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Advantages of the CEG rotation free shell element in analysis and design of thin shell structures

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ABSTRACT

Rotation free shell formulations [1, 2] provide an interesting and effective option for the FE analysis of Kirchhoff-Love type shells. Due to their well defined discretization parameters, which consist only of displacements, they are especially advantageous for geometrically nonlinear structural analysis (static and dynamic) and shape optimization of thin shell structures, as no difficulties occur in a unique definition of rotational degrees of freedom during large deformations.

The proposed CEG element (Curvature Calculation through Enhanced Geometry) is a multi-purpose general rotation free element [1]: Isoparametric displacement elements (triangles and quadrilaterals) are used as basic geometric description and to determine the membrane strains. The calculation of curvature is based on discrete nodal directors, which are assigned to each node and determined by the geometry of a surrounding element patch (Fig. 1). With their help, an additional rotation field is generated within each element in order to determine the otherwise missing curvature information. The kinematics is formulated completely nonlinear.

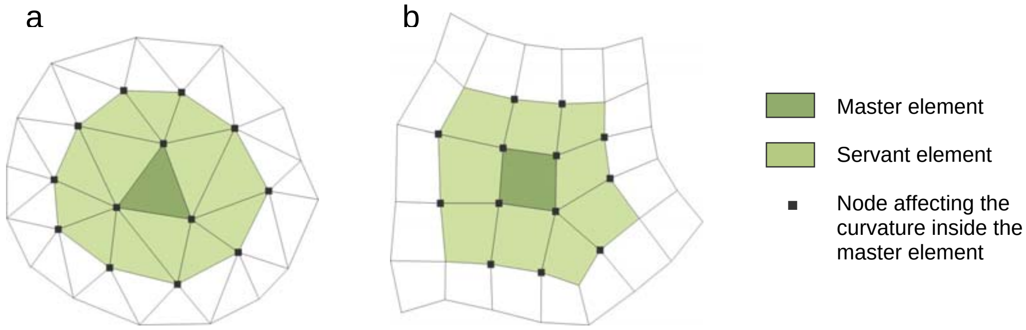

**Fig. 1: Element patch for bending part -
(a) Linear triangular element and (b) bilinear quadrilateral element.**

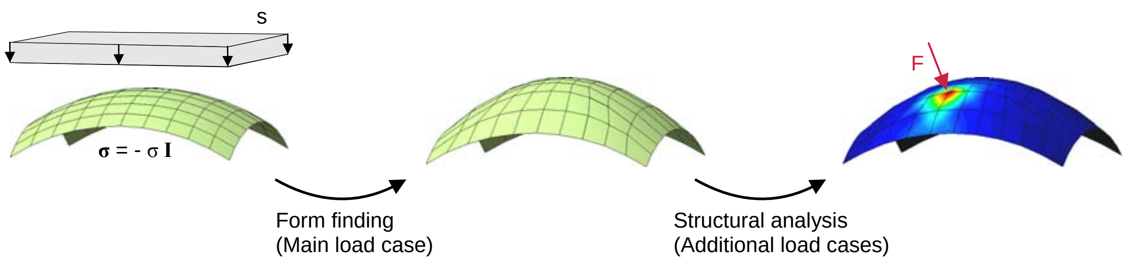

Fig. 2: Exemplary design process of a thin shell structure

One basic advantage of this element formulation is the modular technology allowing for adding bending stiffness to an initial membrane model using the same geometrical discretization and, thus, supporting the entire design procedure: E.g., it can be favourable to design the shape of a shell structure in such a way, that it bears its main load case only by membrane action. This geometry can be obtained with a form finding procedure [3] using only membrane elements. Yet, as other load cases will generally occur in the lifetime of this structure, it is nevertheless necessary to check its load bearing capacities in a series of structural analyses using shell elements (see Fig. 2 for an illustration). It is furthermore possible, to additionally optimize the structure according to various objective functions and constraints by applying free form optimization using exact semi-analytical derivatives [4]. If the CEG rotation free shell element is used, the original discretization can be retained at all design steps and, hence, a time consuming change from membrane to shell elements is avoided.

The efficiency and effectivity of the proposed element formulation is shown in several examples ranging linear static to nonlinear dynamic analysis and optimization.

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