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ALEATORIC & EPISTEMIC UNCERTAINTY IN THE ANALYSIS OF TENSILE STRUCTURES

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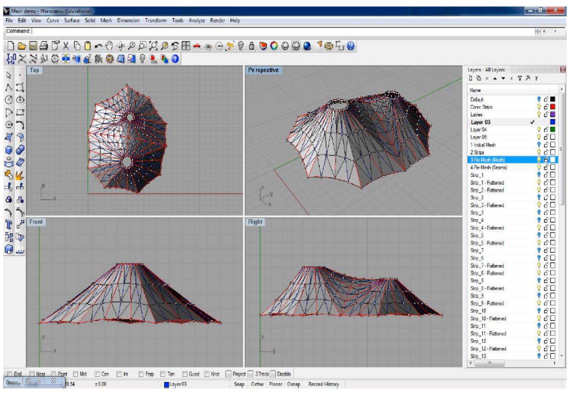
Uncertainty pervades all aspects of life, with the consequences judged through acceptable risk. In many fields of engineering the risk is managed through the use practice guides and the application of partial safety factors, thereby controlling the probability of failure. Risk is then linked to the probability of failure by associating it with the consequences of failure. For building applications in Europe, engineering design is mandated through the Eurocodes which are probabilistic-based, as set out in Eurocode 0 [1]. A Eurocode (EC) for Membrane Structures is being prepared to contribute to EC10, and to be supported by a set of European Standards (EN) covering aspects including material testing.

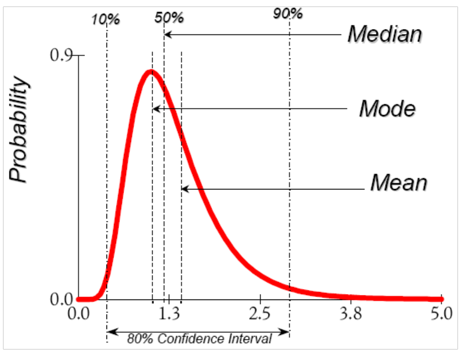
Currently, tensile structures are arguably designed within a mixed deterministic-stochastic framework where stress-reduction factors are used to account for particular phenomena such as, for example, tear resistance, environmental exposure, amongst others. The design principles are suggested here to be of this mixed type because some of the factors are not necessarily derived from statistical considerations, such as a 95 percentile or characteristic value, for example, but are associated with serendipity. Partial factors of the type defined in the Eurocodes need careful consideration when applied to tensile structures owing to their geometric non-linearity and the design phases that are required. For example, prestress can be argued to act on both the load and resistance sides depending on whether considering installation or medium-long term behaviour. EC 0 provides guidance on permissible safety indices for particular classes of structure and corresponding probabilities of failure in the range 10^{-5} to 10^{-4}. Calculation of a safety index requires a structural reliability analysis, which is significantly beyond current industry practice, but may be required in future EC releases. In addition to these complex considerations it is also clearly important to understand the nature of the uncertainties associated with tensile structure analysis.

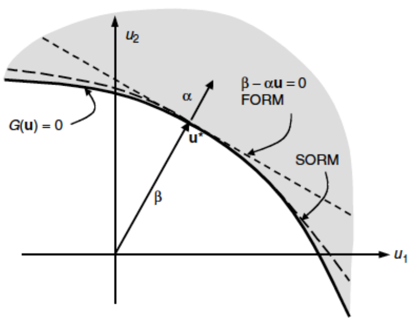
In this paper the principles behind the requirements of EC0 are briefly summarised to place into context the remainder of the presentation. Concepts of aleatoric and epistemic uncertainty are introduced in a general sense. Epistemic uncertainty, being associated with the intrinsic uncertainty of a system and of greater familiarity to design engineers, is illustrated using material test data, including the need to consider spatial variability.

Conversely, epistemic uncertainty is perhaps less well understood and is often not so obvious in its manifestation and significance. Two examples are provided in this paper. The first illustrates the effect of assuming small strains in the development of a triangular finite element used extensively in the analysis of membrane structures. The consequence of adopting a small strain formulation could be argued as incorrect. Alternatively, it may be considered as a source of epistemic uncertainty requiring special treatment in interpreting stress and strain analysis outcomes. The significance of the small-strain computations are described in the context of a reliability analysis and how they may be ameliorated using filtering techniques on selected “erroneous” strains and stresses and assumed distributions for the remaining epistemic variables. The second example considers the introduction of epistemic uncertainty to a simulation or analysis methodology that satisfies the assumptions associated with the problem (e.g. large strains, ref. preceding example). This is demonstrated in the form of constitutive modelling; firstly, and briefly describing the problem of using a plane stress formulation, and secondly in representing the fabric behaviour using a neural network to link strains to stresses within the finite element formulation.

The paper is concluded with an example of how these uncertainty measures can be incorporated into a structural reliability analysis and subsequently linked to an equivalent stress reduction factor approach in the context of current practice.







Load type	Unfactored combination		Factored combination	
	Wind	Snow	Wind	Snow
Minimum strength (*kN/m*)	12.4	11.3	14.8	14.1
Stress reduction factor	6.2	6.8	5.2	5.5
Safety index (β)	3.8	3.8	3.8	3.8

REFERENCES

[1] BSI (2002). Eurocode - Basis of structural design. BS EN 1990:2002 + A1:2005. Brussels, British Standards Institute.