Robustness analysis of traditional timber trusses

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Abstract In the present work, the safety of existing traditional timber trusses is evaluated, with particular emphasis on the structural robustness. Traditional Portuguese timber trusses are analyzed probabilistically, using the information provided in the JCSS model code, combined with action and resistance models provided in the Eurocodes.
Robustness is evaluated through introduction of a localized defect, simulating deterioration, construction error or damages. The comparison between the reliability index considering a defect and the corresponding index for an intact structure is defined as a measure of susceptibility to local damage.
The reliability index is computed using Monte-Carlo simulation combined with linear elastic finite elements for different examples.

Keywords traditional timber trusses, probabilistic analysis, Monte-Carlo simulation, defects and robustness.

1. INTRODUCTION

The deterioration process, human errors in design and construction, as well as, damage causes by humans or other sources, are extremely difficult to predict. Although significant effort has been placed on modeling some of these events, in particular, deterioration, more recently, a different approach has been suggested by different authors. In this approach, these defects are assumed unpredictable, and the consequences on safety are evaluated based on the definition of different damage scenarios. This approach allows the comparison between different structures to unexpected events of similar magnitude and the identification of critical events that should be monitored more closely.

However, existing codes have significant limitations in assessing robustness. On one hand, robustness can only be defined at the structural (global) level, rather than the element level, as under a significant defect, several elements are subject to stresses above the design values, and redistribution of stresses must be possible. On the other hand, robustness analysis requires the comparison between different levels of safety, which can only be achieved in a probabilistic framework, as semi-probabilistic methods, as used in current codes, provide only a pass/fail information.

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2. ROBUSTNESS ASSESSMENT

A simple method to analyze the robustness of the structure is to evaluate the structural safety assuming an element is removed. If the structure is safe to ultimate limit states, considering this notional removal, allowing repair works to take place, with a safety margin deemed acceptable, the structure can be considered robust. The first proposal presented (Frangopol and Curley, 1987) defines robustness in terms of the reliability index of the damaged and intact structure as:

$$\beta_r = \frac{\beta_i}{\beta_i - \beta_d} \quad (1)$$

where β_i is the reliability index of the intact structure and β_d is the reliability index of the damaged structure. The redundancy index β_r can vary from zero (unredundant system) to infinity (very redundant structural system).

3. EXAMPLE OF APPLICATION

In order to evaluate the robustness of traditional timber roof structures, a typical typology was selected. The structure analyzed is a queen post truss, used for medium spans in Portugal. The probability of failure can be computed through Monte-Carlo simulation by generating a large number of samples and evaluating the fraction of samples for which failure occurs.

The structure was modeled considering the removal of several structural elements.

4. CONCLUSIONS

The truss analyzed is structurally redundant, meaning that failure of one member will not, necessarily, lead to failure of the all structure. However, the results presented showed that, for this particular type of truss, the inner elements (post and struts) are fundamental to guarantee safety, and can be defined as key-elements. The defects or deterioration in the outer struts and inner posts result in a reduction in safety acceptable considering the magnitude of damage considered. The removal of the outer did not result in any reduction in safety. Moreover, it was observed the removal of the element connecting the tie-beam to the main post did not result in a significant change in safety.

It was also observed that, although the comparison between the required dimensions, according to a design based on Eurocode, and the dimensions used in traditional structure, shows that the posts and struts are overdesigned, this can be extremely beneficial from a robustness point of view, as these elements are fundamental in ensuring safety in case of damage.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of Cost Action E55 “Modelling of timber performance”.

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