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Status of the ASME Guidance Document on Computational Modeling for Explicit Dynamics

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Abstract

Modern explicit dynamics finite element computer codes used for the design and evaluation of spent fuel transportation packages and storage casks are sufficiently sophisticated and robust that they are able to produce accurate results for complex impact events (i.e., energy-limited events) that include spent fuel cask drops and aircraft impact. However, based on the authors' experience, there is considerable variability among users when implementing these computer codes. Compounding this is the fact that there is no clear guidance explaining the computational modeling requirements necessary to achieve accurate results.

To address this issue ASME and the NRC formed the Special Working Group (SWG) on Computational Modeling for Explicit Dynamics in 2008 for the sole purpose of developing a guidance document on computational modeling for explicit dynamics, which can be used to guide users in the construction of quality (accurate) finite element models. Members of the SWG include many internationally recognized experts in the use, implementation and benchmarking of explicit dynamics codes.

Introduction

The finite element method has evolved in its ability to accurately predict the nonlinear response of structures subject to energy-limited events. Advances in computer technology have allowed highly refined models of entire packages to be created and analyzed; however, the finite element method has many pitfalls that are frequently not recognized or understood by users and their management. This can lead to the false impression that answers emanating from a finite element analysis are valid and usable.

To develop a finite element model of a sophisticated structure exhibiting significant nonlinear behavior takes years of dedicated learning and experience. Even the best analysts have a healthy respect for the pitfalls that may be encountered when using the finite element method.

The problem is that virtually any finite element model can produce results. The question is, how accurate are they? Did the analyst follow good practice in developing the model or introduce any unintended behavior?

The ultimate goal of a finite element analysis is to produce stress, strain, and displacement results to compare to acceptance criteria found in governing codes. In the design of any structure, incentives to minimize cost and weight could drive designers to develop structures that come close to the acceptance criteria limits. This places a premium on developing accurate models. By accurate it is meant that the calculated stresses and strains would, within some tolerance, be representative of the actual stresses and strains that would occur in the structure as a result of the event being analyzed.

Quality Models

In the 2013 ASME Code Edition strain-based acceptance criteria was introduced in Section III, Division3. Sub-Article A-1240 of Appendix A of the ASME Code Section III, Division 3 states the following:

> "These strain-based criteria should be applicable only to strain results from "Quality Models." A "Quality Model" is a model that adheres to the guidance set forth in the ASME Computational Modeling Guidance Document for Explicit Dynamics (currently being developed by the Special Working Group on Computational Modeling for Explicit Dynamics), or using a model with suitable convergence and sensitivity studies already completed."

Explicit dynamics finite element codes are now sufficiently sophisticated and robust that complex impact events can be simulated and accurate results obtained. Such results are only achievable, however, by analysts who possess intimate knowledge of structural behavior and an understanding of how to properly construct a finite element model using these codes. Unfortunately, the ability of some users to properly implement the features that make these codes so sophisticated and robust can be a problem.

For example, consider the convergence study results shown in Figure 1 for a uniformly loaded propped cantilever beam constructed of thin shell elements. The element length is plotted on the horizontal axis and the maximum plastic strain occurring in the element adjacent to the fixed end of the beam is plotted on the vertical axis. The plot shows that in order to achieve reasonably accurate results the element adjacent to the fixed end should be no longer than 1/4 inch. However, in a finite element model submitted to the NRC the analyst used a minimum element length of 3.5 inches, which results in a significant underestimate of maximum plastic strain.

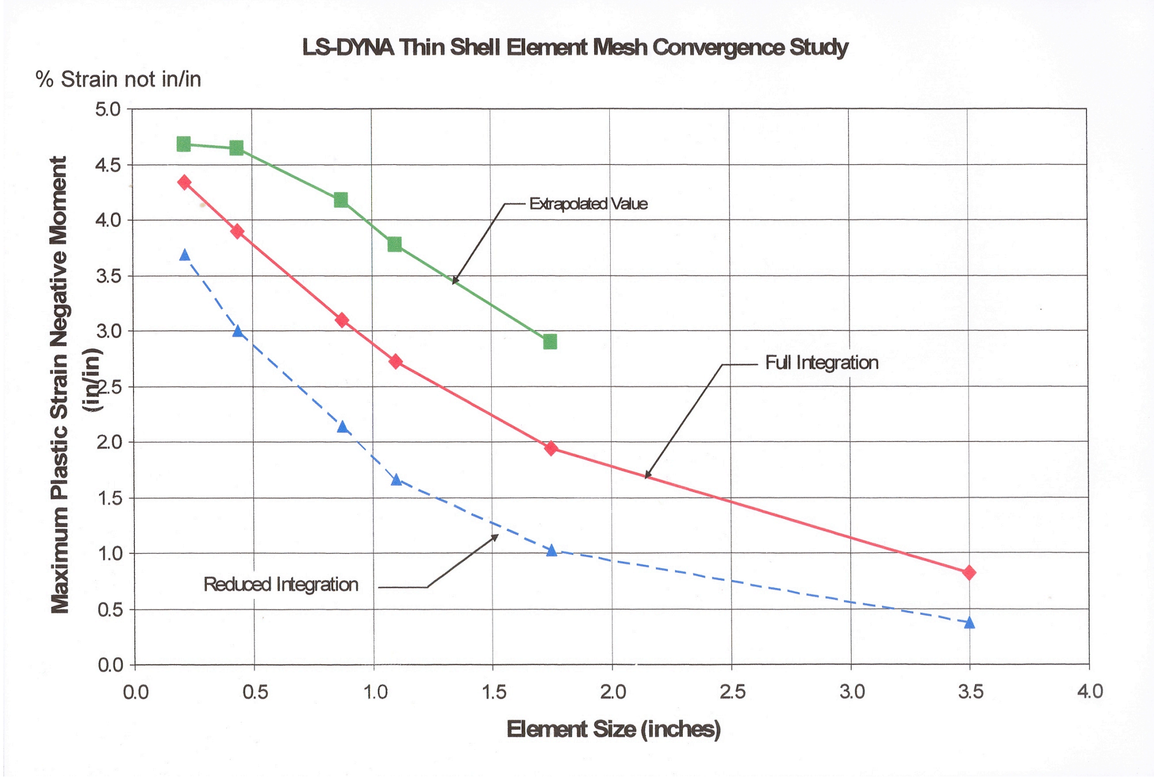

Figure 1: Convergence study results for a uniformly loaded propped cantilever beam constructed of thin shell elements.

Hierarchy of Finite Element Codes

Often not recognized by finite element users and their management is the fact that there is a hierarchy of complexity among finite element analysis codes. The more complex the code the greater the amount of time hands-on time to master it. The most complex codes require vast experience and many years to master. The simplest finite element analysis codes to implement are those used to perform linear and nonlinear static analysis. More complex codes are those used to perform linear and nonlinear implicit dynamic analysis. These codes are primarily used in the analysis of forced vibrations and ground motion problems. Finally, the most complex finite element analysis codes are those used to perform explicit dynamic analysis These codes are primarily used to evaluate crash and impact problems (i.e., energy-limited events).

Engineers who first encounter explicit dynamics codes, and who may be well versed in static analysis and implicit dynamics, soon become aware of the new challenges presented by crash and impact problems using explicit dynamics codes. To help address these new challenges, the ASME Special Working Group (SWG) on Computational Modeling for Explicit Dynamics was formed in August 2008 to create a quantitative guidance document for the development of finite element models used to analyze energy limited events.

Purpose

The purpose of the ASME Computational Modeling Guidance Document is to provide guidance for developing quality finite element models to assure, with reasonable certainty, that the model produces accurate results before comparing those results to the strain-based or stress-based acceptance criteria of Section III, Division 3, Subarticles WB/WC-3700. Models developed following the guidelines provided in this document meet the definition of a "Quality Model," as described in Section EE-1240 of the Nonmandatory Appendix EE (Strain-Based Acceptance Criteria Definitions and Background Information). However, it cannot be emphasized enough that the guidelines provided herein are not requirements. Rather, the intent of the guidelines is to give practical direction to analysists on how to go about constructing a quality finite element model using explicit dynamics analysis codes. This guidance document is an "evolving" document and will be revised as software programs, technology, and FEA techniques change.

Scope

This guidance document sets out current 'good practice' in using the explicit finite element analysis (FEA) method for the evaluation of the behavior of transport and storage packages in energy-limited impact events. While much of the document discusses the modeling of storage casks and transportation packages, it is universally applicable to all types of structures modeled using explicit dynamics finite element programs to evaluate the response to energy-limited events.

A sampling of topics addressed in the guidance document include:

- use of coordinate systems to define geometry, material property orientation, and load application
- element selection
- element aspect ratios
- element and mesh transitioning
- element mesh design
- use of mass scaling
- hourglass control
- modeling of components that buckle
- modeling of welded and bolted joints
- material models and material property input
- consideration of contact definitions, contact points, friction, gaps, and boundary conditions
- modeling of material failure
- modeling of impact limiters
- modeling of impact targets
- application of loading

- proper calculation of the triaxiality factor
- correct solution technique
- stress and strain output

SWG Committee Members and Guidance Document Status

Members of the SWG on Computational Modeling for Explicit Dynamics include many internationally recognized experts in the use, implementation and benchmarking of explicit dynamics codes.

Doug Ammerman	Sandia National Laboratories (Vice Chairman)
Gordon Bjorkman	U.S. Nuclear Regulatory Commission (Chairman)
Michael Breach	U.S. Nuclear Regulatory Commission
Ginny Broz	BMPC - Bettis Laboratory (Secretary)
Jeff Jordan	Savannah River National Laboratory
Soahan Kuehner	BMPC - Knolls Laboratory
David Molitoris	Westinghouse Electric Company
Jason Piotter	U.S. Nuclear Regulatory Commission (Contributing Member)
Wolf Reinhardt	Candu Energy
Peter Shih	Transnuclear
Spencer Snow	Idaho National Laboratory
Chi-Fung Tso	ARUP, United Kingdom (Author TCSC-1087)
Frank Wille	BAM, Germany
Michael Yaksh	NAC International
Uwe Zencker	BAM, Germany

The committee usually meets for two and a half days at ASME Code Week which occurs every three months. There is also significant public participation at committee meetings.

The ASME Computational Modeling Guidance Document and companion Examples Document are currently in draft form. They are scheduled to be circulated to the ASME Code Committees for review and comment after the February 2017 Code Week.

Acknowledgements

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