

# TEST CASE DOCUMENTATION AND TESTING RESULTS

LSTC-QA-LS-DYNA-AWG-ERIF-9-17

## TEST CASE ID AWG-ERIF-9

### Single Element Comparison Tests

Tested with LS-DYNA® R11.2 Revision 26-gd2ace36

Wednesday 9<sup>th</sup> December, 2020

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## Document Information

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# **1 Introduction**

## **1.1 Purpose of this Document**

This document specifies the test case AWG-ERIF-9. 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	Single Element Comparison Tests
Test Case ID	AWG-ERIF-9
Test Case Status	active
Test Case Classification	Example
Test Case Source	NCAC / George Washington University
Tested Keyword	*MAT_TABULATED_JOHNSON_COOK, *MAT_PIECEWISE_LINEAR_PLASTICITY, *MAT_JOHNSON_COOK
Member of Test Suite	AWG ERIF SUITE
Metadata	AWG ERIF

Table 1: Test Case Summary

## **3 Test Case Specification**

### **3.1 Test Case Purpose**

The purpose of Test Case ID AWG-ERIF-9 is the comparison of \*MAT\_TABULATED\_JOHNSON\_COOK (\*MAT\_224) to \*MAT\_PIECEWISE\_LINEAR\_PLASTICITY (\*MAT\_024) and \*MAT\_JOHNSON\_COOK (\*MAT\_015) , and, in particular, demonstrating the influence of thermal softening and stress triaxiality.

The reliability and consistency of LS-DYNA<sup>®</sup> as a finite element solver for the single solid element models is evaluated by performing analyses on different cpu architecture platforms and comparing \*MAT\_224 with reliable implemented material laws in LS-DYNA<sup>®</sup>.

### 3.2 Test Case Description

This Test Case contains 24 elements (6 rows times 4 columns) see figure 2. Each of the 4 columns specifies a different load case (see table 2 and figure 1), and each of the 6 rows contain elements with different material descriptions and input parameters (see table 3). The specification of element id's with load case, material type, and input properties can be found in table 4.

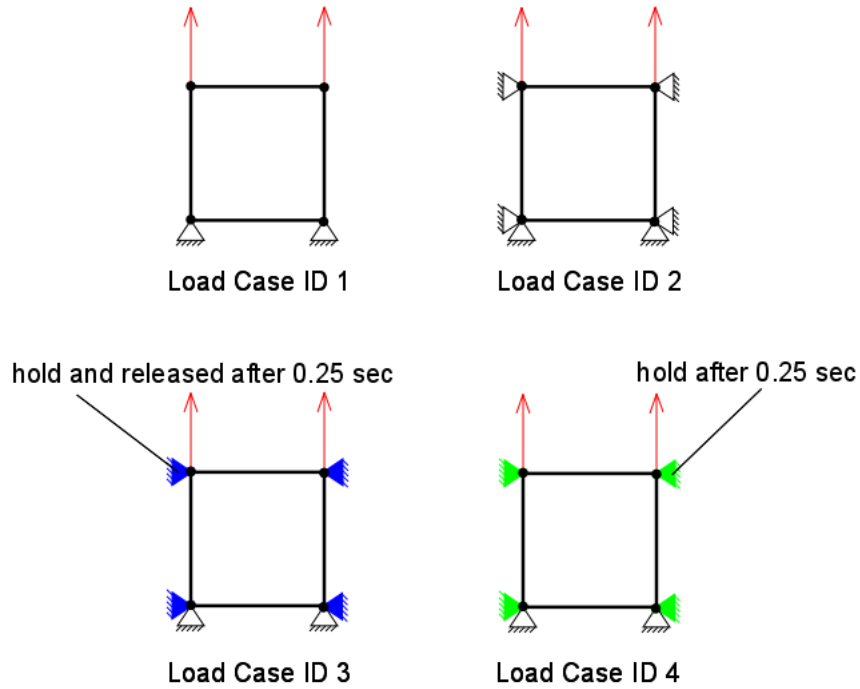


Figure 1: Load Cases

Load Cases ID	Load case specification
1	Uniaxial tension, orthogonal directions free
2	Uniaxial tension, orthogonal directions hold
3	Uniaxial tension, orthogonal directions hold and released after 0.25 seconds
4	Uniaxial tension, orthogonal directions hold after 0.25 seconds

Table 2: Load cases for the single elements test



Material ID	Material specification and parameters
1	Johnson-Cook (MAT_015), vp=1 viscoplastic formulation, m=0, thermal decoupled
2	Piecewise Linear Plasticity (MAT_024), vp = 1 viscoplastic formulation
3	Johnson Cook (MAT_015), vp=1 visco plastic formulation, m=1 fully thermal coupling
4	Tabulated Johnson-Cook (MAT_224), beta = 1 Amount of plastic work converted into heat
5	Tabulated Johnson-Cook (MAT_224), beta= 0.6 Amount of plastic work converted into heat
6	Tabulated Johnson-Cook (MAT_224), beta = 1 Amount of plastic work converted into heat, kt = 0

Table 3: Material types for the single elements test

Element ID	Material ID	Load Case ID
1	1	1
2	1	2
3	1	3
4	1	4
5	2	1
6	2	2
7	2	3
8	2	4
9	3	1
10	3	2
11	3	3
12	3	4
13	4	1
14	4	2
15	4	3
16	4	4
17	5	1
18	5	2
19	5	3
20	5	4
21	6	1
22	6	2
23	6	3
24	6	4

Table 4: Material ID and load case ID for the single elements

### 3.3 Model Description

The model contains 24 solid elements (see figure2). There are 4 columns each with different loading conditions defined on figure 1. Each row contains six solid elements each with different material types and input properties (see table 3).

The model specifications can be found in table 5, and table 6 defines the sub test case specification.

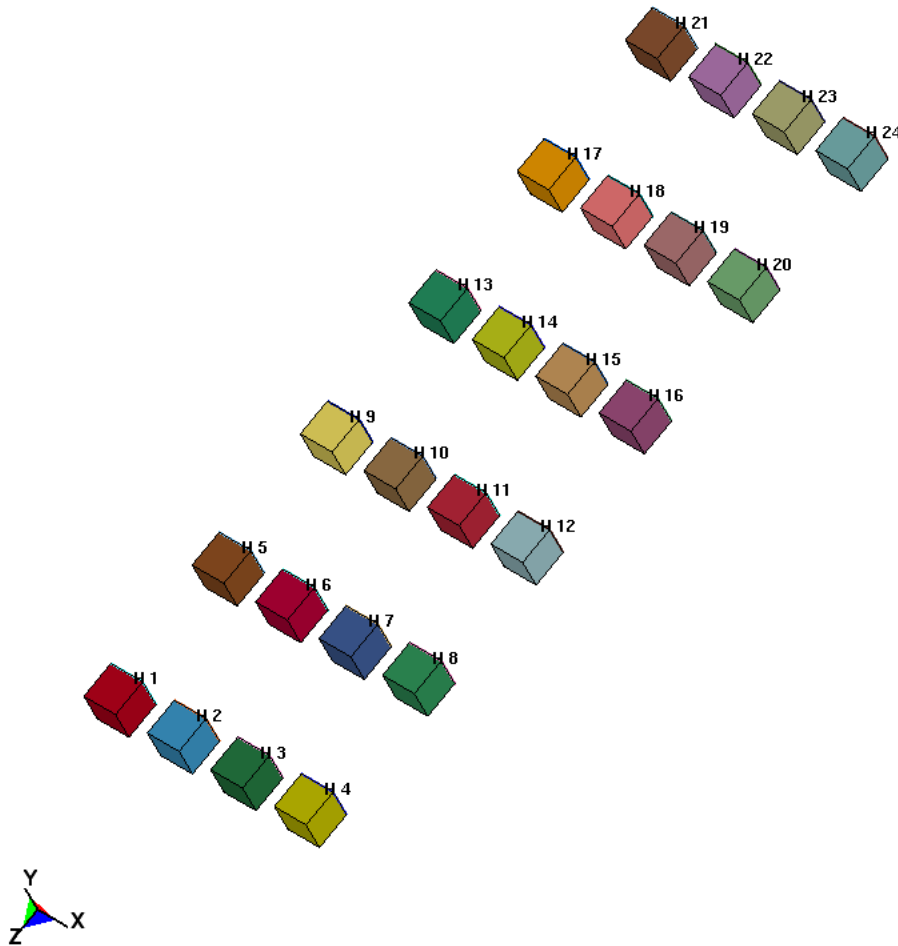


Figure 2: FEA model: 24 elements test, for detailed specifications see table 3

The material definitions and their parameters can be found in the input decks.

<b>FEA Model information</b>	
Nodes	192
Solid elements	24
Solid materials	24
Parts	24
Units	mm (length), sec. (time), tonne (mass), N/mm <sup>2</sup> (stress), Nmm (energy)

Table 5: FEA Model Information

<b>Sub Test Case ID</b>	<b>Input Deck Name</b>
1	MAT_224_single_element.k

Table 6: Specification of sub test cases

## 4 Test Specifications

### 4.1 Test Case Targets

Table 7 displays the test case targets. The test case targets specify values or a series of values taken from the finite element analysis solution of the test case and they are used in comparisons with each other.

Test Case Targets				
Target number	output	component type	component id	retrieved from
1	sigma zz	elout	1	binout/elout file
2	sigma zz	elout	2	binout/elout file
3	sigma zz	elout	3	binout/elout file
4	sigma zz	elout	4	binout/elout file
5	sigma zz	elout	5	binout/elout file
6	sigma zz	elout	6	binout/elout file
7	sigma zz	elout	7	binout/elout file
8	sigma zz	elout	8	binout/elout file
9	sigma zz	elout	9	binout/elout file
10	sigma zz	elout	10	binout/elout file
11	sigma zz	elout	11	binout/elout file
12	sigma zz	elout	12	binout/elout file
13	sigma zz	elout	13	binout/elout file
14	sigma zz	elout	14	binout/elout file
15	sigma zz	elout	15	binout/elout file
16	sigma zz	elout	16	binout/elout file
17	sigma zz	elout	17	binout/elout file
18	sigma zz	elout	18	binout/elout file
19	sigma zz	elout	19	binout/elout file
20	sigma zz	elout	20	binout/elout file
21	sigma zz	elout	21	binout/elout file
22	sigma zz	elout	22	binout/elout file
23	sigma zz	elout	23	binout/elout file
24	sigma zz	elout	24	binout/elout file

Table 7: Test Case targets for Test Case ID AWG-ERIF-9

Test case targets 1 to 24 are used to evaluate the cross cpu architecture consistency.

## 4.2 Pass/Fail Criteria

These are the Pass/Fail criteria used for the cross cpu architecture consistency of the Test Case ID AWG-ERIF-9.

The sub test case passes if all of the following criteria are reached:

- The test case target data falls within the corridor bounds.
- The sigma zz time history of targets 1, 5 and 21 are equal (excluding failure)
- The sigma zz time history of targets 2, 6 and 22 are equal (excluding failure)
- The sigma zz time history of targets 3, 7 and 23 are equal (excluding failure)
- The sigma zz time history of targets 4, 8 and 24 are equal (excluding failure)
- The sigma zz time history of targets 9 and 13 are equal (excluding failure)
- The sigma zz time history of targets 10 and 14 are equal (excluding failure)
- The sigma zz time history of targets 11 and 15 are equal (excluding failure)
- The sigma zz time history of targets 12 and 16 are equal (excluding failure)
- The sigma zz time history of target 17 lies in between targets 13 and 21 (excluding failure)
- The sigma zz time history of target 18 lies in between targets 14 and 22 (excluding failure)
- The sigma zz time history of target 19 lies in between targets 15 and 23 (excluding failure)
- The sigma zz time history of target 20 lies in between targets 16 and 24 (excluding failure)

Otherwise the the cross cpu architecture consistency 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<sup>®</sup> R9.0 Revision 108899 binaries by the following process:

- For a specific test case target, interpolate the data from different platform and executable (R9.0 Revision 108899) 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 (R9.0 Revision 108899) 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.

## 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 8 and the results are calculated with software versions defined in table 9.

Platform Name	Operating system	CPU type	MPI-Protocol	Number of cpu's <sup>1</sup>
mars	CentOS 6.5	Intel <sup>®</sup> Xeon <sup>®</sup> E5- 2640 @ 2.50GHz	Platform MPI 8.2.0.0	4
dinar3b	SUSE LES 11	AMD <sup>®</sup> Opteron <sup>®</sup> 6276 @ 2300MHz	Platform MPI 8.2.0.0	4

<sup>1</sup> Number of cpu's used for calculation of the test case

Table 8: Used Platforms and CPU Type's

Product	Version	Release	Revision	Parallel type <sup>1</sup>	Precision <sup>2</sup>	executable
LS-DYNA <sup>®</sup>	971	R11.2	26-gd2ace36	SMP	SP	ls971.26-gd2ace36.R11.2
LS-DYNA <sup>®</sup>	971	R11.2	26-gd2ace36	SMP	DP	ld971.26-gd2ace36.R11.2
LS-DYNA <sup>®</sup>	971	R11.2	26-gd2ace36	MPP	SP	mpp971.26-gd2ace36.R11.2
LS-DYNA <sup>®</sup>	971	R11.2	26-gd2ace36	MPP	DP	mpd971.26-gd2ace36.R11.2

<sup>1</sup> MPP = Massively Parallel Processing, SMP = Symmetric Multiprocessing

<sup>2</sup> SP = single precision, DP = double precision

Table 9: Tested LS-DYNA<sup>®</sup> version

## 5.2 Results Summary

Table 10 contains the results of the Test Case ID AWG-ERIF-9 completed with all combinations of software and hardware defined in section 5.1 (1 \* 4 \* 3 total calculation runs).

Details on the test results can be found in the section 5.3.

The table 10 cross cpu architecture consistency and validation 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	<b>PASS</b>

Table 10: Validation results summary for Test Case ID AWG-ERIF-9



### 5.3 Result Details

The following subsections contain detailed results for the Test Case ID AWG-ERIF-9 for LS-DYNA® R11.2 Revision 26-gd2ace36.

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 result file name, output, platform, executable and number of cpu's separated by comma. A minus sign before the number of cpu's refers to the compatibility option for SMP calculations (see [1] for details on this option).

#### Example for title and legend:

*Title:*

'AWG\_ERIF\_TEST\_CASE\_9: MAT\_224\_single\_element.k' states the test case ID 9 and name of the input deck for sub test case 1.

*Legend:*

'glstat\_internal\_energy,ham,ls971.26-gd2ace36.R11.2,4' states that the graph shows the internal energy derived from the 'glstat' output file for an input deck which was calculated on the 'ham' platform with a LS-DYNA® R11.2 Revision 26-gd2ace36 binary (SMP, single precision) on four processors.

### 5.3.1 Sub Test Case ID 1 - Test Target 1

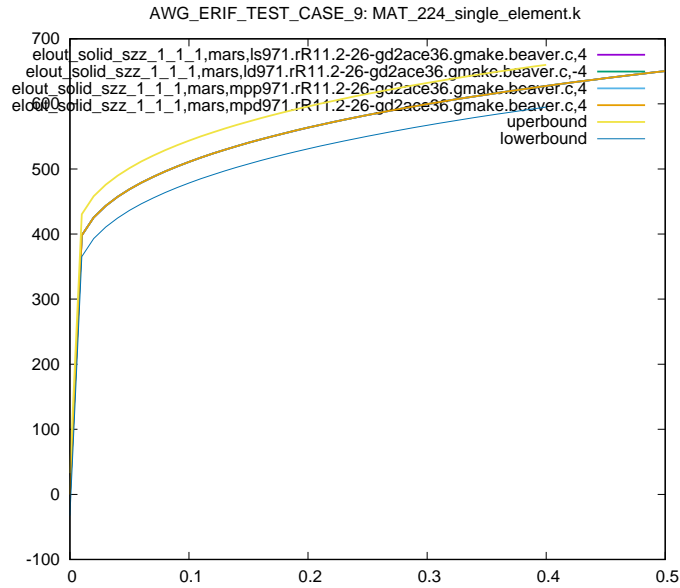


Figure 3: Cross platform results, zz stress element id 1, sub test case ID 1

### 5.3.2 Sub Test Case ID 1 - Test Target 2

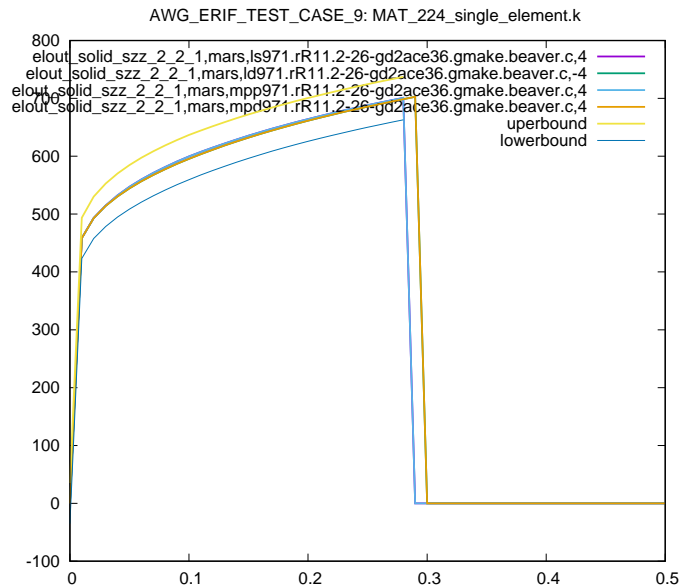


Figure 4: Cross platform results, zz stress element id 2, sub test case ID 1

### 5.3.3 Sub Test Case ID 1 - Test Target 3

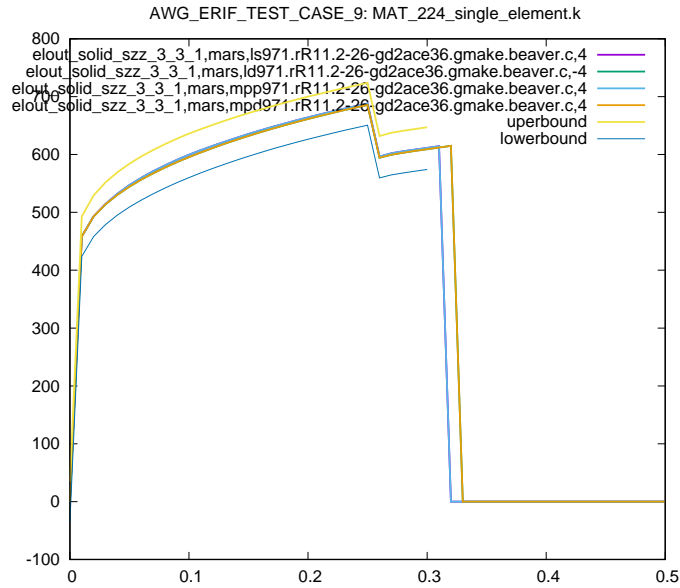


Figure 5: Cross platform results, zz stress element id 3, sub test case ID 1

### 5.3.4 Sub Test Case ID 1 - Test Target 4

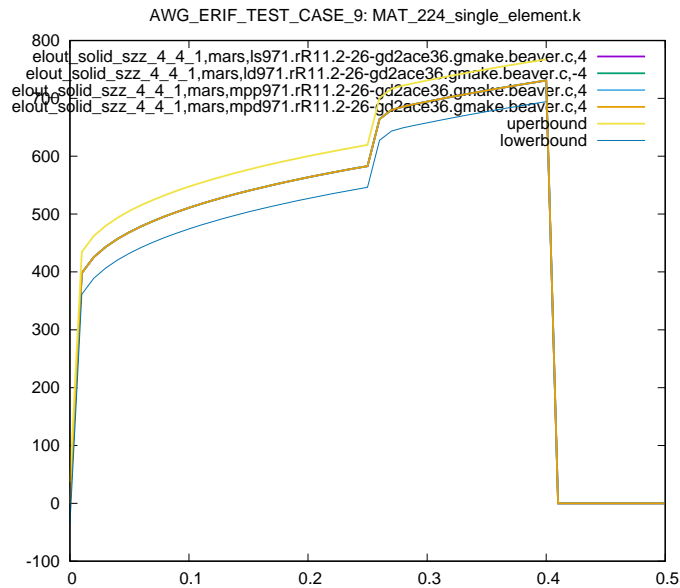


Figure 6: Cross platform results, zz stress element id 4, sub test case ID 1

### 5.3.5 Sub Test Case ID 1 - Test Target 5

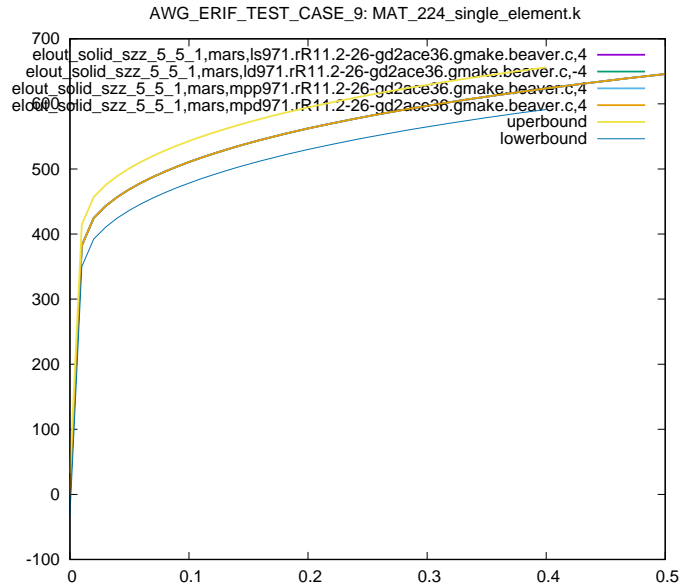


Figure 7: Cross platform results, zz stress element id 5, sub test case ID 1

### 5.3.6 Sub Test Case ID 1 - Test Target 6

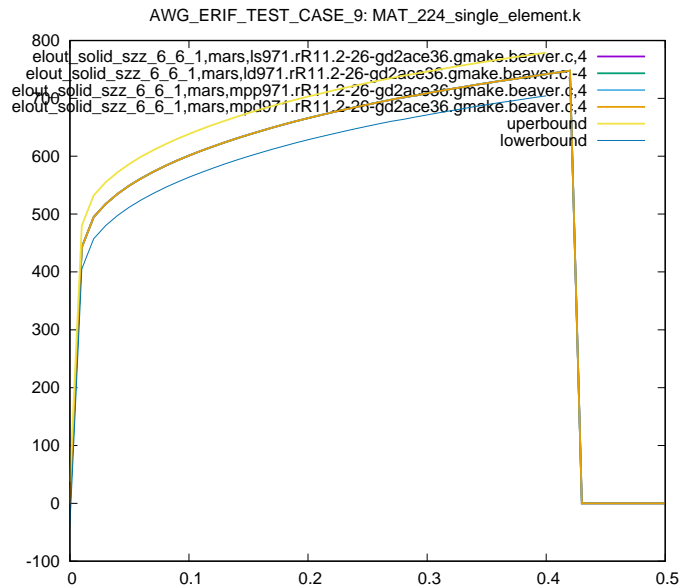


Figure 8: Cross platform results, zz stress element id 6, sub test case ID 1

### 5.3.7 Sub Test Case ID 1 - Test Target 7

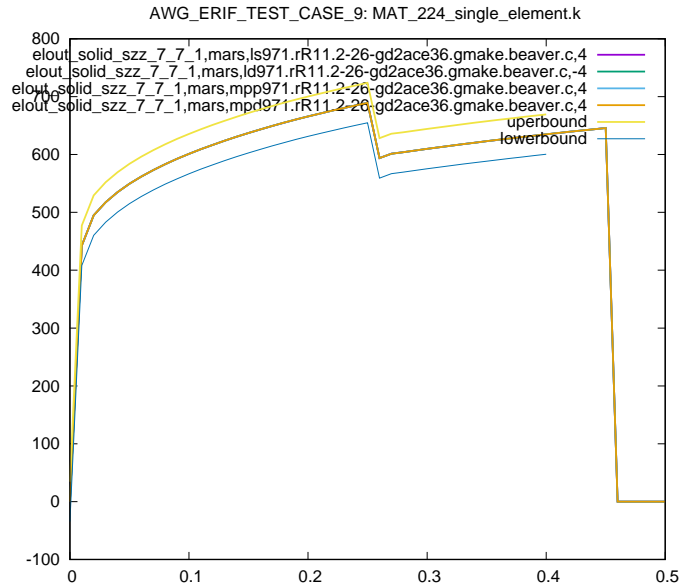


Figure 9: Cross platform results, zz stress element id 7, sub test case ID 1

### 5.3.8 Sub Test Case ID 1 - Test Target 8

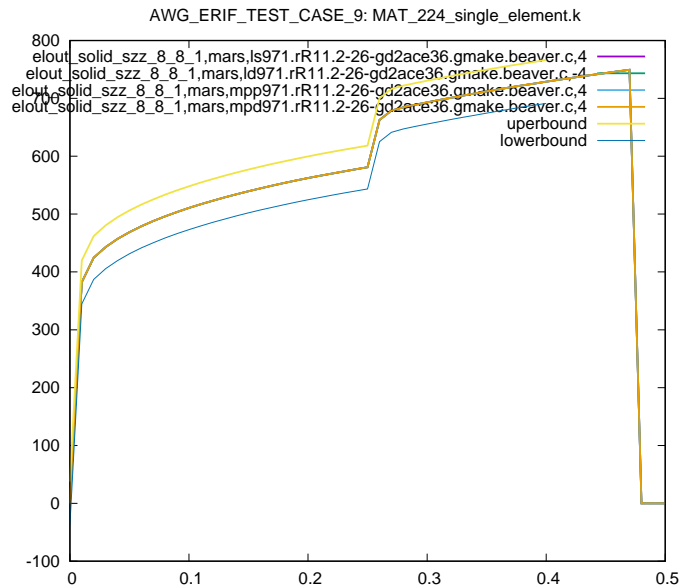


Figure 10: Cross platform results, zz stress element id 8, sub test case ID 1

### 5.3.9 Sub Test Case ID 1 - Test Target 9

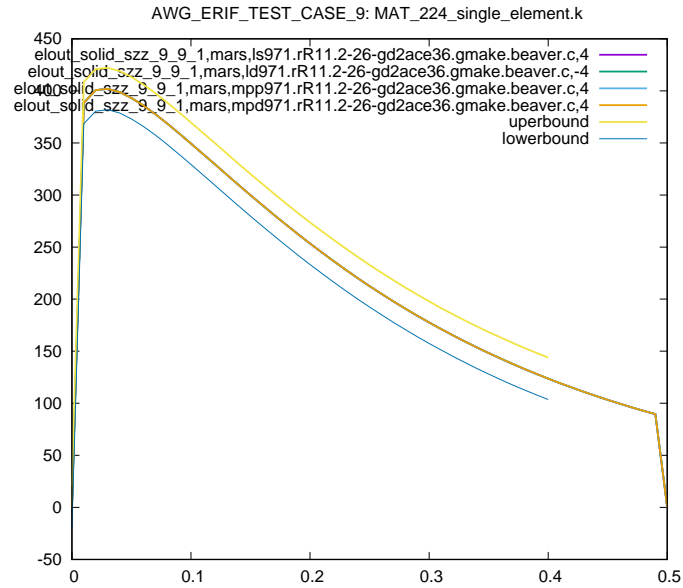


Figure 11: Cross platform results, zz stress element id 9, sub test case ID 1

### 5.3.10 Sub Test Case ID 1 - Test Target 10

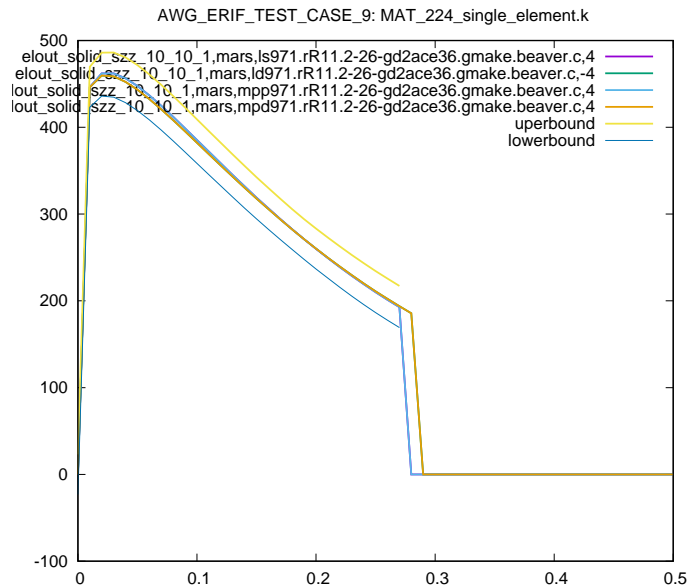


Figure 12: Cross platform results, zz stress element id 10, sub test case ID 1

### 5.3.11 Sub Test Case ID 1 - Test Target 11

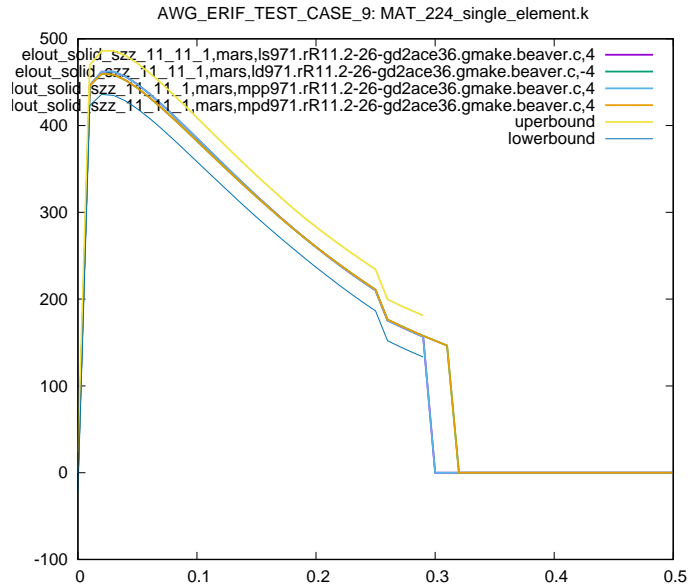


Figure 13: Cross platform results, zz stress element id 11, sub test case ID 1

### 5.3.12 Sub Test Case ID 1 - Test Target 12

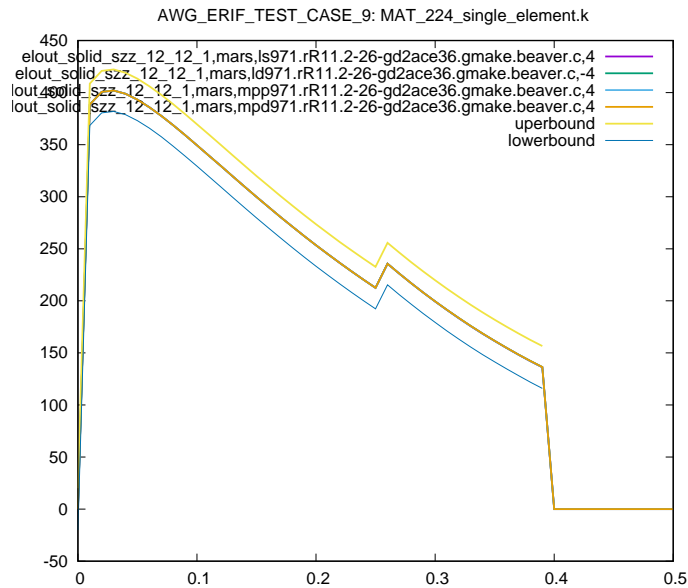


Figure 14: Cross platform results, zz stress element id 12, sub test case ID 1

### 5.3.13 Sub Test Case ID 1 - Test Target 13

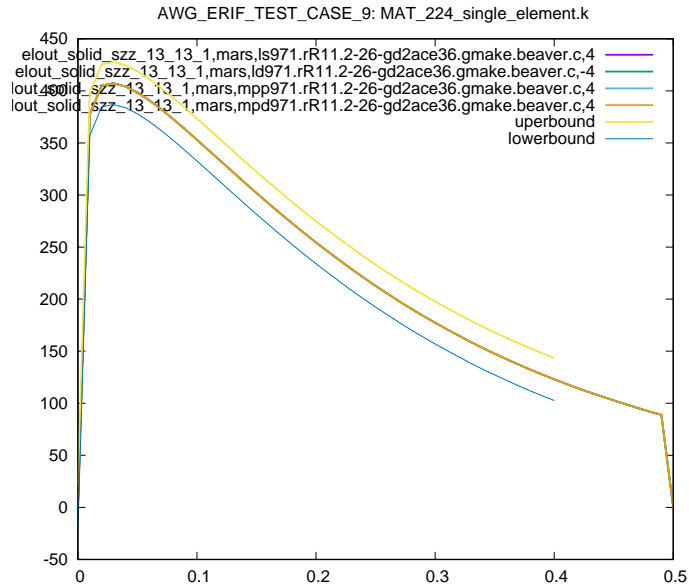


Figure 15: Cross platform results, zz stress element id 13, sub test case ID 1

### 5.3.14 Sub Test Case ID 1 - Test Target 14

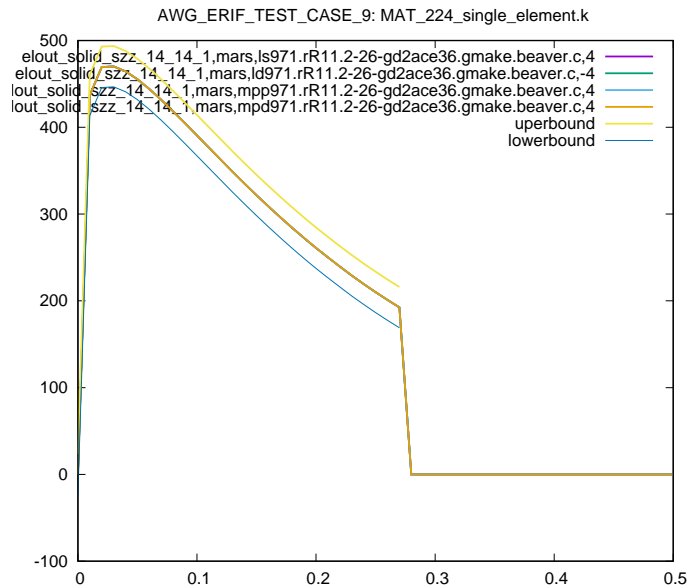


Figure 16: Cross platform results, zz stress element id 14, sub test case ID 1



### 5.3.15 Sub Test Case ID 1 - Test Target 15

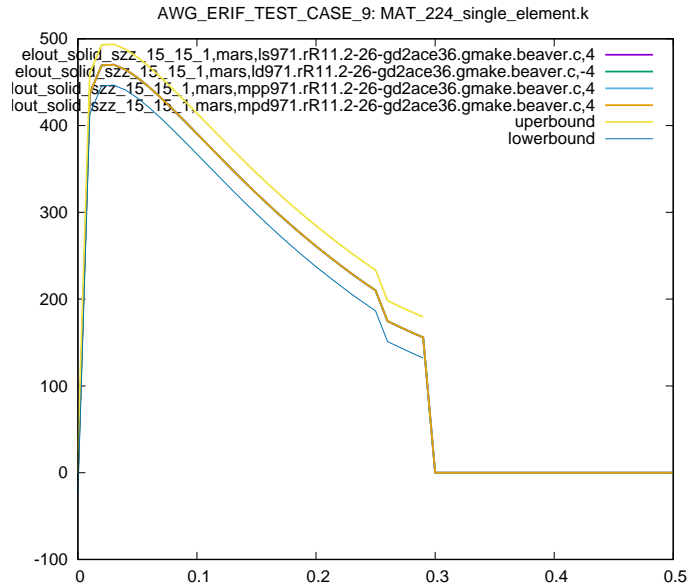


Figure 17: Cross platform results, zz stress element id 15, sub test case ID 1

### 5.3.16 Sub Test Case ID 1 - Test Target 16

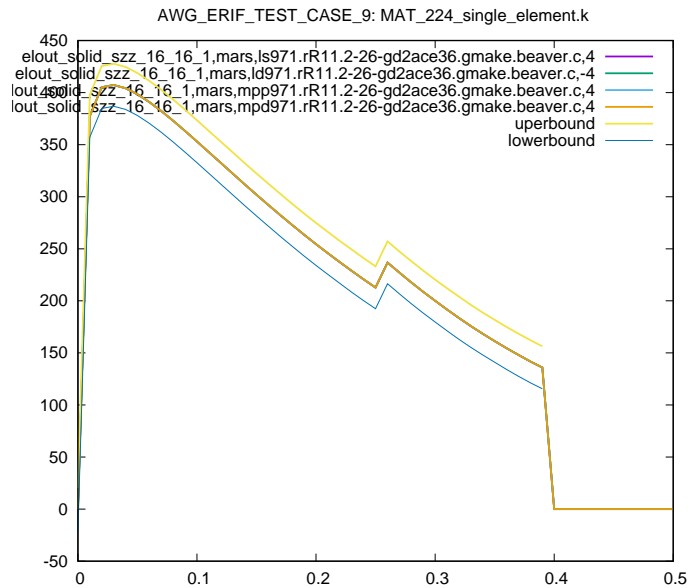


Figure 18: Cross platform results, zz stress element id 16, sub test case ID 1

### 5.3.17 Sub Test Case ID 1 - Test Target 17

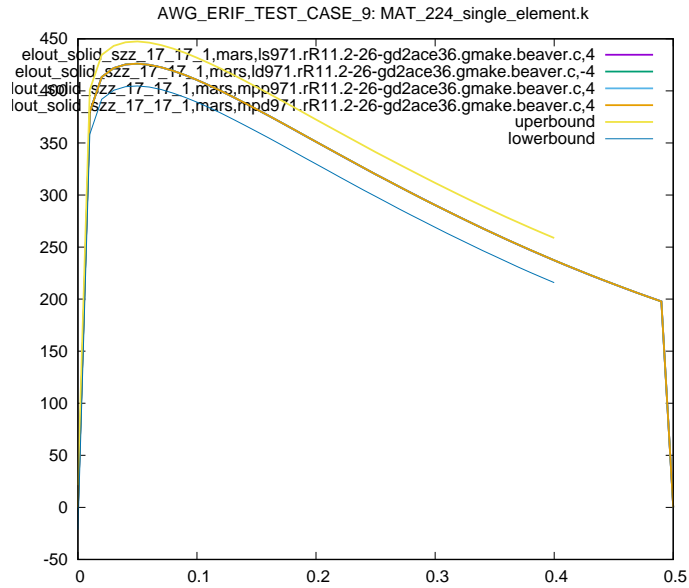


Figure 19: Cross platform results, zz stress element id 17, sub test case ID 1

### 5.3.18 Sub Test Case ID 1 - Test Target 18

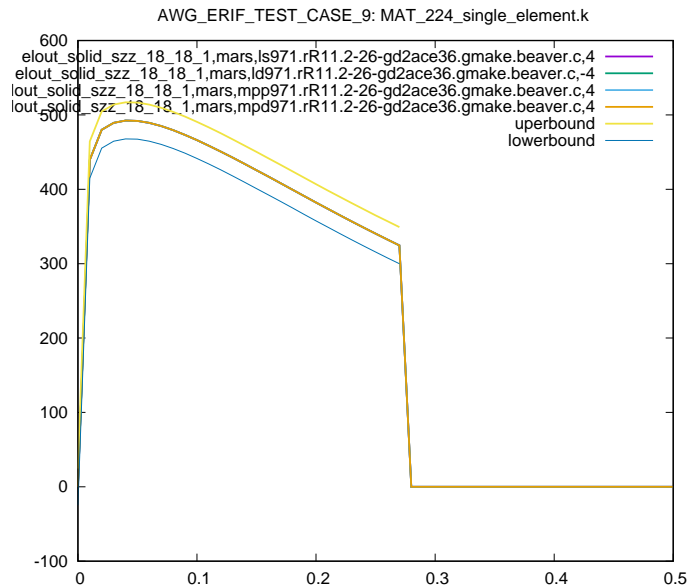


Figure 20: Cross platform results, zz stress element id 18, sub test case ID 1

### 5.3.19 Sub Test Case ID 1 - Test Target 19

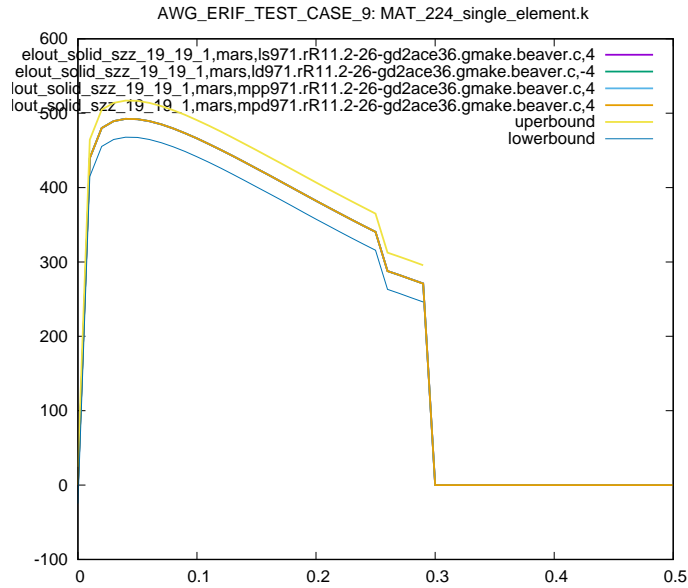


Figure 21: Cross platform results, zz stress element id 19, sub test case ID 1

### 5.3.20 Sub Test Case ID 1 - Test Target 20

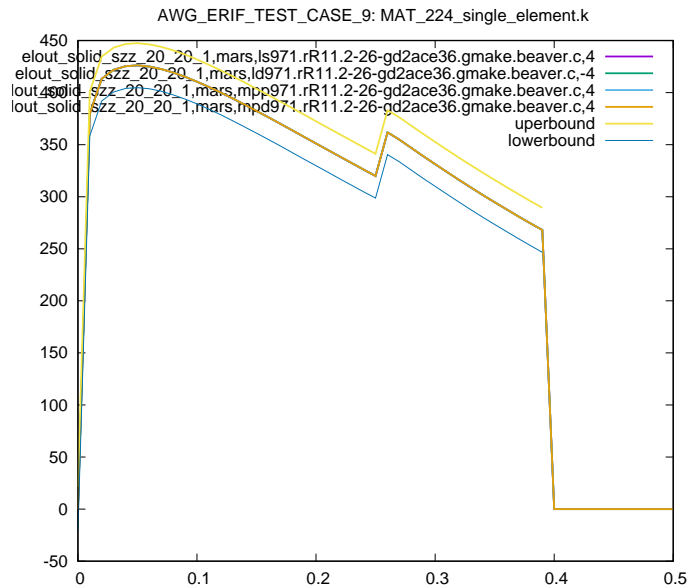


Figure 22: Cross platform results, zz stress element id 20, sub test case ID 1

### 5.3.21 Sub Test Case ID 1 - Test Target 21

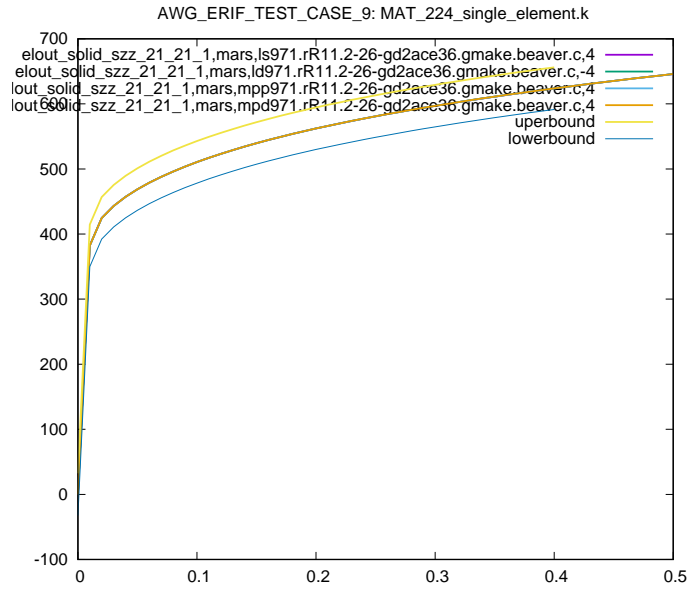


Figure 23: Cross platform results, zz stress element id 21, sub test case ID 1

### 5.3.22 Sub Test Case ID 1 - Test Target 22

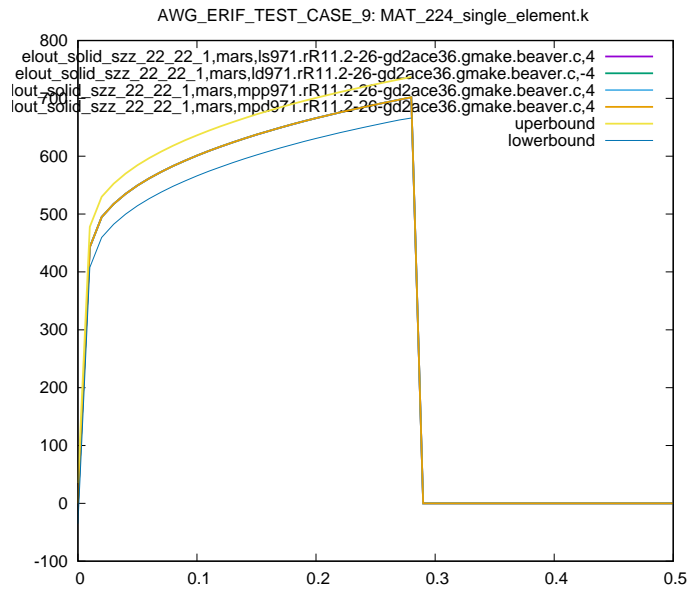


Figure 24: Cross platform results, zz stress element id 22, sub test case ID 1

### 5.3.23 Sub Test Case ID 1 - Test Target 23

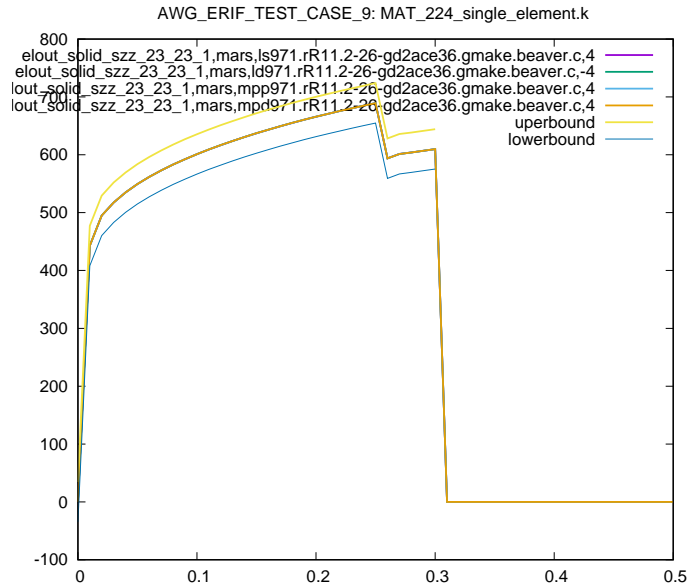


Figure 25: Cross platform results, zz stress element id 23, sub test case ID 1

### 5.3.24 Sub Test Case ID 1 - Test Target 24

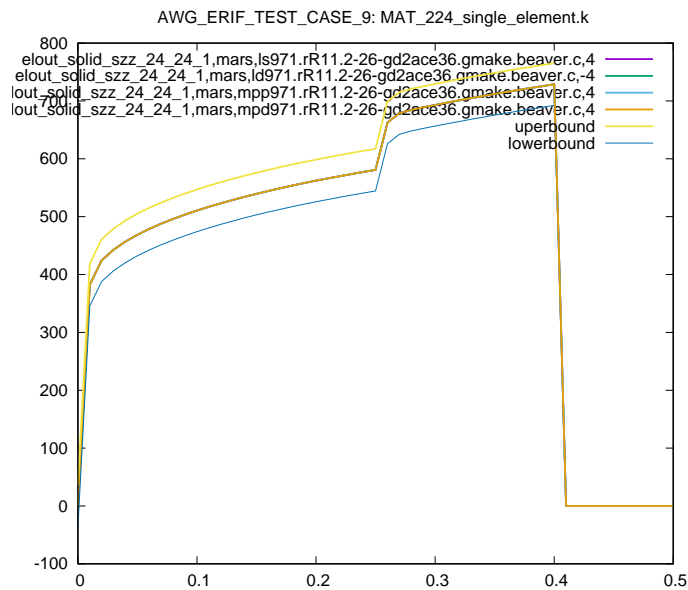


Figure 26: Cross platform results, zz stress element id 24, sub test case ID 1

## References

- [1] LSTC, *LS-DYNA KEYWORD USER MANUAL*, 7374 Las Positas Road, Livermore, CA, 94551, USA, version 971 ed., May 2007.