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Assessment of model uncertainties for structural resistance

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ABSTRACT

Uncertainties in resistance models play a significant role in the reliability analysis of structures and code calibration of partial factors for semi-probabilistic design. In spite of this importance, existing knowledge concerning model uncertainties and their characteristics seems to suffer from imprecise definitions and lack of available experimental data. Currently used probabilistic models and derived factors for model uncertainties are mostly based on intuitive judgements and limited data. This often leads to an unrealistic description of model uncertainties. The present study attempts to improve definitions of model uncertainties and proposes a general methodology for their quantification by comparing experimental and model results. It appears that model uncertainty should be always related to a specific model and scope of its application. The proposed approach seems to offer better understanding of model uncertainties and enables the specification of their real characteristics.

1. Introduction

Appropriate safety formats for the analysis of civil engineering structures have been investigated in numerous previous studies. For instance reliability of concrete structures has been addressed in Refs. [1–4] and steel structures in Refs. [5,6]. It has been shown that structural resistances can be predicted by appropriate modelling of material properties, geometric parameters and uncertainties associated with a model under consideration. The effect of variability of materials and geometry is relatively well understood and has been extensively addressed by the aforementioned studies. However, better description of model uncertainties is desired.

It is widely recognised that uncertainties in resistance models and also in load effects play a significant role in the reliability analysis of structures. Consequently they affect material and action models applied in engineering practise such as those based on the partial factor method, *EN 1990:2002*. Existing knowledge concerning model uncertainties and their characteristics seems to be mostly based on intuitive judgements and to suffer from imprecise definitions and lack of experimental data. Test campaigns are mostly focused on verifications of a particular model for a specified material and failure mode under assumptions that may be incompatible with other studies. This often leads to discrepancies in description of the uncertainties related to a particular theoretical model. Moreover, as a full overview of test parameters and conditions is often missing, a subsequent identification of causes of the differences may be impossible. That is why a general methodology for assessment and reporting on model uncertainties seems to be urgently needed.

The present paper attempts to improve definitions of model uncertainties, propose a general methodology for their quantification by comparing experimental and model results, and suggest their treatment in practical applications. More specifically, the study is focused on:

- Uncertainties in resistance models (physical, structural or statistical) – hereafter “theoretical models”.
- Ultimate limit states; recognising serviceability limit states equally important and possibly associated with significant economic consequences, but being more complex and requiring a separate study.

Implications of model uncertainty for new and existing structures are explored. Examples based on the recent studies concerning shear and flexural resistance of reinforced concrete beams are provided to illustrate different steps of the methodology. The present study is a substantial extension of the recent contributions [7,8].

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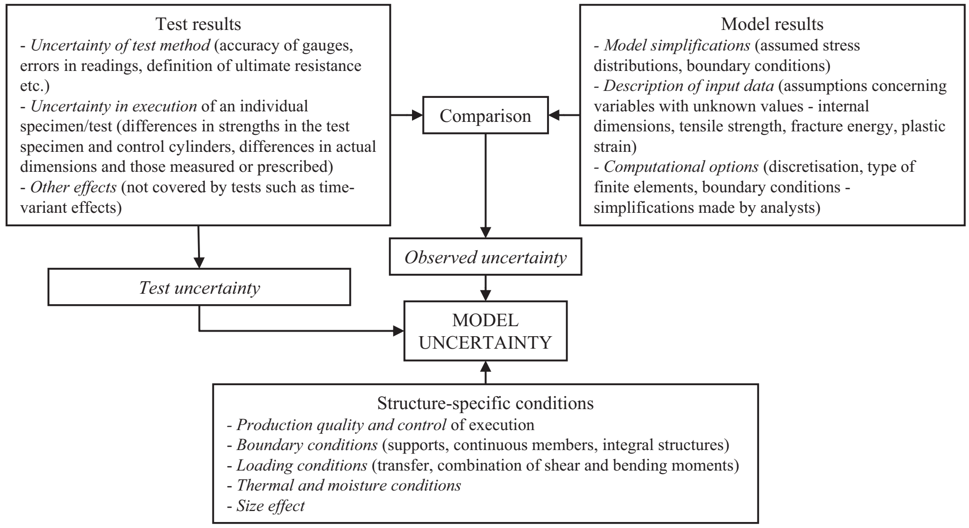

Fig. 1. General concept of model uncertainty.

2. Model uncertainty

2.1. General concept

When considering structural reliability, model uncertainties can be related to:

- Models for action effects (assessment of load effects and their combinations).
- Resistance models (based on simplified relationships or complex numerical models).

Structural reliability modelling is focused on the representation of actions and their combinations. Explicit effort is applied not only to develop appropriate probability models particularly for variable actions, but also to provide for these effects in design procedures through schemes of partial factors. In contrast, investigations on structural resistance focus more on improving the prediction models, even when it is compared to experimental results, neglecting to a large extent the statistical differences between measured and predicted resistance, or a reliability assessment of the resistance model. However, it is often found that resistance model uncertainty is significant, accounting for the balance of other sources of uncertainty. Therefore, in this study uncertainties in resistance models are included. However, the developed principles form a basis for treatment of uncertainties in load effects as well.

As a rule the theoretical model is incomplete and inexact due to the lack of knowledge or deliberate simplifications of the model accepted for the convenience of use. Obviously model uncertainty should be associated with the specific computational model under consideration. *ISO 2394:2015* defines model uncertainty as a basic variable related to the accuracy of physical or statistical models. Consistently, the Probabilistic Model Code of the Joint Committee on Structural Safety [9] indicates model uncertainty to be generally a random variable accounting for the effects neglected in the models and simplifications in the mathematical relations.

Apparently it is common practise to consider model uncertainty as a random variable. However, it can only be regarded as an independent random variable, if this uncertainty is not related to variations of other basic variables [10], see Section 3.5.

According to *ISO 2394:2015* the deviation of the model and from the real value can be then expressed by one or several random variables – model uncertainties. As far as possible their statistical properties shall be derived from experiments, observations and from calculations using more accurate models. In setting up a performance function, model uncertainties are then treated as independent random variables. In principle the approach is the same as for other basic variables such as material properties or action effects.

2.2. Importance of model uncertainty

In principle the distinction between the following cases can be made:

- Modelling of a physical process is sufficiently accurate; in such cases model uncertainty has commonly a low to medium effect on structural reliability and is treated as situation 1 or 2 as defined in Section 3.2.
- Modelling of a physical process is approximate or even impossible; in such cases model uncertainty often dominates structural reliability and is treated as situation 3 (Section 3.2), recognising a strong need to quantify and include model uncertainty explicitly in the reliability analysis.

Examples of the former case include bending of ordinary-sized reinforced concrete beams or verifications of steel members without local instabilities. Examples of the latter case are shear of concrete members analysed by simplified design formulas, verifications of steel members with local instabilities including cold-formed steel profiles, or resistance of geotechnical structures. Typically, the latter case can be identified by the lack of consensus amongst experts, the derivation of alternative models from research studies and in practical applications, and different levels of approximation introduced in codes of practise.

2.3. Contributing factors

Commonly model uncertainty is obtained from comparisons of physical tests and model results. Real structural conditions not covered by tests should be taken into account if needed. A general concept of model uncertainty is indicated in Fig. 1.

The significance of factors affecting test and model results and real structural conditions depends directly on an analysed structural member and specific failure mode, similar to the role played by basic variables in a limit state function for reliability analysis. The following general remarks should be considered: