European Design Guide for Tensile Surface Structures

Brian Forster Marijke Mollaert
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword</td>
<td>5</td>
</tr>
<tr>
<td>Frei Otto</td>
<td></td>
</tr>
<tr>
<td>The TensiNet Partners</td>
<td>8</td>
</tr>
<tr>
<td>The TensiNet Associate Members</td>
<td>10</td>
</tr>
<tr>
<td>Acknowledgement</td>
<td>11</td>
</tr>
<tr>
<td>Chapter 1: Introduction</td>
<td>17</td>
</tr>
<tr>
<td>Brian Forster, John Chilton</td>
<td></td>
</tr>
<tr>
<td>1.1 The need for the guide</td>
<td>18</td>
</tr>
<tr>
<td>1.2 Origins of TensiNet</td>
<td>19</td>
</tr>
<tr>
<td>1.3 Aims and objectives of TensiNet</td>
<td>20</td>
</tr>
<tr>
<td>1.4 The TensiNet Team</td>
<td>20</td>
</tr>
<tr>
<td>1.5 Communication</td>
<td>20</td>
</tr>
<tr>
<td>1.6 TensiNet Activities</td>
<td>22</td>
</tr>
<tr>
<td>1.7 Future of TensiNet</td>
<td>24</td>
</tr>
<tr>
<td>1.8 References</td>
<td>24</td>
</tr>
<tr>
<td>Chapter 2: Engineered fabric architecture</td>
<td>25</td>
</tr>
<tr>
<td>Brian Forster, Marijke Mollaert</td>
<td></td>
</tr>
<tr>
<td>2.1 Introduction</td>
<td>26</td>
</tr>
<tr>
<td>2.2 Form and Behaviour of Fabric Structures</td>
<td>28</td>
</tr>
<tr>
<td>2.3 Design Sequence</td>
<td>35</td>
</tr>
<tr>
<td>2.4 References</td>
<td>41</td>
</tr>
<tr>
<td>2.5 Picture credits</td>
<td>42</td>
</tr>
<tr>
<td>Chapter 3: Form</td>
<td>43</td>
</tr>
<tr>
<td>Jürgen Bradatsch, Peter Pätzold, Cristiana Saboia de Freitas,</td>
<td></td>
</tr>
<tr>
<td>Rudi Scheuermann, Juan Monjo, Marijke Mollaert</td>
<td></td>
</tr>
<tr>
<td>3.1 The Minimal Art of Tensile Membrane Structures</td>
<td>44</td>
</tr>
<tr>
<td>3.2 Wealth of Forms</td>
<td>46</td>
</tr>
<tr>
<td>3.3 Anticlastic Tensioned Membrane Structures</td>
<td>48</td>
</tr>
<tr>
<td>3.4 Synclastic Tensioned Membrane Structures</td>
<td>50</td>
</tr>
<tr>
<td>3.5 Membrane Support Structures</td>
<td>54</td>
</tr>
<tr>
<td>3.6 Design Development and Detailing</td>
<td>63</td>
</tr>
<tr>
<td>3.7 Applications and Classification</td>
<td>68</td>
</tr>
<tr>
<td>3.8 Qualities of Membrane Architecture</td>
<td>82</td>
</tr>
<tr>
<td>3.9 Bibliography</td>
<td>90</td>
</tr>
<tr>
<td>3.10 References</td>
<td>91</td>
</tr>
<tr>
<td>3.11 Credits</td>
<td>92</td>
</tr>
</tbody>
</table>
Chapter 4: Internal environment

John Chilton, Rainer Blum, Thibaut Devulder, Peter Rutherford

4.1 Thermal Environment
4.2 Visual Environment
4.3 Acoustics
4.4 Fire Safety
4.5 References
4.6 Image credits and information

Chapter 5: Detailing and Connections

Rogier Houtman, Harmen Werkman

5.1 Detailing Principles
5.2 Seams
5.3 Edges
5.4 Field Supports
5.5 Corners
5.6 Base plates
5.7 Anchorage
5.8 Case Studies
5.9 References

Chapter 6: Structural design basis and safety criteria

Mike Barnes, Brian Forster, Mike Dencher

6.1 Basis for Design
6.2 Membrane Stress Factors: A Review of Code Recommendations
6.3 Tear Propagation
6.4 Seam Strengths and Temperature Effects
6.5 Cables, Ropes and Webbing Belts: Stress Factors
6.6 Supporting Steelwork: Stress Factors
6.7 Support Systems to be Checked for Overload Stability
6.8 Fully Coupled Stability Analyses
6.9 Deformations: Limit States and Ponding
6.10 Limit State Conditions for Failure of Components / Rupture of Fabric
6.11 References

Chapter 7: Design loading conditions

Markus Balz, Mike Dencher

7.1 Lightweight Structures Subject to External Loading
7.2 Prestress
7.3 Selfweight
7.4 Wind
7.5 Snow
7.6 Temperature
7.7 Seismic Loading
7.8 Construction Tolerance
7.9 Load Combinations
7.10 Disproportionate Collapse
7.11 References
# Table of Contents

**Chapter 8: Form-finding, load analysis and patterning**  
*Mike Barnes, Lothar Gründig, Erik Moncrieff*

- 8.1 Characteristics and Modelling of Tension Structures  
- 8.2 Form Finding  
- 8.3 Physical Modelling  
- 8.4 Numerical Methods for Form Finding and Analysis  
- 8.5 Numerical Models for Fabric Stress/Strain Properties  
- 8.6 Assessment of Material Properties and Test Procedures  
- 8.7 Fabrication Patterning  
- 8.8 References  

206

**Chapter 9: Material properties and testing**  
*Rainer Blum, Heidun Bögner, Guy Némoz*

- 9.1 The Formulation of Membrane Materials  
- 9.2 Description of Yarns  
- 9.3 Description of Base Fabrics  
- 9.4 Description of Coatings  
- 9.5 Coated Fabrics  
- 9.6 ETFE Foils  
- 9.7 Mechanical Characteristics of Coated Fabrics  
- 9.8 References  

219

**Chapter 10: Fabrication, installation and maintenance**  
*Klaus Gipperich, Roberto Canobbio, Stefania Lombardi, Marc Malinowsky*

- 10.1 Introduction  
- 10.2 Qualification of Membrane Fabricator and Staff  
- 10.3 Cutting Pattern Determination, Workshop Drawings  
- 10.4 Acquisition of the Membrane Material  
- 10.5 Incoming Goods Inspection  
- 10.6 Processing, Cutting  
- 10.7 Processing, Welding  
- 10.8 Particulars in PTFE Processing  
- 10.9 Final Inspection Prior to Shipping  
- 10.10 Packaging and Transportation  
- 10.11 Erection  
- 10.12 Maintenance  

243

**Appendix A1: $C_P$ Values for simple tensile structure shapes**  
*Mike Dencher, Markus Balz*

- A1.1 Introduction  
- A1.2 Conical Structures  
- A1.3 Ridge and Valley Structures  
- A1.4 Hypar / saddle structure  
- A1.5 Cantilevered Canopy  
- A1.6 Credits for the supply of data  

259
Appendix A2: $C_p$ values for open roof stadiums

Markus Balz, Mike Barnes

A2.1 Introduction
A2.2 Wind tunnel testing
A2.3 Data for preliminary design
A2.4 Standardisation of roof zones
A2.5 Geometry and spans of the stadiums investigated
A2.6 Discussion of results

Appendix A3: Testing methods and standards

Rainer Blum, Heidrun Bögner, Guy Némoz

A3.1 Testing procedures with regard to a general approval
A3.2 Proposal for a general approval of fabric materials for use in textile architecture
A3.3 Data sheet with commonly used standards
A3.4 Fire reaction for building construction products
A3.5 References

Appendix A4: An example of the application of the testing procedure described in Appendix A3 on a PTFE coated glass fabric

Rainer Blum, Heidrun Bögner, Klaus Gipperich, Sean Seery

A4.1 TASK
A4.2 Test Results
A4.3 Safety concept
A4.4 Reference

Glossary

Erik Moncrieff, Brian Forster