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Cyclic behavior of the components of a dowel-type assembly - variability

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ABSTRACT: Among the rod-type assemblies, the dowel-type assembly allows connections with smooth rods with a metal plate fitting inserted into the wood. This type of assembly transfers forces between wood members by shearing the dowels. Energy dissipation is possible due to the yielding of dowels and the wood in contact with the dowel. Due to the heterogeneity of the materials, the behavior of such an assembly has a significant variability, which increases the difficulty to characterize key parameters. In this study, the assembly is divided into its components; each component is tested under a cyclic loading with four increasing amplitudes. Samples are tested with compressive loads parallel or perpendicular to the grain of the wood. The envelope curve of the force-displacement responses shows higher variability of tests including wood. The energy dissipation is obtained per loading amplitude, showing the linear behavior of the dowel before yielding and a nonlinear behavior for all the other components. The results obtained in this study show the need for a statistical approach to model the behavior of the assembly, with consideration for the contribution of each component.

KEYWORDS: Wood construction, dowel assemblies, cyclic behavior, hysteresis, variability

1 – INTRODUCTION

In recent years, the construction of large wooden buildings has increased. These structures require specific construction techniques that depend not only on the materials used, but also on the forces to be transmitted. Among these techniques, rod-type wood joints have emerged as essential components, widely used in both low-rise and high-rise wooden structures.

For these assemblies, different types of fasteners are used, the dowel being one of them. The connection is made with a plate and dowels (Figure 1). The mechanical performance of these joints is influenced by the geometric design, the material properties and the characteristics of the contact zones. This type of connector is generally designed to transmit loads in the plane of the assembly (tension or compression). In addition, it can also transmit bending moments [1], [2], [3], [4].

Eurocode 5 [5] provides guidance for calculating the mechanical performance of the dowel-type assembly. Spacing of dowels in a row is given to avoid brittle failure. The Johansen model [6] (limit analysis theory) is used as a reference for calculating the resistance of an assembly.

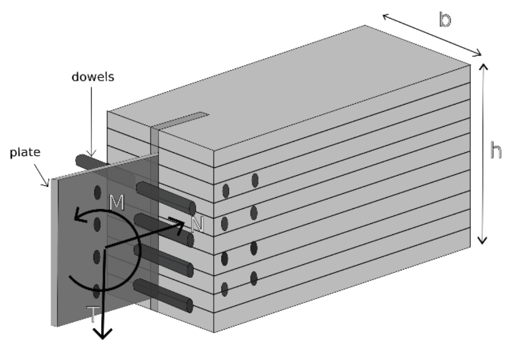

Figure 1. Dowel-type assembly

The performance under dynamic/variable load of this connector is usually evaluated with cyclic tests. EN 12512 [7] defines a cyclic test protocol for timber connectors with increasing amplitude until failure. It allows to evaluate different parameters such as energy dissipation, yield point, initial stiffness, secant stiffness

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and permanent deformations. These properties give some clues about the dynamic behavior of connectors.

2 – BACKGROUND

Variability is strongly present when testing the mechanical performance of a dowel assembly. To unravel it, researchers have focused on different parameters that have an incidence on the resistance of the assembly. For example, this type of assembly behaves differently depending on the geometric configuration of the elements [8], [9], [10]. The spacing of dowels influences the stiffness and the resistance of the assembly. The geometric configuration is also used in the Johansen theory to calculate the resistance of assemblies; the main parameters are the length of wood foundation and the dowel diameter [6]. In terms of material performance, the density of the wood is often taken into account, since a correlation between resistance and density has been demonstrated [11]. An effective resistance is also introduced in the Eurocode 5 by using an effective number of dowels in a row [8], it allows to take into account the stress redistribution in the connectors. For the stiffness of this type of assembly, Eurocode 5 defines a formula that includes the diameter of the dowel and the density of the wood. This formulation does not take into account the different deformation modes described in the Johansen yield model [6]. The deformation modes are related to the length of wood foundation for the dowel.

The embedding resistance of wood is an important parameter and it is used in the Eurocode 5 to calculate the resistance of an assembly. EN 383 defines the experimental procedure for determining the embedding resistance of wood [12]. Based on experimental tests, formulas are provided to calculate the embedding capacity according to the wood density and to the dowel diameter [13], [14], [15]. The contact roughness influences the embedding resistance [16], [17], but in the case of standard dowels (smooth surfaces), the roughness is mostly defined by the drilling quality on the wood.

Regarding the cyclic behavior of the dowel assembly, the following phenomena have been observed: stiffness degradation, pinching and resistance degradation [18], [19]. The standard proposes a displacement-controlled cyclic test (EN 12512). Using a force-controlled test in the elastic domain of the assembly, the previous degradation phenomena are also observed [18].

The objective of this paper is to study the variability of the cyclic response of the assembly. For this purpose, a load-controlled test is applied to the different components. The variability of each component is analyzed according to key parameters. The wood fiber direction is considered in the analysis. Parameters such as dimensions and dowel type are considered fixed for this study. The wood samples have the same depth.

3 – THE COMPONENTS OF A DOWEL-TYPE ASSEMBLY

The dowel assembly is examined element by element (Figures 2 and 3). First, the dowel is analyzed in two configurations, both with a three-point bending test. The second component is the embedding of the dowel in the wood. The same type of dowel is used on half drillings (according to ASTM D5764). The embedding is defined according to the direction of the load (parallel or perpendicular to the grain of wood). In the third configuration, a one-dowel assembly is tested with a plate inserted into the groove of the wood, allowing dowel to shear on the wood foundation. The direction of the grain is also taken into account. Finally, the four-dowel assembly is tested parallel and perpendicular to the grain. The dimensions of the samples of one or four dowels are the same. The depth of the samples is defined according to the dowel length. The same plate is used for all tests.

All tests are performed with force-controlled cyclic loading. Four load levels are defined based on previous tests on each component. Two levels are in the elastic domain of the tested element and the others are in the plastic domain. The applied cyclic load has five peaks (repetitions) at each load level. All tests are performed in compression.

4 – EXPERIMENTAL PROGRAM

4.1 SPECIMENS DETAILS

The wood specimens are made with GL24H softwood. The steel dowels have 8 mm of diameter, the steel plate is 10 mm thick. The dimensions of the specimens follow the recommendations of Eurocode 5 and have a uniform depth of 8 cm (Figures 2 and 3). The dowels (8 cm and 5 cm spans) are tested in a three-point bending test. These two configurations correspond to a case where the wood foundation is weak (8 cm span) or taking into account half of the foundation length as supports (5 cm span). Four tests are carried out for each case.

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The groups and dimensions of specimens are specified in Figures 2 and 3. The moisture content of wood is measured with a pin moisture meter. The test quantity is given in Table 1. The value of ΔF corresponds to the variation of each load level (Figure 4). This parameter is defined from previous tests on the same assembly configuration.

Table 1: Characteristics of the samples.

Group	Number	W (%)	ρ (kg/m3)	ΔF
1	6	12.2 ± 0.6	490 ± 17	4
2	6	11.8 ± 0.4	486 ± 26	2
3	8	12.3 ± 0.5	493 ± 19	8
4	8	12.2 ± 0.4	502 ± 18	2.5
5	8	12.8 ± 0.7	488 ± 29	2
6	8	11.9 ± 0.5	495 ± 21	6

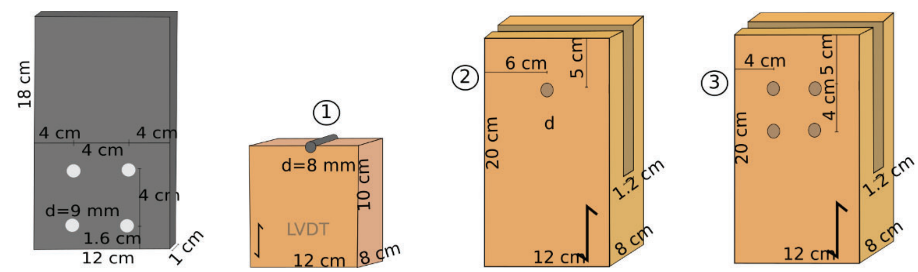

Figure 2. Dimensions of specimens for tests parallel to the grain.

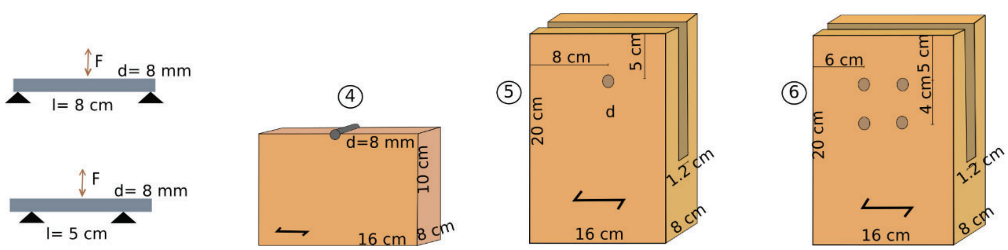

Figure 3. Dimensions of specimens for tests perpendicular to the grain.

4.2 SET-UP AND LOADING PROTOCOL

The specimens are connected to the compression machine with a pin connector for specimens 1 and 4, to prevent bending of the dowel. For the other specimens, the plate is rigidly connected to the machine. This choice reduces the rotation of the plate from the specimen. In a building, the assembly connects different wooden elements, so the plate is generally limited in rotation.

Two LVDTs are used to measure the relative displacement of the plate from the wood. One on each side of the wood specimen. The applied load has four levels, each step increasing by ΔF. The maximum load is four times ΔF (Figure 4). The loading speed is in the interval defined by the EN 12512 [7] (0.02 mm/s-0.2 mm/s) and varies with the load level to provide similar frequencies for all cycles.

4.3 PARAMETERS MEASUREMENT

Figure 5 (left) shows a typical force-displacement result. In this curve, the energy dissipation is calculated as the area within a cycle. In addition, the stiffness is measured in the reloading and unloading path (from 60 % to 90 % of the maximum force); this section has a close linear path. Standards define other parameters such as equivalent viscous damping coefficient (ν_{eq}), strength degradation, etc. In research, pinching is also included, but these other parameters can be calculated or deduced from the energy dissipation or tangent stiffness.

When five cycles are applied, energy dissipation can be observed, especially in the first cycle. Figure 5 (right) shows a typical energy dissipation response as a function of cycles. The first cycle shows a higher energy dissipation. This cycle strongly deforms the wood under the dowel and can cause the dowel yielding depending on the load level. For these reasons, the minimum, maximum and average values are evaluated for each type of test and for all the cycles after the first one at each load level. Figure 5 (right) shows an exemple of the representation of minimum, mean and maximum values for the cycles after the first one at each load level. This representation is used for the key parameters in the sections 5.2 and 5.3.

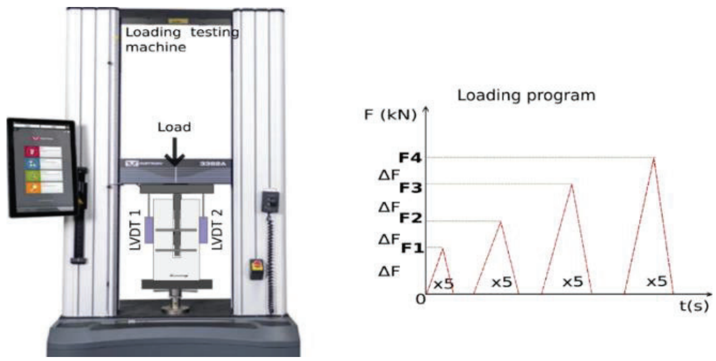

Figure 4. Tests set-up (left) and loading protocol (right).

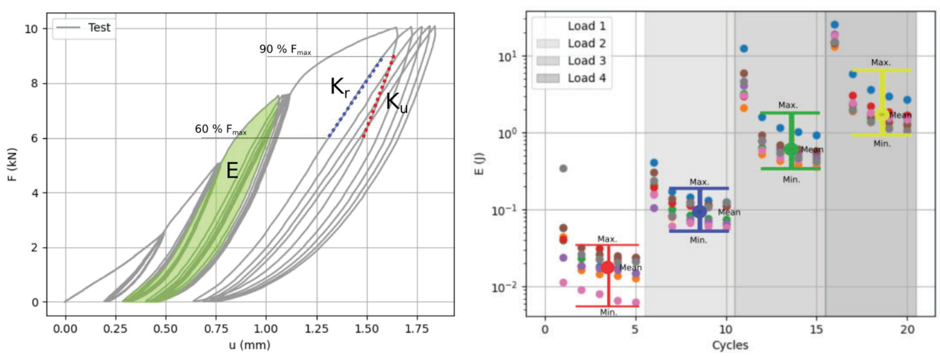

Figure 5. Parameters measured in the force-displacement response (left), representation of the variation of a parameter on the four last cycles at each load level and for given group (right).

5 – RESULTS

5.1 LOAD ENVELOPES

Figures 6, 7 and 8 show the envelope curves for each component. The envelope is defined by the maximum force-displacement response for a given specimen. The limit curves and the average are obtained by filtering (smoothing) the maximum, minimum and average of all the curves. These values are calculated according to the y-axis, since the tests are controlled in force (Figure 4 right).

From the envelope curves, the initial secant stiffness (0-40 % of F_{max}) and the maximum displacement are analyzed. The yield point is not included because it cannot be clearly defined for the tests on wood. Table 2 shows the average, standard deviation and coefficient of variation (μ, σ, CV=σ/μ) for each configuration.

Table 2: Parameters on the envelope curve.

Group	K_{ini} (kN/mm)	U_{max} (mm)
Dowel (span=5cm)	21.2 ± 2.2 (CV 10 %)	2.1 ±0.1 (CV 5 %)
Dowel (span=8cm)	3.9 ± 0.4 (CV 10 %)	4.7 ± 0.8 (CV 17 %)
1	24.8 ± 7.6 (CV 31 %)	0.6 ± 0.1 (CV 17 %)
2	14.4 ± 3.3 (CV 23 %)	0.8 ± 0.1 (CV 13 %)
3	22.2 ± 6.0 (CV 27 %)	2.1 ± 0.4 (CV 19%)
4	10.3 ± 5.2 (CV 50 %)	1.6 ± 0.6 (CV 38 %)
5	6.8 ± 2.3 (CV 34 %)	3.8 ± 0.5 (CV 13 %)
6	9.0 ± 2.4 (CV 27 %)	2.6 ± 0.7 (CV 27 %)

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Regarding the initial stiffness, the dowel tests show less variation than the wood tests. Higher variation is obtained for embedding perpendicular to the grain. The initial stiffness of tests parallel to the grain are slightly more than twice the stiffness of the tests perpendicular to the grain.

In terms of initial stiffness, the four-dowel assembly does not have four times the stiffness of a single dowel assembly. However, in terms of resistance (Figure 7 right), the load carrying capacity seems to be equivalent (four times the resistance of one dowel assembly).

The final displacement variation of the dowel at 5 cm span is the lowest (5%). The perpendicular to the grain embedding presents the higher variation for this parameter. The dowel tests show a high ductility (>5). Higher displacements are observed for the perpendicular to the grain tests. As a reminder, all configurations are tested up to 80 % of F_{limit}. The latter is taken from previous tests.

Figure 7 (left) represents the parallel to the grain embedding tests, a soft initial slip appears in all specimens. The mean curve does not show a clear yield point. Brittle failure may occur under the dowel at higher loads. As shown in Figure 5 (left), the unloading path does not match the loading path at any load level.

Figure 7 (middle) shows the envelope for one dowel assembly tested parallel to the grain. It shows initial soft slip. The yield point cannot be clearly determined. The non-linear behavior can be observed in the cyclic curves (as in the Figure 5, left). The displacement obtained (Figure 7 right) are much higher than those for the single assembly test.

The embedding tests perpendicular to the grain show a greater variation of the force-displacement curve with increasing load (Figure 8 left). Most of them present an initial soft slip. There is no brittle failure in any of the tests. Non-linear behavior is observed (energy dissipation at each load level).

The one-dowel assembly test (perpendicular to the grain) exhibits high variability in the force-displacement curve at the beginning of the loading. The plastic domain shows a positive tangent stiffness on contrast to the same test configuration parallel to the grain (Figure 8, middle).

The four-dowel assembly (perpendicular to the grain) exhibits high dispersion as the load increases. Soft initial slip is observed. There is no brittle failure in any specimen (Figure 8 right).

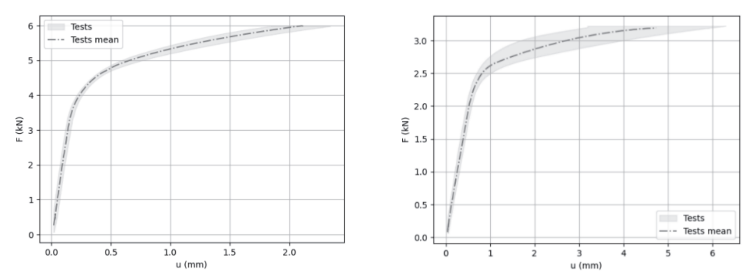

Figure 6. Envelope curves of the dowel tests, of three-point bending test on 5 cm dowel span (left) and 8 cm dowel span (right).

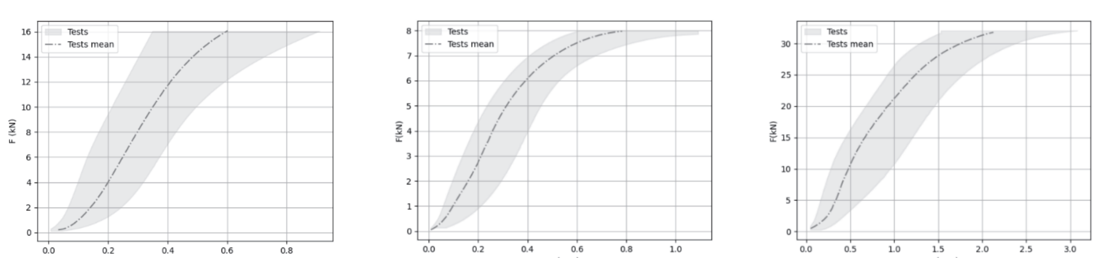

Figure 7. Parallel to the grain envelopes: for embedding tests (left), one-dowel assembly tests (middle) and four-dowel assembly tests (right).

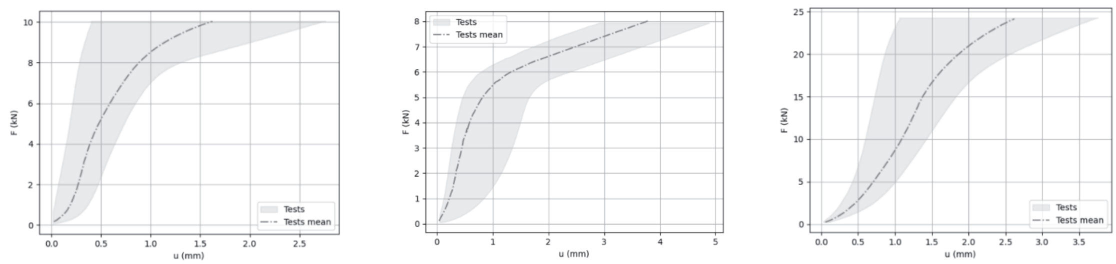

Figure 8. Perpendicular to the grain envelopes: for embedding tests (left), one-dowel assembly tests (middle) and four-dowel assembly tests (right).

5.2 RELOADING AND UNLOADING STIFFNESS (C2-5)

Figure 9 shows the evolution of the reloading stiffness in the four load levels. The values of the last four cycles are considered. As explained in Figure 5 (left), the plot shows the variation of the parameter values after the first cycle. An average, a minimum and a maximum are obtained per load level. For the dowel tests, the reloading stiffness varies for the 5 cm span configuration and remains almost constant for the 8 cm span test.

For the parallel to the grain tests, the reloading stiffness increases on average. This occurs as the load level increases. The one dowel assembly parallel to the grain test presents smaller variation (Figure 9).

For tests perpendicular to the grain, the average increases only in the four-dowel assembly configuration. However, the variation is important, so no clear tendency can be observed. The unloading stiffnesses obtained are lower than those obtained parallel to the grain. This response is related to the anisotropy of the wood. The average value is generally centered in all configurations, except for the four-dowel assembly tests perpendicular to the grain.

Figure 10 shows the variation in unloading stiffness per load level. For the dowel tests, the average does not show a clear trend as the loading level is increased. The unloading and reloading stiffnesses for the dowel are equivalent. The unloading stiffness for the parallel to the grain tests is higher than the reloading stiffness (~50%). For the perpendicular to the grain tests, it is slightly higher. The unloading stiffness perpendicular to the grain is lower than the unloading stiffness parallel to the grain (anisotropy of wood). Higher variation is observed in the embedding tests and in the four-dowel assembly.

The unloading stiffness increases on average for parallel to the grain tests. In the perpendicular to the grain tests, only the four-dowel assembly has an increasing average as the load level increases.

The unloading stiffness is almost twice as high as the reloading stiffness for tests parallel to the grain, and only slightly higher for tests perpendicular to the grain. This phenomenon explains the hysteresis (energy dissipation) in the cycles.

5.3 ENERGY DISSIPATION AND EQUIVALENT VISCOUS DAMPING COEFFICIENT (CYCLES 2-5)

Figure 11 shows the energy dissipation in the elastic domain for all test configurations. The energy dissipation increases as the load increases. The dowel tests dissipate almost no energy, this is due to the elastic behavior of the dowel during the cycles even after yielding. The parallel to the grain tests dissipate an equivalent amount of energy as the perpendicular to the grain tests. The latter have larger displacement values but are less stiff. All mean values are mostly centered. The four-dowel assembly dissipates equivalent energy than four times the energy dissipated by the single dowel assembly, but with higher displacements.

For dowels, only the first cycle of loading allows energy to be dissipated by creating a plastic hinge in the dowel. For the same geometry configuration, the tests perpendicular to the grain dissipate more energy than the tests parallel to the grain, even at a lower maximum load value. The variation in energy dissipation is greater in the fourth load level, especially for the four-dowel assembly tests. Most of the mean values are centered, except for the four dowel assembly tests parallel to the grain.

Figure 12 shows the equivalent viscous damping coefficient, which is obtained as follows.

$$\nu_{eq} = \frac{E_d}{2\pi E_p} = \frac{E_d}{\pi F_{max} U_{max}}$$

Ed is the dissipated energy and *Ep* is the potential energy. This value remains mostly constant in all configurations and the average is generally centered. For the dowel tests, this coefficient is close to or below

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1 %. For the wood tests, the average is between 1 % and 3 %. However, the minimum and maximum values vary from 0 % to 5 %. The variation interval is greater than the variation of the averages for a given load level.

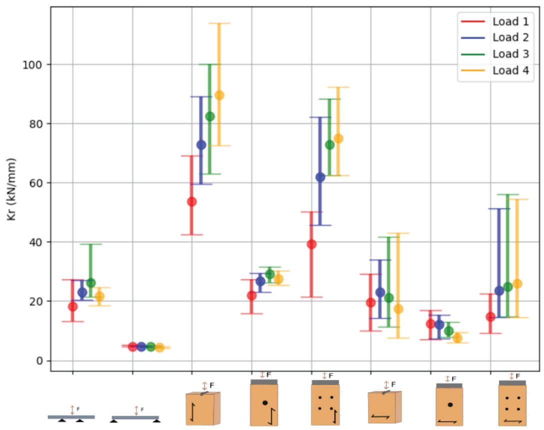

Figure 9. Max., mean and min. of the loading stiffness in the elastic domain and in the plastic domain for all tests configurations.

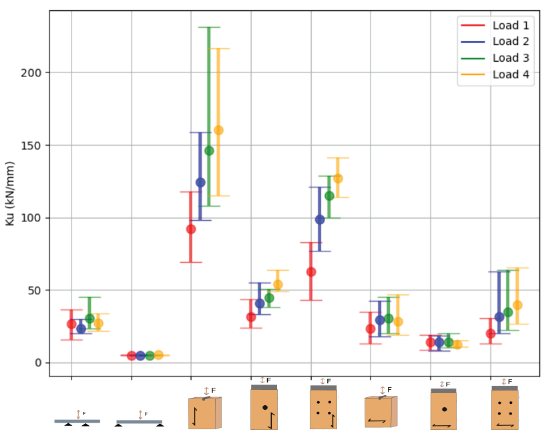

Figure 10. Max., mean and min. of the unloading stiffness in the elastic, and in the plastic domain for all configurations

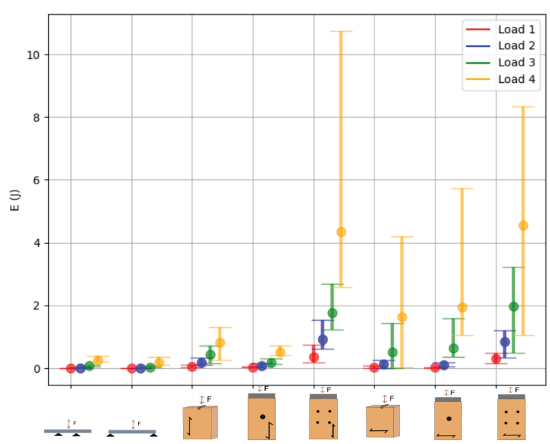

Figure 11. Max., mean and min. of the energy dissipation in the elastic and plastic domain for all configurations.

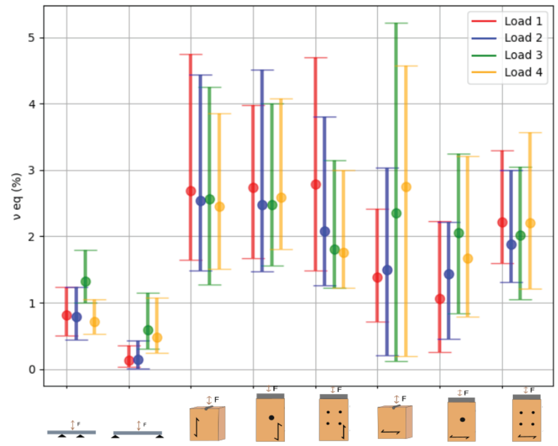

Figure 12. Max., mean and min. of the equivalent viscous damping coefficient for all configurations.

6 – CONCLUSION

The cyclic behavior of the components of a dowel-type assembly is studied. A force-controlled test is used with four levels of loading, two in the elastic domain and two in the plactic domain of each component (up to 80 % of F_{limit}); this type of cyclic loading allows comparison between specimens. The components are the dowel, the wood embedding, the one-dowel assembly and the four-dowel assembly. Specimens are tested parallel and perpendicular to the grain. The geometric configuration of each component is related to the length of the dowel (8 cm) and the diameter of the dowel (8 mm). Energy dissipation, reloading, and unloading stiffness are evaluated for each specimen.

The envelope curve shows that the dowel tests have less variation in initial stiffness compared to the tests on wood. A yield point can be defined for the dowel in both test configurations. For the envelope of the parallel to the grain tests, a soft initial slip is observed in all configurations. The variation in initial stiffness ranges from 23 % to 31 % for the parallel to the grain tests and from 27 % to 50 % for the perpendicular to the grain tests. The dispersion of the force-displacement curve generally increases with increasing load. The variation of the final displacement is higher for the perpendicular to the grain tests. In all configurations, including wood, a non-linear behavior is observed, energy dissipation is present in all load levels.

The reloading stiffness remains constant for the dowel tests. For the tests parallel to the grain, this parameter increases with increasing load level. For the tests perpendicular to the grain, no clear tendency is observed. The stiffness for tests perpendicular to the grain is lower than for tests parallel to the grain for the same geometric configuration (due to the anisotropy of wood).

For dowel tests, the unloading stiffness is similar to the reloading stiffness. For tests on wood specimens, the unloading stiffness is higher than the reloading stiffness. In general, higher stiffness variation is observed in embedding tests and four-dowel assembly tests, both parallel and perpendicular to the grain.

Energy dissipation is close to zero for dowel tests. This parameter increases with the load level. The energy dissipation for parallel and perpendicular to the grain tests are similar, but the parallel to the grain tests are performed at higher load levels. Higher variability is observed for the four-dowel assembly.

For each component, different parameters of variability can be mentioned. The simplest case (dowel in bending) can vary because of the material (steel) and geometric dimensions. For the embedding tests, the wood material increases the variability, the quality of drilling can also influence the behavior. In the one-dowel assembly tests, the same parameters are present as in the embedding tests, in the latter the dowels are inserted by force, it can reduce the influence of the drilling quality. In the four-dowel assembly tests, the heterogeneity of the wood foundation for each dowel modifies the overall behavior, in addition, there is a gap between the plate and the dowels, it leads to a progressive contact, thus a different level of deformation of each dowel. These factors can explain the variability observed in the embedding tests and in the four-dowel assembly tests.

7 – REFERENCES

[1] Z. Chen, J. Zhao, S. Zhao, X. Wang, H. Liu, L. Zhang, Q. Xu. “Experimental study and theoretical analysis on the rotational performance of large-size glulam bolted joints with slotted in steel plates.” In: Construction and Building Materials 341 (2022) 127785.

[2] F. Bru¨hl, U. Kuhlmann, A. Jorissen. “Consideration of plasticity within the design of timber structures due to connection ductility.” In: Engineering Structures 33 (11) (2011) 3007–3017.

[3] T. K. Bader, M. Schweigler, G. Hochreiner, B. Enquist, M. Dorn, E. Serrano. “Experimental characterization of the global and local behavior of multi-dowel lvl connections under complex loading.” In: Materials and Structures 49 (2016) 2407–2424.

[4] G. Hochreiner, T. K. Bader, M. Schweigler, J. Eberhardsteiner. “Structural behaviour and design of dowel groups experimental and numerical identification of stress states and failure mechanisms of the surrounding timber matrix.” In: Engineering Structures 131 (2017) 421–437.

[5] EN 1995-1-1. “Eurocode 5: design of timber structures; part 1-1: general rules and rules for buildings.” Standard EN 1995-1-1, European Committee for Standardization, Brussels (2005).

[6] K. Johansen. “Theory of timber connections.” In: International Association of Bridge and Structural Engineering (1949).

[7] EN 12512/A1. “Structures en bois–Méthodes d’essai–Essais cycliques d’assemblages réalisés par organes mécaniques.” (2006)

[8] N. Gattesco, I. Toffolo. “Experimental study on multiple-bolt steel-to-timber tension joints.” In: Materials and structures 37 (2004) 129–138.

[9] A. Jorissen. “Double shear timber connections with dowel type fasteners.” PhD thesis. Technische Universiteit Delft, 2000.

[10] P. Quenneville, M. Bickerdike. “Effective in-row capacity of multiple- fastener connections.” In: CIB-W18 meeting Proceedings, 2006.

[11] J. Natterer. “Construction en bois : matériau, technologie et dimensionnement.” volume 13. PPUR presses polytechniques, 2004

[12] EN 383. “Méthode d’essai : détermination de caractéristiques de fondation et de la portance locale d’éléments d’assemblage de type broche.” (2007).

[13] J. C. M. Schoenmakers, A. J. M. Jorissen and A. J. M. Leijten. “Evaluation and modelling of perpendicular to grain embedment strength”. In: Wood Science and Technology (2010), 44, 579-595.

[14] I. Smith, L. R. J. Whale and B. O. Hilson. “An integrated approach to modelling load-slip behaviour of timber joints with dowel type fasteners.” In: Proc., Int. Conf. on Timber Engineering (Vol. 2, pp. 285-293). (1988).

[15] H. Werner. “Tragfähigkeit von Holz-Verbindungen mit stiftförmigen Verbindungsmitteln unter Berücksichtigung streuender Einflussgrössen”, PhD thesis, Karlsruher Institut für Technologie (KIT), 1993.

[16] M. Dorn. “Investigations on the Serviceability Limit State of Dowel-Type Timber Connections”,

https://doi.org/10.52202/080513-0205

Doctoral thesis, Vienna University of Technology, 2012.

[17] J. Sjodin, E. Serrano, B. Enquist. “An experimental and numerical study of the effect of friction in single dowel joints.” In: Holz als Rohund Werkstoff 66 (5) (2008) 363–372.

[18] T. Reynolds, R. Harris, and W.-S. Chang. “An analytical model for embedment stiffness of a dowel in timber under cyclic load.” In: European Journal of Wood and Wood Products, 71(5) :609–622, 2013.

[19] C. Boudaud. “Analyse de la vulnérabilité sismique des structures à ossature en bois.” PhD thesis, Université de Grenoble, 2012