TEST CASE DOCUMENTATION AND TESTING RESULTS

TEST CASE ID AWG-CI-4

Clamping Preload on Structural Joint

Tested with LS-DYNA® R12.2 Revision 0-g0294a6e436

Monday 6th February, 2023

Ansys

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Contents

1 Introduction

1.1 Purpose of this Document

This document specifies the test case AWG-CI-4. It provides general test case information like name and ID as well as information to the confidentiality, status, and classification of the test case.
A detailed description of the test case is given, the purpose of the test case is defined, and the tested features are named. The test case specifications also state the target measures for testing and the expected results, as well as their pass and fail criteria.
Testing results are provided in section 5 for the therein mentioned LS-DYNA® version and platforms.

2 Test Case Information

Test Case Summary	
Confidentiality	external use
Test Case Name	Clamping Preload on Structural Joint
Test Case ID	AWG-CI-4
Test Case Status	active
Test Case Classification	Verification
Test Case Source	Naval Air Warfare Center Aircraft Division
Tested Keyword	*MAT_SPOTWELD *INITIAL_AXIAL_FORCE_BEAM *ELEMENT_BEAM *ELEMENT_SHELL *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE *ELEMENT_SOLID *CONSTRAINED_NODAL_RIGID_BODY *CONTROL_DYNAMIC_RELAXATION
Member of Test Suite	AWG CI SUITE
Metadata	AWG CI

Table 1: Test Case Summary

3 Test Case Specification

3.1 Test Case Purpose

The purpose of Test Case ID AWG-CI-4 is to develop a model in which shell components (typically cross-tubes) and solid components (typically legs, spreaders, etc.) are clamped together using bolts with preload. A comparison of bolts modeled with 3D-solid elements (Subcase 1) and a single beam (1-D) element (Subcase 2) is investigated. The model is defined with the shell offset turned on so that the parts contact on the shell's physical surface, which develops the expected preload on the structure.

3.2 Test Case Description

The model consists of a cross-tube modeled using shell elements and a clamping structure modeled using solid elements as shown in Figure 1. The fastener is modeled with 3D-solid elements in Subcase 1 and a single 1-D beam element in Subcase 2. The details of the bolt prestress calculation are shown in Table 2.

Figure 1: 3D-Solid and 1D-Beam Bolts.

Parameter	**Symbol**	**Value**	**Units**	**Formulation**
Torque	T_{in}	60	in-lb	-
Diameter	D	0.313	in	-
Area	A	0.077	in^2	$A = \pi * (D/2)^2$
Nut Factor	k	0.2	-	Empirical value
Force	Fp	960	lb	$T_{in} = F_p * k * D$
Stress	σ	12516.45	lb/in^2	$\sigma = F/A$

Table 2: Bolt Prestress Calculations

3.3 Model Description

The model consists of the cross-tube modeled with shell elements, the clamping structure modeled with solid elements, and the fastener modeled with 3D-solid elements (Subcase 1) and beam elements (Subcase 2). The fastener preload is defined in the 3D-solid element model using *INITIAL_STRESS_SECTION and for the 1D-beam element model using *INITIAL_AXIAL_FORCE_BEAM.
The bolt is assumed to be threaded into the lower portion of the clamp and is in frictional contact with the upper part of the clamp. To simulate this behavior, tied contact (merged nodes) is applied between the bolt and threaded part of the clamp. The "single surface" frictional contact is applied to the rest of the system.
Depending on the torque applied to the bolt, the initial stress is assumed at the cross section of the bolt, which is not connected to the surrounding structure.
A dynamic relaxation analysis is performed to activate the contacts and place the model in a quasi-static state. The quasi-static applied prestress of 12516.45 psi is applied using *INITIAL_STRESS_SECTION at the solid bolt cross-section and a 960 lb axial load is applied using *INITIAL_AXIAL_FORCE_BEAM in the beam model. The clamped end is constrained in all three directions.

Model information		
	Subcase 1 - Solid Bolt	Subcase 2 - Beam Bolt
Nodes	5817	5573
Solid Elements	3800	3640
Shell Elements	418	418
Beam Elements	0	1
Parts	3	3
Materials	1	2
Unit System	in (length), s (time), lbf-s^2/in (mass), lbf (force), psi (stress)	in (length), s (time), lbf-s^2/in (mass), lbf (force), psi (stress)

Table 3: FEA Model Information

Model information	
Test Case ID	Input Deck Name
1	AWG_CI_TEST_CASE_4_SOLID.key
2	AWG_CI_TEST_CASE_4_BEAM.key

Table 4: Specification of sub test cases

4 Test Specifications

4.1 Test Case Targets

Test Case Targets				
Target number	Output	component type	component id	retrieved from
1	Resultant Force	Cross-Section Plane	2: Solid Element	binout/secforc
2	CPU Time			d3hsp

Table 5: Test Case Targets Subcase 1 - 3D-Solid

Test Case Targets				
Target number	Output	component type	component id	retrieved from
3	Axial Force	Element	4221	binout/elout
4	CPU Time			d3hsp

Table 6: Test Case Targets Subcase 2 - 1D-Beam

4.2 Pass/Fail Criteria

These are the Pass/Fail criteria used for the Validation of the Test Case ID AWG-CI-4.

The sub test case passes if the test case target data falls within the corridor bounds. Otherwise the test fails.

The test case corridors are upper and lower bounds for the test case targets. They were defined based on the test target data obtained with LS-DYNA® R14.0 Revision 268 binaries by the following process:

- For a specific test case target, interpolate the data from different platform and executable (R14.0 Revision 268) combinations, so that the time domain is the same.
- Calculate the upper and lower bounds by:

$$bound_{up}(i) = max(i) + 0.2 \times [max(i) - min(i)] + 0.05 \times peak$$
$$bound_{low}(i) = min(i) - 0.2 \times [max(i) - min(i)] - 0.05 \times peak$$

  where $max(i)$, $min(i)$ are the maximum and minimum values at the i_{th} time step across all platforms and executable (R14.0 Revision 268) combinations the test case was calculated with, $peak$ is the maximum absolute y value across the whole time domain, $bound_{up}(i)$ and $bound_{low}(i)$ are the upper and lower bounds for the i_{th} time step.

For CPU Time target, it holds:

$$bound_{up}^{CPU\,Time} = 2 \times Max + 1$$
$$bound_{low}^{CPU\,Time} = 0$$

where Max is the maximum CPU Time (in seconds) across all platforms and executable (R14.0 Revision 268) combinations the test case was calculated with and $bound_{up}^{CPU\,Time}$ and $bound_{low}^{CPU\,Time}$ are the upper and lower bounds.

5 Test Case Results

5.1 Software and Hardware Specifications

In order to ensure cross-platform consistency, the herein mentioned sub test cases are run on platforms specified in table 7 and the results are calculated with software versions defined in table 8.

Platform Name	Operating system	CPU type	MPI-Protocol	Number of cpu's [1]
cdcvdce7mbu01	CentOS 7.9	Intel® Xeon® E5- 2680 v4 @ 2.40GHz	Platform MPI ISV Edition 08.3.0.2 [10692] Linux x86-64	4

[1] Number of cpu's used for calculation of the test case

Table 7: Used Platforms and CPU Type's

Product	Version	Release	Revision	Parallel type [1]	Precision [2]	executable
LS-DYNA®	971	R12.2	0-g0294a6e436	SMP	SP	ls971.0-g0294a6e436.R12.2
LS-DYNA®	971	R12.2	0-g0294a6e436	SMP	DP	ld971.0-g0294a6e436.R12.2
LS-DYNA®	971	R12.2	0-g0294a6e436	MPP	SP	mpp971.0-g0294a6e436.R12.2
LS-DYNA®	971	R12.2	0-g0294a6e436	MPP	DP	mpd971.0-g0294a6e436.R12.2

[1] MPP = Massively Parallel Processing, SMP = Symmetric Multiprocessing

[2] SP = single precision, DP = double precision

Table 8: Tested LS-DYNA® version

5.2 Results Summary

Table 9 contains the results of the Test Case ID AWG-CI-4 completed with all combinations of software and hardware defined in section 5.1 (1 * 2 * 4 total calculation runs).
Details on the test results can be found in the section 5.3.

The table 9 cross cpu architecture consistency summary is:

- **PASS** - Pass criteria in section 4.2 is attained.
- **FAILED** - Pass criteria in section 4.2 is not attained.
- **ERROR** - sub test case terminates due to error.
- **N/A** - sub test case was not calculated.

Sub Test Case ID	PASS/FAILED
1	**PASS**
2	**PASS**

Table 9: Results summary for Test Case ID AWG-CI-4

5.3 Result Details

The following subsections contain detailed results for the Test Case ID AWG-CI-4 for LS-DYNA® R12.2 Revision 0-g0294a6e436.

For each sub test case defined in section 3.3 there is a graph displaying the time history of the result target defined in section 4.1 for the platform and software version combinations defined in section 5.1.

The title of the graph states the test case ID and the name of input deck. The legend contains the type, branch and the revision of the executable.

5.3.1 Subcase 1, Test Target 1: Solid Element Cross-Section Resultant Force

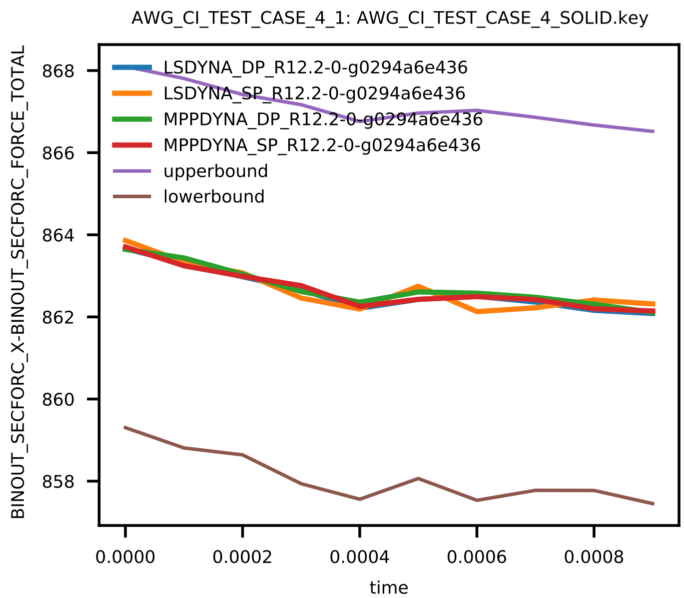

Figure 2: Resultant Force, Bolt Cross-Section plane.

5.3.2 Subcase 1, Test Target 2: CPU time

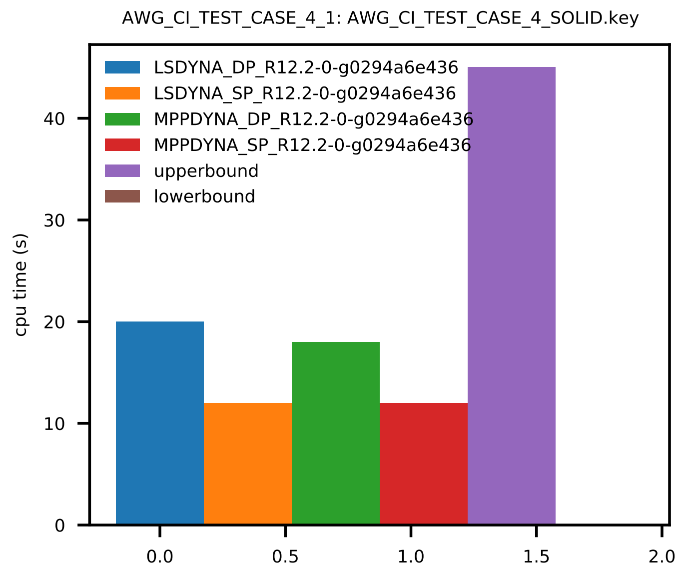

Figure 3: CPU Time Comparison.

5.3.3 Subcase 2, Test Target 1: Beam Axial Force

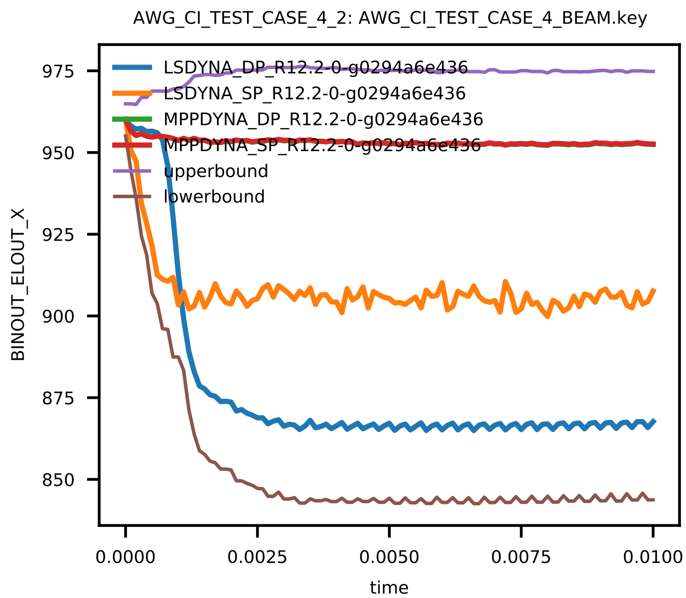

Figure 4: Resultant Force, Beam Element.

5.3.4 Subcase 2, Test Target 2: CPU time

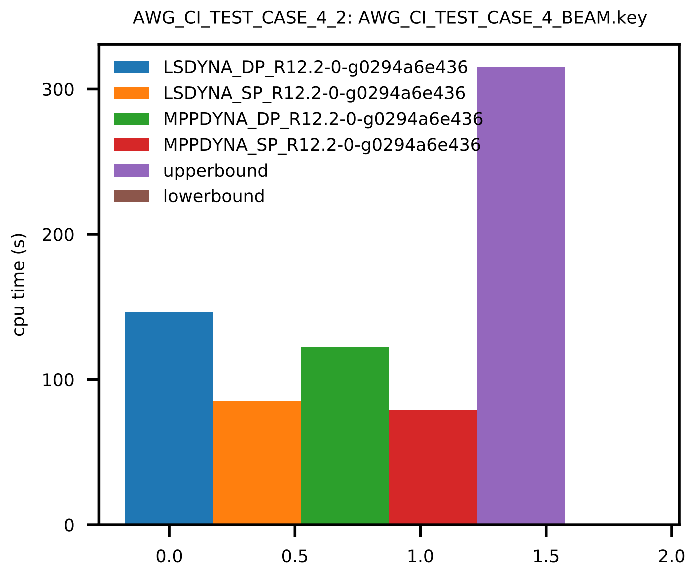

Figure 5: CPU Time Comparison.

References