Disposal Container Safety Assessment - Drop Tests with a 'YOYUSHINDO-DISPOSAL' Waste Container onto a Concrete Target

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ABSTRACT

The paper presents technical details of the drop test performance as well as some experimental results of tests carried out with the Japanese 'Yoyushindo-Disposal' waste container for intermediate depth disposal. The drop test program comprises three single 8-m drop tests in specimen's corner edge orientation onto a concrete slab. The slab was connected to the unyielding IAEA-target of the BAM's 200 tons drop test facility. The three tested specimens had masses between 20,000 kg and 28,000 kg depending on their content mass. The tests were accompanied by various metrology such as e.g. strain and deceleration measurements, optical 3D-deformation methods, leak tightness testing and test installation for potential particle release measurements to collect a data basis for safety assessment.

INTRODUCTION

In context with Japanese disposal container safety assessment of containers for intermediate depth disposal the German Federal Institute for Materials Research and Testing (BAM Bundesanstalt für Materialforschung und – prüfung) performed drop tests contracted by Kobe Steel, Ltd. (KSL) for a consortium of Japanese electric power plant companies represented by Chubu Electric Power Company, Japan. The tests were carried out in autumn 2008 at the BAM 200-tons drop test facility situated on the BAM Technical Test Site (BAM TTS) nearby Berlin, Germany.

The drop tested containers are designed for low-level waste such as channel boxes, control rods of boiling-water reactors as well as burnable poisons and control rods of pressurized-water reactors and are part of a sub-surface disposal concept, the Japanese Yoyushindo-Disposal [1].

The drop test program comprises three single 8-m drop tests with three specimen in corner edge orientation onto a concrete slab. The boundary conditions for the specimens temperatures were equal or less 0°-Celsius. The drop tests were accompanied by extensive and various measurement techniques: strain and deceleration measurements to obtain the structural, kinematic and kinetic impact responses, high-speed video to visualize and analyze the impact scenario, temperature measurements to observe the cooling process and to verify the goal temperature, leakage testing of the container's lid system, optical 3D-metrology of the impacted corner edge and particle release measurements.

The directly impact targets for the specimens were concrete slabs connected with a thin mortar layer to the impact pad of the unyielding IAEA- target with a mass of 2,600,000 kg.

In the following some technical details of the drop test and specimen preparation as well as the performance of the drop tests itself and the applied measurement techniques are described beside selected experimental results. The aim of the tests was to collect comprehensive data for safety assessment and the verification of numerical results obtained from finite element calculations.

SPECIMENS FOR THE DROP TESTS

The drop tests were conducted with a number of in total three specimens of the 'Yoyushindo-Disposal' waste container [1]. The specimens are built in original scale and delivered ready assembled by KSL to the BAM Test Site Technical Safety (BAM TTS), at Horstwalde nearby Berlin, Germany. Figure 1 shows the specimens standing on their lid side inside the drop test facility. For handling reasons the specimens are equipped with special lifting lugs at the four edges of the bottom plate (pink coloured) and at the corners of the side walls opposite to the impact corner each with a lifting capacity of 20,000 kg.

Figure.1. The three specimens A, B and C of the 'Yoyushindo-Disposal' waste container ready assembled for testing with different content masses inside the BAM drop test facility.

The geometric design of the container is of cubic shape with outer dimensions of 1,600 mm x 1,600 mm x 1,600 mm. The material of the side walls is carbon steel with a thickness of 50 mm, and material properties of 330 MPa for actual yield and 1130 MPa for actual tensile strength. The container is closed by a welded lid. The content of a container was simulated during drop testing by massive steel layers. Under the lid a free volume was created for the filling with zirconium oxide powder of approximately 20 kg as indicator substance for the particle release measurements, which could have been carried out after the drop tests. The total weights of the specimens differs between approx. 20,000 kg (specimen B) and approx. 28,000 kg (specimen A, C) depending on the simulating content mass.

The dummy-content of specimen A and C, weighting 21,310 kg, is made of a block consisting of eight single massive steel layers. Internal movements of the content inside the cavity is hindered by the direct contact of the lower side of the block to the bottom of the container, by embedding the block to the side walls of the container with mortar and finally using distance holders in form of steel tubes between the block's upper side and the lid.

Table 1. Specimens A, B and C with same design but different content masses.

	mass dummy loading	total weight
specimen A	21 310 kg	28 150 kg
specimen B	10 920 kg	20 450 kg
specimen C	21 310 kg	28 159 kg

The weight of the dummy loading for specimen B is 10,920 kg. The construction of the dummy-weight is analogues to that of the specimens A and C, but the number of steel layers is reduced to four accordingly. The volume between steel layers and container is filled up with mortar.

DROP TEST PROGRAM

The drop test program comprises three single 8-m drop tests, each with a new specimen, onto a concrete slab - the drop test matrix gives an overview (see table 2). The main boundary conditions for all drop tests are the corner edge drop orientation with lid side downwards, a drop height of 8.00 m, a lid welding temperature of equal/ less 0°-Celsius and a concrete slab as impact target.

Table 2: Drop test matrix.

<table>
<tr><th>specimen</th><th>drop orientation</th><th colspan="2">target</th><th>drop height</th></tr>
<tr><td>A</td><td rowspan="3">corner edge, lid side downwards,
centre of gravity over impact corner</td><td>A</td><td rowspan="3">concrete slab
in combination
with IAEA- target</td><td rowspan="3">8.00 m</td></tr>
<tr><td>B</td><td>B</td></tr>
<tr><td>C</td><td>C</td></tr>
</table>

Drop tests and attending tests/ measurements were performed according to the specified test parameters from KSL and the consortium respectively. Table 3 shows an overview of the attending tests and measurements within the drop test performance.

Table 3. Attending tests and measurements.

item	specimen		
strain and deceleration measurements at the specimen		B	C
deceleration measurements at the concrete slab		B	C
temperature measurements at the specimen	A	B	C
particle release measurements	A	B	
3D-measurement of the impacted corner edge	A		
3D-measurement of an impacted concrete slab			C
high speed video of the impact scenario	A	B	C
leakage testing (bubble emission technique according to DIN EN 1593, DIN EN 1779	A	B	C

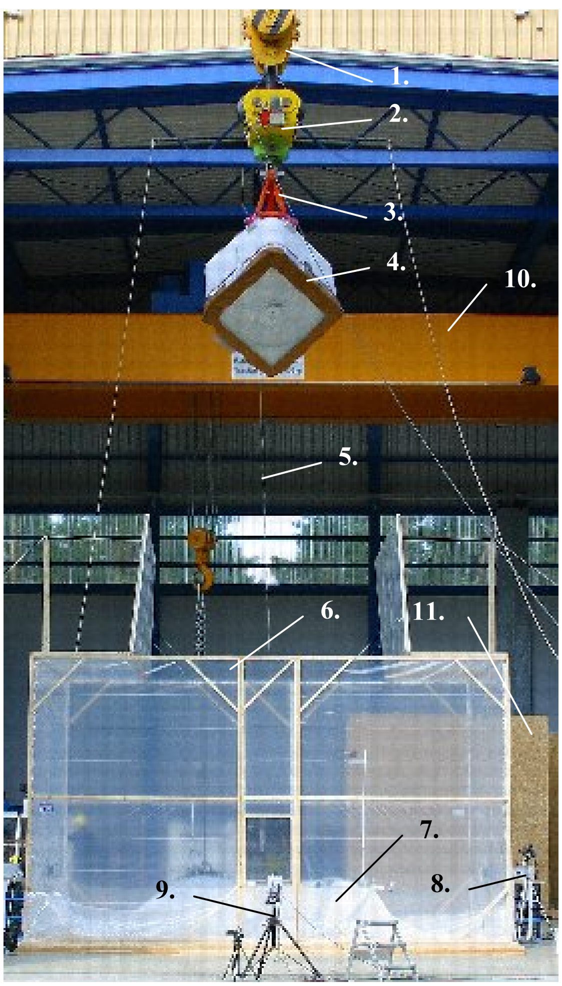
Specimen A and C are identical representing a serial container with maximum content, specimen B represents a serial container with lower contents. The aim of the drop tests was to investigate experimentally the structural effects of impact loading to the corner edge and the welding seam under 0°C-temperature conditions. The geometry of the deformation of the directly impacting part of the specimen shall be determined using 3D-metrology. In case of ruptures in the part of the corner edge or welding seam a possible particle release has to be determined by particle release measurements. With leakage measurements -here the bubble emission technique- eventually defects in leak tightness shall be detected. Specimen B and C were instrumented with strain gauges and accelerometers to measure the structural response to an impact for further structural analysis and as validation data for finite element calculations.

TEST ARRANGEMENT AND MEASUREMENT TECHNIQUES

BAM's DROP TEST FACILITY

The 200-tons drop test facility is located on the BAM Test Side for Technical Safety (BAM TTS) at Horstwalde, nearby Berlin [2]. The facility design is characterized by three main components: the drop tower with hoist, the assembling hall with movable roof and impact target. The drop tower, a 36-meter high steel frame construction, is placed over the assembling hall on four separate pile foundations. The hoist is located in a height of 33 meter. The lifting capacity is limited to a mass of 200,000 kg, the maximum lifting height belongs to 30 meters. A gantry crane with a lifting capacity of 80,000 kg and an action radius over about the whole area of the assembling hall is available for all kinds of handlings. The movable roof has the dimension of 10 m x 12 m.

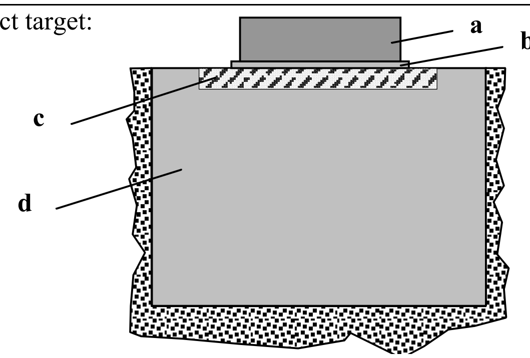
The impact target is built according to the IAEA Regulations as an unyielding target for specimens up to 200,000 kg [3], [4], [5]. It consists of an concrete block (German concrete quality B25/B35) with the geometrical dimension 14 m x 14 m x 5 m and an embedded steel plate as impact pad. This 220 mm thick, 4.5 m wide and 10 m long steel plate is form- and force-fitted fixed with 40 pieces of M36 anchor bolts to the concrete block. The total mass of the target is 2,600,000 kg. The release of the specimen is performed using a momentum free working release system. The adjustment of the drop height is done with the digital altitude counter of the hoist. The release of the specimen is performed by an BAM developed momentum free working electro-hydraulical release system. Figure 2 gives a look inside the drop test facility with the drop test arrangement.



legend:

1. hoists crane hook
2. momentum free release system
3. nylon slings for the specimen attachment to the release system
4. specimen in corner edge drop orientation
5. measuring cables
6. closed volume construction for release measurements
7. concrete slab as impact target covered with vinyl sheet
8. dust sampler
9. high-speed video camera
10. 80-tons gantry crane
11. cooling box

impact target:



a reinforced concrete slab, **b** mortar, **c** impact pad of the IAEA-target, **d** reinforced concrete block of the IAEA target

Figure 2. Drop test arrangement.

DROP TEST ARRANGMENT

The drop test setup is shown in figure 2. It shows the drop positioned specimen (here specimen B) in a drop height of 8 m attached with nylon slings to the release system ready for drop testing. The setup consisted of following parts and components:

- impact target, built as concrete slab and connected by mortar to the IAEA- target of the drop test facility
- closed volume construction for the particle release measurement after drop test with the dimensions 6800 mm x 5000 mm x 4000 mm and built as wooden frame construction with vinyl sheet endwalls and closable roof
- two dust-samplers for the particle release measurements
- digital high-speed camera with lightning system
- strain and deceleration measurement system
- leakage measurement system
- 3D- metrology

The directly impact targets for the drop tests were concrete slabs connected by mortar to the impact pad (steel plate with a thickness of 300 mm) of the drop test facility's unyielding IAEA target. The concrete slabs (in total three pieces) were manufactured in Japan according to the specifications of KSL and delivered to BAM Horstwalde. The dimensions of the concrete slabs were 3,000 mm x 2,000 mm x 800 mm (length x width x thickness) with a compression strength > 100 MPa. For connection to the IAEA target liquid mortar was added directly to the surface of the impact pad bordered by a small steel frame. In order to avoid the subsidence of the concrete slab into the fresh liquid mortar some small flagstones were used as distance holders placing them onto the impact pad. After hardening the mortar layer thickness was approximately 30 mm and performed a very stiff connection between both targets with very small energy dissipation during impact. For each drop test a new target setup was installed.

CASK HANDLING AND POSITIONING INTO DROP ORIENTATION

For handling and positioning, every specimen was equipped with special lifting lugs each with an lifting capacity of 20,000 kg at the four edges of its bottom plate and at the bottom-corner which lay opposite to the impact corner.

The positioning of the specimen into the corner edge drop orientation was complex and performed in two steps:
In a first step (pre-positioning) the specimen was turned over the impact corner edge, attached at three lifting lugs using a mobile crane and the gantry crane of the facility. In this position the specimen was deposited into the so-called corner skid (see figure 3).

Figure 3: Cask handling (*a, b*: Pre-positioning, *c*: cooling, *d*: adjustment of exact drop orientation).

This skid, a welded steel plate construction allowed to place the specimen with the impacting corner edge downwards. Using this setup the specimen was moved into the cooling box and subsequent onto the concrete slab for final preparation of the drop test.
In a second step the specimen was attached to the release system and adjusted to the exact drop orientation.

The exact drop orientation was realised beside hanging the specimen at two attachment points using in addition a nylon sling in combination with an adapter of variable length to adjust the right drop angle, so that the centre of gravity lies over the impact point.

COOLING TECHNIQUE AND TEMPERATURE MEASUREMENTS

The cooling of the specimens was solved with a large cooling box located in the drop test hall using liquid nitrogen as refrigerant. The goal temperature of the specimens for drop testing with focus on the welding seam was defined as equal/ less 0°-Celsius (temperature criteria for the welding seem). But for drop test preparation reasons and the need of adequate working time the final temperature of the specimens was chosen to be lower considering the warming up of the specimen during the directly preparation of the drop test after cooling.

The cooling setup consisted of following technical equipment:

- a double walled, 4 m x 4 m x 4 m - cooling box with isolation material between inner and outer walls made of wooden composite plates,
- circulate ventilators installed at the top wall of the cooling box for the processing of liquid nitrogen,
- temperature sensors inside the cooling box (PT100) and at the specimens surface area (thermo couples) for controlling the containers temperature and cooling process,
- control unit with tube- and valve-system,
- road tank car with liquid nitrogen.

The cooling operation had to be organized in a way that the specimen were already pre-positioned in drop orientation. Therefore the skid was connected with tension belts to the specimen and transported inside the partly disassembled cooling box under the use of the drop test facility's gantry crane (see figure 3c). After closing the cooling box and final assembling of the cooling equipment the box was directly charged by cryogenic nitrogen (LN_2) with a temperature of - 196°C and circulated inside by ventilators, placed in the top of the cooling box. The entry of LN_2 is carried out regulated in dependence of the defined goal temperature of the specimen measured by thermo couples and the inner temperature of the cooling box.

The temperatures of the specimens were measured at the surface area using type K leaf thermocouples Ni-CrNi. The measuring points were defined by the instrumentation plan and located directly on the welding seam, the impacting corner edge, the middle of one side wall and the middle of the bottom plate. Additional measuring points were the mounting base of an accelerometer, inside and outside the cooling box. The temperature measurements comprised the whole cooling process and the following drop test preparation time until the specimen impacts during drop test.

STRAIN AND DECELERATION MEASUREMENT

Strain and deceleration measurements are an important tool to evaluate a specimens mechanical behaviour during impact. Test results as deceleration-time and strain-time functions constitute the main basis for validation of assumptions in the safety analysis, for the evaluation of calculations based on finite-element methods and extrapolation of scale model testing on full sized package within approval design tests. Also, these test results could be an advantageous basis for design alterations. Strain gauges are useful to determine the time dependent magnitude of any deformation as well as associated stresses. Accelerometers are widely used for the measuring of motion i.e. speed or displacement of the rigid cask body, of vibration and shock. Appropriate electronic devices in regard to the range of analogue bandwidth, the sample rate, etc. are utilised to acquire, record and store data on a high technical level [6].

Here in this project specimens B and C were fitted with strain gauges to measure the structural response and accelerometers to determine the cinematic behaviour of the cask due to the impact. In total, each specimen was instrumented with 11 units of two-axial foil strain gauges, 3 units of three-axial foil strain gauges and two accelerometers.

Two-axial foil strain gauges with a gauge length of 5 mm and a 120 Ω- resistance from type Kyowa Electronic Instruments KFEL-5-120-D34 were applied to the measuring points on the cask body and lid of the specimens as well as 0°/45°/90°- three-axial foil strain gauges from type KFEL-5-120-D35. For both types of strain gauges a cyano-acrylate based adhesive from type ‘KYOWA, CC-36’ (-30°C…+100°C) was used for application. The applicated strain gauges were protected against moisture and water as first with cover medium from type ‘KYOWA, C-5 2’ than followed by ‘KYOWA VM- Aluminium tape’ (see figure 4).

The strain gauges were connected in a 3- wire Wheatstone Quarter-Bridge circuit, a commonly used technique in experimental stress analysis. At the exterior long side of the cask a central soldering terminal merges all ribbon cables coming from sensors. The terminal is connected to the data acquisition units by means of 50 m long and shielded measuring cables.

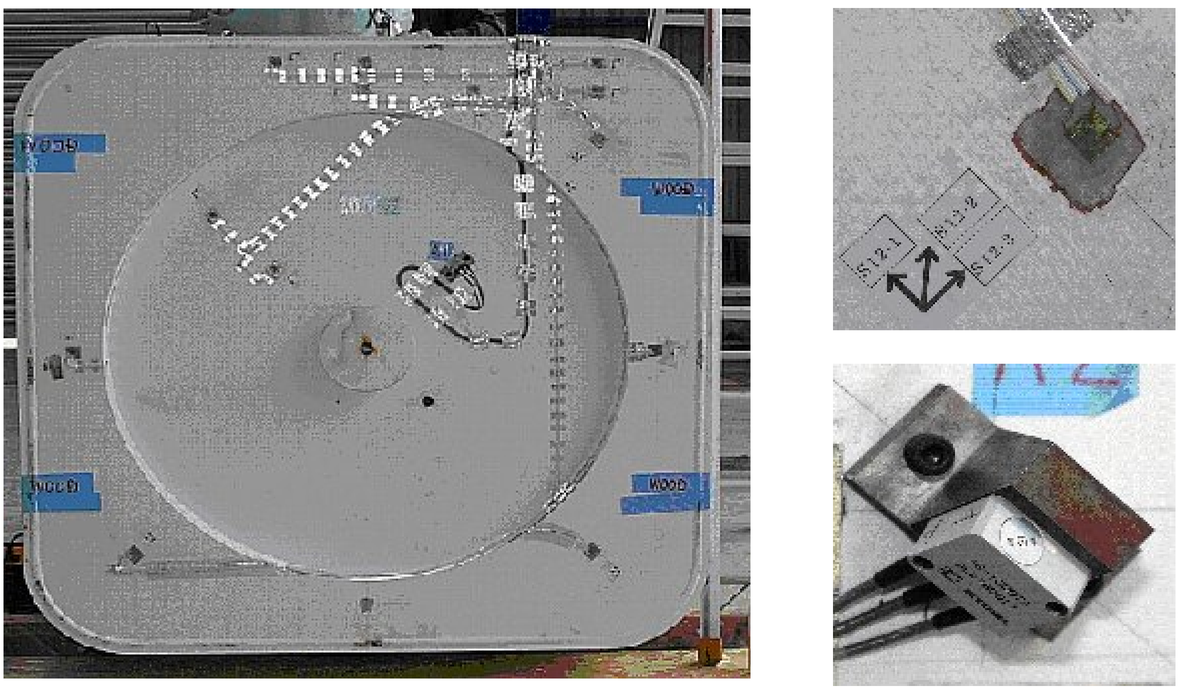


Figure 4: Lid side of the specimen instrumented with strain gauges and accelerometers.

The deceleration measurements at the specimens were performed using triaxial piezo- resistive accelerometers from type ‘Kyowa Electronic Instruments AS-1000 TA’ with an amplitude range of ± 1000 g and a frequency range of 0 Hz – 7600 Hz (± 3 dB). A six-wire Wheatstone Full-Bridge circuit with sense wiring of the power supply was chosen for the connection of the accelerometers; 50-m long measuring cables connect the sensors with the measuring devices analogue to the strain measurements with the data acquisition units. The accelerometers were mounted with two bolts to a special mounting base (which in turn was mounted to the specimen) equalising the angles from corner drop orientation so that the Z- measuring direction of the sensor is in line with the direction vector of the falling (and impacting) cask; X- and Y- measuring direction lay parallel to the target plane.

The data acquisition was carried out using two multi-channel measuring devices from DEWETRON mbH with wideband differential bridge amplifiers (analogue bandwidth up to 200 kHz, -3dB) for direct connection of all bridge type devices. A pre-sampling filter with a cut-off frequency of 30 kHz for strain signals (10 kHz for deceleration signals) and a 500-MHz sampling frequency for each channel with a 12-bit vertical resolution was applied. The external triggering of the measurement devices is simultaneous for all devices and measuring channels and realized by a mechanical circuit breaker released by the falling specimen.

OPTICAL 3D- DEFORMATION MEASUREMENT

The complex deformation geometry of the specimens impacted corner edge as well as the crater demolition of the concrete slab were determined using optical 3D-measurement methods – the method of projected fringes in combination with the close range photogrammetry [8]. Figure 5 (left photo) shows a 3D-digitization of the deformed corner edge after the 8-m drop test. This digitization allows the comparison to the original geometry obtained by zero-measurement so that for any shape the divergence and therefore the deformation can be determined. The blue line in the left photo for example represents the original geometry and the red curve the deformed. The calculated maximum deformation belongs to 14 mm and the maximum bending to 18 mm. The photos on the middle and right side shows the deformation as fringe plot in two different scaling over the whole specimen.

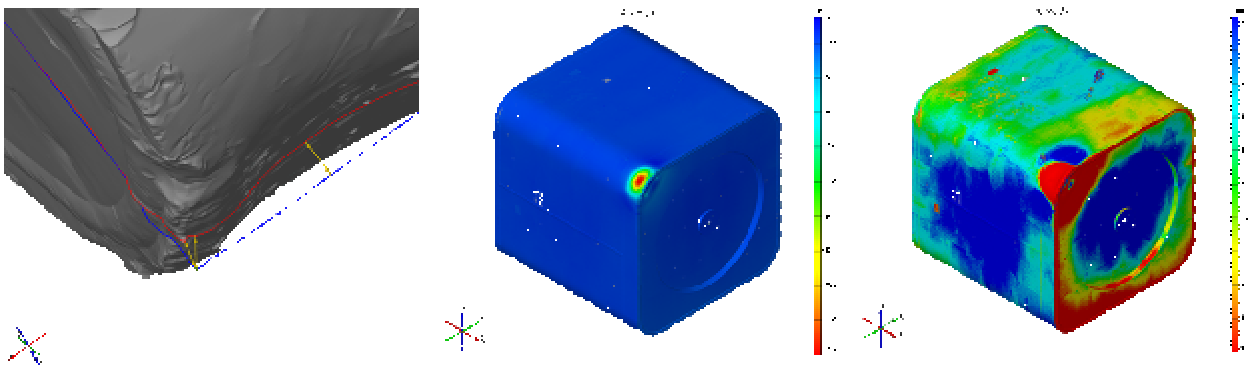


Figure 5: Results of the optical 3D-measurements. Deformations of specimen A caused by the impact.

LEAKAGE TESTING

The leak tightness of the welding seam as well as of the deformed corner edge after impact was decided to be confirmed by an leakage testing method the so-called ‘bubble emission technique’ according to European Standard DIN EN 1593 and DIN EN 1779. This method is applicable to any object in which a pressure differential can be created across the boundary to be examined and refers to objects that can be pressurized. A suitable liquid surfactant must be applied on the low pressure side by brush, spray or other methods. Afterwards, it must be waited for a sufficiently long inspection time to realise even slow production of foam from small leaks. A growing foam originating from any isolated points shall be interpreted as a leakage (see figure 6).

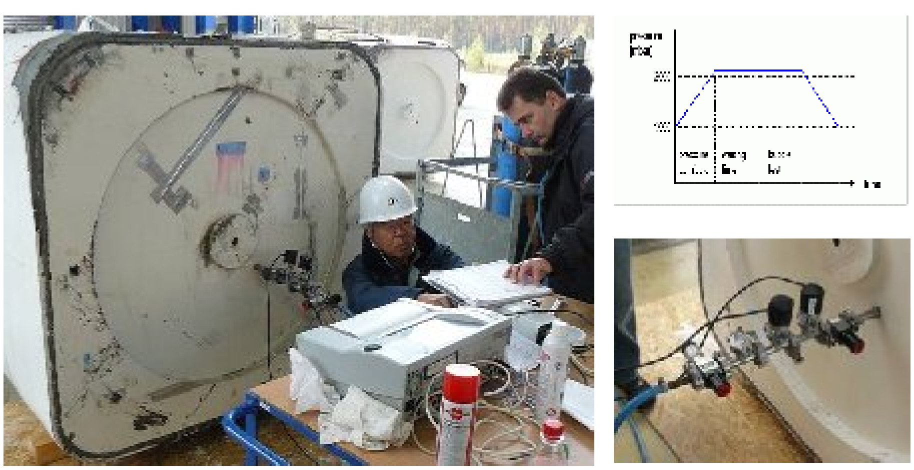


Figure 6: Leakage testing.

After each drop test every specimen was leak tightness tested with the above described bubble emission technique. The pressure admission was > 2000 mbar and the waiting time for stable conditions was > 30 minutes. The test setup comprises a compressed gas cylinder with nitrogen, two valves, two pressure sensors with amplifier and measurement device to acquire the test data, some adapters and pipes. Before each test the specimen's white painting was fully removed from the part of the welding seam by solvent. As liquid surfactant a leak finder spray was applied to the whole welding seam and deformed corner edge for tracing possible leaks. After application of the leak finder spray an observation of any bubbles started.

HIGH SPEED VIDEO

The impact of the specimens onto the concrete slab was filmed during all three drop tests using a high speed colour video camera. The chosen resolution was 1024 pixels x 1024 pixels and the frame rate 2000 fps. For realization of that high frame rate adequate lighting must had been installed. The position of the camera in relation to the specimens and concrete slabs was chosen in a way that the lid side with the impacting corner edge was seen.

DROP TEST RESULTS

Boundary conditions

All three specimen had the same boundary conditions in regard to drop orientation, drop heights and impact targets (see table 2). The temperatures of the specimen varied between -5.4°C and 0°C at the welding seem and fulfilled the defined range.

High speed video

The high speed video demonstrated for all three drop tests that every of the three specimens A, B and C impacted the defined point at the surface of the concrete slab without any change of its drop orientation.
The further analysis of the high speed video showed that also no change of the drop orientation occurs during the main impact while the corner edge of the specimen is demolishing the upper area of the concrete slab until to a maximum deformation depth (see figure 7). Not till then specimens A and B started to tilt over to a side wall on which they kept laying on the slab after impact; specimen C kept its drop position also after impact which underlines the perfect orientation. The impact was accompanied by a heavy dust and concrete boulders cloud which propagates away from impact point.

Figure 7. Single photos extracted from the high speed video of specimen C showing the specimen directly before impact (left photo) and at time of maximum penetration into the concrete slab (right photo).

Visual inspection of the specimens

The visual inspection directly after drop test showed a significant plastic deformation of the impacted corner edge for every specimen (see figure 8). The analysis results of the 3D-metrology showed that the deformation of the corner edge was approximately 14 mm in moving direction. Further a buckling of 18 mm was determined at a neighbouring side wall of the impacted corner edge. The welding seam was visually undamaged and showed only some grooving on its surface. Other parts than the impacted corner edge of the container are visually unaffected by the impact without any visible damages.

Figure 8. Specimen after drop test (left) with a detail photo of the impacted corner edge (right).

Inspection of the target

All concrete slabs showed a crater-shaped local demolition by the impact of the specimen (see figure 9). The maximum depths are shown in the table 4. The connection to the IAEA target by a mortar layer was nearly undamaged in all three drop tests.

Figure 9: Disassembled and cleaned concrete target after the drop test with impact zone in the middle.

Table 4: Inspection results of the concrete target.

	total mass	impact velocity	crater depth
specimen A	28 150 kg	12.5 m/s	209 mm
specimen B	20 450 kg		185 mm
specimen C	28 159 kg		227 mm

Deceleration measurements

The deceleration signals of the accelerometers reflect the dynamic response of the specimens excited by their impact onto the concrete slab. Two categories of dynamic response, the vibration and quasi-static response can be clearly distinguished in the measured deceleration signals. The vibration response is the result of the specimen's structure responding to the impact in the natural vibration modes of the container; this is represented in the signal by higher frequency parts. The quasi-static response is the result of the whole-body or rigid-body motion represented by a low-pass filtered signal or smoothed original deceleration curve.

Figure 10 shows exemplarily for the whole drop test program specimen C's deceleration time history measured in drop and impact direction respectively choosing the signal of one accelerometer (measuring point A1). The diagram on the left side shows the original deceleration signal with a bandwidth of 3 kHz including the quasi-static and vibrational response; the rigid body response in the right diagram was obtained by low-pass filtering with a Butterworth filter and a cut-off frequency of 200 Hz.

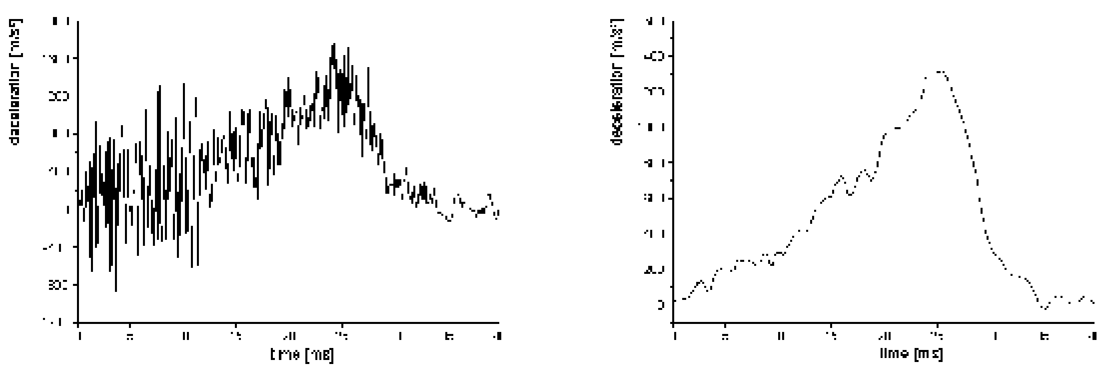


Figure 10: Deceleration vs. time history. Original deceleration signal (bandwidth 3 kHz) *(left)* **and low-pass filtered (Butterworth, 200 Hz) as rigid body behaviour** *(right)***.**

The impact time was considered reasonable to be defined here as the time period between the first contact of the specimen's corner edge with the concrete target (time $t_1 = 0$) and the maximum penetration into it (time t_2). Naturally, this second point of time t_2, laying approximately at $t_2 = 25$ ms corresponds with the zero-crossing of the cask's rigid body velocity-time history, the maximum deceleration as well as the maximum displacement. The signals in figure 6 show that the rigid body deceleration increases continuously to its maximum at time $t_2 = 25$ ms. At that time both velocity time curves show zero-crossing and the displacement curve its negative maximum; the specimen rigid body motion achieved its reversal point after that the specimen rebounds in contrarious to the drop direction. In Table 5 some characteristic values are listed, taken from the time histories of the rigid body response of the specimen. It can be noticed that the values from the two measuring points are quite good together; the mean decelerations with values of 550 m/s² (sensor A1-Z) and 520 m/s² (sensor A2-Z) are close together. The comparison of the values of maximum displacement obtained from the sensors A1 and A2 (185 mm and 212 mm) with the maximum demolition depth of the concrete (227 mm) and the value obtained from the motion analysis of the high speed video (200 mm) show that the signals of both sensors are relatively close to the mechanical facts.

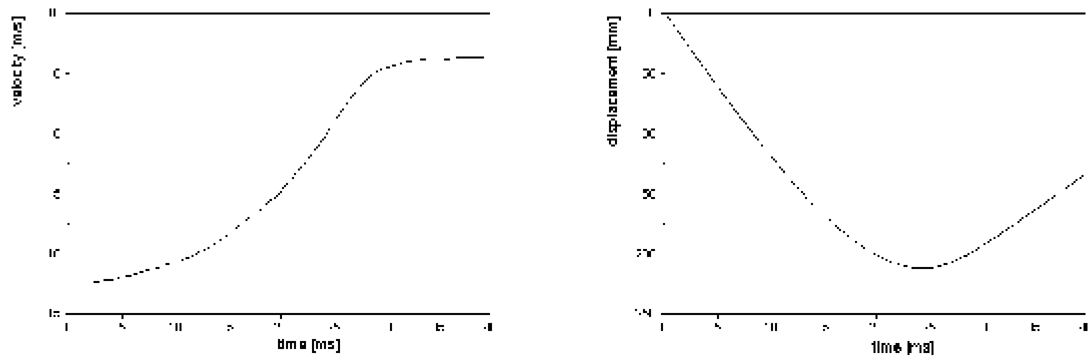


Figure 11: Velocity *(left)* and displacement *(right)* vs. time history of the container's rigid body motion during impact using the example of specimen C.

The X- and Y- direction signals are mainly excited by vibration responses of the specimen without any rigid body responses during impact time. That means that the cask keeps his drop orientation unchanged during impact, which is also affirmed by the high speed video. First after the reversal point the specimen starts a rotary motion changing its original drop orientation and tilted over to a side wall.

Table 5: Rigid body response of specimen C.

sensor	impact time T in ms	maximum deceleration a_{max} in m/s²	mean deceleration $\overline{a}$ in m/s²	impact velocity v_0 in m/s	Maximum displacement d_{max} in mm
A1-Z	22	1470	550	12.5	185
A2-Z	24	1226	520		212

Strain measurements

The strain signals correspond with the time history characteristics of the specimen deceleration curves. The maximum stresses and strains respectively occur at the time point of maximum deceleration in the time interval *I* with *I* = [25 ms; 30 ms]. Figure 12 shows an example of measured strain signals with a 3-axis strain gauge located on the lid of the specimen and the deduced principal strains.

The required calculation formulas for the analysis of 3-axis strain measurements can be deduced from the geometrical relations within the Mohr's circle of strain [8]. Accordingly the well known conditional equation for the principal strains $\varepsilon_1(t)$, $\varepsilon_2(t)$ is

$$\varepsilon_{1,2}(t) = \frac{\varepsilon_a(t)+\varepsilon_c(t)}{2} \pm \frac{1}{2}\sqrt{2}\sqrt{[\varepsilon_a(t)-\varepsilon_b(t)]^2+[\varepsilon_c(t)-\varepsilon_b(t)]^2} \qquad \text{(Eq.1)}$$

where $\varepsilon_a(t)$, $\varepsilon_b(t)$ and $\varepsilon_c(t)$ are the measured strain signals of a 0°/45°/90°- three-axis strain gauge. On basis of the calculated principal strains $\varepsilon_1(t)$, $\varepsilon_2(t)$ the determination of the principle stresses can be achieved with the equations of Hook's law for the biaxial state of stress

$$\sigma_1(t) = \frac{E}{1-\nu^2}[\varepsilon_1(t) + \nu\varepsilon_2(t)] \ , \ \sigma_2(t) = \frac{E}{1-\nu^2}[\varepsilon_2(t) + \nu\varepsilon_1(t)] \qquad \text{(Eq.3)}$$

were E is the modulus of elasticity and ν Poisson ratio.

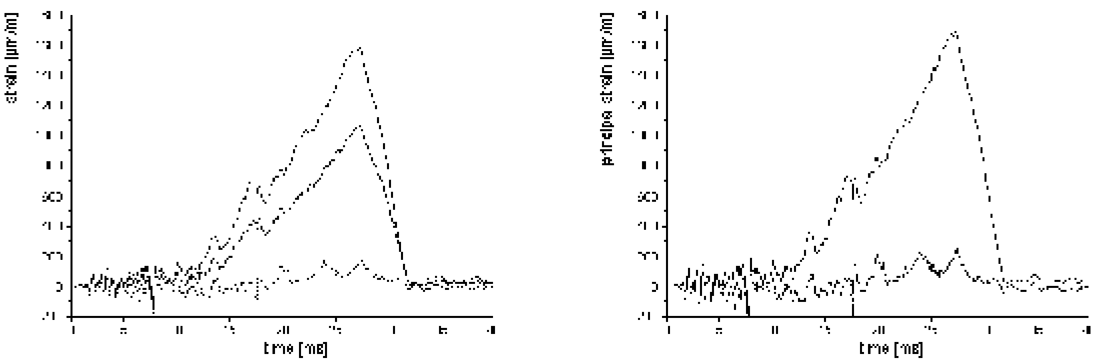


Figure 12: Original measured strain time history with a 3-axis strain gauge and the deduced principal strain for a measuring pint on the lid side of the specimen.

Leakage testing

The leakage test results showed no bubbling at all could be recognized neither on the welding seam nor on the deformed corner edge for all three drop tests.

SUMMARY

In context with Japanese disposal container safety assessment of containers for intermediate depth disposal the German Federal Institute for Materials Research and Testing (BAM Bundesanstalt für Materialforschung und –prüfung) performed drop tests contracted by Kobe Steel, Ltd. (KSL) for a consortium of Japanese electric power plant companies represented by Chubu Electric Power Company, Japan. The tests were carried out in autumn 2008 at the BAM 200-tons drop test facility situated on the BAM Technical Test Site (BAM TTS) nearby Berlin, Germany.

The drop test program comprises three single 8-m drop tests in corner edge orientation, each with a new specimen, onto a concrete slab and a specimen temperature equal or less 0°-Celsius. The drop tests were accompanied by extensive and various measurement techniques: strain and deceleration measurements to obtain the structural, kinematic and kinetic impact responses, high-speed video to visualize and analyze the impact scenario, temperature measurements to observe the cooling process and to verify the goal temperature, leakage testing of the container's lid system, optical 3D-metrology of the impacted corner edge and particle release measurements.

The visual inspection of the specimens after drop test showed for all three specimens similar results: a plastic deformation of the impacted corner edge and a visually undamaged welding seam except groovings on its surface. Other parts of the specimens than the impacted corner edges were visually unaffected by the impact without any visible damages. The concrete slabs showed crater-shaped local demolition by the impact of the specimens. The results of the leakage test 'bubble emission technique' according to European Standard DIN EN 1593 and DIN EN 1779 showed no bubbling neither on the welding seam nor on the deformed corner edge for all three specimens. The specimens completely preserved their integrity.

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