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System reliability of timber structures with ductile behaviour

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ABSTRACT

The present paper considers the evaluation of timber structures with the focus on robustness due to connection ductility. The robustness analysis is based on the structural reliability framework applied to a simplified mechanical system. The structural timber system is depicted as a parallel system. An evaluation method of the ductile behaviour is introduced. For different ductile behaviours, the system reliability is estimated based on Monte Carlo simulation. A correlation between the strength of the structural elements is introduced. The results indicate that the reliability of a structural timber system can be significantly increased due to the ductile behavior.

1. Introduction

For reduction of the risk of collapse in the event of loss of structural element(s), a structural engineer may take necessary steps to design a collapse-resistant structure that is insensitive to accidental circumstances, e.g. by incorporating characteristics like redundancy, ties, ductility in the structural design. However the designer can also use key elements, alternate load path(s) etc. These issues are strongly related to the robustness of structural systems, which has obtained a renewed interest due to a much more frequent use of advanced types of structures with limited redundancy and serious consequences in case of failure. The increased focus on robustness is also due to recently severe structural failures such as the incident at Ronan Point in 1968 and the World Trade Centre towers in 2001. In order to minimise the likelihood of such disproportionated structural failures, many modern building codes consider the need for robustness in structures and provide strategies and methods to obtain robustness. One of the main issues related to robustness of structures is the definition of robustness. The most general definitions are very similar to each other, particularly those taken from codes despite the use of different terms (robustness, structural integrity, but also progressive collapse prevention). These definitions are focussed on the prevention of an escalation of damage within the structure, given a certain initial (localised) failure/damage. The requirement for robustness is specified in most building codes such as the general requirements in the two Eurocodes: EN 1990 [1] and EN 1991 [2,3]. The first provides principles, e.g. it is stated that a structure shall be "designed in such a way that it will not be damaged by events like fire, explosions, impact or consequences of human errors, to an extent disproportionate to the original cause". The second provides strategies and methods to obtain robustness and the actions to consider. The design situations to consider are: (1) designing against identified accidental actions, and (2) designing against unidentified actions (where designing against disproportionate collapse, or for robustness, is important).

Due to many potential means by which a local collapse in a given structure can propagate from its initial extent to its final state, there is no universal approach for evaluating the potential for disproportionate collapse, or for robustness [4]. E.g. it has been proposed in [4] to incorporate physical characteristics like redundancy, ties, ductility in the structural design, or by choosing a structural system with inherent key elements, alternate load path(s) etc. In general these characteristics can have a positive influence on the robustness of a structure, however in Eurocodes ductility is only awarded for concrete and steel structures and not for timber structures. However, structural codes for timber do not award that ductility will result in a semirigid behavior plus a higher level of safety due to a lower probability that premature brittle failures occur. Further, a possible redistribution of forces for statically undetermined timber structures either internally in the joint or within other structural elements is not taken into account. A redistribution of forces, a so-called statistical system effect, will usually increase the reliability of the whole structural system and provide an extra safety margin compared to the deterministic code results. A Monte Carlo simulation study of the statistical system effect in timber structures found an extra capacity in the order of 12%–24% [5]. This effect together with a ductility behavior of joints as well as the behavior of timber in compression [6–9] could have a positive influence on the robustness of timber structures.

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