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Experimental tests and finite element analyses of the aircraft impact resistance of CASTOR transport and storage casks

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ABSTRACT

Already in the years of 1978 to 1980 projectile impact experiments on a full-scale CASTOR cask have been performed. The results of such a projectile impact test are used for benchmarking a finite element approach simulating the effect of an aircraft impact on the lid system of CASTOR casks. The simulation approach is validated by comparison with the experimental results. The calculation results confirm the experimental ones that no principal effects on the primary lid system were detectable.

EXPERIMENTAL PROJECTILE IMPACT TESTS

Special penetration tests, in which a heavy projectile was fired at a representative section of a CASTOR II a cask, were carried out in the years of 1978 to 1980 and served as evidence that the cask could survive a mechanical load resulting from the crash of an aircraft.

A cylinder approx 5000 mm long, approx. 600 mm in diameter, and weighing approx. 1000 kg was used as the projectile (Fig. 1). It consisted of an outer sheet-steel jacket, with a convex head at the front, closed by a steel plate at the back. Inside the jacket was a massive steel pipe, about 3200 mm long, supported by crosswise braces. After the projectile exited from the accelerating device, it flew free at a speed of about 300 m/s and impacted on the cask section.

Altogether three tests were performed. In test 1 the projectile impacted perpendicularly on the cask-wall cooling fins. In test 2 the specimen was set up at an angle of 60° to the horizontal and the projectile impacted on the face of the cover portion.

In test 3 the projectile impacted perpendicularly on the middle of the lid system [1]. The specimen was a shortened CASTOR II a section with the bottom and lid ends resembling the original (total weight about 53 metric tons including internals). A concrete wall 200 mm thick stood immediately behind the horizontal cask and the wall was backed with compacted earth (Fig. 2).

The force of the projectile shifted the cask about 400 mm backward through the concrete wall; the angle between the lid surface and the horizontal was altered to 80° (Fig. 3). The projectile was completely destroyed, leaving a piece about 1 m long . Deformations caused by the massive pipe inside the projectile could be seen on the protection plate. After the test the cask was investigated in detail by the specialists of the German competent authority BAM. Whereas the protection plate and also the secondary lid were heavily deformed no plastic deformations could be detected at the primary lid. Also no affect on the primary lid metal-o-ring was detected. Furthermore the tightening torques of primary lid bolts were unaffected by the test. The loading of the projectile was quantified in terms of an idealised load time curve serving as important load input for subsequent analyses.

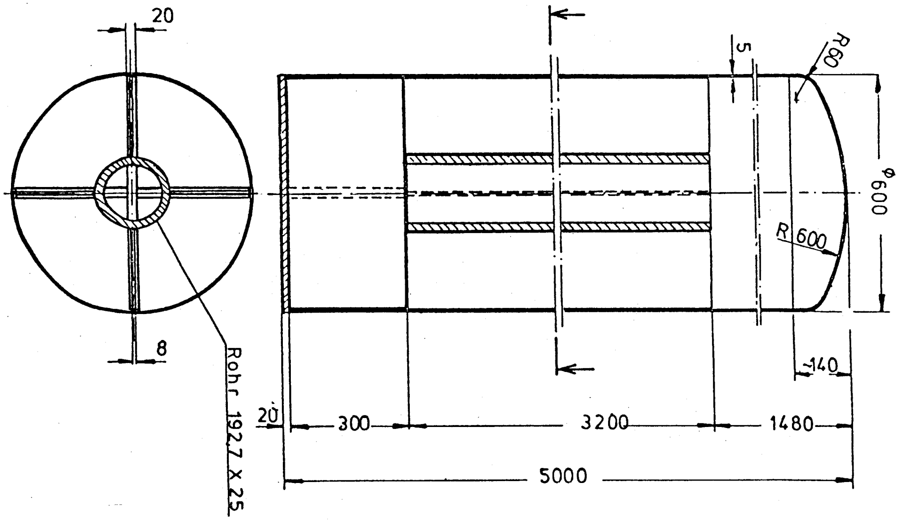

Fig. 1: Projectile used in the test

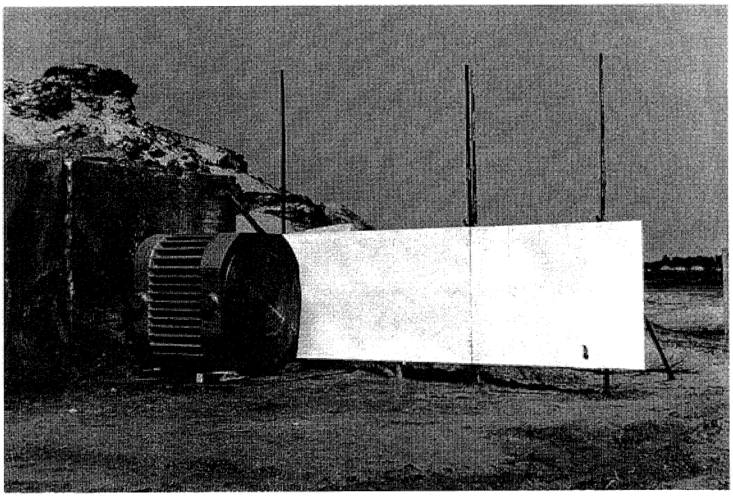

Fig. 2: CASTOR II a before the test

Fig. 3: CASTOR II a after the test

NUMERICAL ANALYSIS OF A PROJECTILE IMPACT ONTO THE LID SYSTEM

To benchmark a numerical assessment of the aircraft impact resistance of topical CASTOR casks, test 3 described above was simulated using the FE code DYNA3D [2]. By comparison of experimental and numerical results, the approach is validated..

DYNA3D is a three-dimensional finite element program which works explicitly and was developed especially for the solution of dynamic problems. The code takes into account geometric and physical nonlinearities as well as contact problems. The relatively simple element assumption in DYNA3D guarantees a numeric stability for large displacements and large strains. DYNA3D has a variety of possibilities for formulating the boundary conditions for contact problems. With approx. 40 different material models, DYNA3D provides a detailed material library for the user.

The structure of the finite element model used is shown in Fig. 4. It consists of the protection plate, the secondary lid, the primary lid, all corresponding plate and lid bolts and a section of the cask body. Quarter symmetry was used. Lid bolts were simulated by beam elements with the rod cross section corresponding to the stress cross section of the different lid bolts. Bolt pre-stress is not considered in the calculation. Lids and cask body are separated from each other by contact surfaces. A penetration of the cask body into the supporting concrete wall was not considered.

The idealised load-time curve derived from the experiment is shown in Fig. 5. The duration of the total impact is about 20 ms. The stepwise increase of the load from 13 to 26 MN is due to the inner massive steel pipe hitting the protection plate after a period in which only the relatively thin outer steel jacket of the projectile is deformed. From the deepest imprint in the protection plate having a diameter of 200 mm as measured after the experiment it can be concluded that the impact force was mainly transmitted over an area corresponding to the cross section of the massive steel pipe. Therefore the load was simulated by an time dependent force equally distributed over a circular area with a diameter of 225 mm.

Because of the high loading rate leading to large deformations in a relatively short period of time, elastic-plastic material models with dynamic hardening were used for the volume elements.

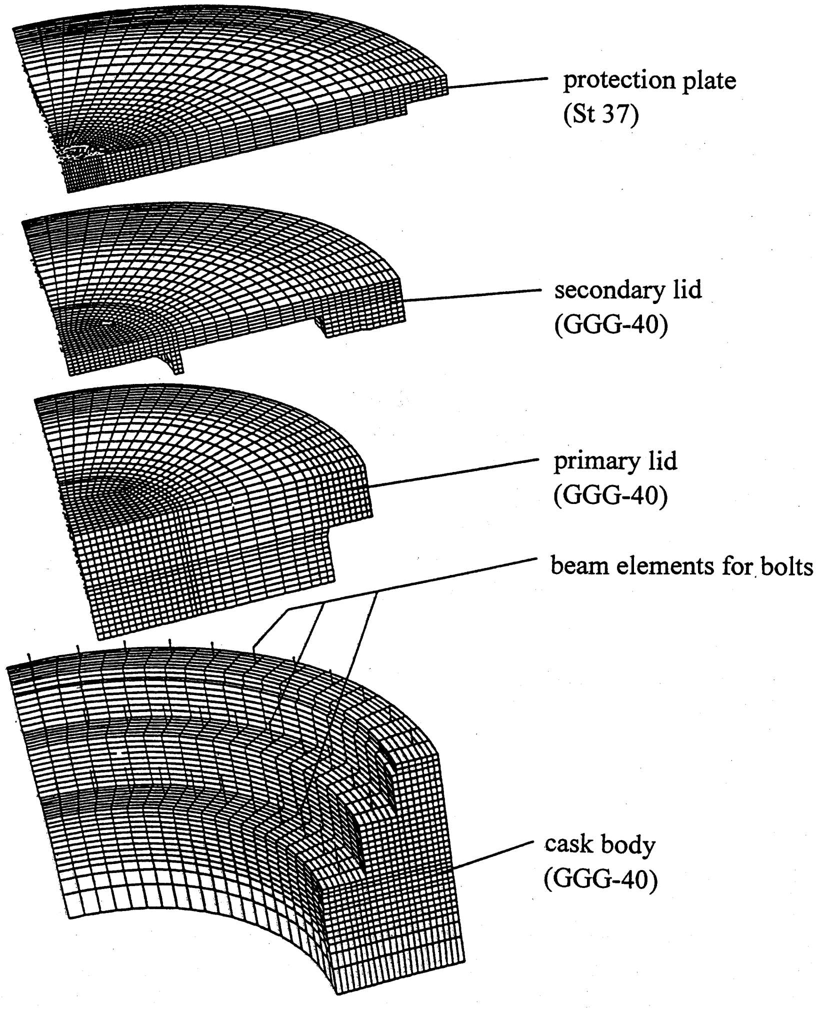

Fig. 4: Finite element model of CASTOR II a

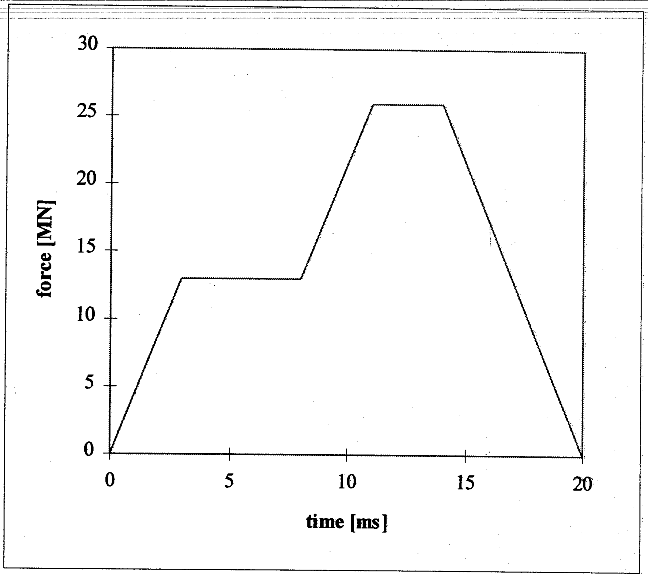

Fig. 5: Idealised load time curve

RESULTS

The calculated deformed structure after the impact is shown in Fig. 6 in combination with the fringes of eff. plastic strain. In correspondence to the post test inspections of the lid system, plastic deformations are basically restricted to the protection plate and secondary lid whereas the primary lid behaves elastically. The max. effective plastic strain of 46 % occurs in the protection plate. The deformations calculated in the centre of the protection plate and the secondary lid are in conservative agreement with the post test measurement data as shown in Tab. 1.

deformation in the centre of	measurement	calculation
- the protection plate	-73 mm	-87 mm
- the secondary lid	-68 mm	-72 mm

Tab.1: Comparison of calculated and measured deformations

The time history of the nodal displacements in the centre of the protection plate, secondary and primary lid is shown in Fig. 7. The deformations of the protection plate and the secondary lid increase stepwise according to the time function of the load. Superimposed to the basic movement are oscillations of the lid system. The displacements of the primary lid exhibit mainly oscillation behaviour with a max. amplitude of 2 mm at 3,5 ms and vanishing to zero at the end of the impact process. Due to these oscillations a temporary opening of the two tightening surfaces of primary lid and cask body is calculated. However even these slight movements vanish if the pre-stress of the bolts as well as the enormous elasticity of the metal-o-ring are taken into account. Therefore the calculation results are again in agreement

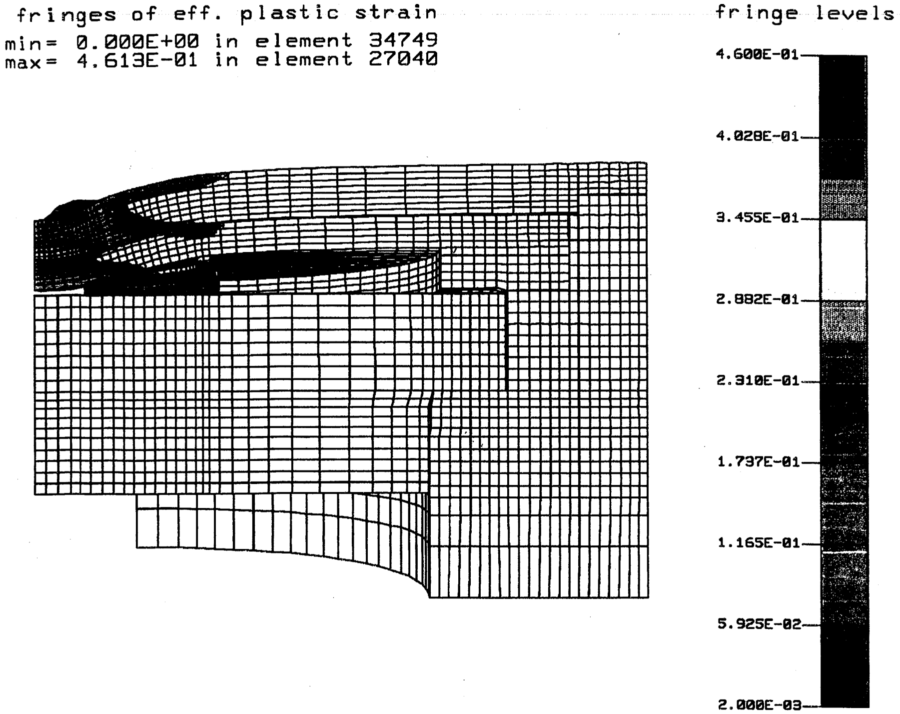

Fig. 6: Deformed structure

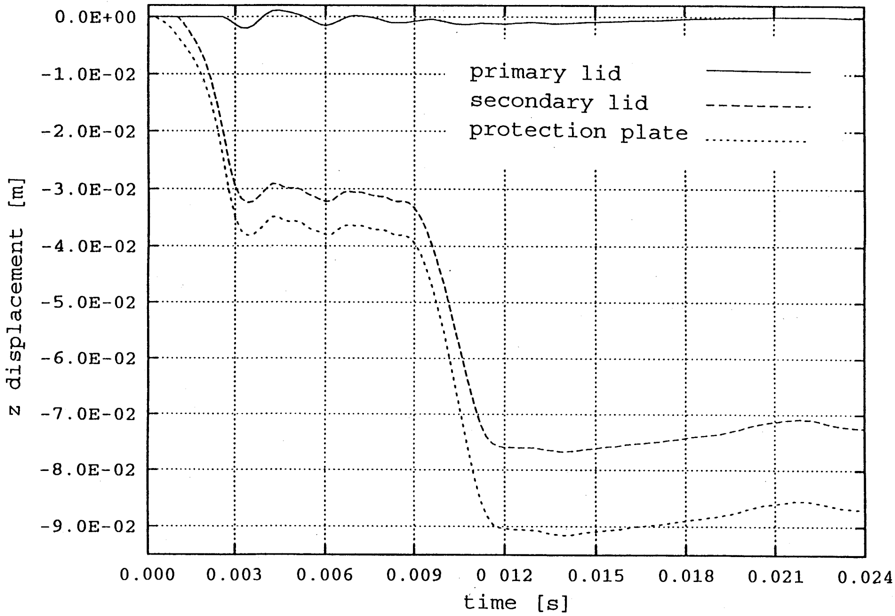

Fig. 7: Time history of nodal displacements in the centre of the lids

with the post test investigations in that no principal effects on the leaktightness of the primary lid seal took place.

COMPARISON WITH TOPICAL CASTOR DESIGNS

Having proved that the basic results of an aircraft impact test are simulated in an accurate manner, the same approach was used to investigate the resistance of topical CASTOR designs against an aircraft impact. The investigations comprise

- CASTOR V/19 designed for transportation and storage of up to 19 PWR fuel elements,
- CASTOR V/52 designed for transportation and storage of up to 52 BWR fuel elements,
- CASTOR VVER 440/84 designed for transportation and storage of up to 84 VVER 440 fuel elements,
- CASTOR MTR2 designed for transportation and storage of up to 33 fuel elements from research reactors.

In the following the bolt stresses are chosen as an indicator for the loading of the primary lid itself. In Tab. 2 the calculated primary lid bolt stresses of the CASTOR II a specimen are compared to the corresponding values of the above mentioned CASTOR designs.

CASTOR type	**max. stress in primary lid bolts [N/mm^2]**
CASTOR II a	300
CASTOR VVER 440/84	260
CASTOR MTR 2	159
CASTOR V/19	179
CASTOR V/52	157

Tab. 2: Calculated primary lid bolt stresses

A comparison shows clearly that the bolt stresses of CASTOR MTR 2, CASTOR V/19 and CASTOR V/52 reach only about half the value obtained for CASTOR II a, indicating a reduction of the primary lid loading itself. The reasons for this reduction are in case of CASTOR MTR 2 smaller lid diameters at the same thickness. In case of CASTOR V/19 and CASTOR V/52 the reduction was achieved by inserting a PE-moderator plate between the primary and secondary lid which absorbs some of the impact energy and distributes the load onto the primary lid over a larger area.

Taking the primary lid bolt stresses as the characterising value it can be stated that also the topical CASTOR designs can survive the event of an aircraft crash and are even safer than the tested CASTOR II a specimen.

REFERENCES

1. N.N. 1980. *Flugkörperbeschuß auf einen Transport- und Lagerbehälter CASTOR II a* Gesellschaft für Nuklear-Service GmbH. Essen. Germany

2. Whirley, R.G., Engelmann, B.E., 1993. *DYNA3D: A Nonlinear, Explicit, Three-Dimensional Finite Element Code for Solid and Structural Mechanics - User Manual, Methods Development Group, Mechanical Engineering, UCRL-MA-107254 Rev. 1.*. Lawrence Livermore National Laboratory. USA

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