WASTE CONTAINER DROP TESTS 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 tests were accompanied by various metrology to collect data as basis for safety assessment.

INTRODUCTION

In context with Japanese disposal container safety assessment of L1-containers for intermediate depth disposal [1] the German Federal Institute for Materials Research and Testing (BAM) performed drop tests contracted by Kobe Steel, Ltd. (KSL) and a consortium of Japanese electric power plant companies. The tests were carried out in the year 2008 at the 200-tons drop test facility situated on the BAM Technical Test Site (TTS) nearby Berlin, Germany.

The drop tests were conducted with three specimens of the so-called ‘Cubic Disposal Container Type L1’ which is produced by Kobe Steel, Ltd.. The drop test program comprises three single 8-m drop tests accompanied by various extensive measurement techniques.

SPECIMEN

The specimen were built in original scale and delivered ready assembled by KSL to the BAM Test Site Technical Safety (BAM TTS). Figure 1 shows the specimen standing on their lid side inside the drop test facility.

The geometric design of the container was of cubic shape with outer dimensions of 1,600 mm x 1,600 mm x 1,600 mm. The material of the side walls was 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 was closed by a welded lid.

The content was simulated by massive steel layers. In order to avoid an internal movement of the dummy-content inside the cavity, it was embedded with mortar. Under the lid a free volume was created with distance holders for the filling with zirconium oxide powder of approximately 20 kg as indicator substance for the particle release measurements.

The total weight of the specimens differs between≈ 20,000 kg and ≈28,000 kg depending on their dummy-content.

Figure.1. Specimen of the 'Yoyushindo-Disposal' waste container ready assembled for testing with different content masses.

DROP TEST PROGRAM

The drop test program comprises three single 8-m drop tests, each with a new specimen, accompanied by extensive and various measurement techniques: strain and deceleration measurements to obtain the structural, cinematic and kinetic impact responses, high-speed video to visualize and analyze the impact scenario, temperature measurements to observe the cooling process, leakage testing of the container's lid system, optical 3D-metrology of the impacted corner edge and particle release measurements.

The main boundary conditions for all drop tests were the corner edge drop orientation of the specimen with lid side downwards, a drop height of 8.00 meters, a lid welding temperature of equal or less 0°-Celsius and a concrete slab as impact target.

TEST ARRANGEMENT AND MEASUREMENT TECHNIQUES

DROP TEST FACILITY

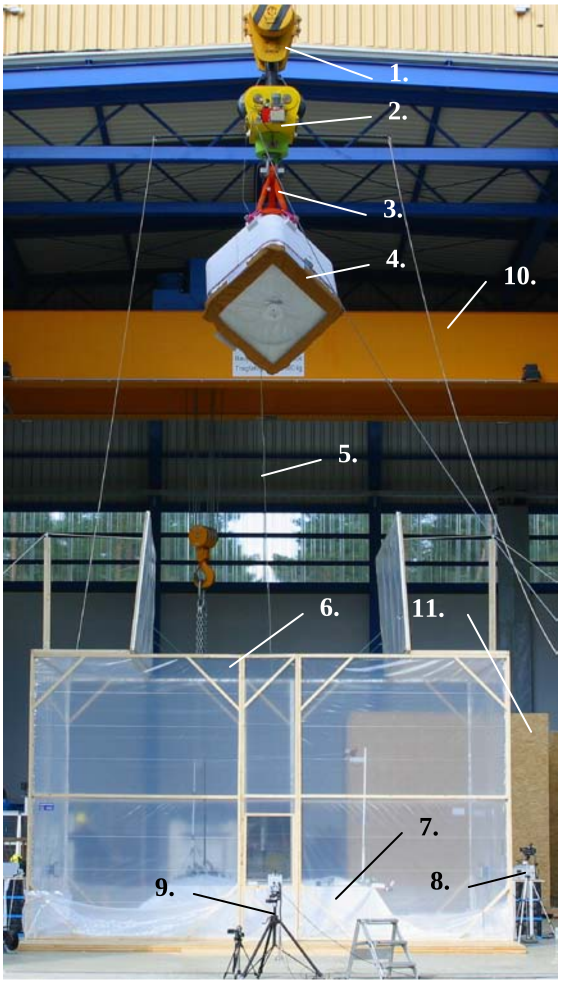
The 200-tons drop test facility is located on the BAM Test Side for Technical Safety (BAM TTS) at Horstwalde, nearby Berlin [1]. The facility design is characterized by three main components: the drop tower with hoist, the assembling hall with movable roof and impact target. The drop tower, a 36-meter 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 [2]. It consists of a 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 a BAM developed momentum free working electro-hydraulical release system. Figure 2 gives a look inside the drop test facility showing the drop test arrangement.

DROP TEST ARRANGMENT AND IMPACT TARGET

The drop test arrangement and impact target is shown in Figure 2. It shows the drop positioned specimen in a drop height of 8 m attached with nylon slings to the release system ready for drop testing.

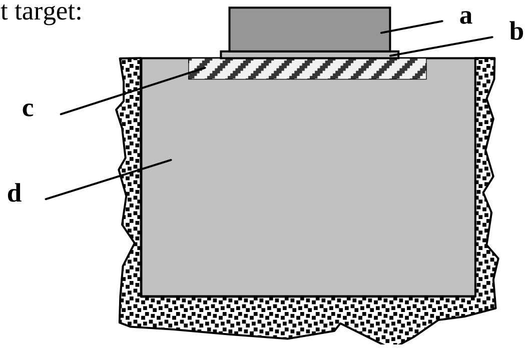
The directly impact targets for the drop tests were concrete slabs manufactured in Japan and connected by mortar to the impact pad (steel plate, thickness of 300 mm) of the unyielding IAEA target. The concrete slabs have a dimension of 3,000 mm x 2,000 mm x 800 mm (L x W x T) with a compression strength >100 MPa. 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.



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.

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 or 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 temperatures of the specimens were measured at the surface area using type K leaf thermocouples Ni-CrNi.

STRAIN AND DECELERATION MEASUREMENT

The specimens 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 tri-axial accelerometers.

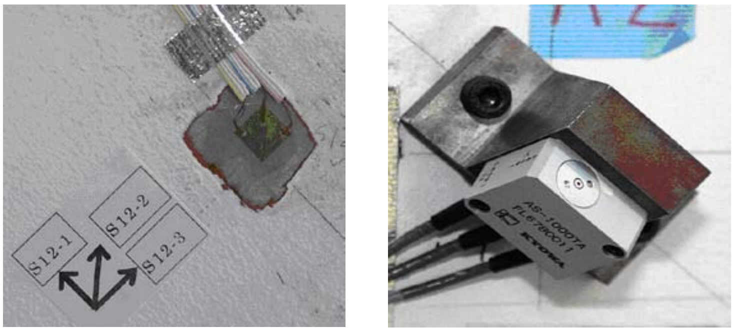


Figure 3: Specimen instrumented with strain gauges (left) and accelerometers (right).

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. The strain gauges were connected in a 3- wire Wheatstone Quarter-Bridge circuit, a commonly used technique in experimental stress analysis.

The deceleration measurements were performed using tri-axial piezoresistive 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. 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 with wideband differential bridge amplifiers (analogue bandwidth up to 200 kHz, -3dB). 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.

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.

DROP TEST RESULTS

The high speed video demonstrated for all three drop tests that every of the three specimens 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 a specimen is demolishing the upper area of the concrete slab until to a maximum deformation depth. The impact was accompanied by a heavy dust and concrete boulders cloud which propagates away from impact point.

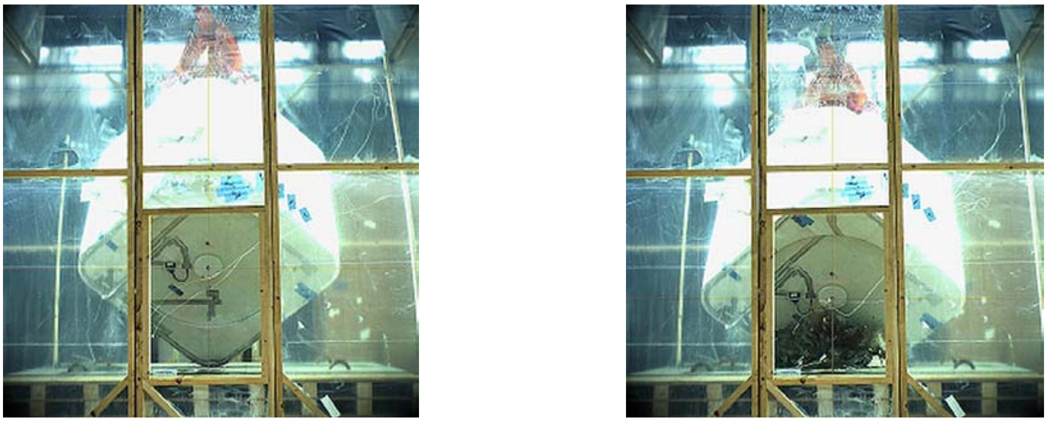


Figure 4. Specimen directly before impact (left) and at time of maximum penetration into the concrete slab (right).

The visual inspection after the drop test showed a significant plastic deformation of the impacted corner edge for every specimen. The analysis results of the 3D-metrology showed that the deformation of the corner edge was some Millimeters in moving direction. Further a buckling 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 were visually unaffected by the impact without any visible damages.

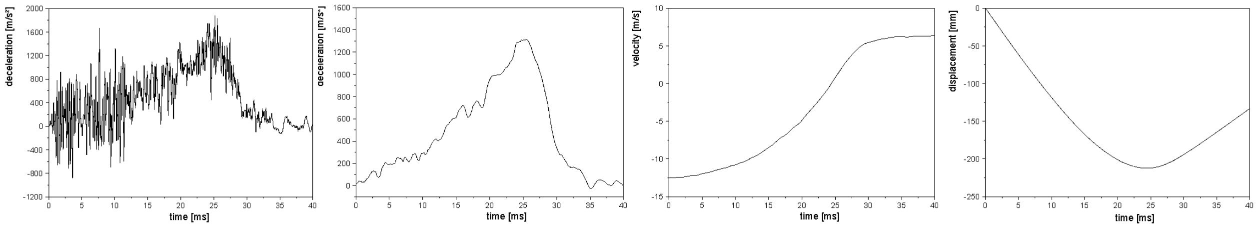
Figure 5. Specimen (left) and impact target (right) after drop test. Detail impacted corner edge (middle).

All concrete slabs showed a crater-shaped local demolition by the impact of the specimen. The maximum depths varied between 185 mm and 227 mm. The connection to the IAEA target by the mortar layer was nearly undamaged in all three drop tests.

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 6 shows exemplarily a specimen's deceleration time history measured in drop and impact direction respectively. Diagram (a) shows the original deceleration signal within a bandwidth of 3 kHz including the quasi-static and vibrational response; the rigid body response in diagram (b) was obtained by low-pass filtering with a Butterworth filter and a cut-off frequency of 200 Hz.



(a) (b) (c) (d)

Figure 6: Deceleration (a), (b), velocity (c) and displacement (d) vs. time history.

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 time $t_2 =$ 25 ms corresponds with the zero-crossing of the cask's rigid body velocity-time history (diagram (c)), the maximum deceleration as well as the maximum displacement (diagram (d)). 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's rigid body motion achieved its reversal point after that the specimen rebounds in contrarious to drop direction.

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 7 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. Accordingly the well known conditional equation for the principal strains $\varepsilon_1(t)$, $\varepsilon_2(t)$ is

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

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

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

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

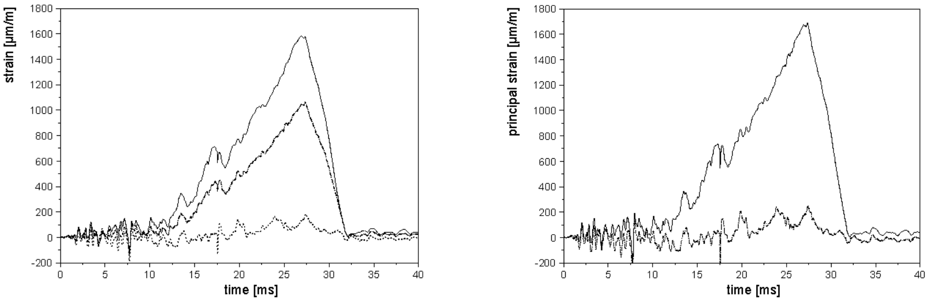


Figure 7: Measured strain time history (3-axis strain gauge) and the deduced principal strain.

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.

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

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 [3]. Figure 8 (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 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 show the deformation as fringe plot in two different scalings over the whole specimen.

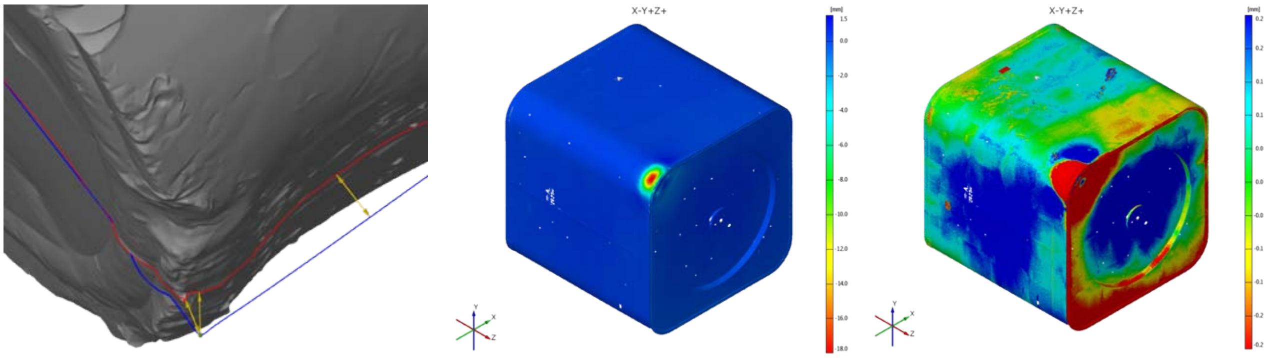


Figure 8: Results of the optical 3D-measurements.

CONCLUSIONS

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 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.

The visual inspection of the specimens after drop test showed for all three specimens similar results: 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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