A dynamic model for the cyclic behaviour of wood assemblies

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Context

The whole vibration behaviour of a wooden building is partly governed by the assemblies. Non-linearity is a characteristic of rod-type connectors, this behaviour is thus transposed to the building. Among the rod-type assemblies, the dowel-type assembly allows connections with smooth rods with a metal plate fitting inserted into the wood. Energy dissipation is possible thanks to the plasticization of dowels and the wood in contact with the dowel.

The cyclic behavior of this type of assembly shows complex phenomena of degradation. The aim of this study is to propose a model for the dynamical behavior (cyclic behavior) of this type of assembly.

Experimental results

The experimental results here presented (Sousseau 2022) are related on a control displacement test in accordance with the EN 12512 (2002) protocol (Fig. 1 right) on a three-dowel assembly.

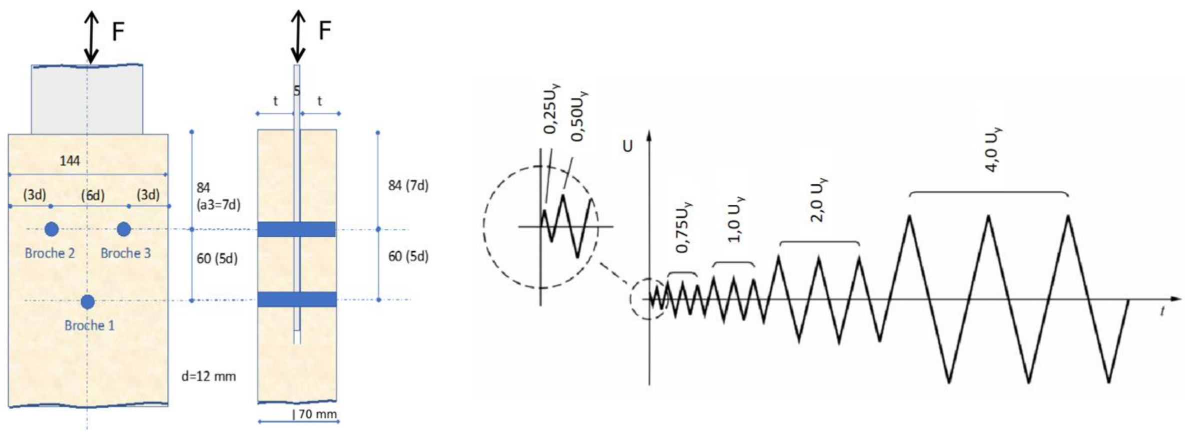

Fig. 1 : Sample dimensions (left) and loading protocol (right).

The result thus obtained, correspond to a cyclic curve going from a zero load to the failure limit (Fig. 2). From this curve, different parameters can be studied (ductility, energy dissipation, stiffness degradation, pinching, etc). This study is focused on modelling the phenomena in a differential formulation of the force displacement curve.

The 3D representation (Fig. 3) shows the evolution of force and displacement with the time. Because the test is made with a displacement control, the measured displacement does not correspond to the driving displacement and two different tests have always different level of deformation and loading responses.

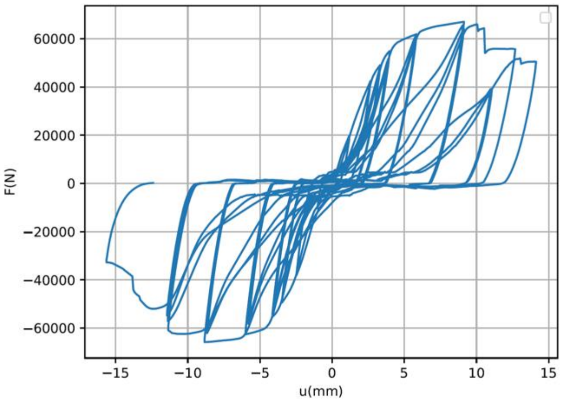

Fig. 2 : Force-displacement response

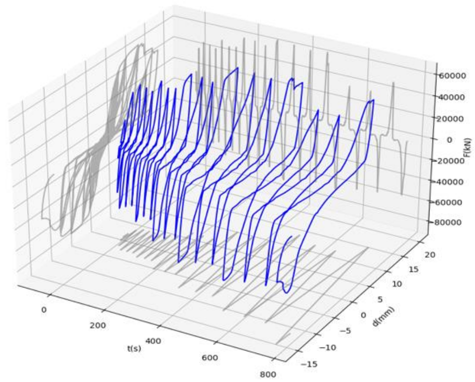

Fig. 3 : 3D representation

Dynamic model

From the tests (Fig. 2), a non-linear response is observed, with residual energy dissipation. Since non linearities are present, differential formulation is needed. One of this type of model is the one proposed by Dahl (1968). This model is generally used for friction phenomena.

One of its current formulations has three parameters (Fc, α, σ in equation 1) (Fig. 4). The parameter α is for higher variations of the stiffness with the force (Fig. 5). This parameter is set as one (linear variation of the stiffness with the force).

$$\frac{df}{dx} = \sigma(1 - \frac{F\, sgn(\dot{x})}{Fc})^{\alpha} \quad (1)$$

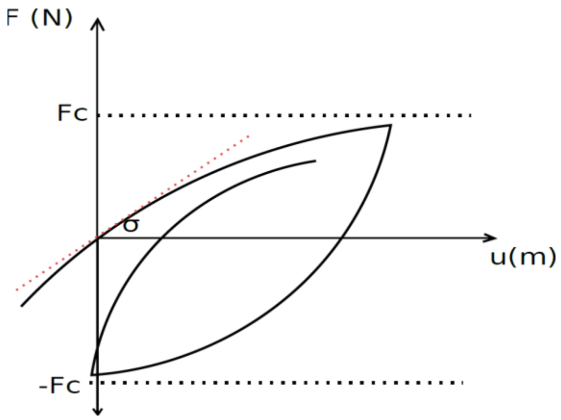

Fig. 4 : Dahl model parameters

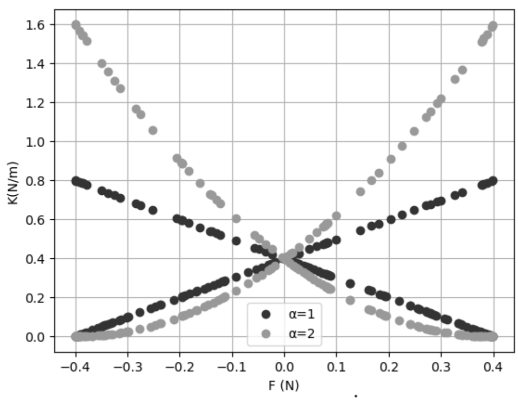

Fig. 5 : Dahl stiffness with the applied force

The equation (1) can be expressed as a differential according to the time by multiplying that formula by the speed ($\dot{x}$). Similarly, the cyclic response of the assembly (Fig. 2) can be approximated by this king of model, the stiffness shows a hardening phenomenon on loading and softening in the unloading (Fig. 5). The evolution of the stiffness with the force is nonlinear but can be separated in a loading and unloading path (Fig. 6).

Two nonlinear functions instead of four can be thus defined, since the cyclic behavior of the assembly can be considered symmetric in compression and tension.

$$\frac{df}{dx} = \sigma + \sigma\, \frac{F\,(sgn(\dot{x}) + sgn(x))}{2Fc1} + \sigma\, \frac{F\,(sgn(x) - sgn(\dot{x}))}{2Fc2} \quad (2)$$

The equation (2) takes into account two different stiffness to define the relation of the stiffness with the force, it is called the Dal model hereafter. Applying this model to the complete cyclic curve, leads to an underestimation of the assembly response and overestimation of the energy dissipation (Fig. 7). This model can be appropriate for the ‘elastic’ zone and for a consolidated foundation of the assembly after ‘n’ cycles (Fig. 8).

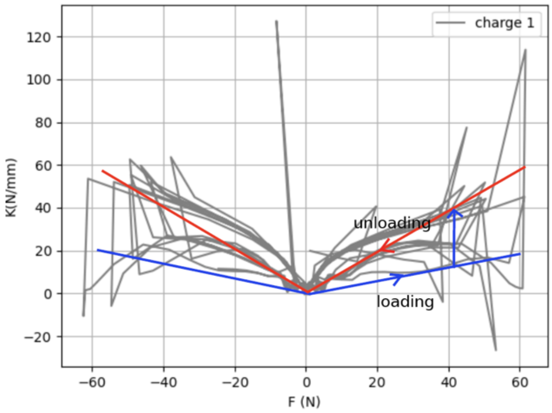

Fig. 6 : Stiffness with the force for a test

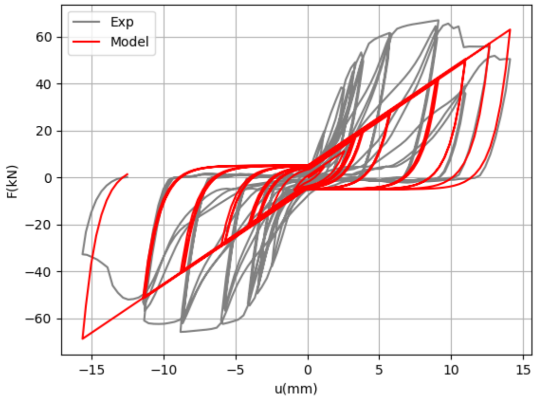

Fig. 7 : Optimisation of the complete curve

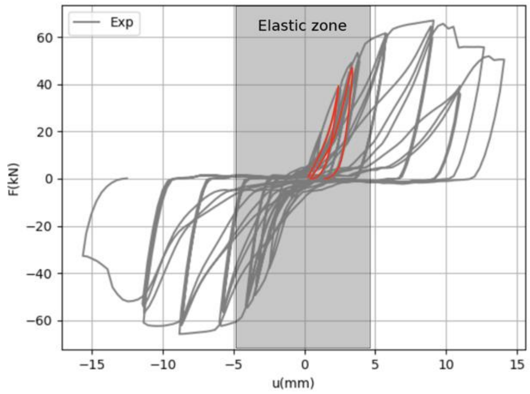

Fig. 8 : Domain to optimize the parameters of the dynamic model

In this domain, the model here proposed is optimised. To add a comparison, the BWBN model (Bouc 1967) is optimized for the same domain. This complex model with some modifications (Xu et al 2009) is defined by the following equations:

$$m\ddot{x} + c\dot{x} + \alpha k x(t) + (1-\alpha) k z(t) = F(t) \tag{3}$$

$$\frac{df}{dx} = h(z)\left\{\frac{1 - v\left(\beta sgn(\dot{x})|z|^{n-1} z + \lambda z^{n}\right)}{\eta}\right\} \tag{4}$$

$$h(z) = 1 - \varsigma_1 e^{\frac{-(z sgn(\dot{x}) - q z_u)^2}{\varsigma_2^2}} \tag{5}$$

where, k, $\alpha, \varsigma_1, \varsigma_2, q, \beta, \eta, z_u$, v, n ; are parameters of the model. This model has more than 9 parameters compared to the Dal model (three). However, this model includes phenomena like pinching and stiffness degradation.

Results

Fig. 9 shows the force displacement response of the optimization for the two models. The general shape is obtained for both.

Fig. 10 shows the relation of the energy dissipation (surface inside the cycles) in function of time, this parameter is important in describing the hysterical dissipation of the model in order to describe the dissipation on the assembly for a given cyclic or dynamic loading.

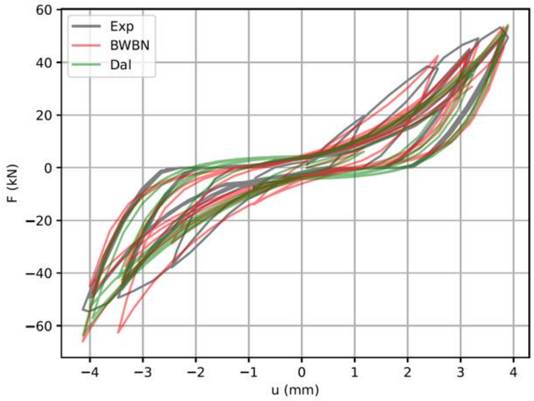

Fig. 9 : Force-displacement comparison

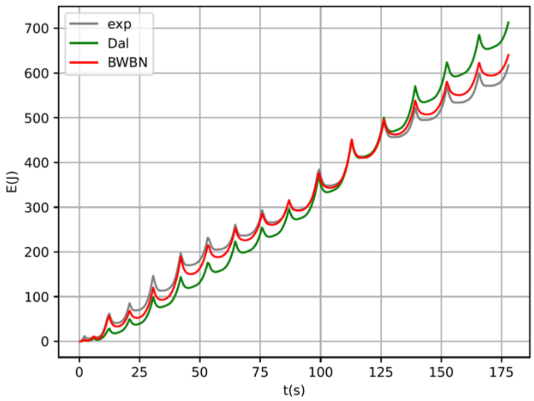

Fig. 10 : Energy dissipation comparison

Conclusion

The cyclic behaviour of a dowel assembly shows a high non-linear response. Phenomena as stiffness and strength degradation appear. Pinching and energy dissipation are strongly present. To model this behaviour for a dynamic use, a differential model based on the Dahl model is proposed, this model is appropriate only for the 'elastic' domain of the assembly. A comparison of the model to the BWBN model shows good approximation in terms of force displacement response and in terms of energy dissipation. For further work, other parameters can be included to take into account other phenomena, despite an increased complexity.

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References

Bouc R (1967) Forced vibrations of mechanical systems with hysteresis. Proc. of the Fourth Conference on Nonlinear Oscillations, Prague.

Dahl PR (1968) A solid friction model. The Aerospace Corporation, 18, 1-24.

EN 12512 (2002) Méthodes d'essai – Essais cycliques d'assemblages réalisés par organes mécaniques, NF EN 12512.

Sousseau Y (2022) Lois de similitude et modélisation du comportement mécanique des bâtiments bois multi-niveaux: apports, limites et prise en compte de l'incertain. PhD. Université de Bordeaux.

Xu J, Dolan JD (2009) Development of nailed wood joint element in ABAQUS. Journal of Structural Engineering 135.8: 968-976.