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Background to the Science and Policy Report for Tensile Membrane Structures

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Abstract

Nowadays, comprehensive design standards for tensile membrane structures exist neither on European level nor in most European countries on national levels. Currently, the development of a European design standard for membrane structures made from technical textiles and foils is under way. One of the first steps towards a new Eurocode for membrane structures is the preparation of a "Science and Policy Report", so-called "SaP-Report". It is published by the Joint Research Centre (JRC). The SaP-Report for the structural design of membranes was drafted by CEN/TC 250/WG5 "Membrane structures", titled "Prospect for European guidance for the Structural Design of Tensile Membrane Structures". This is an important milestone. The SaP-Report will be the basis of discussions and specifications in the process of creating a new standard throughout the next years. This paper gives background on the meaning, structure and content of the SaP-Report as well as the state of the art regarding the code development.

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Keywords: Standardisation; Tensile Membrane Structures; Structural Eurocodes

1. Introduction

The Eurocodes are a set of European Standards for the design of buildings and other civil engineering works. The preparation and publication of the Eurocodes is mandated by the European Commission to CEN, the European

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Committee for Standardization. They are drafted by the CEN Technical Committee 250 (CEN/TC250 "Structural Eurocodes") [1]. CEN/TC250 itself organizes a bunch of Sub Committees (SCs) and Working Groups (WGs), one for every structural field, see Fig. 1. Up to now, 10 Eurocodes with in the sum 58 separate parts are published, see Fig. 2. They are currently introduced in most of the member states, together with the National Annexes (NAs), which give details on how to apply the Eurocodes in the relevant country. At the same time the former national codes are withdrawn.

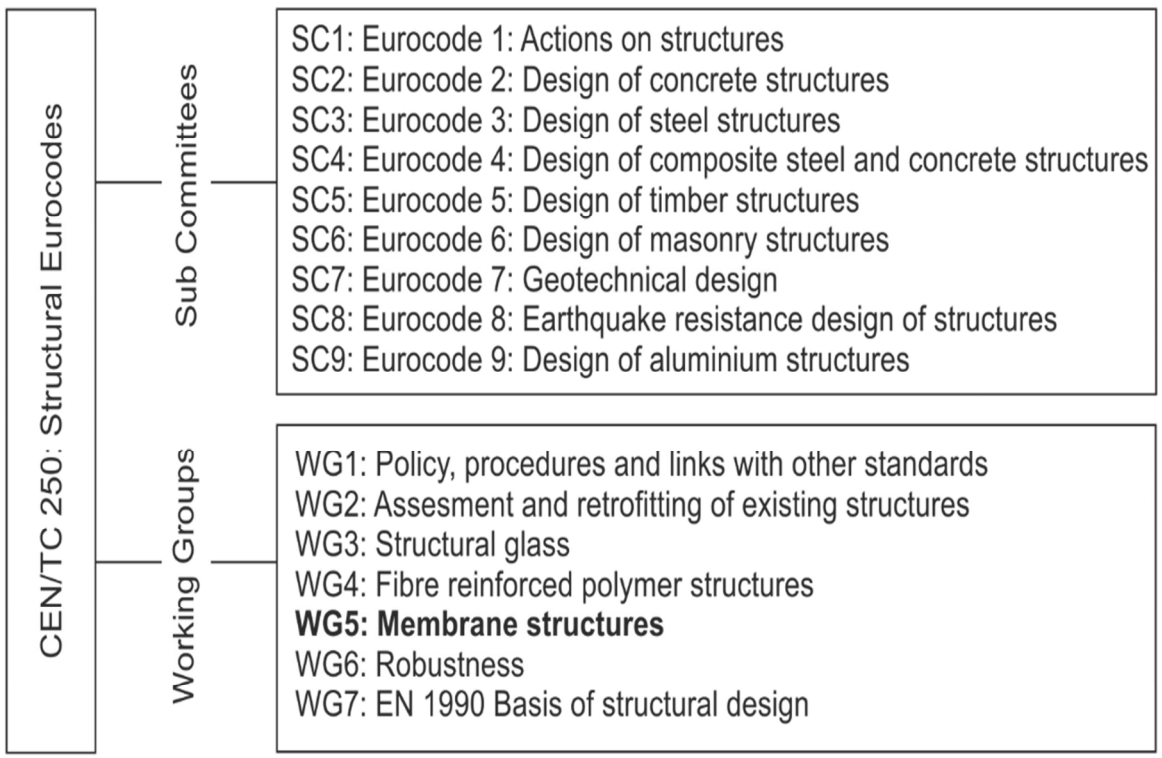

Fig. 1. Sub Committees and Working Groups of CEN/TC 250.

The wish for a harmonized European standard on Tensile Membrane Structures was brought up by the membrane structure industry, science bodies related to textile architecture and civil engineering and the TensiNet Association, a European association for tensioned membrane constructions. As a result, CEN/TC 250 "Structural Eurocodes" has implemented the Working Group (WG) 5 "Membrane Structures".

One of the first steps towards a new Eurocode on Tensile Membrane Structures is the development and publication of the so called "Science and Policy Report" (short: SaP-Report). The present paper illustrates how the SaP-Report is embedded in the development of the new Eurocode. It gives background on the meaning, structure and content of the SaP-Report. This paper is an updated version of [2].

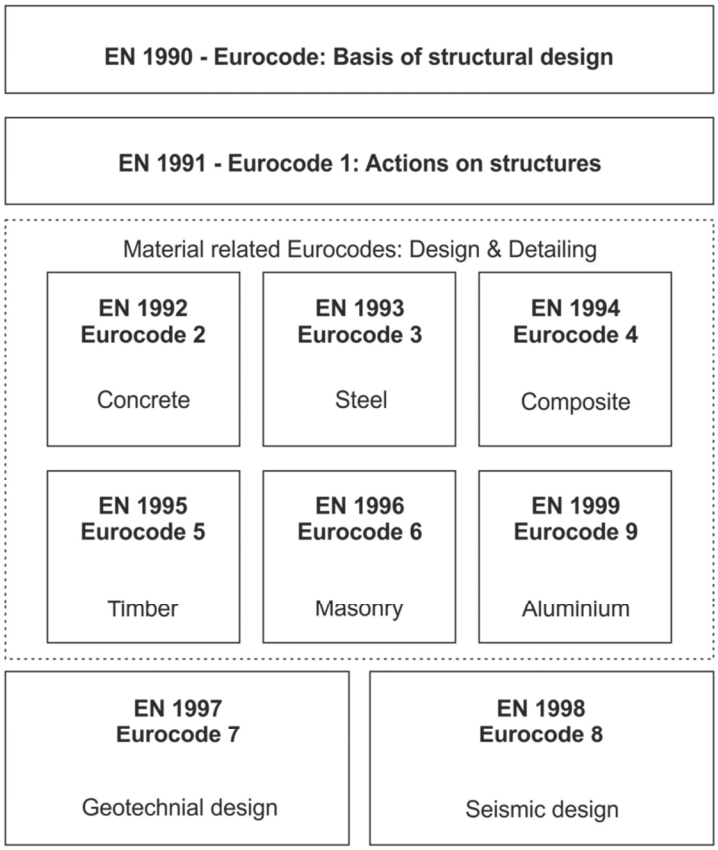

Fig. 2. The existing ten Eurocodes [1].

2. Road Map to and requirements for a Eurocode

In 2010 and 2012 the European Commission mandated CEN, the European Committee for Standardization, with the further evolution of the Eurocodes (Mandate M/466 and Mandate M/515) [3]. CEN is requested amongst others to provide the development of new standards or new parts of existing standards and amend existing standards. It is foreseen, that at least one additional structural Eurocode and substantial additions to the existing codes shall be developed as part of the action on European level [3]. The mentioned additional Eurocode will be on structural glass. Other new Eurocodes are currently not in the scope, but it is envisaged that the mandate may be amended in future to include the development of further additional structural Eurocodes covering fibre reinforced polymer structures and tensile surface structures [3], see Fig. 3. To receive the mandate eventually, the preparation of a "Science and Policy Report" (SaP-Report) as well as the existence of product standards or at least technical approvals for membrane materials are required.

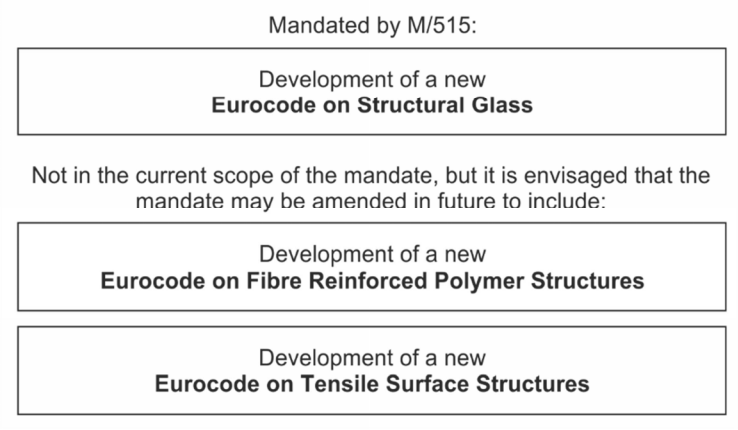

Fig. 3. Perspective future Eurocodes as addition to the existing regarding to mandate M/515 [3].

In the response of CEN/TC 250 to the mandate M/515 [4], May 2013, CEN/TC 250 had scheduled for WG 5 "Membrane Structures" to prepare the SaP-Report until the end of 2014. In the meantime, the SaP-Report was finished [5]. It is published by the Joint Research Centre (JRC), the European Commission's in-house science service and can be downloaded for free from the JRC-website (https://ec.europa.eu/jrc/). The SaP-Report gives a state of the art report on the design of membrane structures in the EU member states as well as background information, code reviews on existing European or national codes and an outlook on possible future design rules, in view of the latest research results.

After agreement by the Commission and the CEN Member States, the scheduled next step will be the preparation of a CEN Technical Specification (CEN TS) – previously known as an ENV – from 2016 until the end of 2018. The SaP-Report will be the basis of discussions and specifications in the process of creating the CEN Technical Specification throughout the next years. In case a Eurocode on Tensile Membrane Structures will be mandated, it is aimed that this CEN TS will be converted into a Eurocode draft afterwards, see Fig. 4.

Parallel to the development of the design code itself, a bunch of accompanying standards will be developed by CEN/TC 248 "Textiles and textile products", Working Group 4 "Coated fabrics". These will be material and test standards for the specification and determination of specific input values in the structural design, e.g. tensile stiffness parameters, shear stiffness parameters, compensation values etc. Furthermore, the standardization work will be accompanied by the development of wind pressure coefficients (c_p-values) for typical forms of textile architecture, aiming to introduce them eventually into Eurocode 1 part 4.

The work of CEN/TC 250 WG 5 on European level is accompanied by the national mirror committees on national level. The objective is to discuss and comment the draft code found by consensus on the European level and to prepare a national opinion on specific items of the draft. Furthermore, the mirror committees are able to define National Defined Parameters where the Eurocode allows to and to create the National Annexes.

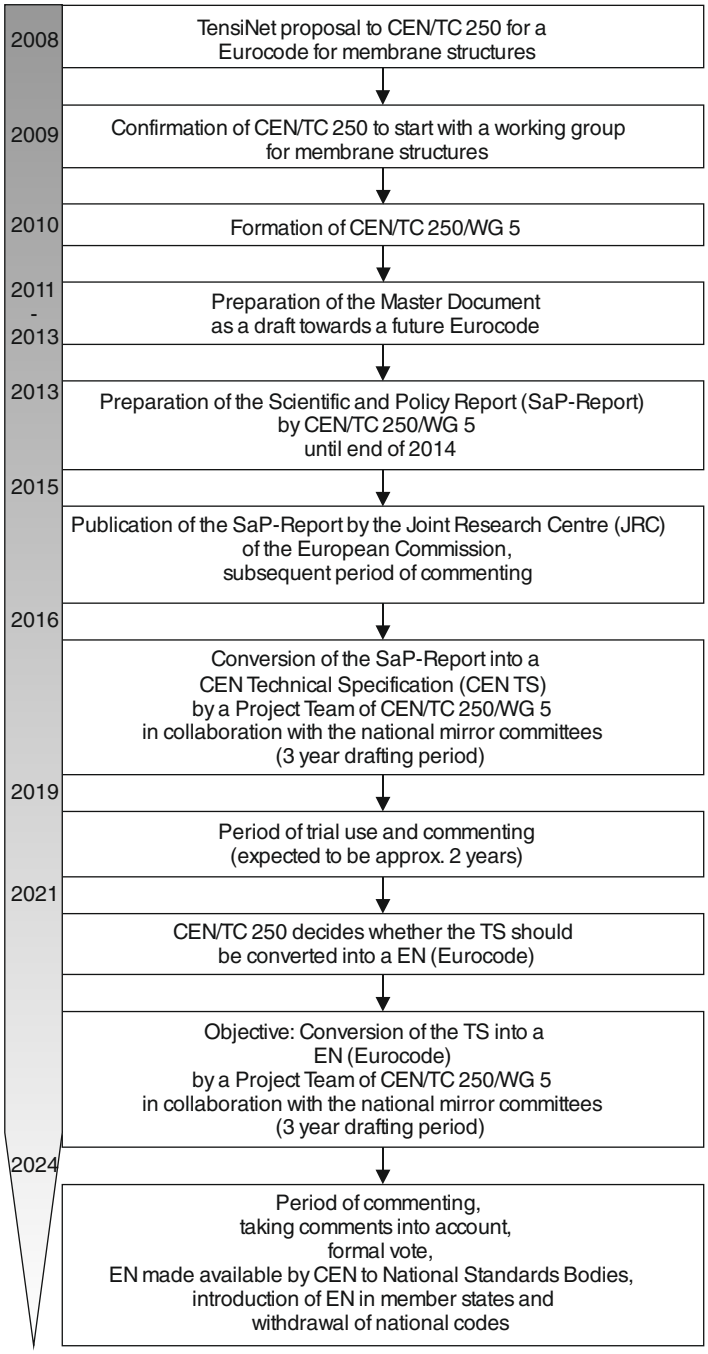

Fig. 4. Steps to a Eurocode “Membrane Structures”, based on the schedule of CEN/TC 250.

3. Structure and content of the Science and Policy Report

The structure and content of the SaP-Report [5] strictly orientates towards the expected structure and content of the future Eurocode. The content of the Eurocode is aimed to incorporate general rules for the design as well as specific rules for mechanically and pneumatically prestressed structures. Furthermore, the Eurocode is going to incorporate a part about structural fire design (this is not part of the current SaP-Report).

The code is intended to cover the structural design of membrane structures made from coated and uncoated fabrics as well as foils. At this stage, it is planned to implement three parts of the Eurocode: the first part with all design related regulations, the second part regarding structural fire design and a third part dealing with rules for the execution of tensile membrane structures. The first part should cover the general structural design and the design of details and connections and is drafted as follows:

1. General,
2. Basis of design,
3. Materials,
4. Durability,
5. Basis of structural analysis,
6. Ultimate Limit States (ULS),
7. Serviceability Limit States (SLS),
8. Details/ Connections,
9. Design assisted by testing.

Chapters 1 to 8 of part 1 as well as execution rules of part 3 are represented in the SaP-Report. Every chapter of the SaP-report consists of three major parts: (a) general explanations giving scientific and technical background for the respective topic, (b) state-of-the-art overview on existing national and European rules, summarized in “Code Reviews”, and (c) proposals for European harmonized design rules, which could be part of the future Eurocode for Tensile Membrane Structures, summarized in “Eurocode Outlooks”. For several sub-topics the harmonized approach still has to be specified.

4. Current state of the standard development and outlook

One of the first steps towards a harmonized code was the performance of a round robin exercise [6] dealing with the design of four more or less “simple” membrane structures: It revealed a very high level of variability in terms of stresses, displacements, reactions and material design strengths for the different participants, although the exercises were based on precisely defined geometry, material properties and loading. The results demonstrated the need for a harmonization in membrane structures analysis, which is aimed to provide with the future code. The results may also serve as the basis for the assessment of existent uncertainties in the structural analysis models as well as uncertainties resulting from modelling the material properties (biaxial stiffness etc.) and the loading.

The fundament for the future harmonized design concept will be EN 1990. Current discussions in WG5 concern the core part of the design concept, i.e. the application of partial safety factors on the action side and the application of strength reduction factors on the resistance side.

Regarding the partial safety factors on the action side, the difficulty of applying them reasonably and in line with the regulations in EN 1990 comes from the nonlinearity of tensile structures. Tensile structures can behave over- or underlinear, which may be different from structure to structure and even from load case to load case. In case of nonlinearity, where a superposition approach is not possible, the question arises, whether the partial safety factors should be applied to the actions before the structural analysis is performed or to the effects of the actions subsequent to the analysis performance. The implications on the membrane structure design are complex, particularly as membrane forces are strongly related to the shape and deformation of the structure [7]. The complexity can even raise when the combination of the membrane structure (secondary structure) with the supporting primary structure (often a rigid steel or steel cable structure) is noticed. Several authors have investigated this issue recently, e.g. [7-13]. The discussion in the Working Group is ongoing. Particular concerning this topic, the question arises, to which

degree the code should only give guidance or compulsory define the design procedure(s). However, the future code is expected to define a partial safety factor for prestress in membrane structures, like it is recommended in EN 1990. As mentioned above, a reliability analysis is planned to be performed in order to generally determine the partial factors depending on a certain reliability level.

Regarding the resistance side – particularly for fabric materials – WG5 aims to harmonize and enhance existing design concepts. Exemplary, two existing concepts are briefly introduced in the following, in order to demonstrate similarities and differences in the state of the art. The German design practice, which oftentimes refers to DIN 4134 "Air supported structures" [14] in combination with the PhD-Thesis of Minte [15], is based on strength reduction factors that take into account for several physical influences on the material strength. These are biaxial stress states and deterioration due to UV-rays, high temperatures and long-term loads. Furthermore, DIN 4134 defines several design situations, which are mainly characterized by the duration of the loads and the temperature belonging to a specific load case, e.g. the "summer storm" which combines short term wind loads with a high temperature environment. The French design recommendations for permanent tensile fabrics [16] introduces a security factor, that reduces the design strength due to environmental degradation, too, but does not consider biaxial stress states, high temperatures or the duration of loads. Instead of that, further factors consider the quality of the membrane (seams and fabric tested and certified or not) and the panel size. The latter takes into account the increased risk of a critical defect as the surface area increases [17]. Other national concepts (Italian, Japanese, US-American) as well as the IASS Working Group 7 recommendations are briefly presented in the TensiNet European Design Guide for Tensile Surface Structures [17].

It will be one main task of WG5 to harmonize and advance these European concepts. Further research is required to determine numerical values and probabilistic data for the reduction factors. In special cases, e.g. for the strength reduction factor for biaxial stress states, an appropriate test method has still to be verified, see e.g. [18, 19]. Furthermore, the combination of reduction influences on the overall strength reduction should be investigated more in depth and more refined models for the combination of reduction factors have to be developed.

Regarding structures made from ETFE-foils, no European code exists at all, but several design concepts have already been proposed, see e.g. [20-22]. The approaches are different and the scientific discussion has just begun.

The characteristic material resistance will be based uniformly on 5%-fractiles. Within already planned future research activities the coefficients of variation for the different materials will be well investigated. A recent preliminary enquiry for widely used materials showed rather small numbers [23], confirming or falling below recommendations given in the literature, e.g. [15]. A precise knowledge of the variation enables an efficient utilisation of the materials by increasing the 5%-fractile values.

Concerning the above mentioned requirement for a standardization of materials, material producers are planning to go forward to apply for technical approvals for often used material products. Proposals for the required data in technical approvals related to the future code are currently a topic of discussion [24]. A much more purposeful and desirable alternative would be the establishment of new product standards for coated fabrics and foils or the extension of existing product standards. Examples for existing product standards are EN 15619 [25] on European level or the German DIN 18204 [26] on national level. Both standards incorporate material specifications for tents and temporary structures and could be extended by specifications for materials used in permanent buildings such as fabric materials with higher tensile strength as well as foils. Regarding an extension for fabrics, DIN 18204 is currently being revised and extended.

The research network "Novel structural skins: Improving sustainability and efficiency through new structural textile materials and designs (COST Action TU1303)" [27] has been established, which is funded by COST (European Cooperation in Science and Technology). The main objective of the COST Action is to continue pushing and accelerating the European harmonization in membrane structure analysis. In this frame, amongst others two working groups concerning structural design aspects (WG4) and standardization (WG5) have been established. New results directly usable for the development of the Eurocode on Tensile Membrane Structures are expected. TU1303 'Novel Structural skins' [28] organized a training school on the topic, entitled 'euromem: from uncertainties to partial safety factors calibration: application to tensile membrane structures' - Discover the birth of a Eurocode.

5. Concluding remarks

The present paper gives a brief overview on the project of developing a Eurocode for Tensile Membrane Structures and how the background document "Science and Policy Report (SaP-Report)" is embedded in this procedure. It shows the scheduled steps to be gone and the harmonization work and research that is required in order to reach the objective. The structure and content of the SaP-Report as well as an exemplary extract of the current discussions within the standard development regarding the design concept as a core part of the code are presented.

The Science and Policy Report (SaP-Report), which was published by the Joint Research Centre of the European Commission this year, gives a detailed overview on the arrangement of the future code. It will be the basis of discussions and development in the coming years.

Experts who are interested to contribute to the development of the Eurocode on Tensile Membrane Structures or the accompanying standards are welcome and requested to contact their national standardization organizations.

Acknowledgement

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References

[1] www.eurocodes-online.com.
[2] N. Stranghöner, J. Uhlemann, M. Mollaert, P. Gosling, The Development of a Eurocode "Tensile Membrane Structures", Proceedings of the 37th IABSE International Symposium, Madrid, 2014, pp. 1572-1578.
[3] The European Commission, Mandate M/515 EN – Mandate for amending existing Eurocodes and extending the scope of Structural Eurocodes, Brussels, 12th December 2012.
[4] CEN/TC 250, Towards a second generation of EN Eurocodes, Response to mandate M/515, May 2013.
[5] N. Stranghöner, J. Uhlemann, F. Bilginoglu, K.-U. Bletzinger, H. Bögner-Balz, E. Corne, N. Gibson, P. Gosling, R. Houtman, J. Llorens, M. Malinowsky, J.-M. Marion, M. Mollaert, M. Nieger, G. Novati, F. Sahnoune, P. Siemens, B. Stimpfle, V. Tanev, J.-Ch. Thomas, Prospect for European Guidance for the Structural Design of Tensile Membrane Structures, Science and Policy Report (SaP-Report), Editors: M. Mollaert, S. Dimova, A. Pinto, S. Denton, 2016. http://eurocodes.jrc.ec.europa.eu/showpublication.php?id=540
[6] P. Gosling et al., Analysis and design of membrane structures: Results of a round robin exercise, Engineering Structures 48 (2013) 313-328.
[7] B. Philipp, R. Wüchner, K.-U. Bletzinger, Conception and design of membrane structures considering their non-linear behaviour, Proceedings of the STRUCTURAL MEMBRANES, Munich, 2013.
[8] U. Peil, Bauen mit Seilen, in: U. Kuhlmann, (Ed.), Stahlbau-Kalender 2000, pp. 690-755, Ernst & Sohn, Berlin, 2000.
[9] J. Uhlemann, B. Stimpfle, N. Stranghöner, Application of the semiprobabilistic safety concept of EN 1990 in the design of prestressed membrane structures, Proceedings of the EUROSTEEL, Naples, 2014.
[10] French Mirror Group, Membrane struct FrMG position partial safety factors, working document for CEN/TC250 WG 5, 2013 (unpublished).
[11] N. D. Gibson, CEN TC 250 – Review of partial factors in membrane analysis, working document for CEN/TC250 WG 5, 2013 (unpublished).
[12] B. Stimpfle, Proposal sensitivity analysis, working document for CEN/TC250 WG 5, 2014 (unpublished).
[13] N. Stranghöner, J. Uhlemann, Study regarding the partial safety factors on the action side, working document for CEN/TC250 WG 5, 2013 (unpublished).
[14] DIN 4134 – Tragluftbauten, 1983.
[15] J. Minte, Das mechanische Verhalten von Verbindungen beschichteter Chemiefaser-gewebe, Dissertation, RWTH Aachen University, 1981.
[16] Société d'Edition du Bâtiment et des Travaux Publics (Ed.), Recommandations pour la conception, la confection et la mise en oeuvre des ouvrages permanents de couverture textile: Édition 2009, SEBTP, Paris, 2009.
[17] B. Forster, M. Mollaert (Eds.), European Design Guide for Tensile Surface Structures, TensiNet Association, Brussel, 2004.
[18] K. Saxe, Membrantragwerke und ihre Prüfmethoden – Biaxialprüfung der Festigkeit textiler Baustoffe, Bautechnik Spezial (2013) 68-73.
[19] H.-W. Reinhardt, Zweiachisge Prüfung und Festigkeit von textilen Baustoffen, Bautechnik 53 (1976) 138-141.
[20] R. Houtman (Ed.), TensiNet European Design Guide for Tensile Structures Appendix5: Design recommendations for ETFE foil structures, TensiNet Association, Brussel, 2013.
[21] K. Saxe, Zur Berechnung und Bemessung von ETFE-Folientragwerken, in: Saxe, K., Stranghöner, N. (Eds.), Essener Membranbau Symposium, Shaker Verlag, Aachen, 2012.

[22] B. Stimpfle, ETFE Design concept with partial safety factors, working document for CEN/TC250 WG 5, 2014 (unpublished).
[23] N. Stranghöner, J. Uhlemann, Determination of 5%-fractiles according to EN 1990, working document for CEN/TC250 WG 5, 2014 (unpublished).
[24] B. Stimpfle, Data abz, working document for CEN/TC250 WG 5, 2014 (unpublished).
[25] EN 15619: Rubber or plastic coated fabrics - Safety of temporary structures (tents) - Specification for coated fabrics intended for tents and related structures.
[26] DIN 18204: Raumabschließende Bauteile aus textilen Flächengebilden und Folien (Zeltplanen) für Hallen und Zelte – Teil 1: PVC-beschichtetes Polyestergewebe.
[27] http://www.novelstructuralskins.eu/.
[28] http://www.novelstructuralskins.eu/events/training-schools/