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State of Development in Experimental and Numerical Stress Analysis of Type CASTOR® Packages under Accident Conditions

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Abstract

For packages of the CASTOR® type, according to the requirements of IAEA, the mechanical integrity for 9-m drop tests under accident conditions has to be verified. In order to reduce the loads acting on the package during the tests, the package is equipped with impact limiters.

To determine the loads occurring under drop test conditions, either experiments or numerical calculations can be carried out. Due to the complexness of the stress state and of the verification of results, in practice both methods are generally used for stress/strain analysis and verification.

From this, the requirements for numerical calculation models are obvious. The models should have the ability to describe the short-term dynamical behaviour of packages cask-comprehensively and, as well, for various drop orientations and temperatures in such a way that local stresses can be quantified and thereby assessed. One difficulty in this sense exists in the general description of behaviour of the material wood which is used for the absorption of drop energy within the impact limiters of type CASTOR® packages.

Therefore, the present established and approved state in mechanical design of type CASTOR® packages at Gesellschaft für Nuklear-Service mbH is to describe the mechanical behaviour of wood by means of an energetic calculation approach.

Perspectively, it is intended to replace this practice by a dynamical calculation approach which meets the requirements described before. For this purpose, the verification of appropriate numerical calculation models on the basis of drop tests, that is to say the quantified comparison of experimentally and numerically determined stresses respectively strains, is obligatory.

In this paper, the state of development, as well as the approach to establish dynamical calculation models, is pointed out. For this purpose, the dynamical calculation model of a type CASTOR® package is presented and the results determined by calculation of drop tests are compared with the results determined experimentally. On the basis of the results it is shown that the dynamical calculation model presented is suited for the determination of the temporal and spatial stress state of the whole package for different drop orientations.

Introduction

In accordance with the IAEA requirements, for type B(U)F-transport packages of the CASTOR® type among others the proof of the mechanical integrity for 9-m drop tests under accident conditions of transport has to be provided. In order to reduce the loads acting on the transport package, it is equipped with a lid and a bottom end impact limiter and, where appropriate, additionally with side impact limiters.

The determination of stresses resulting under drop test conditions can be carried out by experimental or by numerical methods. Due to the complexity of the stress state and of the verification of results, in practice generally both procedures are used for stress analysis and verification.

The requirements for the numerical models can be derived directly. The numerical models have to be capable of describing the short-term dynamical behaviour of the transport packages cask-comprehensively, as well as for different drop orientations and temperatures in a way that local stress states can be quantified and are thus assessable. Here, one difficulty consists in the general description of the behaviour of the material wood, which is used to absorb the drop energy within the impact limiters of the CASTOR® type among others.

Therefore, the currently established and recognized state in mechanical design of transport packages of the CASTOR® type at GNS is to describe the loadbearing characteristics and deformation behaviour of the wood by an energetic calculation approach. As a result, this calculation approach provides the loadings of the transport package which can be utilized for the further design of cask components. The design of the cask components is attributed to a quasi-static problem.

Perspectively, this procedure is intended to be replaced by a dynamic calculation approach which meets the requirements mentioned at the beginning. For this purpose the verification of appropriate numerical calculation models by means of drop tests is obligatory, i. e. the quantified comparison of experimentally and numerically determined stress states. The status of development and the approach for the establishment of these dynamic calculation models are pointed out below.

Energetic calculation approach

The description of the behaviour of impact limiters filled with wood is the basis for the calculation approach to determine the stresses of transport packages under 9-m drop test conditions. This approach is based on the law of conservation of energy, i. e. the potential energy of the transport package is dissipated into deformation energy of the impact limiters and of the wood, respectively. The sheet metal structure of the impact limiters surrounding the wood is not considered by the calculation approach. The calculation algorithm, called DROP programme, can be used for different drop orientations of the transport package, as well as for different shapes of the impact limiters, such as round or octagonal ones.
With regard to the description of the behaviour of wood, the assumption that the stress state along the direction of deformation of the wood is constant and that a failure of the wood will not occur is the basis for the calculation approach. The material behaviour of wood was determined experimentally by means of compression tests with comparably small specimens. As a result, the compressive stresses exist, depending on the deformation of wood. Here, type of

wood, load direction related to the fibre orientation and wood temperature were varied. Fig. 1 shows exemplarily the stress strain curves for spruce wood.

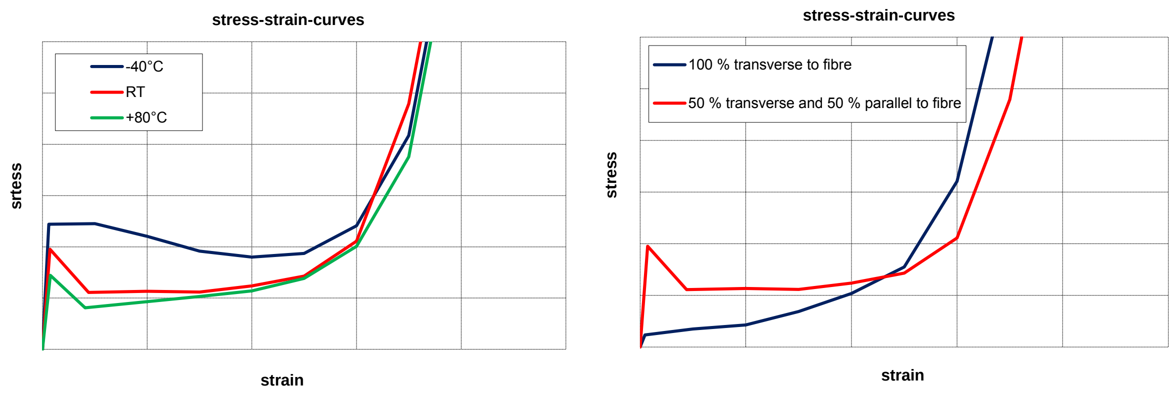

Fig. 1 **Stress strain curves of the wood, depending on temperature (left) and load orientation (right)**

As results, the deformation of the wood within the impact limiter, the loads from the deformation of the impact limiters acting on the transport package, as well as the rigid-body deceleration of the transport package are given. The deformation of the impact limiter and the rigid-body decelerations were verified by means of several drop tests with various designs and test casks. The drop tests were performed for different drop orientations, temperatures of the impact limiters, as well as for round and octagonal shapes of the impact limiters. These tests represent a broad basis for the verification of calculation results.

The results from DROP are used for the determination of the stress state, e. g. of the lid system or the cask body, by utilizing numerical models and assessing quasi-static loads.

Dynamic calculation approach

The calculation approach described before is valid only as long as there is no significant influence on the stress state of the transport package's components by dynamic effects and by time-depending behaviour. Besides, the approach is not valid in general, i. e. due to the assumptions and boundary conditions, it cannot be applied to any drop orientation. Furthermore, DROP does not consider the rigidity of the metal sheet construction of the impact limiter.

Therefore, it is the aim to establish a numerical calculation model which is capable of describing the dynamic behaviour of the transport package during the impact. Beside the requirement to comprise the essential non-linear effects, such as large deformation, large plastic strains and the influence of time on the material behaviour, the calculation model is intended to be valid as general as possible, i. e. to be applicable to various drop orientations.

Fig. 2 shows a dynamic calculation model (semi-model) which was used during the experimental phase of round impact limiters for precalculation of the drop tests, such as the 9-m edge drop on the lid side of the transport package, demonstrated here as an example. In the calculation model, all relevant components of the test cask, for instance cask body with moderator boreholes, or lid system including bolts and stud-bolts with cap nuts respectively, are represented.

Fig. 3 shows the calculation model of the lid side impact limiter. It was modelled with the layers of wood, assembled separately, the metal sheets, the bolts and the washers. The material behaviour of wood was described by the stress-strain curves shown in Fig. 1, determined by means of small test specimens.

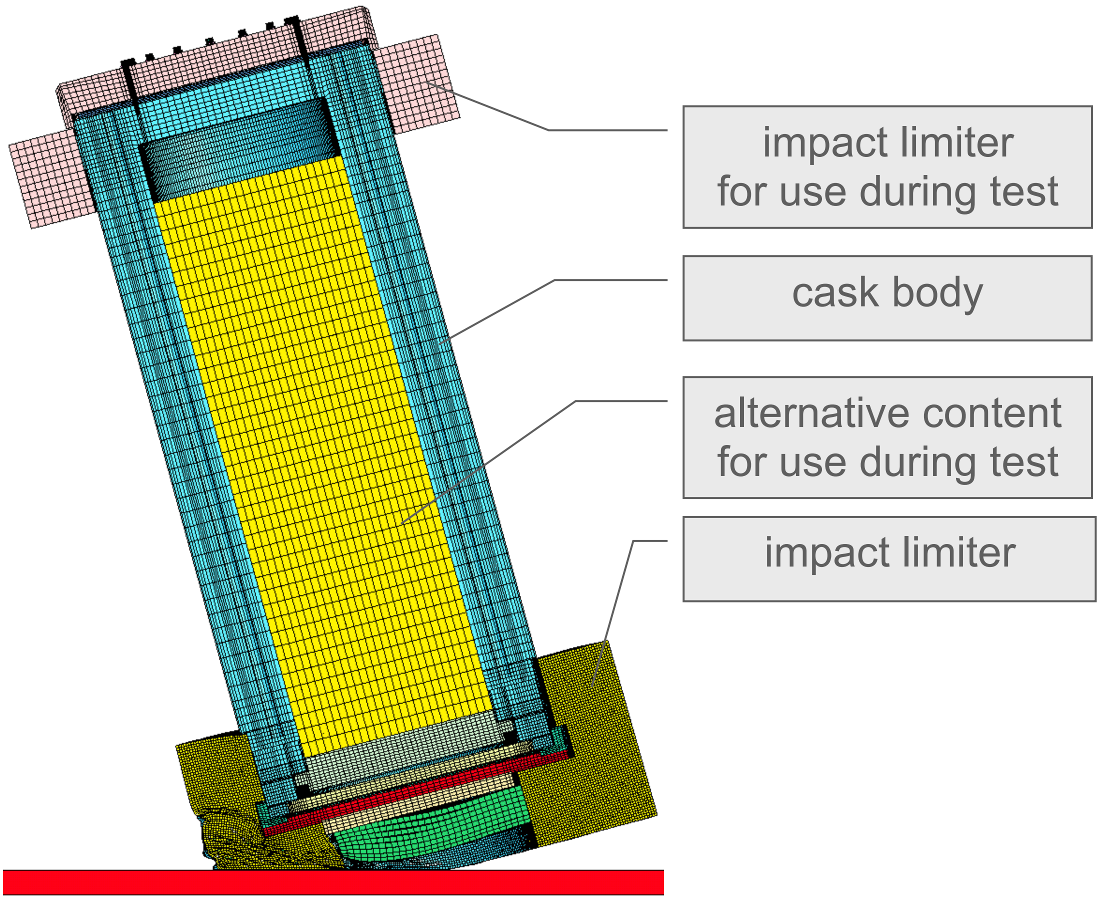

Fig. 2 Dynamic calculation model (semi-model)

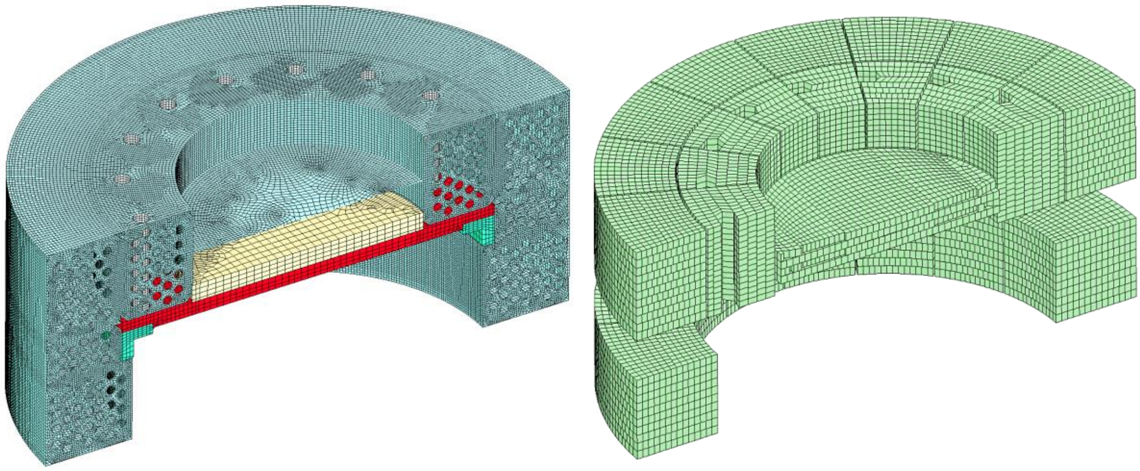

Fig. 3 **Impact limiters including – metal sheet structure, pressure and impact plate (left); separate layers of wood according to wood assembly plan (right)**

Experimental stress analysis

Below, the experimental stress analysis for the verification of the calculation models is described exemplarily by means of drop tests with casks of the CASTOR® V type. With these test casks, drop tests for the qualification of impact limiters with octagonal and round shapes were performed. The drop tests were carried out for various drop orientations, as well as with a minimal impact limiter temperature of -40 °C and a maximum temperature of +80 °C. Fig. 4 shows the test cask after the 9-m drop on the lid side edge of the transport package.

To quantify the loads of the transport package's components and to verify the calculation models, the test cask was instrumented extensively with strain- and acceleration sensors. Thus, the global behaviour of the transport package, as well as for example the bending strain of the primary lid's bolting, can be quantified, depending on time. In addition, after the drop test, the deformed structure of the impact limiters was measured spatially by means of an optical method.

Fig. 4 **Test cask on a scale of 1:2: 9-m lid edge drop at a design temperature of the impact limiters of 80 °C**

Comparison of experimental and numerical stress analysis

In the following, results of the calculations and of experimental testing are compared. On this issue, Fig. 5 shows the deformation of the impact limiters from the dynamical calculation and from the 9-m lid edge drop test.

In Fig. 6, the deformed impact limiter after the 9-m side drop is shown, with the results of the dynamic calculation and of the optical measuring being superimposed. The results of the impact limiter deformations show a good agreement between calculation and experiment. That way, for instance the deformation of the metal sheet structure could be described by the dynamic calculation model as well. Furthermore, in Fig. 6 the rigid body decelerations and the retardation of an acceleration sensor are demonstrated at the cask body in terms of quality. The calculation with DROP, too, provides a sufficiently exact result for the maximum rigid body deceleration.

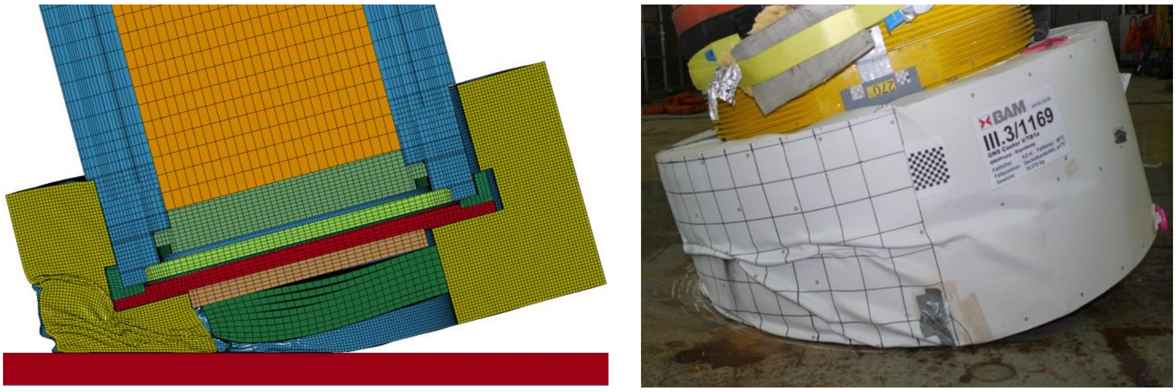

Fig. 5 **9-m lid edge drop: deformed impact limiter from FEM-calculation (left) and drop test (right)**

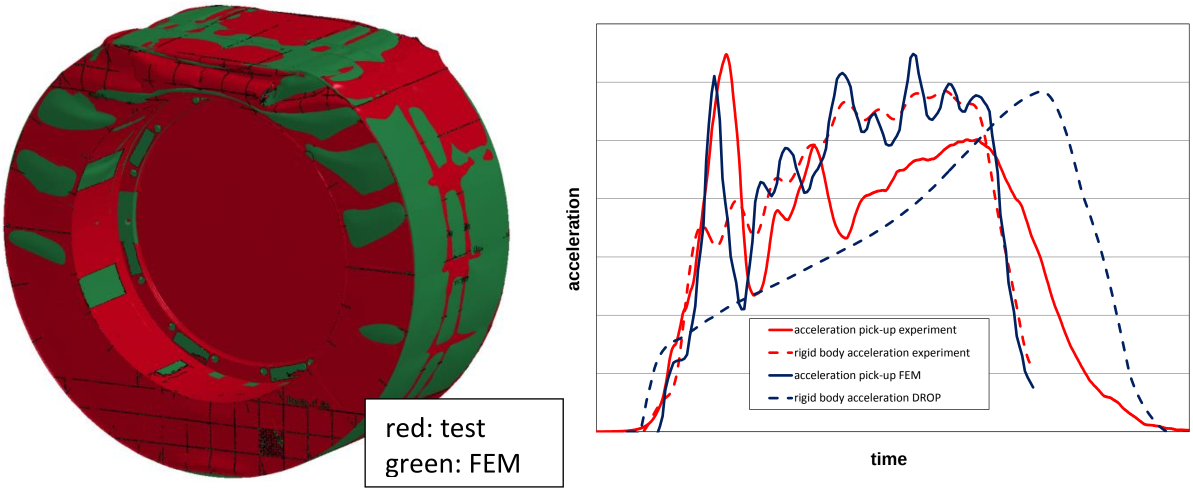

Fig. 6 **9-m side drop: deformed impact limiter (left) and accelerations (right)**

Conclusion

The presented results show that GNS is capable of performing dynamic calculation for transport packages under accident conditions of transport, as the results of the dynamic calculations are in good accordance with the experimental results.