Impulse Excitation of the Outer HDR-Containment with a Pendular Falling Weight

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Abstract

It is reported on impact tests at the HDR-plant, where impulsive loads of 200 kNs and 0.1 s duration have been realized. The test-equipment and the load generation procedure is described and some results of the load propagation along the external containment shell and into the internal concrete structure are discussed.

1. Aim of the Impulse Tests

Within the structural dynamics investigations of the HDR safety program, carried out by the KfK, W.-Germany, tests are performed with impulsive excitation of the external concrete containment of the decommissioned HDR nuclear power plant. These tests serve to study the global response of the containment shell due to local impact and the load propagation to the internal structures and the machanical equipment. Local effects are of secondary interest and penetration has to be avoided.

Design and pretest calculations have been performed by different institutions with different computational models of the reactor building using 3-D shell- as well as coupled shell and beam finite elements.

The comparison of the calculated and measured results finally serves as a means to verify the modelling assumptions of the calculations and input parameters such as material properties, damping values and boundary conditions. Special interest exists with respect to the validation of simplified models and calculational procedures.

This contribution reports results of the first series of tests carried out in September 1984, which served primarily to demonstrate the efficiency of the test equipment, the capability of the specially developed crash pads to generate the desired load time history and additionally the investigation of the load propagation and the global response in the case of an impact region nearly at ground level. The main series of tests will take place in April 1985.

2. Test Equipment

Pendulum Tup

Up to approximately 5 % of the impulse of the German design basis force time history for an aircraft impact has been realized with a pendulum tup, Fig. 1. This exitation system consists of two steel crane towers and a 20 t falling weight, extendable to a falling height of 5 m by means of a jib, Fig. 2. The same construction will be used for the impact tests at the level of 40 m above ground in the main test series, simply by building up additional prefabricated crane elements, Fig. 3.

Crash Pads

A deformable crash pad serves to transform the impulse to a force-time-history comparable to the aircraft impact time history used in the German design procedure as mentioned above. This interface unit consists of an assembly of steel pipes of different diameters, Fig. 4. Due to the load induced by the falling weight, the pipe segments are compressed in a typical manner developing yield hinges at determinable points. The behaviour of such elements is ascertainable with relatively small limits by means of numerical methods [2]. Beside this, full scale dummies of the crash pads have been tested previous to each test to make sure, that the maximum allowed force will not be exceeded. Calculations and pre-tests with scaled models proved the feasibility of these elements to produce the desired force time history. They allow the variation of the shape of the force function (with or without step characteristic), the duration of force increase (0.2 to 0.75 MN/msec.), the peak value of the force (0.5 to 4 MN) and the duration of the impact (0.07 to 0.1 sec.). Fig. 5 shows a comparison of theoretical and experimantal results obtained in pre-tests with models (scale 1:3.5); a comparison of the desired and the actually measured force time history of the full scale tests is to be seen in Fig. 6.

The measurement of the force is done by a total of 8 force transducers in order to maintain the load distribution allready induced by the crash pads, Fig. 7.

According to the safety calculations, the external concrete containment of the HDR with a wall thickness of 60 cm had to be reinforced by an additional 40 cm concrete pad in the impact region to withstand the expected load of more than 3 MN.

Instrumentation

Extensive instrumentation (over 150 channels) was applied to measure impact forces, the response of the concrete, the movement of the foundation, the response of the internal building structure and of some major components, e.g. pressure vessel and piping systems.

All the following statements are related to one of the tests out of a series of 4, whose characteristics are described by the parameters

- falling heigt 3.73 m
- final velocity 8.75 m/s
- shock load 196 kNs
- maximum force 2900 kN
- place of impact 2.7 m above ground level.

3. Results

Load Propagation along the Outer Containment

In Fig. 8 the response spectra (2 % damping assumed) of the measured accelerations are shown for a series of points on the concrete containment. As expected, the acceleration spectrum just behind the point of impact shows the maximum values with two pronounced peaks at 20 and 50 Hz, confirming, that the frequency contents of the aircraft impact has been realized in the outer containment. With the distance from the place of impact the observed accelerations decrease rapidly (the peak amplitude of the response spectrum at the 40 m level is reduced to approximately 20 %, compared to the region of impact) but the frequency content is maintained. The low frequency fundamental modes of the HDR building identified in earlier tests (app. 1.5 Hz for rocking and app. 2.6 Hz for out of-phase bending of external and internal structure) are not descernable, because of the superimposed shell vibrations at 20 and 50 Hz dominating the response of the external concrete containment.

Load Propagation into the Internal Structure

On Fig. 9 the response spectra for two floors and the inner steel containment (2 % damping) are shown. Compared with the spectra from the external containment it is evident, that the maximum values are about 50 times smaller due to radiation of energy into the soil and reflection at the foundation. On the other hand the frequency content of the two floor responses remained unchanged: the peaks at 20 and 50 Hz are still dominant. The fundamental modes of the structure become recognizable, for example the peak at 2.6 Hz is related to the out-of-phase bending mode of the HDR structure. With increasing height of the measurement point in the building this feature becomes more evident. At the steel containment (40 m level) there is a clear gain at 20, 30 and 60 Hz which results from the existence of slightly damped modes of the steel dome partly identified allready in previous tests at the HDR.

Response of the Mechanical Equipment

On Fig. 10 the response of the equipment founded on the floor at 14.5 m level are easily to examine. The floor acceleration is an excitation not only to the pressure vessel but also to the pipe system. Both are coupled, so that the response of the top of the pressure vessel acts additionally as an excitation to the pipe system. In all response signals the frequency content of the impulsive load can still be identified, but the natural modes of the structures under consideration become more evident: the peak at appr. 18 Hz belongs to the first bending mode of the pressure vessel (without cover), the peak at appr. 11 Hz belongs to a horizontal bending mode of the pipe system.

Comparison of Test Results with a priori Calculations

A priori calculations were carried out with the desired load time history according to Fig. 1 acting on the HDR structure at the 40 m level [3]. Anticipating that the induced acceleration time history in the impact region is independent (to some extent) from the place of impact, this result of the calculation should be comparable to the acceleration measured during the test at the 2.7 m level. The comparison is shown on Fig. 11. Both functions show clear features of the acting load: the response to the first and second ascent of the force at 0 and 40 ms as well as to the descent at 75 ms, followed always by a damped free vibration response, are easily to distinguish. The excellent agreement of the amplitude of measured and calculated accelerations is an indication of the adequate modelling of the shell structure, even if the frequency of the response vibrations is slightly higher. This difference can be mainly contributed to the difference in stiffness between the region of impact in the calculation (at the boundary between cylindrical and spherical shell) and in the first test (at the cylindrical shell).

4. Conclusions

The first series of impact tests, carried out in September 1984 at the HDR plant, proved the efficiency of all components of the test equipment, so that the main test series at the 40 m level can be realized with only minor modifications. In particular, it was demonstrated, that it is possible to produce the desired load time history using the selected crash pad design. With reference to the load propagation it was found, that the frequency content of the load time history is in fact traceable in nearly all measurements, but that there is a considerable reduction of the amplitude of vibrations during propagation through the foundation region.

5. References

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[2] Meier-Doernberg, K.-E.: "Knautschelemente für PHDR-Stoßversuche" PHDR-Nr. 4.244/84, Darmstadt 1984

[3] Eibl, J.: "Ermittlung von Beschleunigungszeitverläufen, Auslegungsrechnung" Bericht RS 0123 / B / EIJ 1015, Karlsruhe 1985

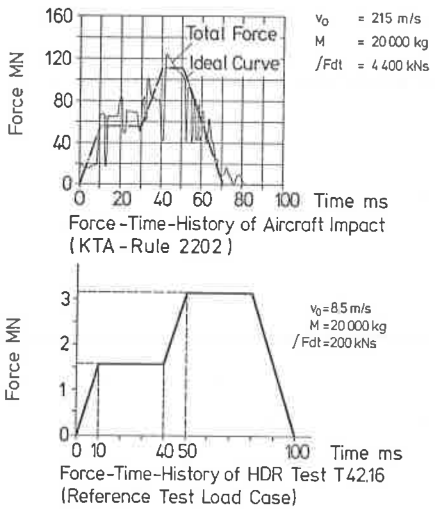

Fig. 1 Comparison of Forces
Aircraft Impact / HDR Test T 42.16

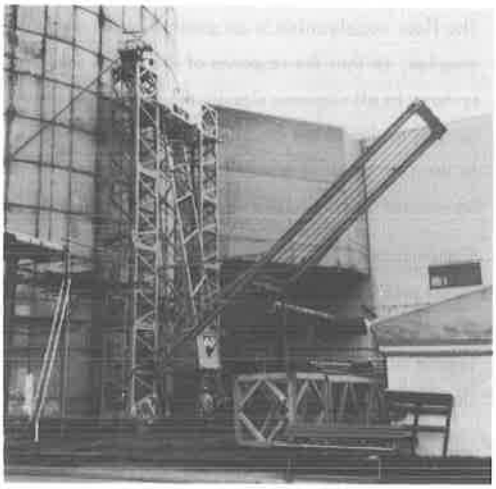

Fig. 2 Pendulum Tup
Impulse Excitation of the HDR-Containment

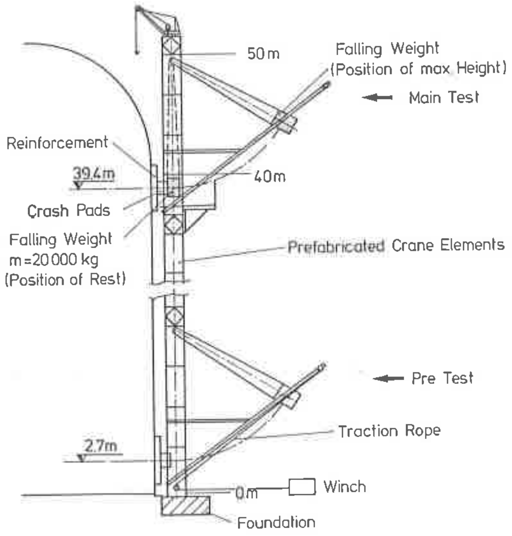

Fig. 3 Arrangement of the Test-Equipment

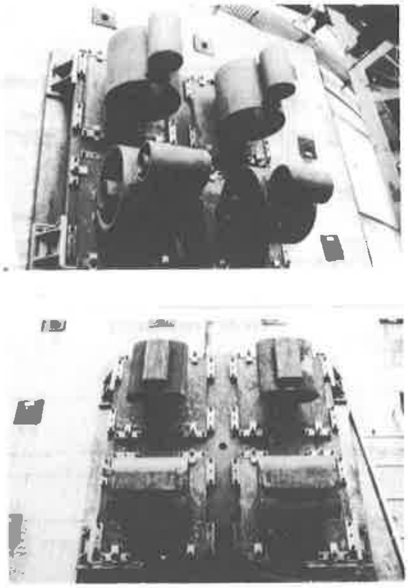

Fig. 4 Crash Pads
(Prior and after the Test)

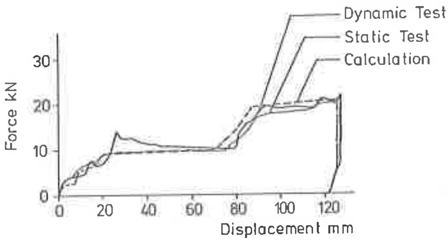

Fig. 5 Crash Pad Model Tests

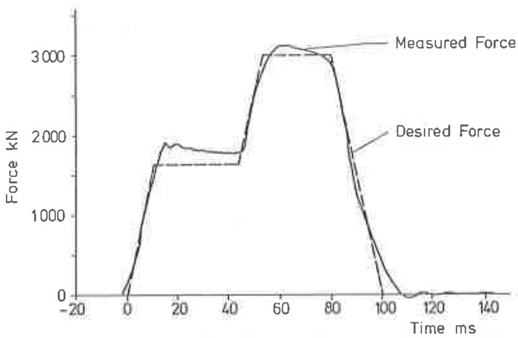

Fig. 6 Test T 42.04
Force-Time-History

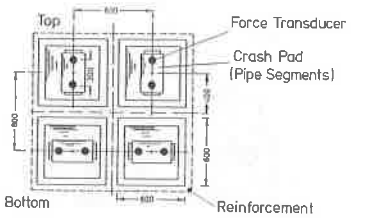

Fig. 7 Arrangement of the Crash Pads and Force Transducers

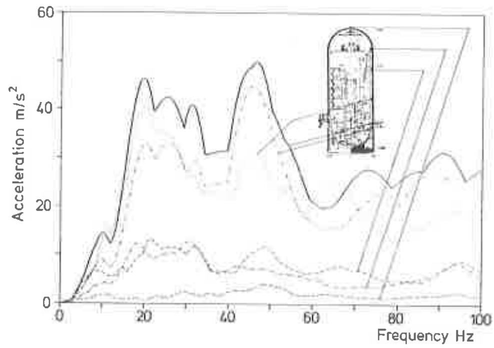

Fig. 8 Load Propagation Along the Outer Containment

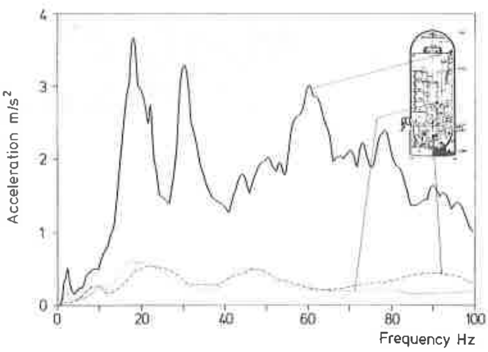

Fig. 9 Load Propagation into the Interior Structure

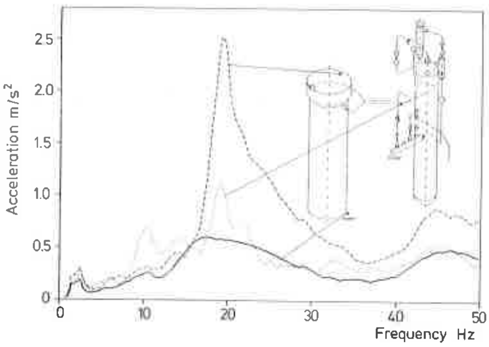

Fig. 10 Response of Pressure Vessel and Attached Pipe

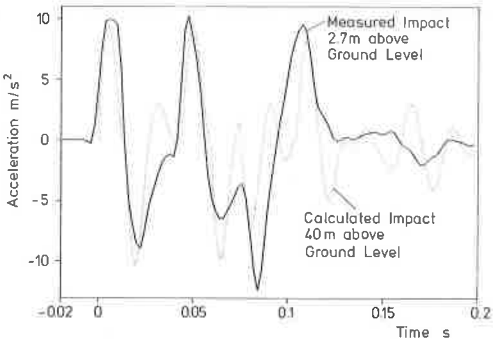

Fig. 11 Comparison of Wall Acceleration in the Region of Impact