Experimental Verification of Dynamic Stress Analysis Performed With DYNA 3D

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1. Introduction

Full scale drop tests of casks to be licensed as type B(U)-packages according to the IAEA-Regulations are in most cases necessary because certain specific cask features (i.e. bolts, welds) are not easily modeled. However, larger shipping casks can weigh up to 100 tons or more. The tests are extremely expensive and only a limited number of test facilities exist. If it can be shown that computer methods give reliable results for simulated drop tests, the number of necessary tests can be reduced. Static and/or one-dimensional computer models in most cases do not give satisfying results. Since the 3-dimensional dynamic finite element code DYNA 3D (developed by LLNL) was made available to us, we were interested in showing the possibilities of this powerful tool by comparison of measured test results with computed stresses in the cask body. For this purpose a series of carefully instrumented drop tests with ductile cast iron casks were chosen.

2. Experimental Tests

In June 1987, three different drop tests with an 8 ton ductile cast iron cask were performed from a drop height of 9 m and in a horizontal cask position (side drop). The impact to the cask was varied by choosing different target hardnesses. The test specifications of these experiments are listed in Tab. 1. The same cask was used for all three different drop tests. The cask body was instrumented with 5 strain gages and 2 accelerometers at 5 different locations at the cask cavity surface and in the cask midplane at the outer surface. In Fig. 1 the installation of the detectors is shown. Standard equipment was used for detection of acceleration and strain.

3. Dynamic Stress Analysis

3.1 Computer Code Characteristics

The 3-dimensional finite element code DYNA 3D, developed by LLNL, was selected for a benchmark calculation of the drop tests. This computer code allows the analysis of transient dynamic problems using explicit time integration as well as the solution of problems involving a very high degree of material and geometric non-linearity. All elements have a large range of strain formulation and can undergo large movement.

3.2 Finite Element Calculation

The finite element mesh of the cask and the position of the detector points are shown in Fig. 1. All calculations with DYNA 3D are performed using a DEC VAX II computer. The code is also implemented on a CRAY XMP-2 computer.

A pre-drop test analysis with DYNA 3D was not possible at the time when the tests were performed. For the post-drop test analysis a series of calculations were done to study effects of major influences to the impact of a cask in a drop test after knowing the test results.

To study the effects of target hardness, five different cases for the foundation properties were simulated in the calculation:

a) Ideal unyielding foundation
b) Elastic steel plate, 10 cm (4 in.) thick
c) Elastic steel plate, 20 cm (8 in.) thick
d) Elastic-plastic plate
e) Test foundation (20 cm steel plate on top of 1000 ton concrete embedded in soil)

To study the effects of cask orientation and small deviation from ideal position, the horizontal drop position of the cask without impact limiters onto the real test foundation was selected.

4. Comparison of Test Results with Calculation

Some test results are listed in Tab. 2. The accelerations observed in the different cases range from max. 205 g for the drop with impact limiters (Case 1) to max. 2450 g for the drop without impact limiters. In all cases the impact to the cask takes place during the first 15 msec.

Since the test results were known, it was tried after the test series to verify these results with DYNA 3D. The first results obtained from calculation were very discouraging.

The g-forces calculated for Case 2 are overpredicted up to a factor of 4 compared to the results observed in the tests. We had no experience with this kind of benchmark problems and investigated several parameters in more detail to find an explanation for the deviations of the calculational results.

For this purpose Case 2 was selected to examine in more detail.

4.1 Effect of Target Hardness

In Tab. 3 results obtained from calculation for different target hardnesses are given. The results show that a deviation i.e. for the g-forces of not more than about 20 % can be expected if the foundation is not properly modeled in the computer model. This is certainly not an explanation for the discrepancies.

4.2 Effect of Cask Orientation

In a second series of calculations the influence of small angular displacements from ideal horizontal drop positions were investigated again for Case 2. The reason for this was found in the observation of high-speed photographs which give an indication of small inclination from the ideal drop position.

In Fig. 2 a typical result (Case 2, DMS 5) for the acceleration calculated in a range of 0 to 2 degrees angular displacement, compared to the measured values, is shown. From these results it can be seen that deviations in the observed range for the acceleration can be expected even for only small angular displacements from the horizontal position. In Fig. 3 the same result is presented for calculated strains (Case 2, DMS 5).

4.3 Verification of Experimental Results

After knowing the different effects, a verification of the DYNA 3D calculation can be shown.

In Fig. 4 a comparison (Case 2, ACC 1) of the calculated and measured acceleration is shown for an inclination of 1 degree from the ideal position. Fig. 5 gives as an example of the results for the strain (DMS 2). The footprint of plastic deformation on cask after the drop test showed that a small angular displacement was present.

5. Conclusion

DYNA 3D is a powerful tool for predicting g-forces and stresses for studying impacts on casks without impact limiters. However, the limitations (i.e. measuring uncertainty) should be known if calculational results are compared to measured ones.

For the calculation of drops for a cask with impact limiters, there is a minor influence of angular displacement. However, the results obtained up till now for this case do not give satisfying agreement between calculation and test. We believe that the reason for this is an insufficient data base for the impact limiters material wood for calculation of large dynamic displacements. We are currently trying to solve this problem.

Test Specimen : Ductile Cast Iron Cask
Type MOSAIK, 8 tons

Drop Height/Position : 9 m, horizontal

Kind of Target :

1. Unyielding, Cask with Impact Limiter
2. Unyielding, Cask w/o Impact Limiter
3. 20 cm Concrete Plate on Top of Unyielding Foundation

Instrumentation : 5 Strain gages
2 Accelerometers

__Tab. 1:__ **Test Specification for the Three Drop Tests**

Drop Test No	ACC 1,2 max. Accel. [g]	DMS 2 max. Strain [cm/m]	DMS 2 max. Stress [N/mm^2]
1	205	0.03	51
2	2450	0.7	250
3	-	0.22	220

Tab. 2: Test Results of Different Drop Tests

(MOSAIK cask, 9m horizontal drop, Case 1: with impact limiters, Case 2,3:w/o impact limiters)

Case	rel. g-Force (ACC 1,2)	rel. Strain (DMS 3)
a	1.00	1.00
b	0.83	0.93
c	0.82	0.90
d	0.90	0.84
e	0.78	0.82

Tab. 3: Effect of Target Hardness

(Calculated for MOSAIK cask w/o impact limiters, 9m drop, horizontal position)

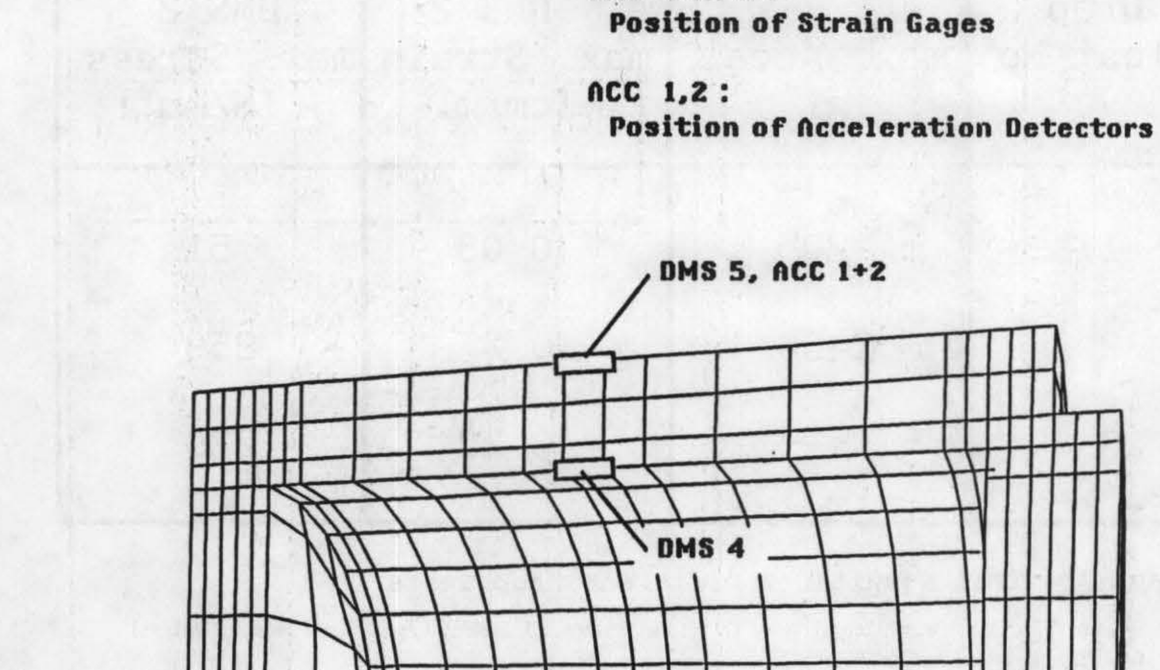

Fig. 1: Finite Element Model and Position of Detectors

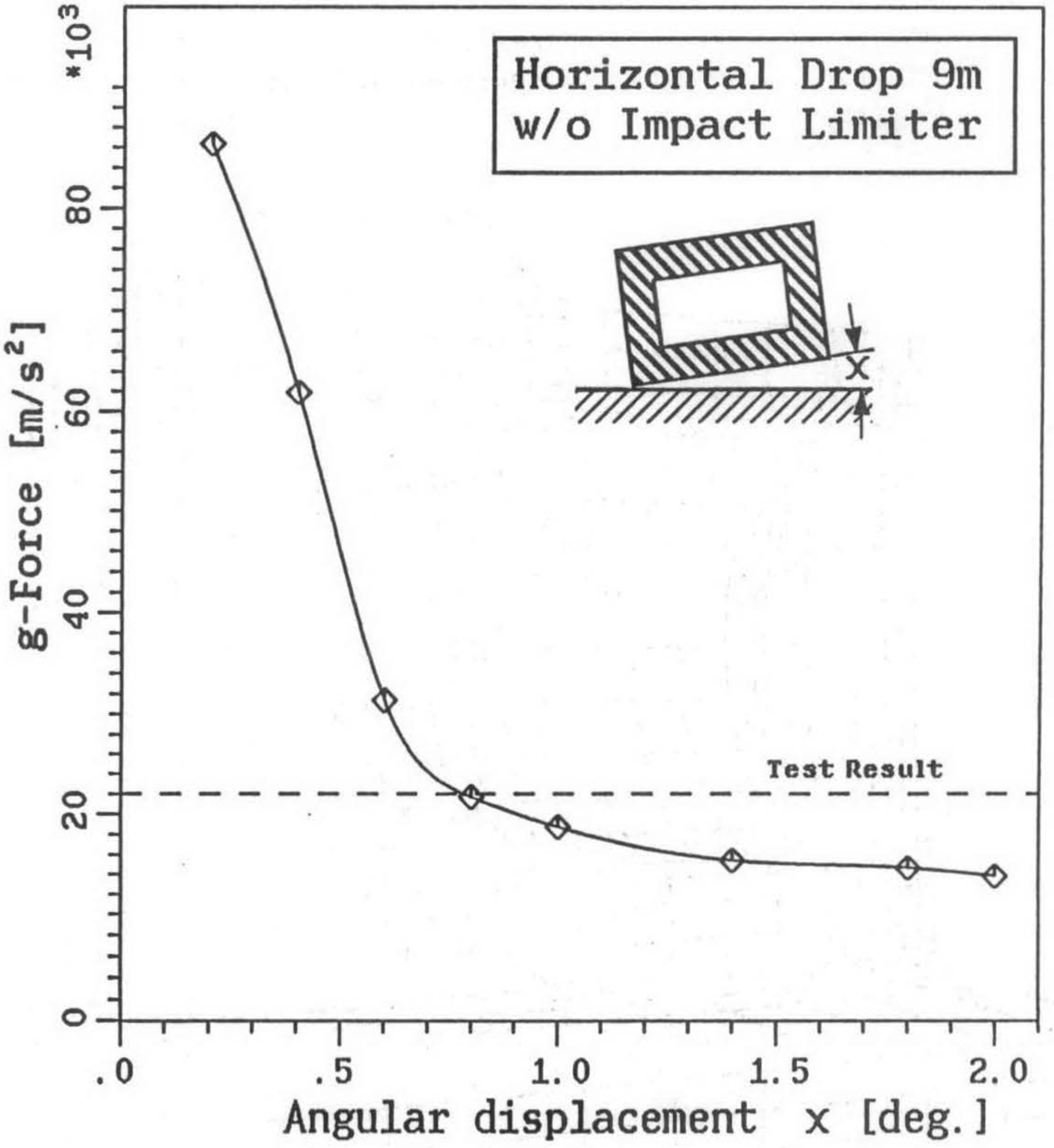

Fig. 2: Effect of Angular Displacement on g-force

(Horizontal 9m drop, MOSAIK cask w/o impact limiters)

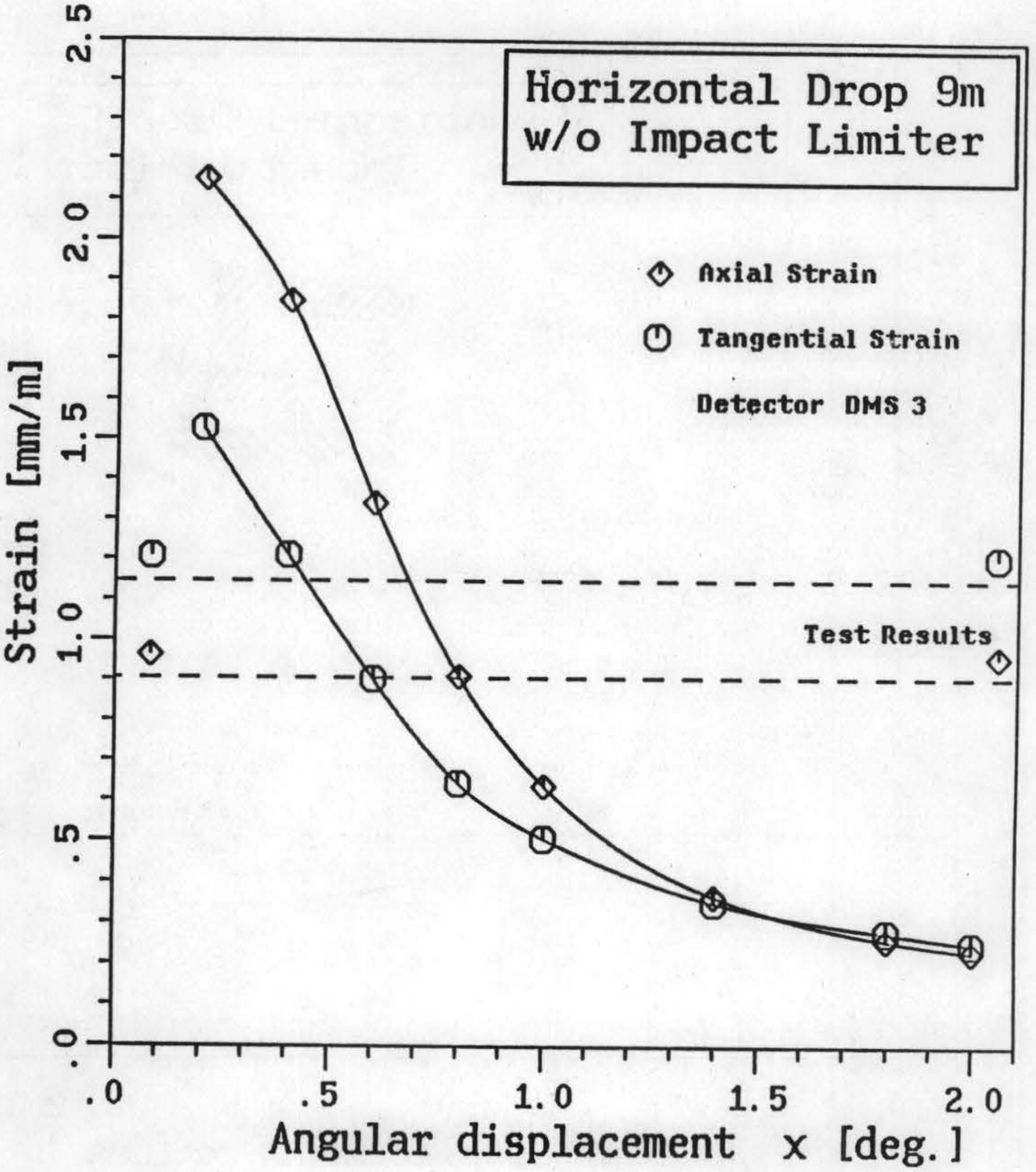

Fig. 3: Effect of Angular Displacement on Strain
(Horizontal 9m drop, MOSAIK cask w/o impact limiters)

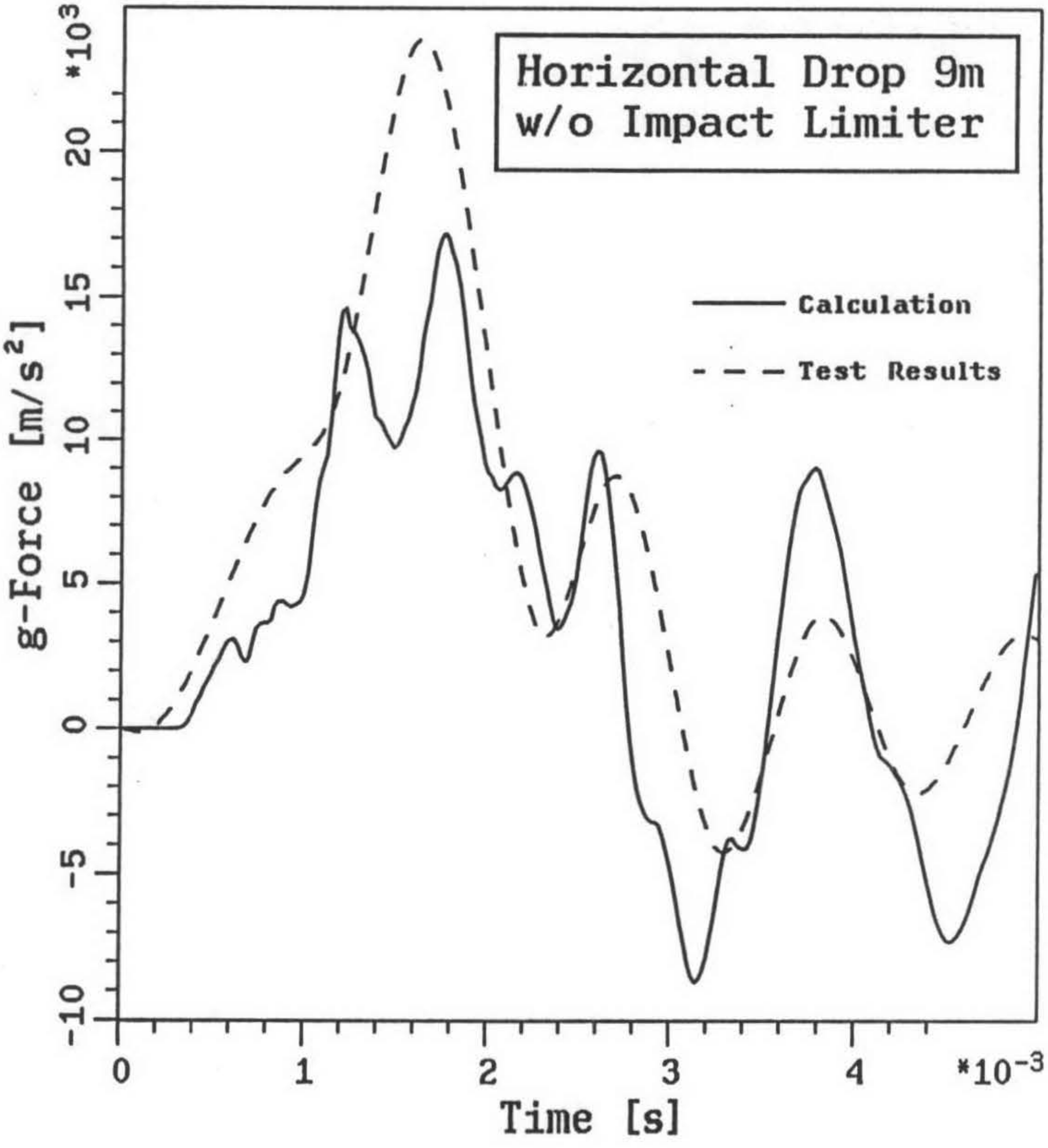

Fig. 4: Comparison of Calculated and Measured g-forces
(Horizontal 9m drop, MOSAIK cask w/o impact limiters, ACC 1)

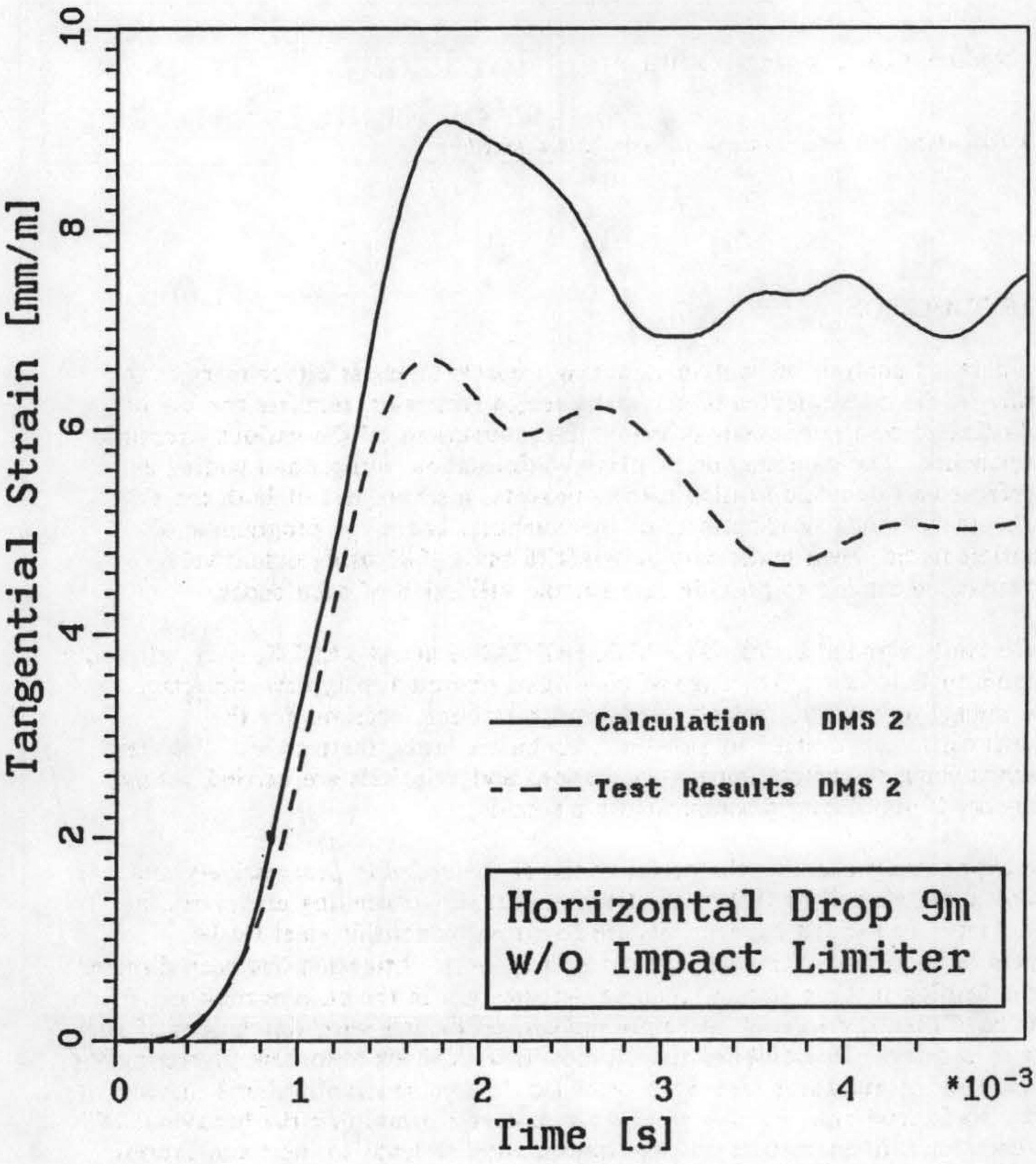

Fig. 5: Comparison of Calculated and Measured Tangential Strain

(Horizontal 9m drop, MOSAIK cask w/o impact limiters, DMS 2)