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General notes on ductility in timber structures

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ABSTRACT

The paper discusses the implications of ductility in design of timber structures under static and dynamic loading including earthquakes. Timber is a material inherently brittle in bending and in tension, unless reinforced adequately. However connections between timber members can exhibit significant ductility, if designed and detailed properly to avoid splitting. Hence it is possible to construct statically indeterminate systems made of brittle timber members connected with ductile connections that behave in a ductile fashion. The brittle members, however, must be designed for the overstrength related to the strength of the ductile connections to ensure the ductile failure mechanism will take place before the failure of the brittle members. The overstrength ratio, defined as the ratio between the 95th percentile of the connection strength distribution and the analytical prediction of the characteristic connection strength, was calculated for multiple doweled connections loaded parallel to the grain based on the results of an extensive experimental programme carried out on timber splice connections with 10.65 and 11.75 mm diameter steel dowels grade 4.6. In this particular case the overstrength ratio was found to range from 1.2 to 2.1, and a value of 1.6 is recommended for ductile design. The paper illustrates the use of the elastic–perfectly plastic analysis with ductility control for a simple statically indeterminate structure and compares this approach to the fully non-linear analysis and with the more traditional linear elastic analysis. It is highlighted that plastic design should not be used for timber bridges since fatigue may lead to significant damage accumulation in the connections if plastic deformations have developed. The paper also shows that the current relative definitions of ductility, as a ratio between an ultimate deformation/displacement and the corresponding yield quantity, should be replaced by absolute definitions of ductility, for example the ultimate deformation/displacement, as the latter ones better represent the ductile structural behavior.

1. Introduction

Ductility is identified as an important requirement in structural design. According to the European regulation for timber structures, the Eurocode 5 Part 1–1 [1], a redistribution of internal forces via connections of adequate ductility is allowed. Unfortunately, *adequate ductility*, which requires that there is no premature splitting in the connection zone, is not defined anywhere. In the case of load redistribution, alternative load paths are activated which may increase the so-called structural robustness. A robust structure is often defined as a structure designed in such a way that possible damage due to exceptional events such as fire, explosions, impact or consequences of human errors is not disproportionate to the cause [2].

The Swiss Code for Timber Structures SIA 265 [3] allows for an increase in design strength for ductile structures. The design strength is calculated with the formula $f_d = (\eta_m\ \eta_t\ \eta_w) \cdot f_k/\gamma_M$, where f_k, η_t, η_w, and γ_M denote the characteristic strength, the factor for load duration and size effect, the factor for moisture effect, and the material partial factor, respectively. The ratio (γ_M/η_m) can be reduced from 1.7 to 1.5 if the connections used have a *static ductility* factor $D_s \geq 3$. In the case of impact actions, the factor η_t should be assumed equal to 1.4, otherwise $\eta_t = 1.0$. The Swiss code SIA 265 [3] also provides detailed ductility requirements for earthquake applications. A so called *response factor* (q) is defined in relation to the *dynamic ductility* factor and used to evaluate the design seismic actions on the structure.

The European regulation for seismic design, the Eurocode 8 [4], clearly describes the relevance of ductility for the structural behavior under seismic actions. Several clauses deal with ductility in relation to energy dissipation.

At least four reasons can be listed for designing ductile structures:

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