EXPERIMENTS ON THE LOAD-DISPLACEMENT BEHAVIOR OF DOWEL-TYPE STEEL-TO-TIMBER CONNECTIONS

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1. Introduction

Dowel-type steel-to-timber connections are typical connections in structural timber-engineering, which can be designed very easily for various loads and load combinations. For practical purpose the design is regulated in national and international codes [1]. Nevertheless, the design codes are not satisfying at the moment. Refined analyses by means of FE-simulations which are currently underway shall provide the basis for improved design rules.

In order to validate the simulation tool a comprehensive test series (78 tests in total) was carried out. Additionally, detailed insight into the loading behavior of dowel-type connections could be gained as well as into the influence of various factors, e.g. density of wood, dowel length, friction between dowel and wood, load speed, un-/reloading cycles, additionally applied reinforcement, etc.

2. Specimens and experimental setup

The wood used was Norway spruce, sampled for knot-free regions so that only clear wood was tested. Density ranged from approx. 330 to 510 kg/m³.

The specimens showed widths of 40, 100 and 200 mm respectively, which were chosen such that all common load bearing mechanisms with and without formation of plastic hinges in the dowels were covered (Figure 1).

The tests were carried out at the Laboratory for Macroscopic Material Testing, part of the IMWS. Simple tension tests were performed and – additionally to machine displacement and force – several displacements were measured by means of transducers. Loads were applied displacement driven until final failure occurred.

3. Results

From the experiments, several loading stages were defined which in total describe the loading behavior (Figure 2):

I) Consolidation: establishment of load transfer (compliant contact behavior)
II) Maximum stiffness: linear loading phase
III) Decrease of stiffness: yielding of wood, formation of plastic hinge(s) in dowel
IV) Maximum load: dependant on wood strength, friction between dowel and wood
V) Ductile loading plateau: influenced by friction, density, possible lateral reinforcement of specimen
VI) Failure: sudden load drop due to brittle cracking

Figure 1: Dimensions of specimens

Figure 2: Loading stages for a typical test specimen (dashed and dotted lines are fictitious lines and not derived from the actual test)
VII) Un-/reloading: distinctively higher stiffness than during first loading

Evaluation of the experiments brought out the previously assumed direct influence of density on the ultimate load (Figure 3). In contrast, maximum displacement at failure is indirectly proportional to density.

The positive influence of increased friction between dowel and wood on both, ultimate load and maximum displacement, could be verified.

The results of the tests were compared with the design procedures according to EC5. Strength estimation is based on the Johansen theory [2] which distinguishes between three different failure modes, depending on the stiffness ratio of dowel and wood, which is expressed in terms of dowel diameter, length, and yield strength as well as density of wood as the main factors. Strength predictions were on the conservative side. In contrast to that, stiffness estimations were not satisfying. Stiffness is well estimated for connections of intermediate slenderness while it is over-/ underestimated in connections of low/high slenderness (Figure 4). The design values for stiffness according to EC5 do not consider the width of the connections as an influencing factor, which is not acceptable from a mechanical point of view.

For improvement of the simulation tool, further experiments will be performed. Focus is set on the interaction properties of dowel and wood which influences mainly stages I, II and III of the loading behavior. Depending on the drilling tool (wear, drilling speed) the surface of the wooden holes is more or less rough and contact is not fully established but only partially.

Another series will determine friction coefficients of wood on steel under high pressure. Tests as well as FE-simulations have shown the high influence of friction on the loading capacity. With higher friction, lateral splitting is constrained and the behavior is more ductile while final failure occurs at higher displacements. A similar effect can be reached by lateral reinforcements with e.g. screws.

Figure 3: Load-displacement curves of single dowel connections with different wood densities (sorted with descending density)

Figure 4: Load-displacement curves for main failure types, compared to the stiffness prediction according to EC5 (black line)

Additionally, embedment tests of dowels on wood will be performed. The procedures will be followed according to European and US standards.

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5. References
