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A scheme for the evaluation of experience of the performance of timber structures

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ABSTRACT

For the future development of a safe and efficient building infrastructure, it is of utmost importance to learn from past experience. In this paper, a scheme for the evaluation of experience gained from failures and malfunctions in timber structures is developed. It is highlighted that the main motivation to analyse structural failures is to learn from them. It is therefore stated that the description of the circumstances that led to structural failures is of highest importance. This is a somewhat different perspective compared to the structuring of information that can be found in existing studies on failed and malfunctioning structures in the literature. There, the focus is on the thorough description of the physical parameters related to the failures. The result of this paper is a proposed template for failure assessment that, in its complete extension, can be downloaded from the World Wide Web. The failure template is "ready to use"; however, it should mainly facilitate further discussions on the formulation on a broadly agreed format for how the structural engineering profession might standardise failure reporting.

1. Introduction

During recent decades, structural reliability methods have been further developed, refined and adapted. They are now at a stage where they are being applied in practical structural engineering problems. Typical problems in structural engineering such as design, assessment, inspection, and maintenance planning are decision problems subject to a combination of inherent, modelling, and statistical uncertainties. Structural reliability theory is concerned with the rational treatment of these uncertainties. In general, failures that result from stochastic variability in loads and resistances are addressed. The modelling of errors introduced by the use of structural mechanics models that are based on idealisations of structural and material behaviour and also the simplified representation of load variables are taken into account.

Modern load and resistance factor design (LRFD) formats are calibrated by the use of structural reliability theory; i.e. the partial safety factors are chosen in a way that failure rates for structures designed according to LRFD formats are sufficiently low. Thus, it is not surprising that structural failures due to the random occurrence of adverse combinations of high loads and low resistance rarely occur.

In contrast, a large fraction of structural failures and therefore the majority of damage costs occur as a consequence of errors in planning, design, construction, and utilisation. This has been shown by several studies in which information about collapsed and malfunctioning structures has been analysed (e.g. [1,2]; timber structures are particularly addressed in [3,4]).

These errors are not explicitly considered by structural reliability methods which are based on the assumption that customary standards of planning, design, construction, and utilisation are efficient, and which are not violated. Several attempts have been made to model the effect of errors on the structural reliability. Most of them are based on standard procedures for risk analysis of technical facilities. Possible errors and their effects are treated as scenarios that are analysed by means of event trees or fault trees. However, any reasonable estimation of the effects of errors on the structural reliability in general is lacking, due to poor information about the types of error that could occur, the probability of these errors, and their effects on the performance of the structure.

The studies of collapsed or malfunctioning structures are part of the experience of the performance of structures gained over time, and they are a valuable source for gaining insight into the corresponding causes of failures. The information about the causes of failures should be continuously used to critically reflect the structural engineering accepted practices in order to reduce failure rates and the associated expected consequences. The studies by Matousek and Schneider [5], Smith [6], and Allen [7] contain a description of the cause of failures that is mostly associated to errors. However, different definitions and classification schemes

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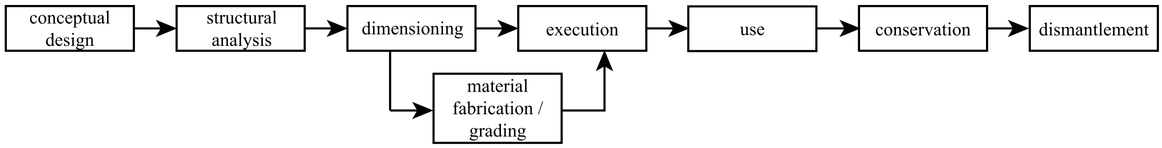

Fig. 1. Phases of the building process.

are used by different authors, and their results may therefore not be compared or accumulated straightforwardly.

In the following, it is discussed how a common scheme for the evaluation of experience gained from failures and malfunctions of structures might be derived, communicated, and maintained.

2. The characteristics of documented experience

It is clear that society gains experience of the performance of structures continuously; most of the structures perform well, i.e. they fulfil their objectives within their lifetime. This experience reinforces the customary standards of planning, design, construction, and utilisation. However, a minor part of the experience is found to be adverse in terms of performance of the structures; i.e. the objectives of structures are not fulfilled: for example, structural components deteriorate, the serviceability is violated, components fail, or entire structural systems collapse. The consequences of these events range from reduced usability of structures to loss of lives [2].

Well-documented and structured experience is mainly available for "bad" structural performance; i.e. among the cases that are analysed in the literature there is a strong bias towards structural failure events that include large consequences. Cases of, for example, serviceability failures with low consequences are generally underrepresented, which is inconsistent in regard to the absolute importance of these types of failure. Due to the higher frequency of "low-consequence" failures, the overall damage to society is also significant. "Good" performance is in general not analysed and documented explicitly.

The description of "bad" experience is often condensed to statistical statements about frequencies of certain building types or components, building materials, and details of where observed failures have originated. It is obvious that such comparisons are of limited use for any reasonable conclusion. In principle, these frequencies have to be seen together with the frequencies of the corresponding attribute within the entire domain of structures ("good" and "bad" performing); for example, the interrelation between the probability of failure and the span of a structure can only be assessed relative to the total number of structures. Furthermore, the physical initiation of failure (e.g. rupture in a certain type of connection) is rarely identical with the causal origin (e.g. misplacement of the fasteners in the connection). Much more information than these frequencies is available through descriptions of the accepted practice utilised for the development of the structure, i.e. the personnel involved and corresponding working conditions, generation of design codes that was applied, material supply, on-site implementation, quality control schemes implemented in the various steps, etc.

3. Classification of causes of failures

A natural way to reduce the frequency of failures is to identify, analyse, and avert the corresponding causes. For every failure, in principle a multitude of causes might be identified. They can be arranged according to their causal relationships so that the "history" that led finally to failure might be described by a complex logical network of all these causes. It is neither possible nor reasonable to describe the complex cause–effect relationships in great detail for every failure that is analysed. Therefore it is important to focus on the primary causes that might be controlled during the planning, design, construction, and utilisation phase of the structure.

A main measure to control the rate of structural failures is structural design according to LRFD codes; i.e. design situations are selected and analysed based on design equations containing load and resistance factors and characteristic values. As mentioned above, LRFD formats are based on an explicit consideration of uncertainties associated with the load effects, material strength, and uncertainties associated with simplified mathematical and physical models. LRFD formats together with the corresponding basis of design are part of the accepted practice in the area of structural engineering. If the accepted practice were correct and never violated it could be stated that the rate of structural failures might be entirely controlled by LRFD formats. However, it is obvious that

- departures from accepted practice always occur, and
- the present accepted practice is not perfect.

The causes of failures and malfunctions might accordingly be structured into three main groups. Type A refers to departure from accepted practice that is generally termed human error. Type B, the second point above, could be understood as improper knowledge and models represented by the accepted practice; i.e. this refers to issues not better known by the research and engineering profession at a certain time. Type C refers to the cause that is explicitly taken into account in LRFD formats, i.e. failure due to the realisation of a very low resistance together with a large load effect. Type A and Type B refer to errors whereas Type C refers to the fraction of failures that is accepted. In civil engineering applications, an error in general can be understood as anything which leads to a difference between the actual and the indented conditions of a construction. A large part of these errors is in an appreciable range (range of tolerance) which can be covered by the applied codes. The residual errors, so-called gross errors, are those which have the potential for causing failure [8,2]. The present (Type A and B) error classification is addressing gross errors; i.e. errors within the range of tolerance are not considered here.

In Table 1, examples for errors Type A and Type B in different phases of the building process are given. It should be mentioned that such lists can never be comprehensive. Both types of error might occur during every phase of the building process. This includes the design process of a building, material fabrication, and for timber the material grading (see Fig. 1). The phases in the design process are conceptual design, structural analysis, dimensioning, execution, use, conservation, and dismantlement [9].

Additionally it has to be mentioned that in some cases the identification of the 'real' cause of failure is impossible or at least difficult; for example, low material strength of a solid wood beam can result from improper timber grading, improper material transport, improper material storing, deterioration, etc. In these cases the real cause of failure might not be identified uniquely, even after intensive investigations. In these cases the several possible causes might be indicated together with the corresponding weighting that should reflect the personal valuation of the expert evaluating the structure.