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# IMPACT TARGET CHARACTERIZATION OF THE BAM DROP TEST FACILITY

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## ABSTRACT

BAM safety related research of containers for radioactive material focuses on advanced mechanical safety assessment methods for verification of the structural integrity and leak-tightness under normal and hypothetical accident conditions during transport and storage.
An essentially unyielding target with a rigid surface is required for impact tests performed for package approval according to IAEA regulations [1]. In addition to specification of a target, e. g. with a combined mass more than 10 times that of the specimen for drop tests, unyielding target characteristics have been investigated with various package designs and different impact tests.
The unyielding target of the BAM drop test facility, a reinforced concrete block together with an embedded and anchored mild steel plate, provides relatively large mass and stiffness with respect to the packages being tested.
For monitoring reasons accelerometers and strain gauges are embedded in the concrete block of the foundation at several positions. Additionally, dynamic impact responses like vibrations and rigid body motion can be measured by seismic accelerometers.
The mechanical characterization of the target's rigidity is based on experimental results from various drop tests. Test containers with weights of 181,000 kg, 127,000 kg and 8,010 kg hit the target with velocities up to 13.5 m/s in the horizontal and vertical drop positions.
The rigidity of the impact target can be demonstrated with experimental results confirmed by analytical approaches. Some conclusions can be drawn about experimental testing as well as analytical calculations in order to compare impact effects.

## INTRODUCTION

In drop tests demonstrating the ability of a package to withstand normal and accident conditions of transport, the specimen has to be dropped so that most possible damage occurs. The package or container has to be dropped onto an essentially unyielding target for qualification reasons and as a simulation of hypothetical accident conditions.
BAM safety related scientific research tests diverse full-scale and reduced-scale test models of spent fuel transport and storage casks within design approval procedures. The mechanical tests prescribed by the regulation [1] are a 9-m free drop onto a target and a 1-m drop onto a vertical bar mounted perpendicular on that target. An unyielding target in the sense of the regulations

means that more than about 95% of the kinetic energy of a dropped cask will be absorbed by the package [2].
Drops onto both unyielding and real targets are taken into consideration when investigating the margin of safety of real cask designs [3]. Unyielding targets differ from real targets in their ability to absorb less kinetic energy from the cask. However, the structural response of the package to impact forces and decelerations, and its relation with real accident events are of specific interest for both unyielding and yielding targets.

## UNYIELDING TARGET

Since 2004 full-scale drop tests up to 200 metric tons have been able to be performed at the BAM drop test facility. The test facility consists of a steel pipe construction drop tower with a height of 36 m. The 200 ton hoist is located on the top of the tower with a maximum hook height of 30 m. Below the drop tower is an integrated test hall with an 80 ton portal crane, movable roof and rolling gates. More details of the drop test facility are given in [4]. The target is built of a reinforced concrete foundation 14m x 14m x 5m deep and with embedded steel plates 10m x 4.5m x 0.22m fixed with 40 anchor bolts (M36) to the concrete block. The concrete quality meets the German standard for strength classes B25/B35. The unyielding target - reinforced concrete block with embedded impact pad - has a total mass of 2,613,000 kg.

Permanent sensors have been placed inside and under the concrete block for monitoring and evaluation reasons. Three accelerometers are inserted at different depths. Strain gauges are also applied directly to the reinforcement at various locations. Two seismic accelerometers and two further accelerometers are located at the target surface. Additionally, five load cells are positioned directly under the concrete block.

## TEST PROCEDURE

### Test Objects

For characterization of the unyielding target, impact tests were determined with two full-scale prototypes and one reduced-scale model, here designated as test containers TC1, TC2 and TC3. TC1 and TC2 are prototypes of spent fuel transport and storage casks with impact limiters; TC3 is a reduced model (1:2.5) of TC2: see *Figure 1*.


**Figure 1. Test Containers TC1, TC2, TC3 (from left) just after Drop Test.**

The main testing parameters of the test objects are summarized in *Table 1*. More details of the full-scale prototypes and the reduced-scale test model, including design features and sensor installation, are given in [5] and [6] respectively.

**Table 1. Parameters of Drop Tests**

| Test Container | Weight | Drop Direction | Drop Height |
|---|---|---|---|
| **TC1** | 181,000 kg | Horizontal | 9.0 m |
| **TC2** | 127,000 kg | Vertical | 9.3 m |
| **TC3** | 8,010 kg | Vertical | 9.3 m |

Metrology

The test containers and foundation were prepared with sensors to record deceleration during the extremely short period of the impact.

Deceleration measurements of the casks were performed using triaxial piezoresistive accelerometers with a range of ±1000 g and 0-4000 Hz (±3 dB): [5].
The accelerometers were positioned according to the drop direction of the test containers and the particular impact. The TC1 was equipped with an accelerometer on the cask shell (cask position 0°) close to the lid side. TC2 and TC3 were equipped with an accelerometer on the middle of the cask body (cask position 180°).

The concrete foundation is prepared with accelerometers and strain gauges at different locations: *Figure 2*. Force-time histories could be measured by five load cells located at depth of 5.2 m, i.e. 0.2 m under the concrete block. The load cells have an averaged sensitivity of 14 mV/mm/s.
In addition, three accelerometers, B1, B2 and B3, are placed in the centre of the concrete block. These piezoresistive accelerometers have a measuring range of ±500 g and a frequency range of 0-4000 Hz (±3 dB). B1 is at a depth of 4.36 m, B2 at 2.4 m and B3 at 1.1 m.

The data acquisition is carried out using multichannel measuring devices with wideband (analogue bandwidth up to 200 kHz (-3 dB)) and differential bridge amplifiers for direct connection of all bridge type devices. A 100 kHz pre-sampling filter with a 500 MHz sampling frequency and 12 bit vertical resolution was applied to each channel.

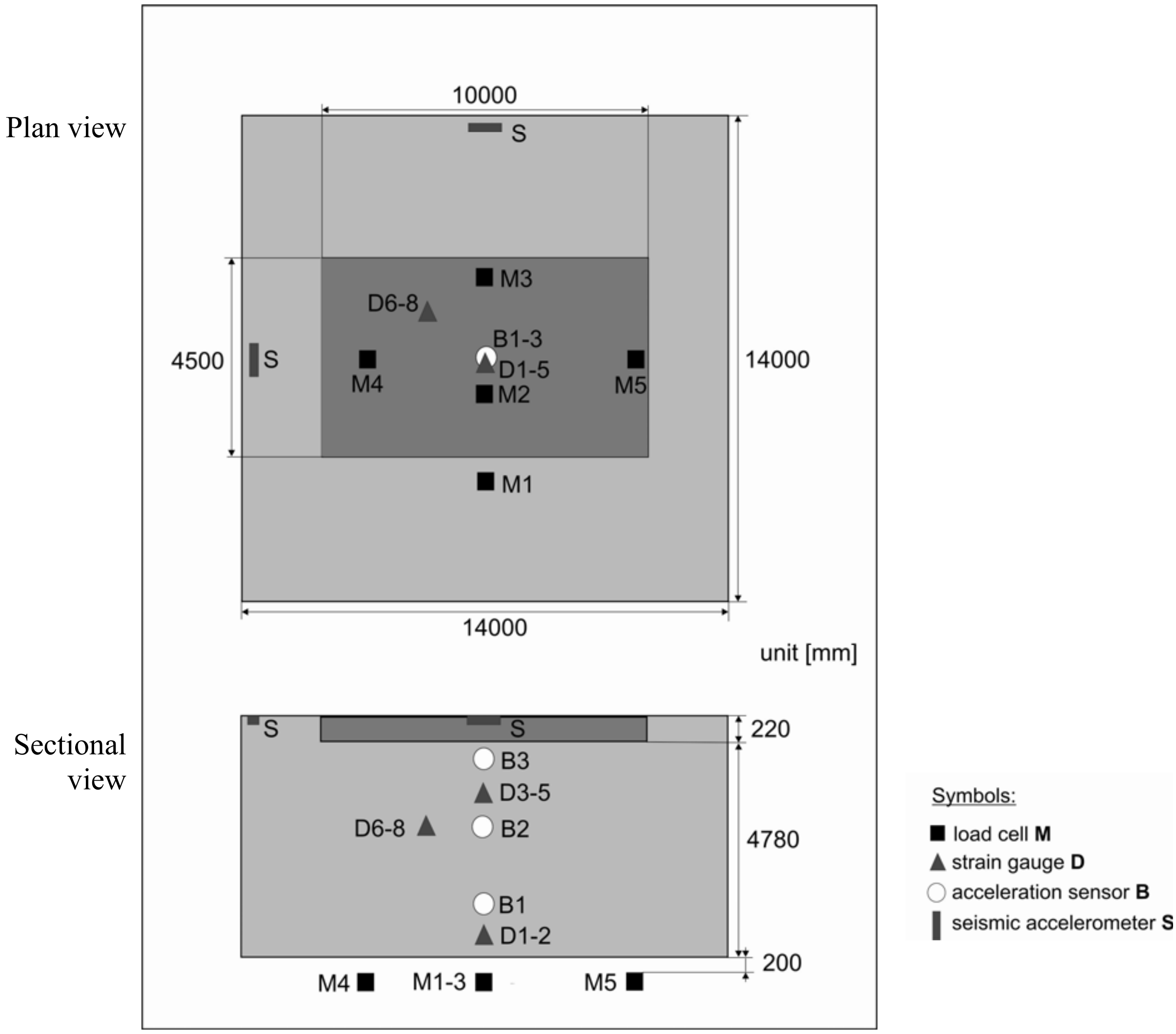


**Figure 2. Schematic View of the Foundation Instrumentation**

## ANALYSIS AND RESULTS

The characteristics of the target were determined by analyzing the measured rigid body response of both impacting test container and target. This was combined with an analytical approach applying the conservation of energy principle. *Figures 3 to 5* show the impact responses of the three test containers TC1, TC2, TC3 and the target with acceleration-time and force-time-histories. After low-pass filtering with an appropriate cut-off frequency the signals mainly represent the rigid body motion of the colliding partners. The rigid body velocity and displacement of the target (concrete block) and test containers due to impact were calculated by integration of the acceleration signals and collecting the corresponding characteristic values.

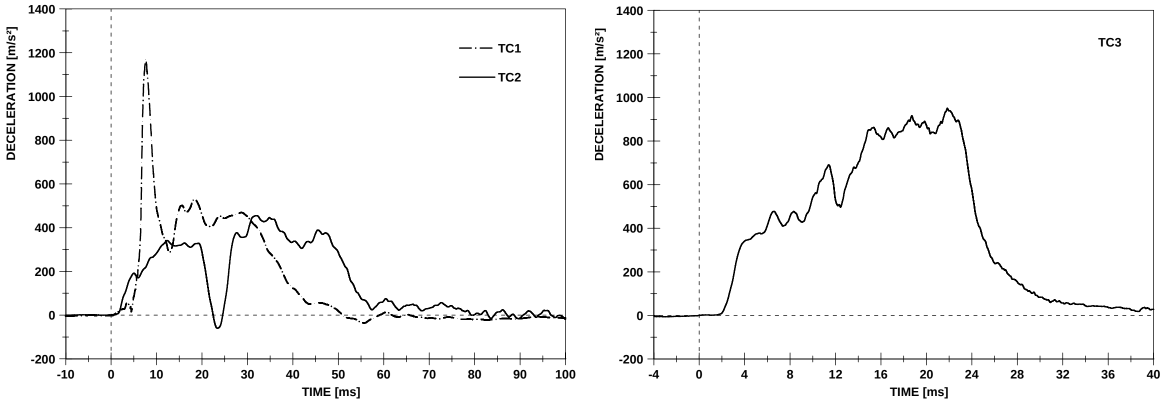


**Figure 3. Impact Tests Data. Deceleration Histories of Cask Body**

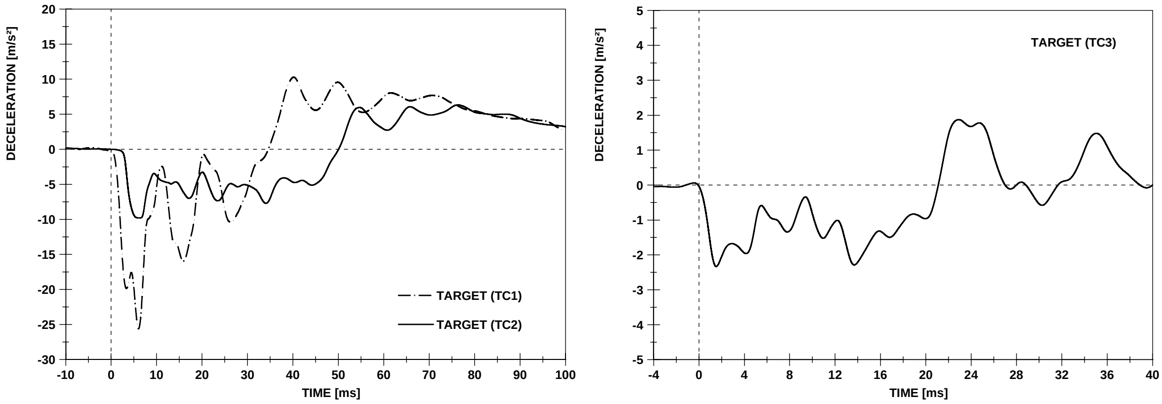


**Figure 4. Impact Tests Data. Deceleration Histories of Target**

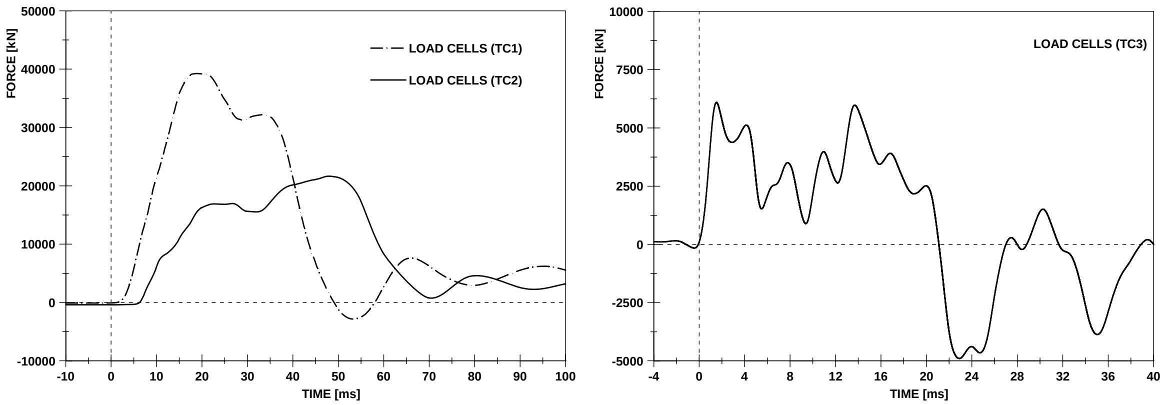


**Figure 5. Impact Tests Data. Force Histories of Target**

Conservation of energy is formed at the point when cask velocity becomes zero at the end of impact. At that point the total kinetic energy $E_{kin,tot}$ of the dropped test container (index: *c*) immediately before impact is transformed into a maximum strain energy $E_c$ in the package and a certain energy dissipation $E_t$ in the target (index: *t*), mathematically expressed by the following equation

$$E_{kin,tot} = E_c + E_t \qquad (1.1)$$

Furthermore, strain energy absorbed by the cask in relation to total energy is expressed by rearrangement of equation (1.1) as a percentage value with

$$\frac{E_c}{E_{kin,tot}} = (1 - \frac{E_t}{E_{kin,tot}}) \cdot 100\,\% \qquad (1.2)$$

Herein is total kinetic energy $E_{kin,tot}$ given by $E_{kin,tot} = 1/2mv_0{}^2$ with $m$ = mass of the package and $v_0$ = impact velocity of package. It is the point of maximum strain energy $E_{c,s.e.}$ in the cask body and maximum strain energy $E_{il,s.e.}$ in the impact limiter

$$E_c = E_{c,s.e} + E_{il,s.e.} \qquad (1.3)$$

The target is assumed to behave as a single spring-mass system where both impact pad and concrete block are represented as one rigid mass and the ground as a spring: see *Figure 6*.

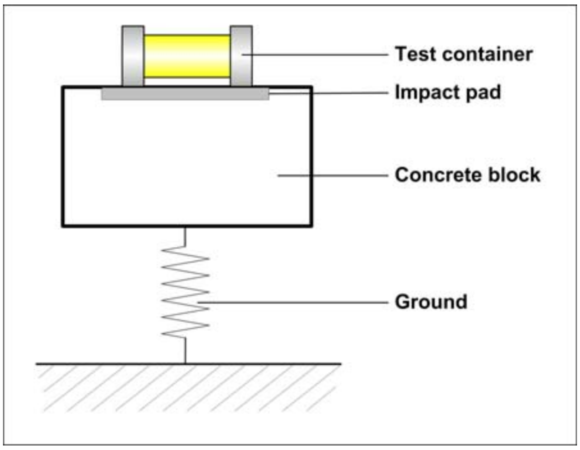


**Figure 6. Simplified Model of Spring-Mass System for Impacts.**

Energy absorption of the target $E_t$ at the point when the package's velocity becomes zero is expressed by the remaining kinetic energy of the concrete block of the target $E_{t,kin}$ and the strain energy in the ground $E_{g,s.e.}$

$$E_t = E_{t,kin} + E_{g,s.e.} \qquad (1.4)$$

Considering the inertial effects of the concrete block of the target and the impact pad respectively, kinetic energy $E_{t,kin}$ is $E_{t,kin} = 1/2Mv_t^2$, where $M$ is the added mass of concrete block and impact pad and $v_t$ the velocity. Strain energy in the ground $E_{g,s.e.}$ is the integral of the force-deflection relationship defined by $F(x)$ within the boundaries $x = 0$ and $x = \delta$, where $\delta$ is the translation value of the concrete block at the point when cask body velocity becomes zero: see equation (1.5).

$$E_{g,s.e.} = \int_{x=0}^{x=\delta} F(x)dx \qquad (1.5)$$

In *Figure 7* the target's force-deflection curve *F(x)* was determined on the basis of the measured force *F(t)* and the deflection *x(t)* obtained from the double integrated measured acceleration *a(t)* versus time during impact.

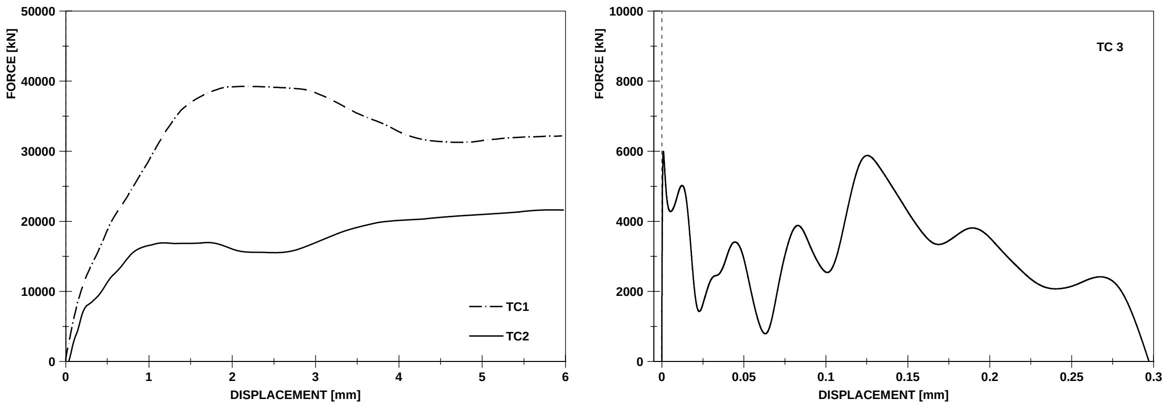


**Figure 7. Target's Force-Displacement Curves**

The energies in *Table 3* are calculated according to the equations (1.1) to (1.5) and with the container's parameters in *Table 2*. With respect to drop testing of large, full-scale casks, the calculated energy values in *Table 3* show that even in these cases approximately 98 percent of the total kinetic energy is transformed into strain energy in the package and only two percent is absorbed by the target, when ignoring energy dissipation by shock waves and vibrations as well as thermal energy.

**Table 2. Calculation Parameters.**

| | | | TC1 | TC2 | TC3 |
|---|---|---|---|---|---|
| $M$ | Mass of concrete block & impact pad | kg | 2,613,000 | 2,613,000 | 2.613.000 |
| $m$ | Weight of test container | kg | 181,000 | 127,000 | 8,010 |
| $v_0$ | Impact velocity of test container | m/s | 13.3 | 13.5 | 13.5 |
| $v_t$ | Target velocity | m/s | 0.3 | 0.25 | 0.01 |

**Table 3. Calculated Energies.**

| | | | TC1 | TC2 | TC3 |
|---|---|---|---|---|---|
| $E_{kin,tot}$ | Total kinetic energy of test container | Nm | 16,008,545 | 11,572,875 | 729,911 |
| $E_{t,kin}$ | Kinetic energy of target | Nm | 117,585 | 81,656 | 131 |
| $E_{g,s.e.}$ | Strain energy of ground | Nm | 190,075 | 103,423 | 950 |
| $\frac{E_c}{E_{kin,tot}}$ | Strain energy of test container in relation to total kinetic energy | | **98.1 %** | **98.4 %** | **99.85 %** |
| $\frac{E_t}{E_{kin,tot}}$ | Absorbed energy of target in relation to total kinetic energy | | **1.9 %** | **1.6 %** | **0.15 %** |

## CONCLUSIONS

The rigidity of the unyielding target is demonstrated by experimental data and verified by analytical approaches. The method applied in this paper for typical impacts with full-scale cask

prototypes from a drop height of 9 meters demonstrates the rigidity of the essentially unyielding target of BAM's 200 ton drop test facility. Besides fulfilling the criteria of an IAEA target weighing more than ten times the dropped cask model, conversion of kinetic to strain energy shows that approximately 98 percent of the total kinetic energy is transformed into strain energy in the tested package in a full-scale drop test of an 181,000 kg test container. This estimated energy value is based on a simplified mechanical model.
The characterization of the unyielding target demonstrates the severity of the regulatory impact by experimental measurements and analytical calculations. More data on the target and its rigid body response will be utilized to predict the package impact response by numerical calculation and FE-modeling. Furthermore, available results seem to be advantageous for verifying the comparison of impact onto an essentially unyielding target with different yielding targets as well as for dimensioning impact targets.

## ACKNOWLEDGMENTS

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## REFERENCES

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