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Collating wind data for doubly-curved shapes of tensioned surface structures (Round Robin Exercise 3)

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Abstract

Membrane structures are typically applied in outdoor applications as sheltering or facade element. Therefore, they are subject to the natural elements and must be designed to resist these external loads. Especially in the field of wind analysis accurate wind load determination on these pretensioned lightweight structures has to be investigated.

In this research, the state-of-the-art in wind loading on tensile surface structures is discussed, with focus on the pressure coefficient distributions for basic membrane shapes. The available but fragmented Cp-distributions for different doubly-curved shapes are explored and the wind loading on basic membrane shapes is assessed (in Round Robin Exercise 3). The available results of wind tunnel tests and computational fluid dynamics simulations are compiled in a uniform way to allow comparison and interpolation. Wind tunnel results and computational fluid dynamics data are presented trough standardised data forms describing test-setup, test model and the computed Cp-distributions for the basic membrane shapes. Furthermore, where crucial data is missing, a methodology is proposed for additional tests and simulations to be run in the future within the scope for a prospective Eurocode section for doubly-curved tensile surface and shell structures.

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1. Introduction

During last decades, the use of tensile surface structures has increased significantly. This increased interest has triggered from the evolutions in design and analysis methods in combination with the development of new high-tech materials, allowing realisation of more complex and larger membrane structures. However, a lot of expertise and research still has to be performed for these fairly young and evolving structures. Especially in the field of wind analysis accurate wind load determination has to be examined. Compared to conventional building typologies, these structures tend to be extremely vulnerable to wind because of the low self-weight-to-load-ratio. In addition, the structural engineer has to deal with uncertainties in wind load estimations for these organically shaped flexible structures, which implies the need for expensive wind tunnel tests or for simplifying assumptions and approximations during the calculation of membrane structures under wind loading. In general, conventional codes on wind design give upper bound values for the majority of structures, but the level of uncertainties increases as the building configuration deviates from the codified norms.

The structural analysis of membrane structures can only benefit from improved and more accurate wind load estimations and analysis methods. Currently wind loading on tensioned surface structures is often based on rough approximations referring to flat or spherical shapes of the building Codes, which do not account for the special nature of the textile covers. Extrapolation from the Standards is acceptable for conventional static structures, but for organically shaped flexible membrane structures additional wind investigation has to be performed. The European standards (EN 1991-1-4 [1] and EN 13782 [2] which refers to EN 1991-1-4 for wind loading) are insufficient for tensile surface structures, dynamic actions, flexible deformations etc. The need for accurate wind load standards on these types of structures has already been stressed in several international publications [3]–[5], stating the lack of the current standards in governing the wind-resisting strength for these structures and the need for an industry-wide set of standards. Appropriate wind pressure data is essential to provide confidence in the analysis and design process, and to ensure the development of a Eurocode that will facilitate the safe and efficient design of membrane structures.

Nomenclature

ABL	Atmospheric Boundary Layer
BLWT	Boundary Layer Wind Tunnel
CFD	Computational Fluid Dynamics
Cp	Pressure Coefficient
RRE3	Round Robin Exercise 3
WTT	Wind tunnel testing

2. State-of-the-Art – Literature review

The European Design Guide for Tensile Surface Structures [5] could be seen as a state-of-the-art report and a first step in the direction of a European Normative document. This guide stipulates the determination of accurate wind loadings on lightweight tensile surface structures as one of the research priorities, because Standards for the calculation and dimensioning of lightweight structures subjected to wind loading do not exist.

The existing Standards, including EN 1991-1-4, point out wind tunnel testing and computational fluid dynamics as complementary or alternative approach to obtain load and response information for complex structures that are