New Features for Structural Elements in DYNA3D

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Due to its ability and efficiency in modeling the nonlinear behaviors of solids, the explicit finite element code DYNA3D has long been a main computational tool at LLNL for the simulation of transient response of solid continuum and structures to fast, impulsive loadings. In addition to its original mission of supporting Laboratory activities, DYNA3D over the years has evolved to encompass other applications such as infrastructure protection, vehicle impact simulation and earth structure analysis. DYNA3D also provides the mechanics functionalities of the highly parallel ParaDyn code. This project funds the ongoing implementation of user-requested features, general technical support and documentation updates.

This project also supports the broader interagency DYNA3D activities through LLNL's Collaborator Program. The Collaborator Program grants selected users licensed access to LLNL's computational mechanics/thermal codes in exchange for their research/development results and acknowledgement. These collaborative members include our sister laboratories, U.S. government agencies, and other education/research institutions.

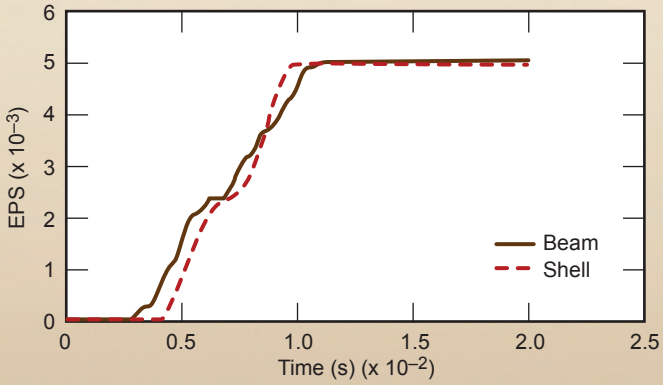

Figure 1. **Comparison of equivalent plastic strains from resultant-based shell and beam element representation of a fixed-end beam subjected to a concentrated mid-span load.**

Project Goals

The planned tasks include user support and code maintenance, implementation of new functionalities for program needs, enhancement of existing features, compliance to software quality assurance (SQA), and FORTRAN 95 standard.

Relevance to LLNL Mission

Many programs supported by LLNL need new/enhanced DYNA3D functionalities and technical support to complete their missions. Many of these programs and projects involve the Laboratory's collaboration with other institutions and federal agencies, such as the Los Alamos National Laboratory (LANL), Missile Defense Agency, the Naval Surface Warfare Center (NSWC), the U.S. Army Corps of Engineers, and the Department of Homeland Security.

FY2009 Accomplishments and Results

In recent years, with the expansion of DYNA3D's use in application breadth and model size, the use of structural

elements (beam, shell, and thick shell) has increased. For efficiency, some beam element formulations describe their response in terms of aggregate quantities: the total moment as a function of the beam bending. The trade-off of this "resultant-based" approach is that an analyst is left to interpret the aggregate response rather than the more familiar point-wise material behaviors, *e.g.*, the peak stress. A common point-wise response of interest is the equivalent plastic strain, a measure of permanent deformation that is often used to judge the margin from failure in ductile materials such as many metals.

Recent modeling of complex aircraft structures often uses resultant-based beam elements for efficiency. Acting upon a user request, we added an equivalent plastic strain output option to that element type. This option was derived from an analogous capability for resultant-based shell elements that already existed in DYNA3D. Due to the lack of a concise analytic expression for the equivalent plastic strain for this model, we created a computational procedure based on the plastic work. The algorithm yields good agreement with the results provided by the shell model (Fig. 1), and can also serve as a template for similar calculations for other material models. The permanent deformation of the rebar in reinforced concretes can be observed through the beam equivalent plastic strains (Fig. 2).

Important classes of LLNL simulations require the inclusion of effects arising from the natural variability of materials. For example, the local strain-to-failure of a material will vary across a part and thereby influence the evolution of its behavior under extreme loads. Often a Weibull statistical distribution is a reasonable, convenient representation of such variability. In response to analysts, our Johnson-Cook Elastic/Plastic material model was extended to accept Weibull distributions on parameters that determine fracture strain behavior.

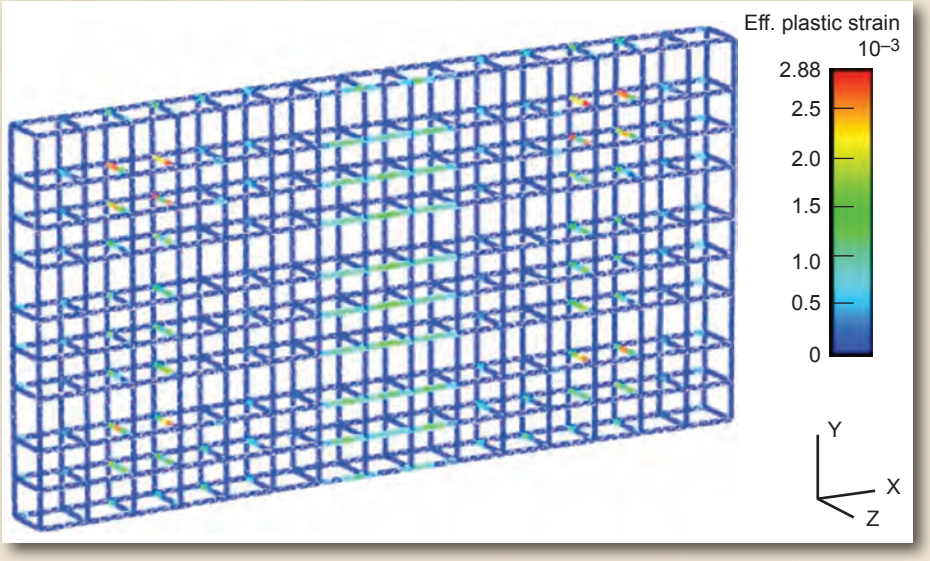

Figure 2. Equivalent plastic strain distribution in the rebar system of a reinforced concrete slab under pressure load at the mid-section. The concrete material is removed for clarity.

We note that DYNA3D is also gaining features under our collaboration with NSWC and its German project partners. A new material model, Tabulated Rate-Dependent Elastic-Plastic with Fracture was integrated into DYNA3D. The inclusion of predefined inputs for common beam cross-sections from the same partner will significantly streamline model preparation for complex, stiffened structures such as ship hulls.

Related References

1. Kennedy, J. M., T. Belytschko, and J. I. Lin, "Recent Developments in Explicit Finite Element Techniques and Application to Reactor Structures," *Nuclear Eng. and Design*, **97**, pp. 1–24, 1986.

2. Johnson, G. R., and W. H. Cook, "A Constitutive Model and Data for Metals Subjected to Large Strains, High Strain Rates and High Temperatures," *Seventh International Symposium on Ballistics*, The Hague, The Netherlands, April 1983.

FY2010 Proposed Work

General technical support of our analysts for DYNA3D will continue. The extension of the existing *Closed Volume* feature to permit gas flows among multiple volumes is now scoped and awaiting further user specification of requirements. Work on hardening in material models for the resultant-based beam element will also be added.