread screw; b) single thread screw

Figure 12 Timber specimens used for double-thread screws

Future developments:

This STSM has set a basis for future collaborations between the Universities of Trento and Bristol. Topics for possible future co-tutored Masters theses (within the FP1004 framework) have already been discussed. During this mission I had the opportunity to work with very motivated undergraduate students who will continue the experimental campaign on the "*self-tapping screw capability to induce internal stress*". In fact, owing to the fact that the characterization of the long-term behavior was part of the mission goal, the testing campaign is still ongoing. More tests have also been scheduled to widen the population of experimental data. The intention is that all the outcomes of this research will be published in a Journal Paper as soon as the project is completed.

Trento, 18th December 2013

Ivan Giongo

Confirmation by the host institution (by Dr Wendel Sebastian)

In the name of the host institution, Bristol University, the undersigned Prof. Wendel Sebastian confirms that Ivan Giongo has undertaken the above-described STSM.

Prof. Wendel Sebastian, Department of Civil Engineering, Queen's School of Engineering, Bristol University