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ROBUSTNESS ANALYSIS OF TIMBER TRUSS STRUCTURE

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EXTENDED ABSTRACT: Progressive collapse is characterized by disproportion between the magnitude of a triggering event and resulting in collapse of large part or the entire structure. Robustness of structures has been recognized as a desirable property because of a several large structural system failures, such as the Ronan Point Apartment Building in 1968, where the consequences were deemed unacceptable relative to the initiating damage. After the collapse of the World Trade Center, robustness has obtained a renewed interest, primarily because of the serious consequences related to failure of advanced types of structures. In order to minimize the likelihood of such disproportional structural failures many modern building codes require robustness of the structures and provide strategies and methods to obtain robustness.

Robustness requirements are provided in two European documents: Eurocode EN 1990: Basis of Structural Design [2] and EN 1991-1-7 Eurocode 1: Part 1-7 Accidental Actions [4]. The first document provides the basic 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 EN 1991-1-7 document provides strategies and methods to obtain robustness, actions that should be considered and different design situations: 1) designing against identified accidental actions, and 2) designing unidentified actions (where designing against disproportionate collapse, or for robustness, is important). In the JCSS Probabilistic Model Code [7] a robustness requirement is formulated as: "A structure shall not be damaged by events like fire, explosions or consequences of human errors, deterioration effects, etc. to an extend disproportionate to the severeness of the triggering event". In order to attain adequate safety in relation with accidental loads, two basic strategies are proposed: non-structural measures (prevention, protection and mitigation) and structural measures (making the structure strong enough to withstand the loads limiting the amount of structural damage or limiting the amount of structural damage). According to Danish design rules robustness shall be documented for all structures where consequences of failure are serious. A structure is defined as robust when those parts of the structure essential for the safety only have little sensitivity with respect to unintentional loads and defects, or that an extensive failure of the structure will not occur if a limited part of the structure fails.

In the last few decades many definitions of robustness have been proposed. In this paper only a brief description of probabilistic measures relevant for robustness assessment is given. Definitions given by Frangopol and Curley [16], Lind [17], Ellingwood and Leyendecker [19] are presented.

This paper will focus on the main hall of the sports centre in Samobor. The main hall of this sport centre was erected in 2005 and it is a plane frame truss spaced equally at 5 meters. The structure was calculated according to Eurocode 5. The design was performed by Chair for the timber structures at the Faculty of Civil Engineering (prof. Rajcic), University of Zagreb.

In this paper probabilistic calculations were done by First-Order Reliability Methods (FORM) where a reliability index is estimated based on limit state functions for each of the considered failure modes. The probabilistic analysis is performed with a stochastic model for the strength parameters for whole structural elements. Based on the deterministic structural analysis four different failure modes are considered: combination of bending and compression (M+N) in the lower chord (1), combination of bending and tension (M+N) in the upper chord (4), tension (2) and compression in diagonal elements (3).

The structure is statically indeterminate, meaning that a loss of one (or more) structural element(s) won't result in collapse of a whole structure i.e. if any of the inner (truss) elements fail, force redistribution will occur and the whole system will not necessarily collapse. For illustration the simplified approach explained in detail in [8] is used. For each of the failure elements defined previously failure is assumed (a failed element is assumed to fail in a brittle manner) and the reliability of the remaining failure elements is calculated. Generally, after failure of one component, reliability of the other components is decreased (as the redistribution of the

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forces implies that the other elements have a higher utilization ratio). However, for an assumed failure of element 4 (e.g. failure in the middle of upper chord) the reliability indices for the tensile and compressive truss elements are slightly increased. In this case, redistribution slightly decreased the load effect for elements 2 and 3, but load effect for element 1 is highly increased and it can be concluded that the reliability is, for this scenario, insufficient. Next, the robustness of the structure is assessed on the system level. For this assessment the reliability of the intact system and damaged system is calculated and based on this the robustness index is calculated. Calculations show that the lowest system reliability occurs when element 4 is in failure. Due to force redistribution, the lower chord is heavily loaded implying that the system reliability is relatively low and based on this robustness index is relatively low. The same conclusion can be drawn for assumed failure of element 1 - but in this case, the robustness index is much higher. For the assumed damages in the elements 2 and 3 (e.g. tensile and compressive elements) no significant effect on the system reliability is observed, so the robustness index is high.

The paper considers robustness of structures in general and probabilistic approaches for robustness quantification. Two different approaches were considered: first, where reliabilities of the remaining components are compared with the reliability indices of the intact structure, and second, where a robustness index is formulated at system level. Progressive collapse analyses are carried out by removing four elements one by one. The results that the timber structure for three of the failure scenarios can be characterized as robust with respect to the robustness framework used for the evaluation. However, for one of the failure scenarios the robustness can be considered as relatively low. Robustness analysis made on system level also shows similar results. For assumed damage in two of the truss elements the structure can be considered robust. Failures of the lower and upper chord of the structure result in a lower robustness index (minimal index is calculated for assumed failure of the upper chord).

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