Improved Shell Quadrilateral for Explicit Dynamics

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KEYWORDS: *Explicit Dynamics, EUROPLEXUS, Shell Quadrilateral, Assumed Natural Strains.*

Shell finite elements are widely used in explicit dynamics codes, such as LS-DYNA, EUROPLEXUS, and RADIOSS, for simulating impact events. Quadrilateral shell elements are generally preferred over triangular ones due to their superior accuracy and stability. Among quadrilaterals, one-point-quadrature formulations (under-integrated with hourglass control) are favoured for their computational efficiency, though they may become unreliable in regions undergoing large deformations. To balance accuracy and computational cost, mixed meshes are commonly employed: more expensive four-point-quadrature (fully integrated) shell elements are applied in areas expected to experience severe deformations, while one-point-quadrature elements are used in regions with mild deformations.

In LS-DYNA, ELFORM 16 is a highly accurate fully integrated quadrilateral shell element with Bathe-Dvorkin transverse shear treatment. It also uses a Hu-Washizu-based hybrid-mixed enhancement along with carefully chosen interpolations for the in-plane strains and stresses. The result is a B-bar formulation briefly described in [1]. As an alternative to this relatively sophisticated approach, we propose a simple yet effective improvement to the standard isoparametric four-point-quadrature quadrilateral shell element with Bathe-Dvorkin transverse shear treatment. Numerical tests show that the improved element achieves performance comparable to—or in several test examples, superior to ELFORM 16. The new element was included in EUROPLEXUS.

The core idea of the proposed formulation is to apply the assumed natural strain (ANS) concept to the membrane strains in a manner that ensures satisfaction of the membrane patch test. Notably, this enhancement affects only the membrane strains of the element, preserving existing code capabilities related to, e.g., material models and parallelization. The membrane ANS approach was originally introduced in [2] and was latter applied in [3] but has not previously been evaluated in explicit dynamics impact simulations. In the Updated Lagrangian framework, commonly applied in explicit dynamic codes, geometric constants of the element are recomputed at each time step to be used in construction of rich membrane ANS strains. The adopted modification softens the membrane response—reducing the highest natural frequency by roughly an order of magnitude—improves representation of near-inextensional bending modes, suppresses parasitic membrane strains, slightly enhances explicit scheme conditional stability in the non-linear regime, and allows marginally larger time steps.

[1] ANSYS LS-DYNA Theory Manual, ANSYS, Inc., 2025. https://lsdyna.ansys.com

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