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Experimental Tests

Initial Experimental Tests, Setups, Discussions and Challenges

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Preface

In order to fulfill all design requirements for the Mobic project, some experimental tests as well as numerical investigations has been conducted. The main intention of the current report is to give an insight into the experimental tests which we expected to get the maximum slip modulus by considering a combination of different and possible nailing distance, nailing positions, and tenon-like wood-wood connections.

In the following sections, a detailed description of test setups as well as experimental results and a brief discussion upon the outcomes are presented. As the main objective of this step, we were seeking the maximum slip modulus which can be obtained, however, elaborating on the technical drawings including construction fabrications in the precambering case as well as mechanical Finite Element model is an issue which can be discussed as the next step.

Testing Setup

In this section, the different tests undertaken are detailed. Two different kind of samples have been tested; first simply nailed OSB samples, then Tenon-Mortise jointed samples.

The goal of these sample testing is to obtain an idea of the rigidity of the joints between the horizontal OSB plates and the vertical webs. This rigidity, represented by the value K_{ser}, will have to be implemented in the FEM model where, initially, an infinite rigidity was considered.

Testing Setup

A standard sample consists of two horizontal and one vertical 400x1100x25 mm OSB plates, in an I-shape assembly.

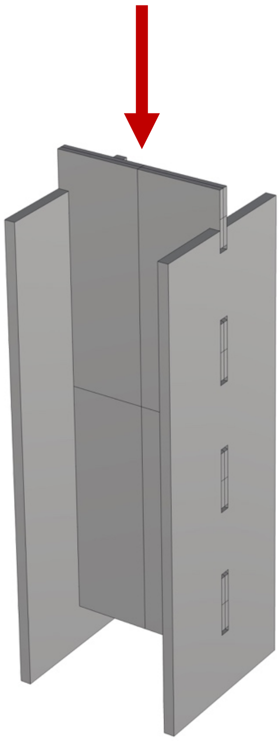

Figure 1: Rhino rendering of 100 mm tenon-mortise joint sample

Figure 2: Standard testing setup, angled nailing sample

The load is applied vertically on the male part to induce shear stress in the joints parallel to the load direction.

The purpose of these tests is to measure the displacement of the central part with respect to the outer parts in function of the applied force. The slope in the linear part of the Force-Displacement curve, from 10% to 40% of the maximum load F_{max}, gives the K_{ser} rigidity of the joints which is the desired information of this study.

Simply Nailed

The first tests where done on simply nailed OSB samples, shown at Figure 2. A first sample was built with vertically nailed spikes, another with inclined nails.

Vertical nails

The expectations for the vertically nailed samples where not high because of the internal structure of OSB panels. An OSB panel grossly consists of 2 different densities: the central part is less dense than the two outer parts.

By nailing vertically, it implies to drive the spikes into the low density part of the vertical

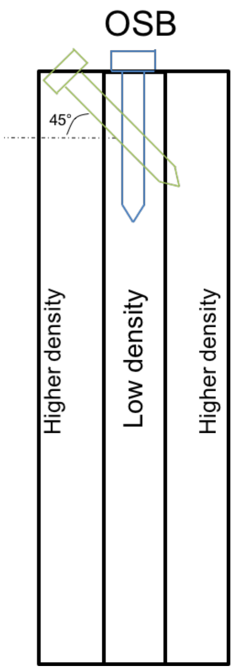

Figure 3: Internal Structure OSB

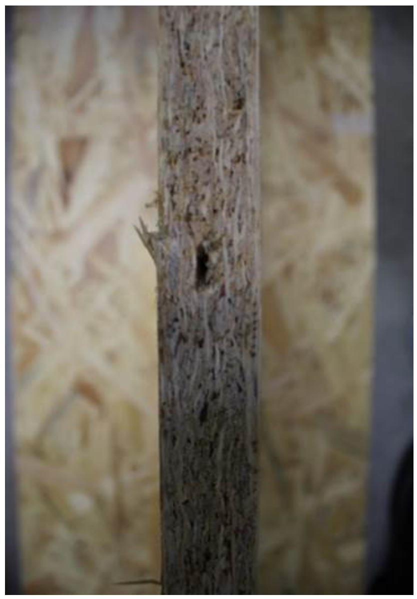
Figure 5: Weakness of local embedment


Figure 4: Testing setup #1

OSB drawn at Figure 3, which results in low strength and rigidity. The results are show at Figure 17 : K_{ser} = 7.1 and 3.4 KN/mm and a maximum load F_{max} of 10,6 and 10.2 KN has been reached.

Angled nails

To prevent from drilling only in the low density central OSB part, a different way of nailing has been tested: 45° orientated nails (Figure 3). First, a sample has been built with nails, afterwards this has been done with screws.

Nails

Ø4 mm nails have been used for the samples. These are laid out in quincunx, spaced at 10 cm from each other, which results in 2 x 18 spikes per sample.

The values obtained in this case are slightly higher than in the vertical case, however unsatisfying with a K_{ser} = 13.3 and 6.1 kN/mm and a maximal load F_{max} of 38,6 and 25.5 kN

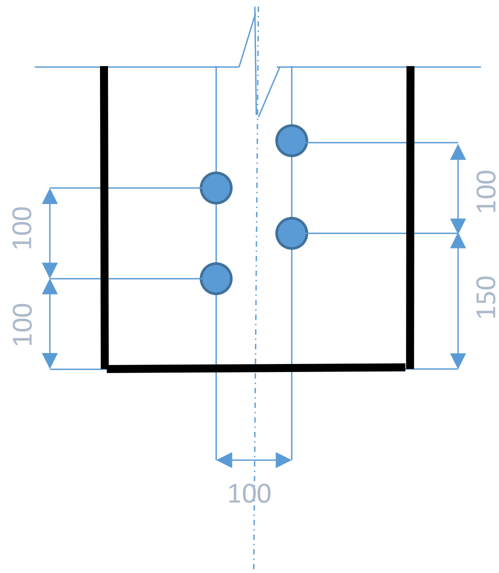

Figure 7: Nail/Screw Disposition, elevation

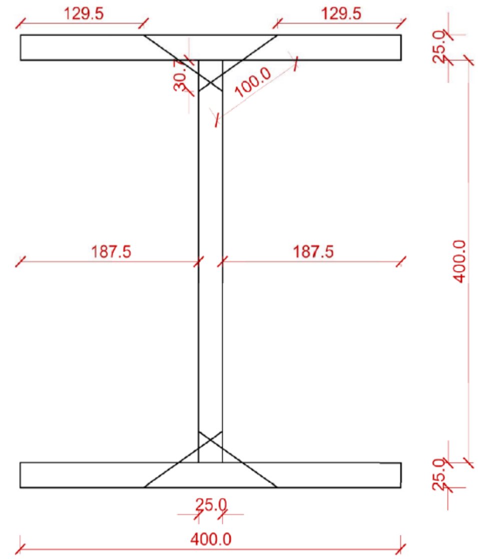

Figure 6; Nail/Screw Disposition, cross-section

This is firstly due to a non-optimal solution for OSB, which should be nailed perpendicularly to its internal orientated structure.

Secondly, an optimal nailing, where the nails would be exactly driven at the interface between the 2 perpendicular pieces, as shown at Figure 5, is hard to achieve manually. Instead, the spikes, which are not perfectly drilled, are subjected to bending moments which they cannot bear (Figure 6).

Screw

Figure 8: Results of Bending Moments in Nails

Figure 9: Ø4mm Screw

The same scenario has been applied to Ø4 mm screws. In this case, K_{ser} = 5.6 kN/m and F_{max} = 63 kN The results are thus slightly better than for nails. Though, this alternative is way more expensive and neither gives the needed rigidity.

Tenon-Mortise

Due to the low results obtained in the previous section, another assembly technique had to be considered. The tenon-mortise assembly allows a more optimized use of the mechanical strength and rigidity of the OSB. In this case, the maximum rigidity and the failure mode should be related to the shear stress in the sheared surfaces.

The challenge lies in the assembly on-site of the structure: the pre-cumbering, needed in the vertical webs to avoid more than 9 cm deflection in the center of the 10 meter span, hinders the use of vertical tenons. Indeed, vertical tenons couldn't allow to assemble the vertical to the horizontal plate while inflected.

Therefore, angled tenons have been drawn and cut to permit the assembly on-site. This results in a single line contact at each tenon-mortise joint, instead of full contact in the vertical case.

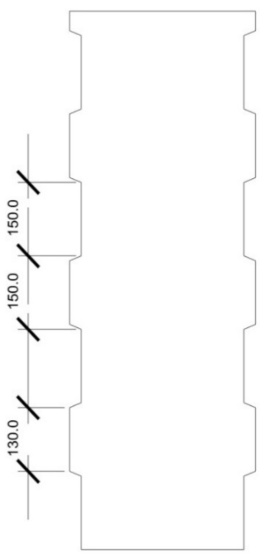

Figure 12: 150 mm tenons, male part

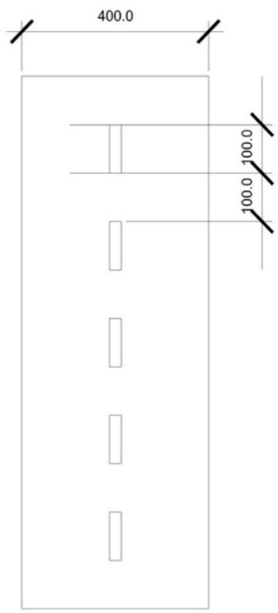

Figure 11: 100 mm tenon, female part

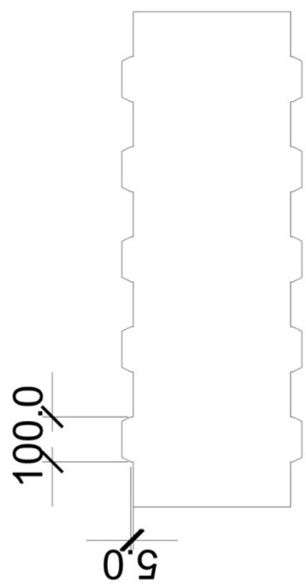

Figure 10: 100 mm tenon, 5 mm vertical edge

Without nails

By using inclined tenons, an additional phenomenon occurs that has to be taken into account. By applying a load during testing, the sample tends to disassemble (Figure 10), which results in a slip movement along the tenon. This scenario has to be avoided and is the reason why no test has been done on “no-nailed” samples.

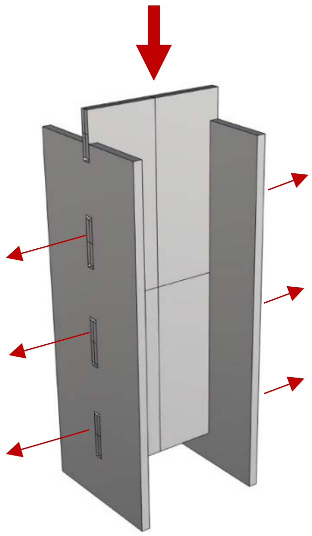

Figure 13: Disconnecting effect

With nails

To avoid slipping, inclin[illegible]itionally to the tenon-mortise joints. Different samples have been built to test the effect of different tenon-lengths. However, the total shear surface on each sample stays the same and is equal to 2 x 125 cm^2.

50 mm

Figure 14: Test #7; 50 mm tenon

Figure 15: Failure of the web

The results for 50 mm tenon are given at Figure 17 and Table 1. The failure of the samples was due to the failure of the web where the load had been applied, despite the addition of enhancement. In this case, an average Kser = 19 kN/mm has been found on the 2 samples.

100 mm

The results for 100 mm tenon are given at Figure 17 and Table 1.
Tests 5 and 12 have been made on standard 100 mm tenon samples shown at Figure 8 .
For this case, another type of tenons has been tested, with a 5mm vertical edge at the bottom followed by the angled top necessary for the assembly of the pre-cumbered beams (Figure 9).

The failures of test 6 and test 12 are due to compression of the wood fibers in the joints.
Test 5 presents a failure of the web where the load has been applied.
One obtains K_{ser} = 14.0 and K_{ser} = 10 kN/mm for tests 5 and 12 and a maximum K_{ser} of 21 kN/mm for test 6.

Figure 16: Failure by compression of the wood fibers

150 mm

The results for 150 mm tenon are given at Figure 17 and Table 1. Only one sample of this scenario has been tested. A K_{ser} of 10,8 and 10.2 kN/mm and a strength of 96.0 and 87.0 kN were obtained.
The failure this time is due to both compression of the wood fibers and slipping of the female part along the tenon edges which has not been prevented by nailing.

Figure 17: Test #11 ; 150 mm tenon

Figure 18: Failure by compression of wood fibers and slip

Discussion

The 12 realized tests, which results can be found in Table 1, show different interesting results:

- The use of vertical nails isn't interesting in OSB due to the internal structure of the wood.

- The use of tenon-mortise joints increases drastically the rigidity and strength of the samples.

- It is essential to add nailing to tenon-mortise joints. However, the angled nailing should be perfectly executed: the nails have to be drilled at the interface between the vertical and horizontal panel to prevent bending moment. Furthermore, shorter nails should be used to not exceed through the vertical panel and allow them to work at their maximum capacity.

- Increasing the amount of tenons by reducing their individual shear area increases the rigidity and strength of the assembly. This is probably due to more uniform distribution of shear and compression forces along the joints.
  The results of 5 cm tenons are slightly better than 10 cm and 15 cm tenons.
  Moreover, the assembly of the samples containing a more important quantity of smaller teeth, was easier.

- As expected, the use of vertical edges at the bottom of the tenons increases the rigidity of the connections. However, this makes the assembly on site more difficult and further analysis has to be made at that level to figure out the maximum length allowed for the vertical edge.

One can conclude of this analysis that the best solution is the use of tenon-mortise assemblies, and this by increasing the amount of tenons and add a vertical edge at the tenon's bottom. Though, the results show an unsatisfying rigidity of the OSB connection with a maximum K_{ser} of 14,6 kN/mm for the half-vertical 100 mm tenons and a K_{ser} of 11,2 kN/mm for 50 mm angled tenons. In other words, considering the K_{ser} value per one tenon and one nail, still the amount is much less than the criteria to be considered as the semi-rigid connection.

Table 1: Measured K_{ser} and F_{max}

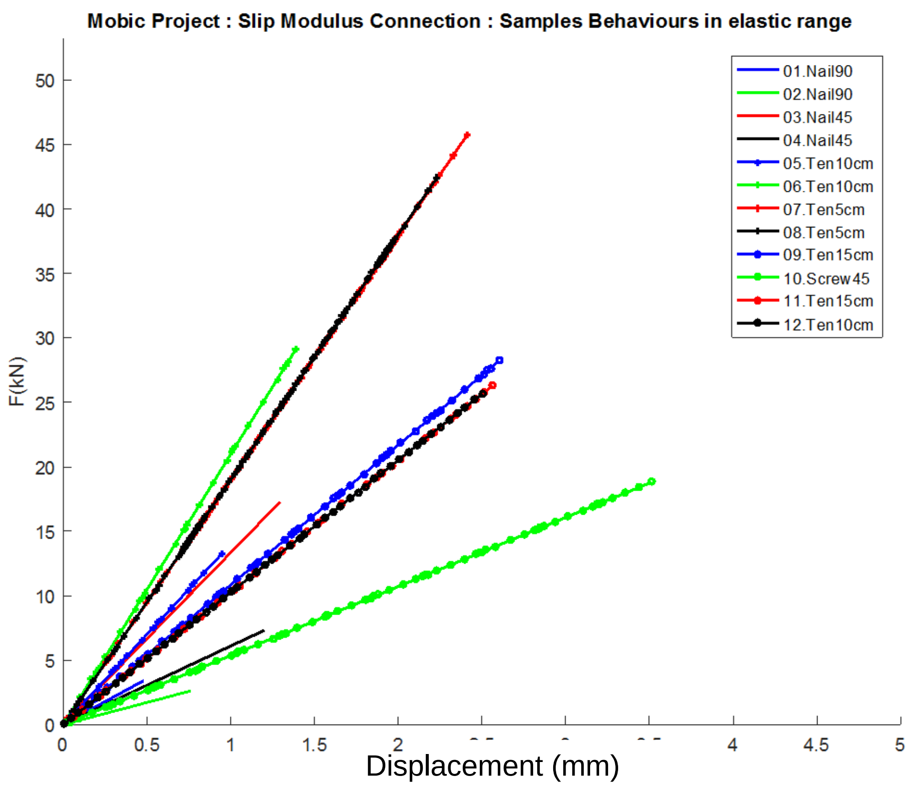

Figure 19: Load-Displacement Curve of the tests, returned to the origin

# Test	1	2	3	4
Description	*- Vertical nails - Every 10 cm as nailing spaces - 18 Total nails in one specimen with length of 1.0 meter - smooth nails*	*- Vertical Nails - Every 10 cm as nailing spaces - 18 Total nails in one specimen with length of 1.0 meter - smooth nails*	*- Angled nails (45°) - Every 10 cm as nailing spaces - 36 Total nails in one specimen with length of 1.0 meter - smooth nails*	*- Angled nails (45°) - Every 10 cm as nailing spaces - 36 Total nails in one specimen with length of 1.0 meter - smooth nails*
K_{ser} (of whole specimen) [kN/mm]	**7.1**	**3.4**	**13.3**	**6.1**
F_{max} [kN]	10,6	10,2	38,6	25,5

# Test	5	6	7	8
Description	*- Tenon 100 mm - Every 10 cm as nailing spaces - 36 Total nails in one specimen with length of 1.0 meter - smooth nails*	*- Tenon 100 mm (+ 5mm vertical edge) - Every 10 cm as nailing spaces - 36 Total nails in one specimen with length of 1.0 meter - smooth nails*	*- Tenon 50 mm - Every 10 cm as nailing spaces - 36 Total nails in one specimen with length of 1.0 meter - smooth nails*	*- Tenon 50 mm - Every 10 cm as nailing spaces - 36 Total nails in one specimen with length of 1.0 meter - smooth nails*
K_{ser} (of whole specimen) [kN/mm]	**14.0**	**21.0**	**19.0**	**19.0**
F_{max} [kN]	42,8	94,2	107,9	104,7

# Test	9	10	11	12
Description	*- Tenon 150 mm - Every 10 cm as nailing spaces - 36 Total nails in one specimen with length of 1.0 meter - smooth nails*	*- Angled screw (45°) - Every 10 cm as nailing spaces - 36 Total nails in one specimen with length of 1.0 meter - smooth nails*	*- Tenon 150 mm - Every 10 cm as nailing spaces - 36 Total nails in one specimen with length of 1.0 meter - smooth nails*	*- Tenon 100 mm - Every 10 cm as nailing spaces - 36 Total nails in one specimen with length of 1.0 meter - smooth nails*
K_{ser} [kN/mm]	**10.8**	**5.4**	**10.2**	**10.3**
F_{max} [kN]	96,0	63,0	87,8	87,8

Conclusion and challenges (key points)

As it has been demonstrated in Table 1, tenon wood-wood connections with 50 mm spaces shows the most proper performance. Specimens with vertical nailing shows the worst performance by having the least slip modulus.

The following issues can be found as the main observed deficiencies.

More the slip modulus of the connection is resistant, less the beam deflection is. Also, local embedment behavior is too weak at the OSB edge (as we can observe on several samples):

- The assembly resistance is weak
- The slip modulus isn't sufficient (shear capacity)
- Disassembly of beam parts (tension capacity)
- Haven't perspective of the sustainability over time for this nailing (creep capacity)

Nailing in the OSB edges does not seem to be a rational solution for the project. Considering the OSB Tenon joints, the shear capacity increase and the slip modulus is more resistant, however, the problem of disassembly remains unsolved yet. More complicatedly, wood-wood connections bring lots of question in regard of precambering case.