

Upper and Lower Bounds Computation and Accuracy Confidence using Sefea (Strain-Enriched Finite Element Analysis) Formulation

H. Theodore Lin¹, Yu Hou²

¹AMPS Technologies Company, Pittsburgh, USA, email:tedlin@ampstech.com

²Suzhou AMPS Software Technologies Company, LTD, Jiangsu Province, China, email:info@ampstech.com
URL: <http://www.ampstech.com>

Key Words: *Finite Element Analysis, Enrichment Method, Error Estimate, CAE*

Sefea (Strain-Enriched Finite Element Analysis) formulation [1] has been incorporated into several industrial CAE products for design simulation for close to a decade. Many users with minimum FEA experience now perform daily realistic design simulations using Sefea-embedded CAD modeling, while more experienced analysts leverage the fast, accurate, convenient, and robust Sefea technologies. In most CAD applications, only tetrahedral element generation is robust and reliable enough for general automatic CAE design analysis. Sefea is specifically suited for such general design analysis as it possesses these critical features:

- Ability to withstand user abuse with tolerance for low mesh density and mesh distortion that commonly occur in an automatic tetrahedron meshing.
- Enriched strain/gradient formulation achieves second-order family accuracy without the computational cost and side-node noise in dynamic analysis; also suitable for large and/or nonlinear strain.
- Unified enrichment method suitable for fully coupled stress, thermal, fluid flow and electromagnetic multi-physics in a single element.

With the increasing prevalence of CAD design analysis simulation, users are seeking additional guidance about the accuracy and reliability of the analysis results. In this paper, we first discuss the Sefea strain enrichment process and review the enriched strain formulation and the zero integral-sum natural of the enrichment process. The enriched strain formulation does not perturb total strain energy and preserves the constant stress state required for passing the patch test and convergence requirement.

We proposed a variational inhomogeneous strain enrichment method [2] to further improve the Sefea solution accuracy and convergence. In reviewing the process of the optimal variational enrichment method, we observed that the numerical lower and upper bounds of a given mesh discretization can be derived from a simplified uniform Sefea enrichment adjustment. Without any enrichment, the Sefea method effectively degenerates into a constant strain low order element with over-conservative results, and when fully enriched without the compatible constant strain, it exhibits similar softened behavior as in nodal integration method [3]. In comparison, the variational enrichment formulation [2] optimizes the enrichment ratio for accuracy using the intelligence gathered during the element integration process and produces the optimal result results within the upper/lower bounds for the given discretization.

The implementation provides quick feedback regarding solution bounds and accuracy confidence indicator with small computational costs by varying only the enrichment ratio

without repeating the costly element integration loop and greatly improves the usability and accuracy projection for general CAE design simulation.

Comparison with analytical results along with other numerical methods will be presented for accuracy, computational efficiency and general usability comparisons. Combination with mesh refinement using energy error estimates is also reviewed. We conclude with discussion of topics for future research and development.

REFERENCES

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