Advanced Numerical Methods for the Form Finding and Patterning of Membrane Structures

Kai-Uwe Bletzinger, Johannes Linhard, Roland Wüchner
Chair of Structural Analysis, Technische Universität München, Arcisstr. 21, 80333 München, Germany, {kub,linhard,wuechner}@bv.tum.de

Abstract. Advanced methods for form finding and patterning of membrane structures are presented based on a consistent nonlinear continuum mechanical formulation. As one of the most general form finding methods, the Updated Reference Strategy is investigated, which is applicable for cables and membranes and for any kind of finite element discretization. The cutting pattern procedure is based on an inverse engineering approach: The yet unknown reference configuration the cutting pattern is modified in such a way, that the difference between the resulting stresses in the final assembled three-dimensional structure and the prescribed stress distribution is minimized. In addition to the individual description of these methods, an extended framework for a detailed analysis and design of membrane structures is presented, whose main focus is to include the influence of the cutting pattern already in the form finding process and structural analysis: Due to the generally existing indevelopability of the spatially curved membrane structure, additional stresses arise in the membrane which have to be included in a detailed modelling of the structure, but have been neglected by conventional approaches.

1 Introduction

Membrane structures represent lightest possible surface structures. As only membrane and no bending stress states appear, the material can be used optimally. This high efficiency and specialization consequently requires to consider some particularities in the design process: The structure has to be shaped in such a way, that it can achieve equilibrium of forces only by tensile forces, as compressive forces would lead to undesirable wrinkles in the membrane. Compared to conventional structures, it is therefore not
possible to design the geometry of the membrane more or less freely at the
drawing board, but it has to be determined by special form finding proce-
dures. The resulting shape of the planned membrane structure is generally
a three-dimensional doublycurved surface. The membrane material itself
is yet only produced in plane panels. This discrepancy is addressed in the
patternning step, which is carried out after the form finding procedure: The
cutting pattern has to be determined in such a way, that the final struc-
ture consisting of the assembled panels has a stress state which matches
the given prestress state the best possible way. For large textile structures,
these two steps are generally assumed to be decoupled and therefore carried
out separately. This assumption holds true if the indevelopability of the
structure is relatively low and the material can deform itself rather stress
free to a doubly-curved state, which is the case for textiles with low shear
stiffness. But for highly curved structures built out of material with a high
shear stiffness (e.g. inflated ETFE-structures), the influence of the cutting
pattern on the overall structural behaviour is in general not negligible: Due
to the indevelopability of the doubly-curved structure, additional stresses
arise in the membrane, which can be of such a magnitude that they have to
be considered in a detailed mechanical description of the structure. In the
following, the individual steps of form finding and cutting pattern genera-
tion are presented in detail, as well as a combination of these two, which
allows a very detailed description of the actual membrane stress state.