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Failure mechanisms of dowel-type fastener connections perpendicular to grain

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ABSTRACT

Dowel-type fastener connections perpendicular to grain may fail in either a ductile or a brittle fashion. Whether the failure mechanism should be classified as ductile, depends on the definition of ductility utilized. Generally, the load–slip response is considered as a means of ductility quantification. In this respect, the elastic potential energy is calculated (being the area underneath the load–slip response) or the ratio of the ultimate slip and the slip at the onset of yielding is used, amongst others. Another approach relates to the European Yield Model which is commonly adopted in design standards to calculate the load-bearing capacity of dowel-type fastener connections. In this respect, ductility may be considered to be associated with plastic deformation of the steel fasteners solely since the deformation ability of connections with dowel-type fasteners at yield is much larger compared to situations with non-yielding fasteners. In the case of connections with rigid dowel-type fasteners, it therefore may be suggested that less ductility is exhibited although it is recognized that timber in compression perpendicular to grain exhibits plastic capabilities as well. Whether these connections behave either brittle or ductile is related to the spacing requirements as well.

In this paper, first an overview of potential fracture and failure mechanisms of dowel-type fastener connections is provided. Experimental results of a variety of connections and corresponding failure mechanisms are presented. Based on mechanical models to predict the load-bearing capacity, classification of these connections in terms of ductility is provided, and the governing parameters involved are distinguished. This paper does not intend to provide a quantification procedure of ductility. Yet, an extensive overview of failure mechanisms and an analytical analysis of parameters involved are given providing expressions to calculate the failure mechanism being governing.

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1. Introduction

In general, it is suggested that structural timber design should be as such, that the connections contain sufficient ductility. Amongst others, this prevents potentially unsafe structures since brittle failure mechanisms at the connections are prevented. In this respect, the question arises what sufficient ductility is and more important, how ductility can be quantified and adopted in structural design. Another aspect is what ductility actually is, and how it can be measured or expressed. Several means have been employed, mostly related to the load–slip response.

Amongst others, Johnsson [1] suggested to express ductility by a ductility number D_f being the ratio of the displacement at failure u_f and the displacement at the onset of yielding u_y:

$$D_f = \frac{u_f}{u_y}. \tag{1.1}$$

Hence, $D_f = 1$ corresponds to linear elastic behavior (no ductility) and $D_f > 1$ to non-linear behavior, with or without harden-

ing. Whether hardening develops results from the constitutive response of timber loaded in compression. As such, the behavior of dowel-type fastener connections is typically dependent upon the angle between the loading direction and the timber grain direction, amongst others. Fig. 1 shows the load–slip response of a single fastener in embedment tests parallel and perpendicular to grain [2]. The embedment displacement (fastener slip) is given on the horizontal axis and the embedment stress (load divided by the specimen thickness and fastener diameter) on the vertical axis.

In the case of parallel to grain loading, the response is initially linear-elastic followed by perfectly plastic behavior. In the case of perpendicular to grain loading, the initially linear-elastic response is followed by a hardening branch. As shown, the fastener diameter substantially affects both the tangent of the hardening branch and the maximum (ultimate) displacement.

According to Johnsson [1], the "connections" of which the load–slip responses are presented by Fig. 1 are rather ductile since $D_f > 1$ in all cases. However, no distinction is made in terms of the tangent of the post-elastic branch and D_f is comparable for each fastener diameter, independent upon the angle to timber grain. This definition of ductility seems appropriate.

Ductility of connections may also be considered in terms of the deformation mode of the steel fasteners. Such an approach

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