Reliability of Cask Designs under Mechanical Loads in Storage Facilities

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Abstract: The storage of radioactive waste is currently managed in Germany with dual purpose metal casks designed for both transport and storage. Various cask designs are available ranging from thick-walled cylindrical designs made of ductile cast iron to thin-walled cubical designs made of steel. The BAM Federal Institute for Materials Research and Testing evaluates the reliability of cask designs for a safe enclosure of radioactive waste including construction, material specifications, manufacturing procedures, and quality assurance measures for production and operation according to the state of the art in science and technology. Mechanical loads arise from accidents during handling procedures of the casks inside storage facilities during interim storage (e.g. stacking or lifting of the cask). These load scenarios are often numerically simulated. Therefore, reliable numerical calculations are essential. Mostly, the cask has to withstand a drop from a given height onto a defined target. For interim storage, this target models the foundation of the storage building. A systematic investigation of effects of small design changes or small variations of test conditions was conducted under horizontal or vertical drop test conditions of cylindrical casks as well as cubical containers. The paper gives advice for a reliable and safe cask design.

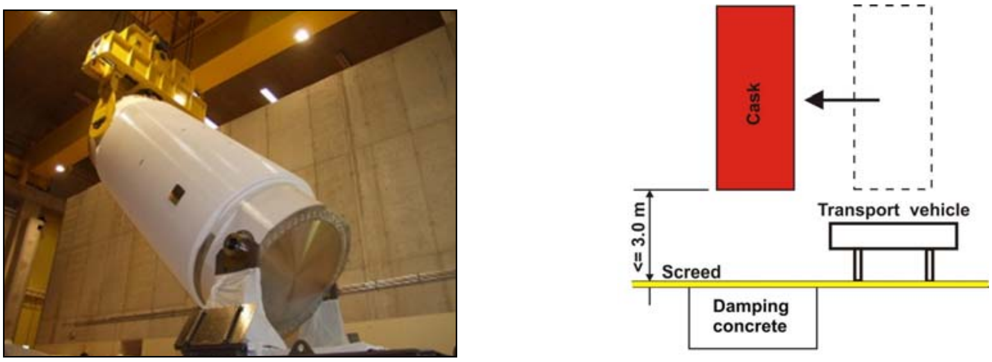
Keywords: dual purpose metal cask, impact load, handling procedure, interim storage, final disposal.

1. INTRODUCTION

Radioactive waste is currently stored in dual purpose metal casks designed for both transport and storage until a repository will be available for final disposal. These casks are placed in storage facilities. Among others, the BAM Federal Institute for Materials Research and Testing is contracted to evaluate all cask related safety issues concerning safe enclosure, decay heat removal, subcriticality, and shielding. In particular, BAM checks the complete cask design including construction, material specifications, manufacturing procedures, and quality assurance measures for fabrication and operation according to the state of the art in science and technology.

Compliance of the casks with applicable national and international regulations must be demonstrated. Requirements for casks for interim storage are defined in technical acceptance criteria of the individual storage site on the basis of guidelines for the storage of radioactive waste with negligible heat generation [1] and for dry cask storage of spent fuel and heat-generating waste [2]. In case of spent fuel casks, their handling procedures are analyzed individually for each interim storage site and typical drop or crash scenarios are derived as possible load scenarios. Conservative load scenarios without additional safety factors or representative load scenarios with appropriate safety factors are considered. Casks for final disposal of non-heat generating waste are certified for the German Konrad repository according to site-specific waste acceptance criteria [3, 4] which contain clearly defined test scenarios. To ensure the safe enclosure of the radioactive contents, the cask design is reliable and safe under mechanical loads if the deformation of the cask structure is within certain limits and fracture mechanical failure can be excluded. A fracture-safe design is important especially for casks made of ductile cast iron which could contain small material defects from manufacturing. Limited deformation may be required at sealed lid systems where a certain leakage rate limits potential activity release to acceptable values.

To illustrate potential accidental load scenarios in an interim spent fuel storage facility, Figure 1 shows a typical handling procedure. After arrival of the transport vehicle in the unloading area of an exemplary interim storage facility, the cask has to be attached to the crane, erected and moved to its final storing position. After leaving the vehicle area and before lowering down, there is typically a maximum distance of about 3 m between the bottom of the cask and the floor. If one element of the load chain fails in that position, the cask would drop in vertical direction onto the storage floor. Damping concrete in the floor construction, covered by screed, would reduce the cask impact load. It has to be shown, that the cask body and its sealed lid systems stay intact under these conditions. The leakage rate must not exceed a specified value after the accident. Minimum and maximum cask temperatures have also to be taken into account. These temperatures are not fixed but derived from thermal analyses of a maximum loaded cask under site specific conditions.



a) b)

Figure 1: Example of a handling procedure [5, 6]

The investigation of load scenarios is performed more and more with numerical simulations instead of experimental investigations especially in case of just modified but not completely new cask designs or when the load scenario cannot be easily reproduced by an appropriate experimental setup. However, such calculations need reliable finite element (FE) models and especially material models. Quite often the accuracy of the calculation results is not exactly known. But knowledge about the accuracy of the numerical procedure is necessary to be able to define and apply safety factors. When cask tests are planned, pre-calculations of the test scenario should be carried out. Then, minimum safety factors can be derived from a comparison of numerical and test results. In most cases, differences will be found because a real test is usually more complex than assumed and certain effects could not have been considered with the pre-calculations. Analysis and modeling of these additional effects are part of the post-calculations. With a better understanding of the physical behavior and relationships, appropriate safety factors can be derived for the investigated scenario. Frequently, experimental results from neither component tests nor tests with original size casks are available. Then, safety factors must be derived from similar analyses. In some cases, technical standards defining minimum safety factors are available. Such standards are regularly applicable to normal but not accidental load conditions. The use of safety factors for normal conditions under accident conditions would typically lead to an inadequate conservative cask design.

Calculation results are also influenced by various numerical effects. The meshing of the cask structure and all other parts of the load scenario with finite elements should be mentioned here and particularly the modeling of physical contacts between individual components or numerical contacts between the global model and its sub-models. In general, investigated load scenarios are very complex because of the quantity of components and their interactions. Ideally, only a reduced number of components (two components as a rule) including their mechanical and thermal interactions are analyzed as a start. Correctness and plausibility of sub-models and calculation results for simpler load cases are assessed on this basis. Additional parameter studies might be helpful at this step. The comparison of calculation results with expected results, e.g. from analytical calculations, tests, or literature, determines the design of sub-models, their interactions and parameters. Finally the complete model is assembled from the sub-models.

In addition to an accurate evaluation of the documents and calculations provided by the applicant of a safety analysis report, the development of a separate finite element model by the proving experts can be necessary to investigate the sensitivity of a finite element analysis towards modified parameters or conditions. This is of particular importance if no results from drop tests are provided for validation. BAM has published guidelines for preparation, calculation and evaluation of finite element computations [7] explaining and describing procedures for reliable dynamic numerical calculations, their documentation, and assessment of safety analysis reports.

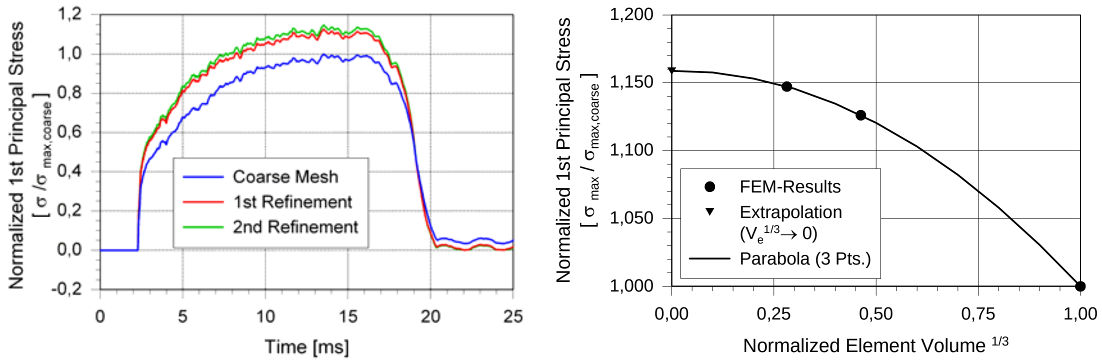
2. RELIABLE NUMERICAL ANALYSES

2.1. Reliable Models

Reliable FE models are essential for numerical simulations. All individual components of a load scenario need an individual verification. At first, the relevant components have to be defined, e.g. cask body, basket, fuel assemblies, lids, impact limiters, puncture bar, foundation. Basis for a reliable FE model is the successive assembling of verified sub-models for the individual components including their interactions and parameters.

Conservative boundary conditions should be chosen to be physically meaningful and realistic. Conservative but non-realistic boundary conditions could result in erroneous cask loading. As a rule, the boundary conditions are chosen as to maximize the cask load. However, impact duration of dynamic load scenarios could be so much shortened by such conservative conditions that the load type changes in an unintended way.

The finite element theory states that the numerical approximation of a body by a mesh of finite elements converges towards the correct analytical solution with mesh refinement in the absence of geometrical or physical singularities. On the other hand, mesh refinement leads to a considerable increase of used computer main memory and computation time. Unfortunately, there exists no general rule for construction of a finite element mesh that ensures a numerically stable and sufficiently accurate dynamic finite element computation.



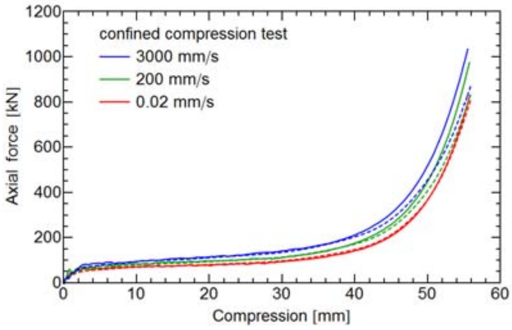
a) b)

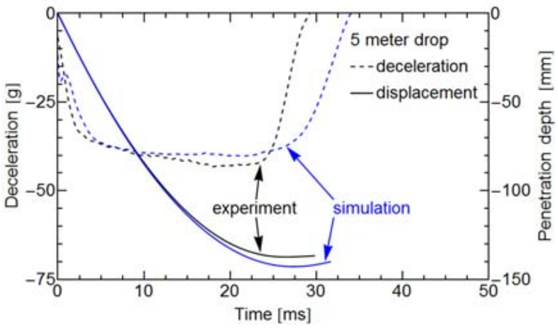
Figure 2: Normalized first principal stress at borehole, (a) History, (b) Convergence [8]

The question, how fine a FE mesh should be, was examined based on the example of a 1 m puncture drop test of a cylindrical cask. Hereby, the center of the cask wall impacted onto a steel puncture bar [8] referring to the IAEA test scenarios for Type B transportation packages. The cask contains two rows of bore holes for neutron moderator material located near the cavity. A coarse mesh was created and then refined in two steps. The element size was bisected in each step. The refined mesh was constructed by incorporation of a sub-model into the global model using tied contact conditions. The puncture bar was not refined. A remarkable influence of the element size on the calculation result was found. Figure 2(a) shows the first principal stress at a borehole. The first refinement step leads to a noticeable stress increase. Further stress increase at the second refinement step is smaller. The solution is numerically stable as it approaches a limit curve. Similar effects have been observed for von Mises equivalent stress. Strains at the body surface can be quantified by extrapolation towards infinitely small elements, cf. Figure 2(b), and thus be used for model validation based on experimental results.

2.2. Material Modeling

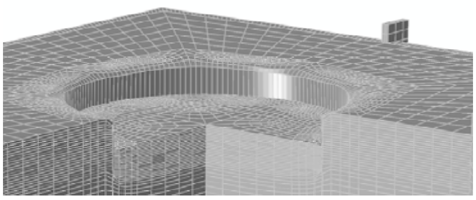
The relevant mechanical, thermal and chemical properties of the materials used must be known for a reliable FE analysis of any load scenario. These properties must be translated into a FE material model with specific parameters. It is not always possible to find suitable material parameters in literature. In the context of dynamic calculations, this concerns primarily strain-rate dependent stress-strain curves (if necessary also dependent upon the temperature). If material data are found in literature, it must be clarified under which conditions they were measured (whether e.g. the appropriate technical standards have been met). If non-standard materials are used, their material properties (yield stress, ultimate strength, fracture toughness, etc.) must be measured independently in laboratory tests. The simulation of the laboratory test itself is sometimes necessary especially in case of dynamic investigations to separate specimen behavior and influences from the test equipment. For example, standard testing machines usually begin to vibrate at dynamic tensile tests with strain-rates above some 100/s and generate oscillations in measured stress-strain curves independently of the specimen behavior. In such cases, other test equipment suitable for highly dynamic tests should be used. Instead, the material behavior of the specimen can be separated from non-perfect measurement results by simulation of the test.





a) b)

Figure 3: Simulation of damping concrete, (a) Dynamic confined compression test, (b) 5 meter drop test with cask-like test object



a) b)

Figure 4: Imprint of the cylindrical cask into the damping concrete block after 5 meter drop, (a) Test, (b) Simulation

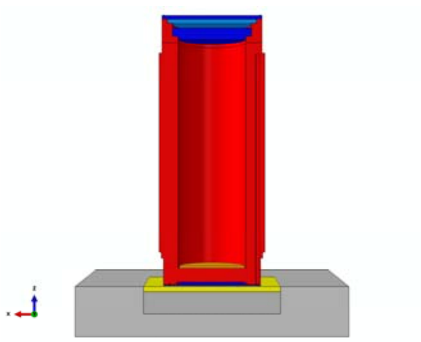
Currently BAM investigates the mechanical behavior of damping materials like polyurethane foam, damping concrete and wood as part of the research project ENREA (Development of numerical methods for analyzing impact limiters subjected to impact or drop scenarios) [9]. Damping concrete is a patented concrete using polystyrene balls as aggregates. Density is 1/3 of standard concrete with essentially lower yield stress. The material behavior is described by crushable foam with isotropic hardening. A damage criterion for ductile damage of the polystyrene balls as well as a shear fracture criterion for failure of the cement matrix can be added. The material model was calibrated by simulation of displacement-controlled compression tests with different temperatures and loading rates as shown in Figure 3(a) [10].

A 5 meter drop test with a 23 Mg heavy cask-like test object was conducted to demonstrate the developed material model under real drop test conditions. The drop test target was a 2400 x 2400 x 500 mm³ block of damping concrete confined in a rigid steel frame. A 30 mm thick mortar layer was applied between damping concrete and the steel slab on top of the test stand foundation at the BAM drop test facility [11]. A detailed finite element model of the complete drop test scenario including the cask-like test object (simplified as rigid body), damping concrete block, steel frame, mortar layer, and underlying test stand foundation was developed. The simulation was carried out with an impact velocity of 9.9 m/s of the drop weight onto the damping concrete block. As shown in Figure 3(b), the calculated maximum rigid body deceleration of about 40 g (with 1 g = 9.81 m/s²) is somewhat lower than the measured deceleration of 43 g. The maximum penetration depth of about 142 mm is approximately 10 mm higher than the measured value of about 132 mm. The comparison of Figure 4(a) and Figure 4(b) shows a good correspondence between drop test and simulation results.

3. RELIABLE CASK DESIGN

3.1. Thick-walled Cask Design

The design of a thick-walled generic storage cask with a mass of about 126 Mg is investigated with the model shown in Figure 5(a) [6, 12]. The Cask body, multi-barrier lid system, bottom closure plate, and appropriate connecting elements are the main parts of the finite element half model. The mass of cooling fins and all other neglected small parts of the construction were considered by an increased density of the cask body. The material behavior of the cask body, made of ductile cast iron, was described with strain rate dependent true stress versus true strain curves. A dummy mass, positioned at the inner bottom side, represents the content (e.g. spent fuel assemblies). In the considered accident scenario this simplification does not influence the kinematic behavior of the cask during the impact. Young's modulus of the simplified content was chosen as very small to avoid an unintended increase of the cask body stiffness. At the beginning of the finite element analysis, the whole cask was positioned 20 mm above the target, loaded by gravity and initialized with a velocity of 7.67 m/s resulting from the drop height of 3 m. The target in the finite element model represents the unloading area in an exemplary interim storage facility. It consists of three parts: concrete foundation slab, a block of damping concrete, and a screed layer (Figure 1). It was assumed, that the concrete foundation slab is very stiff compared to the damping concrete. For that reason it was modeled as a rigid body.



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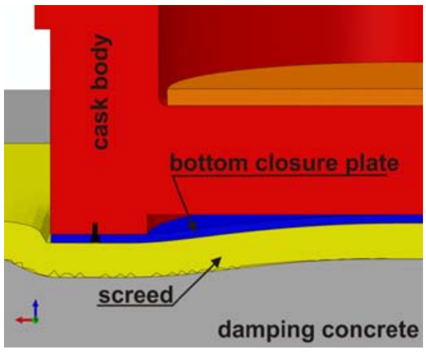


b)

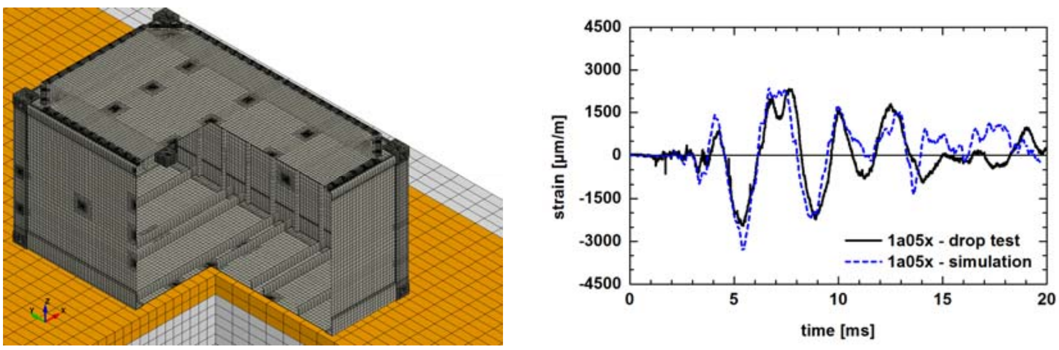
Figure 5: Handling accident scenario with cylindrical cask in vertical position, (a) Finite element model, (b) Detail of deformed impact area [6]

It is known from previous calculations of various drop scenarios that the critical load of the lid and sealing system occurs in other accident configurations than the flat cask bottom drop (see below). Here, effects of design changes in the bottom side impact area are investigated. The behavior of the screed layer is important for the loading of the cask bottom. At first, the cask imprints into the screed. Thereby, failure of the screed layer is assumed. However, the screed strength is not exactly known. Young's modulus, pressure and tension strengths and the assigned strains were adapted to various concrete grades. The influence of these modifications on safety relevant loads remains small. Higher screed strength causes a small increase of the stress normal to the bottom. The calculated stresses also show that the cask bottom oscillates and is bended downwards after the impact. However, if the center of the closure plate gets in contact, the bottom is bended upwards, Figure 5(b).

Obviously, the bottom closure plate and its attachment influence the cask bottom load. The closure plate was modeled elastically. In the first step, the neutron shielding plate, made from polyethylene, positioned between cask bottom and closure plate in reality, was not implemented in the model. The pretension in the closure plate bolts was generated by definition of a thermal expansion coefficient and a local reduction of temperature in the bolt shanks. Caused by the required bolting torque for closure plate assembling, a range of pretension forces is possible. The bolts were preloaded with lower and upper boundary values. Additionally, in a modified model the pretension was completely neglected. As a result, the cask bottom load is nearly unchanged. The amount of impact force, pressing the closure plate against the cask bottom, is much higher than the resulting pretension force. So, the model is nearly insensitive to this modification. The insertion of the neutron shielding plate between cask bottom and closure plate prevents the upward bending of the bottom. The pressure stress, normal to the bottom, keeps small. It can be realized, that the neutron shielding plate, in reality and in the finite element model, has a positive impact on the decisive loads in the cask. However, it has also to be noted that the chosen linear elastic material model can not fully represent the real behavior of the neutron shielding plate.

3.2. Thin-walled Cask Design

Design assessments were also carried out at thin-walled steel sheet containers. The box-shaped container of Konrad Type V [3] is considered here as an example [13]. A lot of experimental data from drop tests are available for this container type. To investigate the container design, different drop test scenarios were investigated numerically. The FE model is shown schematically in Figure 6(a). Due to the unsymmetrical construction of the container, the experimental setup was rendered as a full model (contrary to a half or quarter model). The model of the steel sheet container includes all relevant structural parts. Thin-walled components like side walls were modeled with shell elements. Solid elements were used for pillars, corner fittings and lid bolts. The welding seams were simplified to tied contacts. The impact target consists of a steel plate and a concrete block beneath. The foundation was confined by non-reflecting boundaries, no further boundary conditions were necessary. As initial condition, the container was placed close above the impact target with imposed velocity corresponding to the initial drop height. The mechanical behavior of the container was described with an elastic-plastic material model, whereas the impact target was assumed to be elastic.



a) b)

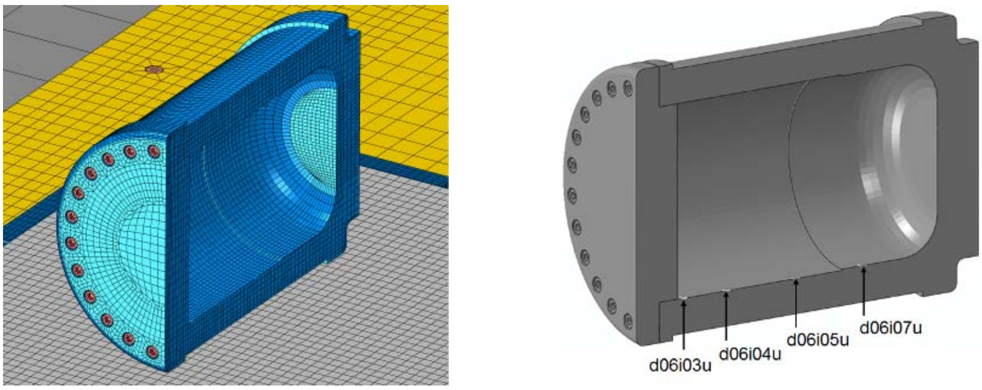
Figure 6: Steel sheet container Type V with impact target, (a) Finite element model, (b) Strains in the middle of the lid in x-direction [13]

In order to obtain comparable numerical results, the simulation of the drop test scenario was carried out with adjusted container orientations taking into account the slight impact angles derived from the measured deceleration signals. Figure 6(b) shows both the measured and the calculated strains in the middle of the lid in x-direction during a drop from 5 m height onto the bottom side. The calculated strain history approximates in sufficient manner the measurement data. However, an evaluation of single signals does not provide an adequate survey of the entire impact scenario and the following free wall-bending vibrations. Therefore calculation results have to be assessed at different positions of the container, particularly at highly stressed areas in the structure. Altogether the comparison of the numerical calculations with test results showed that the developed FE model is suitable to describe the mechanical behavior of a box-shaped steel sheet container during a flat bottom drop test.

The analyses of numerical and experimental results have shown that the highly stressed areas during a flat drop onto the bottom side are located both on the lid side and on the vertical edges connecting the lower and upper corner fittings. During a 0.4 m drop test only elastic strains were detected, whereas a 5 m drop led to plastic strains. Buckling of the pillars with considerable plastic deformation is the major effect. Usually such containers are filled with 200 liter drums and the free volume between the drums and the container walls is filled with a potting compound stabilizing the structure. This results in limited overall deformation of the container and reduced stresses in lid bolts. Hence, a dense and fixed packaging of the contents is necessary for the container to withstand for instance an edge drop.

3.3. Lid System Design

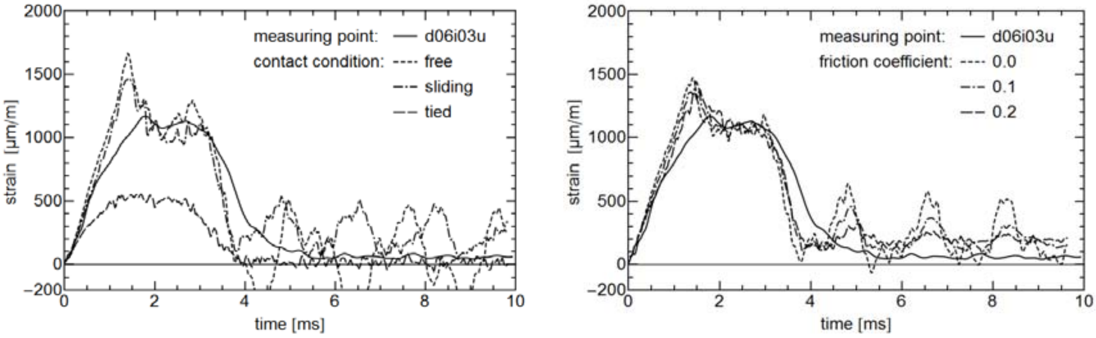
The safety assessment of a lid system is related to the evaluation of the leak tightness of a cask. On the one hand, special gasket elements, which must be adjusted with constructive and material parameters, are implemented in FEA codes to simulate the gasket behavior. On the other hand, the calculated mechanical behavior of the lid system can be correlated with measured leakage rates from mechanically and thermally loaded lid-flange components available at BAM. An exact calculation of deformation and movement of lid and cask body to generate correlation with leakage rates is the decisive issue in this approach. Influence factors are contact modeling (contact type and contact parameters, esp. friction parameters) between lid and cask body, bolt pretension and constructive details like the gap between lid and cask body. These influence factors were examined in detail and recommendations for their modeling were given in Ref. [14].



a) b)

Figure 7: Horizontal drop test without impact limiters from 0.8 meter height onto a concrete foundation, (a) Finite element model, (b) Position of relevant measuring points

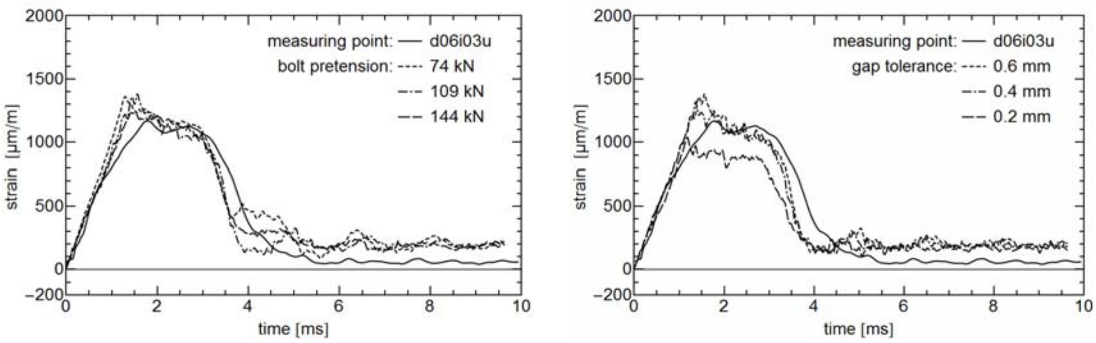
The finite element model of the investigated cylindrical cask comprises all relevant structural components and consists of sufficiently small elements, Figure 7(a). The bolts of the lid system are modeled with solid elements for the bolt head and with beam elements for the bolt shank. Contact definitions are necessary between each bolt head and the lid as well as between the lid and cask body. There are three possible configurations which have to be considered: i) If the bolt is loose, there is a relative displacement between lid and cask body parallel and normal to the contact surface. This situation can be implemented as free contact without friction (free). ii) If the bolt is not tight enough, a relative parallel movement between lid and cask body is still possible. This condition can be specified by sliding contact (sliding). iii) If the bolt is tight, the contact pair of lid and cask body can be realized as fixed contact without any relative displacement (tied). Simulation results for these three different contact definitions are shown in Figure 8(a). Obviously, this parameter has an important influence on the behavior at measuring point d06i03u in Figure 7(b). A tied contact reduces not only the maximum strain amplitude during impact but also strain oscillations after rebound. Yet another important model factor is the size of the pretension forces of the bolts. Although they are specified in the assembly instruction of the cask, it is very difficult to experimentally determine the real conditions at the contact surfaces of lid and cask body which are additionally influenced by the lubricant. Modeling this contact is always a best fit between sliding and tied contact. The contact parameters like contact type or friction can significantly change the calculation results and should be studied in each case in detail.



a) b)

Figure 8: Effect of contact conditions, (a) Contact type, (b) Friction coefficient

Hence, the influence of Coulomb's friction value is considered in more detail. The effects of pressure and temperature on the friction coefficient can be neglected within this study. Figure 8(b) compares calculation results for the cases without friction and with friction coefficient of 0.1 or 0.2 respectively. The contact type applied is defined as sliding contact. The calculation results show that contact friction has only small influence during impact but significant influence after rebound. Simulation of the test without friction gives highest strain amplitudes which decrease with increasing friction coefficient. A good correlation between experimental and numerical results during impact and after rebound could be obtained with a friction coefficient which changes exponentially from a static value to a dynamic value in dependence on the slip rate [14]. In this way, the friction coefficient approaches the dynamic value during impact with a high slip rate and equals about the static value after rebound for a slow slip rate.



a) b)

Figure 9: Effect of details of the lid system, (a) Bolt pretension, (b) Gap tolerance

All bolts are tightened with a given torque to ensure leak tightness of the lid system. This causes a pretension force in the bolt shank in a defined range. Figure 9(a) illustrates the effect of the minimum, middle and maximum pretension force. A sliding contact with constant friction coefficient of 0.2 was used in these simulations. A very small initial impact angle of 0.05° was assumed. Bolt pretension combined with a constant friction coefficient leads to a residual stress state in the lid system. The measuring point d06i03u near the lid shows a remaining elastic strain. The maximum strain value during impact is also influenced by bolt pretension.

There is an inevitable gap between the lid and the internal wall of the cask body. The gap varies between individual casks from a minimum to a maximum value according to the manufacturing tolerances. Simulations with an assumed gap of 0.2 mm, 0.4 mm and 0.6 mm are presented in Figure 9(b). All other simulation parameters were held constant (sliding contact between lid and cask body, friction coefficient of 0.2, pretension force of bolts of 109 kN, initial impact angle of 0.05°). A very small gap has the effect of a tied contact. The slip between lid and cask body during impact is disabled which reduces the ovalization of the cask body near the lid significantly. On the contrary, larger gaps do not have further effects.

4. CONCLUSION

The safe enclosure of radioactive waste in an assumed accident scenario in a storage facility depends on a reliable cask design. Many influence factors exist, some of them were discussed. Constructive details can change the area of highest loads as discussed in the section concerning the drop of a thick-walled cask. The fixed contents stabilize a thin-walled container structure. It is often important and valuable to know these effects quantitatively, e.g. to evaluate design changes or deviations. Therefore, the safety of a cask design is often evaluated by means of numerical simulation of the decisive load scenarios. Reliable finite element calculations are essential for this approach. A validation with experimental data should be done if possible. If test results are not available, it is of particular importance to investigate the sensitivity of the model to various parameters and modifications. The examined load scenarios often seem to be simple. However, their numerical modeling is frequently effortful. Even simple load scenarios could require very fine meshes with many elements. A reliable modeling strategy for dynamic cask analyses is the identification of components, the creation and verification of FE sub-models for the individual components and finally the assembly of the verified sub-models to the complete model. Primarily the material behavior and the boundary conditions are often not exactly known. The performance of the lid system is especially important with regard to safe enclosure of the contents and related leakage rates. The extent of lid motion is controlled by the pretension force level of lid bolts and by the contact conditions between lid and cask body. While the pretension forces are known, there is no reliable evidence about the numerical contact model and friction parameters. They have to be derived from systematic parameter studies. When suppressing lid sliding, strains are excessively reduced. On the contrary, a rather loose connection overestimates the strains. A sliding contact turned out to be the most appropriate concept. A slip rate dependent contact friction reduces the amplitude of free vibrations of the cask wall. A reduction of the small radial gap between lid and cask body reduces the strains in the cask structure particularly near the lid, because the ovalization of the cross section of the cask is limited under horizontal drop test conditions.

Acknowledgements

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References

[1] Nuclear Waste Management Commission (ESK), "*Guidelines for the storage of radioactive waste with negligible heat generation (revised version of June 10, 2013)*," Recommendation, Salzgitter, 2013.

[2] Nuclear Waste Management Commission (ESK), "*Guidelines for dry cask storage of spent fuel and heat-generating waste (revised version of June 10, 2013)*," Recommendation, Salzgitter, 2013.

[3] P. Brennecke (Ed.), "*Requirements on radioactive waste for disposal (Waste Acceptance Requirements as of October 2010) - Konrad Repository*," Report SE-IB-29/08-REV-1, Federal Office for Radiation Protection, Salzgitter, 2011.

[4] S. Steyer (Ed.), "*Radioactive waste product control, Radiological aspects - Konrad Repository - as of October 2010*," Report SE-IB-30/08-REV-1, Federal Office for Radiation Protection, Salzgitter, 2011.
[5] W. Botsch, S. Smalian, P. Hinterding, H. Völzke, D. Wolff, E. Kasparek, "*Safety aspects of dry spent fuel storage and spent fuel management*," Proc. Waste Management Symp. 2013 (WM 2013), Phoenix, February 24-28, 2013.
[6] M. Weber, U. Zencker, D. Wolff, H. Völzke, U. Herbrich, S. Nagelschmidt, "*Numerical analysis of cask accident scenarios in storage facilities*," Proc. 17th Intern. Symp. on the Packaging and Transportation of Radioactive Materials (PATRAM 2013), San Francisco, August 18-23, 2013.
[7] BAM, "*Guidelines for numerical safety assessments within the scope of design testing of transport and storage casks for radioactive materials*," BAM-GGR 008, Rev. 0, Berlin, 2003.
[8] U. Zencker, M. Weber, F. Wille, "*Finite element mesh design of a cylindrical cask under puncture drop test conditions*," Packaging, Transport, Storage and Security of Radioactive Material, 22, pp. 112-116, (2011).
[9] E. Kasparek, H. Völzke, R. Scheidemann, U. Zencker, D. Wolff, "*Experimental and numerical studies of shock absorbing materials for containers for radioactive waste*," atw - International Journal for Nuclear Power, 57, pp. 397-401, (2012).
[10] L. Qiao, U. Zencker, E. M. Kasparek, H. Völzke, R. Scheidemann, "*Development of a finite element model for damping concrete under severe impact loads*," Proc. 17th Intern. Symp. on the Packaging and Transportation of Radioactive Materials (PATRAM 2013), San Francisco, August 18-23, 2013.
[11] R. Scheidemann, E. M. Kasparek, K. Müller, B. Droste, H. Völzke, "*Model-sized and full-scale dynamic penetration tests on damping concrete*," Proc. 17th Intern. Symp. on the Packaging and Transportation of Radioactive Materials (PATRAM 2013), San Francisco, August 18-23, 2013.
[12] M. Weber, U. Zencker, D. Wolff, H. Völzke, U. Herbrich, S. Nagelschmidt, "*Numerical analysis of an exemplary cask accident scenario in a storage facility*," Proc. Waste Management Symp. 2014 (WM 2014), Phoenix, March 2-6, 2014.
[13] C. Protz, H. Völzke, M. Ellouz, E. M. Kasparek, U. Zencker, H. Grünewald, K.-P. Gründer, "*ConDrop – Development of numerical simulation approaches for drop test analyses of steel sheet containers*," Proc. Institute of Nuclear Materials Management (INMM) 53rd Annual Meeting, Orlando, July 15-19, 2012.
[14] U. Zencker, L. Qiao, E. M. Kasparek, H. Völzke, "*Modeling of cylindrical casks under horizontal drop test conditions*," Proc. Intern. High-Level Radioactive Waste Management Conference 2013 (IHLRWM 2013), Albuquerque, April 28-May 2, 2013.