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Summary of Documentation For DYNA3D-ParaDyn's Software Quality Assurance Regression Test Problems

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1 OVERVIEW OF SQA REGRESSION TESTING

The Software Quality Assurance (SQA) regression test suite for DYNA3D (Zywicz and Lin, 2015) and ParaDyn (DeGroot, et al., 2015) currently contains approximately 600 problems divided into 21 suites, and is a required component of ParaDyn's SQA plan (Ferencz and Oliver, 2013). The regression suite allows developers to ensure that software modifications do not unintentionally alter the code response. The entire regression suite is run prior to permanently incorporating any software modification or addition. When code modifications alter test problem results, the specific cause must be determined and fully understood before the software changes and revised test answers can be incorporated.

The regression suite is executed on LLNL platforms using a Python script and an associated data file. The user specifies the DYNA3D or ParaDyn executable, number of processors to use, test problems to run, and other options to the script. The data file details how each problem and its answer extraction scripts are executed. For each problem in the regression suite there exists an input deck, an eight-processor partition file, an answer file, and various extraction scripts. These scripts assemble a temporary answer file in a specific format from the simulation results. The temporary and stored answer files are compared to a specific level of numerical precision, and when differences are detected the test problem is flagged as failed.

Presently, numerical results are stored and compared to 16 digits. At this accuracy level different processor types, compilers, number of partitions, etc. impact the results to various degrees. Thus, for consistency purposes the regression suite is run with ParaDyn using 8 processors on machines with a specific processor type (currently the Intel Xeon E5530 processor). For non-parallel regression problems, i.e., the two XFEM problems, DYNA3D is used instead. When environments or platforms change, executables using the current source code and the new resource are created and the regression suite is run. If differences in answers arise, the new answers are retained provided that the differences are inconsequential. This bootstrap approach allows the test suite answers to evolve in a controlled manner with a high level of confidence. Developers also run the entire regression suite with (serial) DYNA3D. While these results normally differ from the stored (parallel) answers, abnormal termination or wildly different values are strong indicators of potential issues.

2 TEST PROBLEMS

The problems in the regression suite vary in purpose and complexity, are typically small in size (several to a few thousand elements), and many run in about one minute. There are verification problems. Verification problems ensure that feature implementations are coded as mathematically intended. There are validation problems. Validation problems examine how well a feature simulates a particular physical response. As an example, a shell verification problem might examine the resultant nodal forces for a single shell element subjected to a particular set of nodal displacements where as a validation problem might explore how closely a simulated cantilevered beam, modeled with a certain number of shell elements loaded in a specific manner, matches the theoretical solution for the tip displacement. In both types of problems there are well-defined answers. In some cases validation problems are used to serve a verification role for rudimentary behavior. For example, the PLATE suite examines the “static” response of a simply supported plate subjected to an applied pressure and quantifies how different shell element formulations and shell material models perform. Another class of regression test problem, termed “acid test” in this report, is one in which no closed-form theoretical answer exists. These problems exercise the code’s material models, element formulations, hourglass suppression, input parsing, output mechanics, etc., in an inclusive and repeatable manner, and ensure the code behavior remains consistent.

The documentation for the test problems is equally varied. Explicit documentation exists for 107 test problems. The documentation details the problem set up, theoretical results, and the simulation results. In some cases, the documentation pertains directly to a single test problem, e.g., the EOS problems. In other cases, a single problem is described, used for multiple test problems, and the simulation results are discussed collectively, e.g., the BEAM problems. There are 56 additional test problems that are direct variants of the documented test problems. In most cases the existing reports cover the problem setup and theoretical results for these test problems.

Many of the undocumented test problems have theoretical or obvious answers, e.g., the initial simulation velocity is as prescribed or it is not. The answers in these test problems were verified when they were created and added to the regression test suite. The lack of documentation does not diminish their functional utility.

In the following sub-sections, each test suite is described briefly along with its supporting documentation – if any. Unfortunately, the majority of regression problems currently have no formal documentation.

2.1 BAR

The BAR suite contains 82 acid-test type problems. Each problem contains 972 8-node hex elements and models one quarter of a cylindrical Taylor impact bar. The base problem is described in Lovejoy and Whirley (1990). There is one problem for each solid (hex) element material model, and there is a problem for each hex element formulation and hourglass control option.

Aside: The setup and material parameters used for the Material Model 3 test problem match actual Taylor impact bar experiments. Thus, comparisons between experimental and simulation results can be made.

2.2 BASIC

The BASIC suite contains 13 verification/validation hex-element problems. For each of the five hex element formulations examined in each problem, there are six single elements subjected to applied loads and six single elements subjected to applied displacements. These small-strain loadings produce only one non-trivial stress. There are two additional single elements subjected to equal pressure on two opposite faces. One element is perturbed and spins freely in space, and the other element is oriented at an angle with respect to the global coordinate system. There are two ten-element long cantilever beams, made with skewed elements, subjected to point tip loads – one in each direction. Mass proportional damping is used to obtain a static solution. All the single element loadings have obvious closed form solutions. The cantilever beam problems have theoretical solutions for the physically stabilized element formulations only.

2.3 BEAM

The BEAM suite contains 38 beam and truss verification/validation problems that test the basic Hughes-Liu, Belytschko-Schwer, and truss formulations as well as each beam and truss material model. The detailed and thorough report by Rathbun (2007) describes the configurations and loadings explored as well as the theoretical solutions and results for the original 26 test problems. As new beam and truss material models have been developed additional test problems, variants of the original ones, have been added.

2.4 COUNT

The COUNT suite contains 101 problems and covers many different functionalities and features. This suite contains the original example problems developed and documented by Lovejoy (Lovejoy & Whirley, 1990). For some of these problems theoretical answers exist. The suite includes test problems for material models 24 and 71 (Zywicz, 2005; Zywicz, 2008), and two for non-reflecting boundary conditions (Zywicz, 2006). The theoretical answers reported in the associated documentation are the basis for these problems. The remaining 87 undocumented problems are a mix of verification, validation and acid-test type problems covering a broad range of features.

2.5 DAMP

The DAMP suite contains 15 acid-test type problems that test stiffness proportional damping in hex, shell, beam, and thick shell elements. Each problem tests a unique calling sequence in the code.

2.6 DEGEN

The DEGEN suite contains 3 acid-test type problems that ensure degenerate bricks (prism and tetrahedral elements) and quadrilateral shells (triangle shells) are processed correctly within their parent element class.

2.7 EOS

The EOS suite contains 20 verification problems that examine in depth the response of DYNA3D's equations of state. For each EOS type, a series of single elements are subjected to prescribed loadings to verify that each part of the model is behaving as intended. Each EOS type and its corresponding test problem, with theoretical answers, are described in Benjamin (2015).

2.8 HOURGLASS

The HOURGLASS suite contains 9 acid-test type shell problems. Each problem contains three corner-supported plates subjected to an applied pressure or point forces. The three geometrically similar plates have different thicknesses and therefore test different regimes of hourglass control. Each of the three hourglass modes is examined with three hourglass suppression options (stiffness, viscous, and combined stiffness and viscous).

2.9 MASS_AUG

The MASS_AUG suite contains 16 acid-test type problems that test the mass augmentation option for beam, truss, shell, and hex elements. The base problems were copied from the BEAM, PLATE, SHELL and BAR suites, and modified as necessary. Each problem tests a unique calling sequence in the code.

2.10 ML

The ML suite contains 6 acid-test type problems for meshless elements. A Taylor impact bar problem, as used in the BAR suite, is run for each hourglass option and for two different meshless update options.

Aside: these problems replicate an actual experiment, and therefore comparisons between the experimental and simulation results can be made.

2.11 MMD

The MMD suite contains 4 verification type test problems for the material model driver. There are two shell problems and two hex problems each testing material model 1 and model 3.

2.12 NTET

The NTET suite contains 8 acid-test type problems for nodally integrated tetrahedral elements. A Taylor impact bar problem, as used in the BAR suite, is run for each hourglass option and for two different meshes.

Aside: these problems replicate an actual experiment, and therefore comparisons between the experimental and simulation results can be made.

2.13 PLATE

The PLATE suite contains 52 validation type problems for shell elements. A simply supported plated subjected to an applied pressures is simulated. The damped "static" elastic response is examined for each of the different shell formulations, integration rules, and shell material models.

2.14 REDEFINE

The REDEFINE suite contains 1 verification type problem. A cantilever bean made with five shell elements subjected to an applied pressure is simulated. The problem runs for a period of time and is then restarted. The load curve associated with the pressure is modified in the restarted run.

2.15 RESTART

The RESTART suite contains 5 validation test problems. Existing test problems from the BAR, BEAM and PLATE suite are terminated prior to completion and then restarted and run to completion. The answers from these runs are compared to answers generated without a restart.

2.16 SAND

The SAND suite contains 16 acid-type test problems. There are three basic problems that test the SAND slide surface. Various slide surface options and features are considered in the different problems.

2.17 SHELL

The SHELL suite contains 50 verification/validation test problems. The original 36 problems are documented in Zywicz (2008b). The additional 14 problems employ shell formulations that did not exist when the report was written. Each problem contains 30-cantilevered beams made from three shell elements each. Ten beams are aligned with each of the three principal coordinate directions. Tip loads or displacements are imposed individually in each of the (five) independent shell degrees of freedom, and their resultant behavior is examined.

2.18 SLIDE

The SLIDE suite contains 122 verification/validation test problems. The original 21 "sslide" problems are documented in McMichael (2006a, 2006b). The other 81 "sslide" problems are derived from the original problems and cover other slide-surface formulations and options. The “sslide” problems examine the slide surface behavior between two blocks. In general, the blocks are initially compressed together and then slid relative to one another. The 20 “init_slide” problems test the initial penetration option for different slide surface types and enforcement methods. No documentation exists for these problems,

2.19 TPLATE

The TPLATE suite contains 32 verification/validation type test problems for thick shell elements. A simply supported plated subjected to an applied pressure is simulated. The damped “static” elastic response is examined for each of the different shell/thick-shell material models.

2.20 THICKSHELL

The THICKSHELL suite contains 2 problems for thick shell elements - one validation problem and one acid-test type problem. The validation problem is extracted from the BASIC suite, and the other tests material model 52 with thick shell elements.

2.21 XFEM

The XFEM suite contains 2 acid-test type problems for the (serial code only) XFEM option. Aside: The XFEM option is still experimental and is not fully coupled with all code features.

3 REGRESSION SUITE COVERAGE

The table in Lin (2010, 2016) shows the primary features exercised by each test problem as of 2010. The regression suite currently covers the features in sections 4.2 through 4.58 of the DYNA3D User Manual V15.1 (Zywicz and Lin, 2015) except for 4.25 Gemini Coupling, 4.52 CVS Coupling Data, and 4.58 FEusion Segments as these options require co-execution with external software. While one or more test problems contain each of these features, not all options and permutations of each feature are considered.

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