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J. P. Moitinho de Almeida, P. Díez, C. Tiago and N. Parés (Eds)

GEOMETRICALLY EXACT KIRCHHOFF-LOVE SHELL MODEL: THEORY AND MESHLESS IMPLEMENTATION

V. IVANNIKOV[*], C. TIAGO[*], J. P. MOITINHO DE ALMEIDA[*] AND P. M. PIMENTA[†]

[*] Instituto Superior Técnico, Universidade Técnica de Lisboa
Av. Rovisco Pais, 1049-001 Lisboa, Portugal
e-mail: {vladimir.ivannikov,carlos.tiago,moitinho}@civil.ist.utl.pt

[†] Polytechnic School at University of São Paulo,
P.O. Box 61548, 05424-970 São Paulo, Brazil
e-mail: ppimenta@usp.br

Abstract. A geometrically exact shell model based on the Kirchhoff-Love theory, where shear deformation is not accounted for, has been developed in the present contribution. Energetically conjugated cross sectional stresses (first Piola-Kirchhoff tensor) and strains (deformation gradient) are defined. Elastic constitutive equations are consistently derived from fully three-dimensional finite strain constitutive models. A genuine plane-stress condition is enforced by vanishing the true mid-surface normal stress. Since only the bending deformation is included in this model no special technique has to be taken into account in order to avoid shear-locking.

Since the variational basis of the formulation requires the use of C1 approximations, the generation of compatible finite elements is not trivial in the present case. In order to overcome this inconvenience, meshless approximations are used. The first-order Generalized Moving-Least Squares Approximation has been proposed. Although it increases the number of degrees-of-freedom per node, its performance and quality of results are clearly superior to the conventional Moving-Least Squares Approximation in this specific class of problems.

Since the approximation does not possess the Kronecker-delta property, the essential boundary conditions are enforced using a hybrid-displacement version of the shell formulation, by means Lagrange multipliers. The corner reactions which naturally arise from the boundary integrals are carefully treated. This issue requires introduction of extra pointwise Lagrange multipliers. Its significant influence on the accuracy of results is demonstrated in some linear examples.

Imposition of the kinematic boundary conditions along the line also requires extra discussion. The proposed theory has no explicit expression for the boundary rotation angle arising on such boundaries and, moreover, this specific quantity may lead to nonsymmetric tangent matrix. Stitching domains along the line by means of Lagrange multipliers makes it possible to apply the proposed theory not only to smooth continuous shells but also to the folded ones.

Initially curved shells are regarded as a stress-free deformed state from a chosen plane reference configuration. The mapping between both configurations allows the exact consideration of the initial configuration.

The complete linearization of the weak form is presented. For hyperelastic materials,

conservative loadings and most cases of the kinematic boundary conditions the generalized stiffness matrix is symmetric even in points far from the generalized equilibrium positions. Nonconservative loads and some specific essential boundary conditions (as was mentioned above) lead to a nonsymmetric contribution to the resultant tangent stiffness. The latter is derived for several load types.

Results of numerical examples for both linear and nonlinear cases are presented, demonstrating the robustness and efficiency of the approach.