SMiRT-12 / K. Kussmaul (Editor)
1993 Elsevier Science Publishers B.V.



J04/4

# BENCHMARK CALCULATIONS FOR MECHANICAL STRESSES UPON A TRANSPORT CASK

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## BENCHMARK CALCULATIONS

### 1 INTRODUCTION

Due to the regulations for the safe transport of type B(U) packages (/1/ or /2/), transport casks for spent fuel elements have to prove their ability to withstand a series of tests which simulate various hypothetical incidental drops without loss of leaktightness.

According to /1/ or /2/ it is permissible to apply analytical methods instead of tests. One of these methods used for transport casks of the CASTOR type is the finite element method. Thus it is possible to calculate displacements and stresses or strains in the time domain. The knowledge of these quantities makes it possible to compare them with allowable values and to establish the safety margin for the various load cases. This method is also of advantage for design calculations as the variation of parameters can be done with a small amount of effort compared to tests. Due to the progress of hardware development, even large finite element models can be analyzed by means of personal computers nowadays, which makes the application of this method even more interesting.

Supposition for the use of a certain finite element program, however, is the proof that for the analysis of certain problems the code produces results which approach the actual values as close as possible. This can be verified by benchmark calculations.

For the present case it had to be shown that the load due to so-called type B(U) tests can be calculated in a sufficiently accurate manner by means of the finite element program ADINA /3/.

Among others, the type B(U) test cases are load cases submitting transport casks either to a free drop from a height of 9 meters onto a rigid target or to a penetration test during which the cask drops from a height of 1 meter onto a defined bar.

During the verification calculations, the ability of the code to approach the non-linear processes is verified.

Having proved the basic ability of ADINA by means of benchmark calculations of the 9 meter drops for simplified geometries in /4/, some more verifications were made for the more complex geometry of a transport cask. The cases analyzed were the 9 meter drop with impact flat onto the cylindrical shell of the shock absorbers at the top and bottom part as well as the 1 meter drop with impact of the bar in the center of the cylinder wall.

## 2 TEST CASK

Fig. 1 shows the test cask with the position of the measuring points for the 9 meter drop as well as the 1 meter penetration test. The tests were carried out in Japan and are described in /5/. The cask was made of nodular cast iron GGG 40. The major dimensions were: overall length 4700 mm, outer diameter 2350 mm, cylinder wall thickness 425 mm. The cask was bolted with a primary and a secondary lid. The total mass including the shock absorbers at the top and bottom part as well as the dummy loading were 110 000 kg. The cask was equipped with a number of accelerometers as well as strain gauges.

## 3 CALCULATIONS

Benchmark calculations should always be carried out without knowing the test results. Following this principle, as a first step calculations were made and then the results were compared to the measurements.
The transformation of the physical problem of the drop cases into mathematical models by means of the finite element method was done in such a way that the procedure can also be applied to design calculations. This meant that for assumptions for the modelling or boundary conditions, but also for the coarseness of the mesh aspects such as conservativity of the results and computer resources prevailed. Essential was that those strains, which were to subject to a comparison between allowable and calculated values within a design calculation were sufficiently approximated.

### 3.1 9 Meter Drop onto the Cylindrical Shell of the Shock Absorbers Including Primary Lid (Test 1)

First of all the load-deflection of a shock absorber was calculated by means of a three-dimensional finite element model. The shock absorbers of the test cask covered only 180° in circumference. Due to this and taking advantage of the symmetry of the finite element mesh, a 90° model was sufficient (fig. 2). Isoparametric solid elements were used. The shock absorbers were made of wood with a steel cladding. The non-linear material data for the calculation using the theory of large strains and large displacements were taken from /5/. Including the gap elements between the shock absorber's surface and the target, the model consisted of 1153 degrees of freedom. The load displacement behaviour found (fig. 3 was converted into a stress-strain-relationship for truss elements, which simulate the shock absorbers in the three-dimensional model of the cask.

The modelling of the cask itself was done by means of isoparametric solid elements (fig. 4) as well as trusses and gap elements for the bolts and the lid regions (fig. 5). Using symmetry, the model covered half of the cask with 10 155 degrees of freedom. As initial velocity, a value of 13.3 m/s was implied on the model corresponding to a drop from a height of 9 meters. The elasto-plastic material data were set in /5/. The calculation in the time domain resulted in the transient accelerations, displacements, stresses and strains. Fig. 6 shows the position of the locations where the results were plotted relating to the measuring points. The time histories of accelerations and stresses are shown as examples in fig. 7 and 8.

### 3.2 9 Meter Drop onto the Cylindrical Shell of the Shock Absorbers without Primary Lid (Test 2)

This second 9 meter drop was carried out without primary lid. Due to this, the finite element model was modified, yielding in 9712 degrees of freedom. The analysis procedure as described in chapter 3.1 remained the same.

### 3.3 1 Meter Penetration Test

At first the load displacement history (fig. 9) of the bar (150 mm diameter, 300 mm length) was calculated by means of an axisymmetric elasto-plastic finite element calculation under consideration of the theory of large displacements and large strains. The deformation shape of the bar for a bulging of 80 mm, 160 mm and 240 mm is shown in fig. 10. This behaviour was converted into a stress-strain-relationship for truss elements simulating the bar in the three-dimensional cask model (fig. 11). The model was similar to the one in chapter 3.1 except for the impact area. It comprised a total of 10 865 degrees of freedom. The initial velocity was 4.4 m/s. Other than that the procedure for the calculation corresponds to chapter 3.1.

## 4 COMPARISON MEASUREMENTS TO CALCULATIONS

Having done all calculations, the measurements were analyzed. It was found that a relatively small number of values were reliable. During the test many of them were destroyed or showed incorrect results. As far as the values were reliable, they were used for the comparison.

### 4.1 Accelerations

The comparison of the accelerations is to be seen in tab. 1.

Tab. 1. Comparison of Accelerations

| load case | measuring point | calculations | test |
|---|---|---|---|
| 9 m drop | lid | 143 g | 248 g |
| test 2 | cylindrical part | | |
| | center top | 138 g | 121 g - 150 g (4 meas.pts) |
| | bottom | 143 g | 104 g |
| 1 m penetration test | cylindrical part | | |
| | center top | 38 g | 35 g |

The measuring results of top and bottom lead to the result that the impact onto both shock absorbers does not take place at the same time. Compatibility is good.

### 4.2 Shock Absorber and Bar Deformations

The comparison is shown in tab. 2.

Tab. 2. Comparison of Shock Absorber and Bar Deformations

| load case | location | calculations | measurements |
|---|---|---|---|
| test 1 | lid | 144 mm | 184 mm |
| | bottom | 142 mm | 172 mm |
| test 2 | lid | 142 mm | 166 mm |
| | bottom | 142 mm | 180 mm |
| penetration test | bar | 75 mm | 94 mm |

Regarding the relatively simple modelling of the shock absorbers, the compliance is satisfactory. The analysis of the bar deformations in /3/ led to the conclusion that the bar hit the cylindrical part obliquely instead of perpendicularly. This resulted in an additional bending which is not included in the calculation model.

### 4.3 Strains

Tab. 3 shows the comparison for test 1. The difference of the strains between test 1 and test 2 can be neglected for the calculation. The same refers to the strains measured. Tensile strains show positive sign.

Tab. 3. Test 1, Comparison of Strains

| location | longitudinal strain in o/oo | |
|---|---|---|
| cylindrical part center | calculations | measurements |
| 12:00 a.m. outer surface | -0.235 | -0.25 |
| 3:00 p.m. outer surface | -0.164 | -0.16 |
| 6:00 p.m. outer surface | 0.7 | 0.52 |

Especially with regard to the tensile strains, important for fracture mechanics, the measurements are met by the calculations conservatively.

Tab. 4 shows the comparison of strains for the 1 m penetration test.

Tab. 4. 1 Meter Penetration Test, Comparison of Strains

| location | strain in o/oo | | | |
|---|---|---|---|---|
| cylindrical part center | calculations | | measurements | |
| | longi-tudinal | circum-ferential | longi tudinal | circum-ferential |
| 12:00 a.m. outer surface | 0.904 | 1.053 | 0.2 | 0.4 |

The strains found by means of calculation are higher than those measured due to the bending of the bar not considered in the calculation model.

## 5 CONCLUSIONS

Considering that for complex structures such as a transportation cask the assumption of boundary conditions for the calculation as in this present case cannot always exactly meet the boundary conditions valid for the test and that measured values may be incorrect, it can nevertheless be said that the calculations meet the measurements. Thus it is possible to do design calculations in a conservative way by means of the finite element method using ADINA.

## REFERENCES


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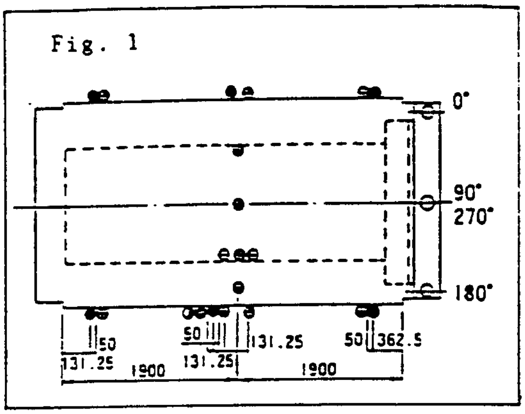



Fig. 1

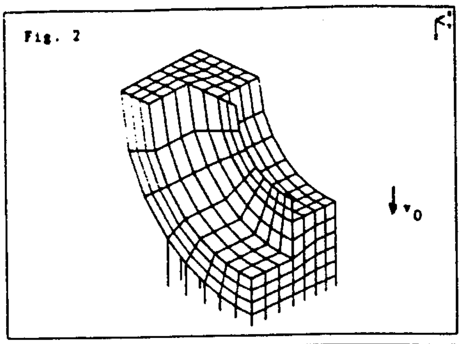


Fig. 2

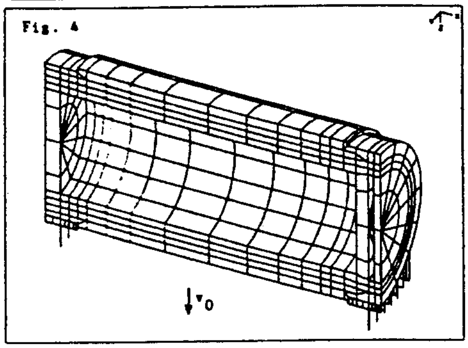
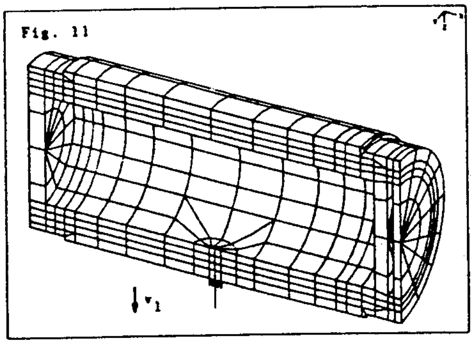


Fig. 4



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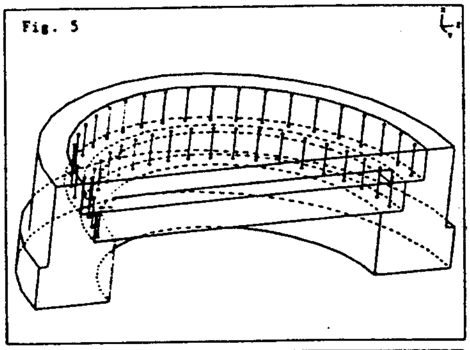

Fig. 5

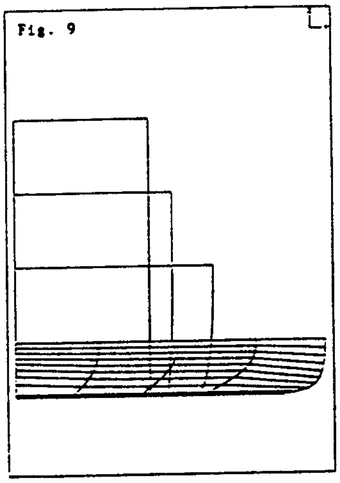

Fig. 9

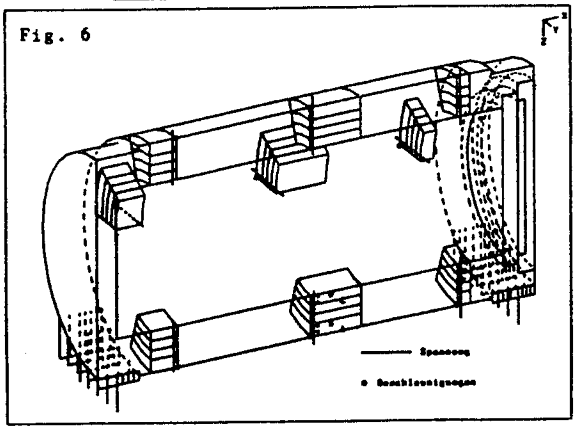

Fig. 6

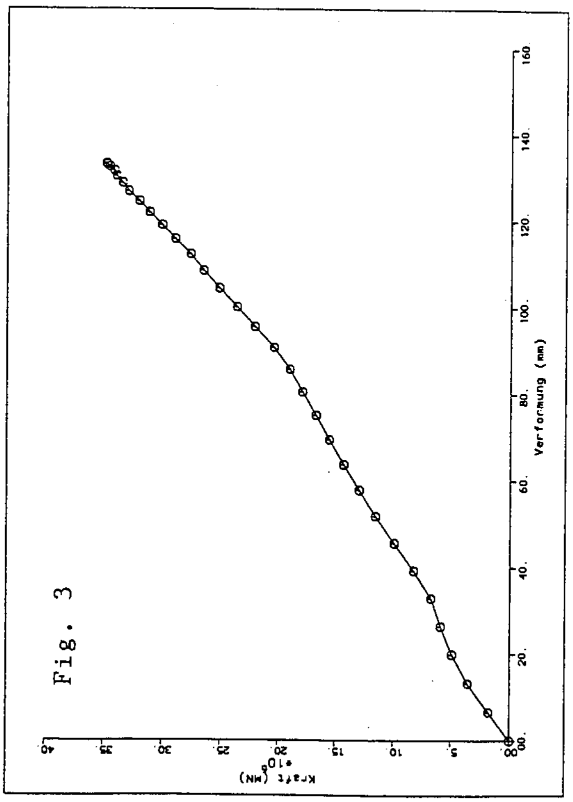

Fig. 3

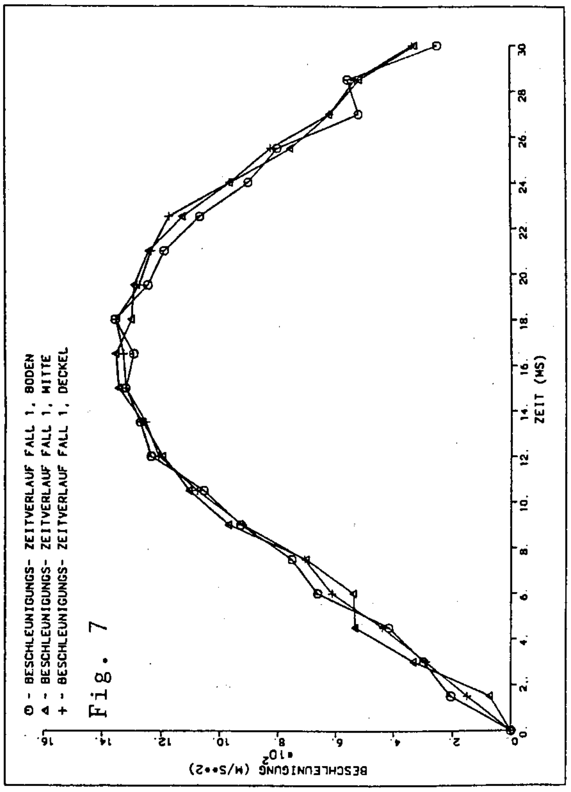

Fig. 7

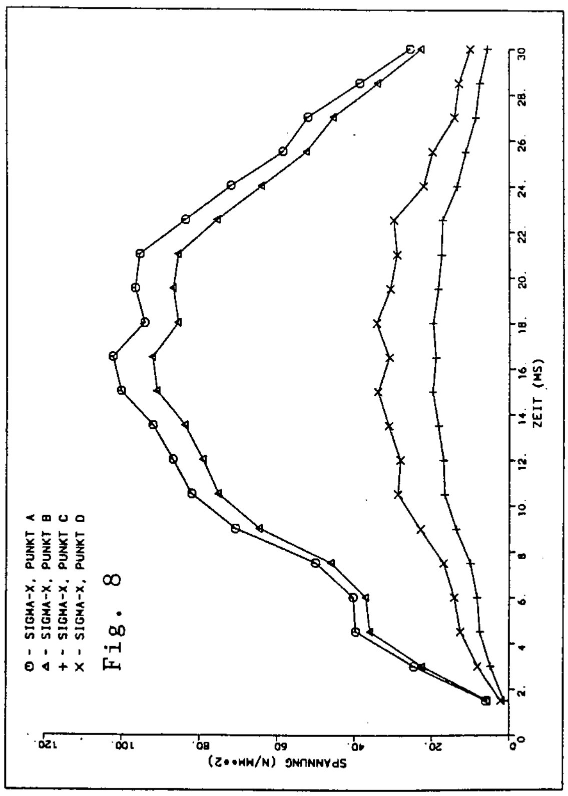

Fig. 8

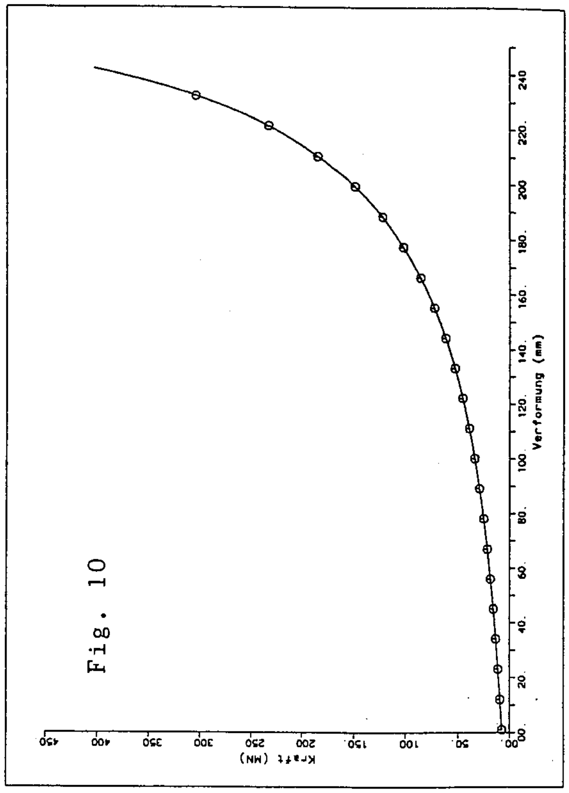

Fig. 10