Global Response of Concrete Structures to Explosive Loading

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SUMMARY

Within the HDR Safety Program experiments are being performed on the demolition of concrete structures and pipes by explosive charges. The main objective, besides demonstrating the safe handling of 15 kg explosive charges inside the plant, is to generate basic data about the local and global impacts on adjacent structures and a nearby situated second NPP with a view to further optimizing blasting methods and computer models.
Measurements are made in different compartments throughout the reactor containment to obtain results on the acceleration of structures and components, oscillation amplitudes, concrete blast wave pressures in the different compartments, and the transmission of vibration to neighboring installations.
The present tests have proved that up to 15 kg explosives per blasting can be safely performed in nuclear power plants which are to be demolished. The loadings occurring on the building as well as the vibrations of the building can be predicted with sufficient accuracy by computations.

INTRODUCTION

During demolition of components by blasting in decommissioned NPPs the vibrations of the internals and of the entire building must remain below the limits of damage. The HDR dismantling tests carried out on a model shield - see papers 0393 and 0396 - were intended to clarify whether this requirements can also be complied with if rather large amounts of explosive are used.

BLASTING CHARACTERISTICS

The concrete ring installed in HDR has the following dimensions: 4.7 m diameter, 3.3 m height, 0.7 m wall thickness, and 40 metric tons weight. It corresponds to the 1:2 downscaled biological shield of a real plant. The ring was built against the inner wall of the supporting rotunda of HDR (Fig. 1).
The ring was removed layer by layer in three blastings. The explosive charges were introduced to a specified depth into the concrete for each test individually.
An important boundary condition was the simultaneous initiation of charges uniformly distributed in the respective ring segment.
The amount of explosive was increased from 2 kg up to 14.5 kg.
The calculations were made for the maximum amount of explosive charge used.
Stepwise ignition as practiced in conventional blasting operations

to conserve the building had been dispensed in order to satisfy the following conditions:

- maximum loading of the concrete structure,
- minimum possible complexity of the load function acting on the building.

The blasting experiments have been enveloping tests. The same amount of explosive with an ignition in groups staggered in time will reduce the load acting on the building. But now the responses of the building can be interpreted more easily, especially with a view to a comparison of the measured results with the computational simulation.

CHARACTERISTIC COMPONENTS OF THE LOAD FUNCTION

Knowledge of the impact forces released during blastings has been refined in the course of the HDR tests. Whereas the explosive loading in the first tests had still been characterized globally by one single load-time function /3/, a threecomponent load function was defined in the specification for the present test performed on the model ring. It has been confirmed by the measured results.

The three components offer a complete representation of the forces occurring at the location of the blasting.

- Blast wave: The blast wave causes a pressure rise in the blasting space due to the release of clouds of smoke produced during explosion of the charge (blasting). In Fig. 2 the average blast wave pressure of the three experiments has been represented. A high peak pressure (abrupt discharge of cloud) with subsequent quick decrease characterises a blastings with short boreholes drilled.
- Radial impact on the building: Due to the simultaneous detonations of the individual charges an impact wave runs into the surrounding concrete structure. This wave is composed of the equal-phased superposition of the individual shock waves as the envelope. These shock waves are recorded by probes measuring the forces acting on the surface which are embedded between the model shield and the rotunda. The average pressure in this interface is presented in Fig. 3.
- Falling load: The falling load component is of secondary importance due to the relatively low masses of fragments (< 10 metric tons) produced in concrete demolition blastings. The falling load is composed of the abrupt pressure release in the containment due to detachment of the scaled off concrete mass from the static structure and the gradually effective load resulting from the impact of fragments on the bottom of the shield, see Fig. 4.

The overall load is composed of the temporal superposition of the three components. These three-component load function serves as an input for the computations.

The three components of this function will be described in detail in another contribution to this conference /8/.

COMPUTATIONAL MODEL AND CALCULATIONS

The HDR reactor building is modeled by an axisymmetric shell model consisting of thin shell elements and solid elements for the superstructure and spring elements for the soil foundation, see Fig. 5.

In the vicinity of the blast room, the element mesh is refined in order to account for the expected high-frequency loading.

The computations yield inter alia the acceleration-time behavior at safety related locations in the containment within a frequency range up to about 400 Hz.

Eigenvalues and modal shapes of the model are in agreement with the measured in-situ behavior of the HDR-containment up to 15-20 Hz, which is known from former large-scale earth quake tests.

To solve the equations of motion, a numerical integration scheme was used with a time step 0.1 ms; structural damping was introduced as Rayleigh damping with the parameters = 16.76 and β = 0.0000212 resulting in an equivalent modal damping of about 2% in the relevant frequency range. The dynamic responses in case of axisymmetric systems are computed by using the Fourier series expansion techniques; in the present case of an axisymmetric load, only the 0th circumferential Fourier term is needed.
The values of maximum accelerations of the building resulting from measurements and computations have been compiled in Table 1 for some selected locations of the building. It appears that the order of magnitude of the measured values is presented well by the calculations after appropriate filtering.
In addition to the computations of the global HDR containment, response calculations have been carried out by using a FE-model of the blast room and neighbour floors and walls. This model is much more refined than the above mentioned global model, see Fig. 6, and allows a better prediction of concrete stresses and strains in order to furnish the safety proof for the experiments intended to approach the limit of loading of the rotunda. On that basis, approval was granted to perform blastings with 15 kg explosive at the maximum.

INTERCOMPARISON OF MEASUREMENT AND CALCULATION

The wall zone of the HDR rotunda surrounding the model shield is subjected to dynamic deformation, but still in the elastic/plastic limit range (Fig. 7). The computations which are based on purely elastic material behaviour reflect the dynamic deformation in the proper order of magnitude.
Permanent deformation cannot be expressed due to the elastic nature of the computations; it adapts values $\leq$ 0.1 ^{o}/oo and is uniformly distributed over the total cross section as microcracks. No cracks visible to the eye appeared on the extgernal wall of the rotunda. Only in the edge zone of the door opening represented in Fig. 7 (weak point in the otherwise closed rotunda ring) macroscopic cracks can be observed.
Response vibrations of the structure resulting from the explosion mainly occur at very high frequencies (250 - 400 Hz), which are not safety related. By beam and shell modeling of impact only frequency ranges up to 30 - 80 Hz can be calculated. Within these ranges, safety related frequencies are normally found. Comparison of selected accelerations measures, which have been filtered to cut off frequencies higher than 30 or 80 Hz together with beam and shell modeling of the HDR structure leads to sufficiently accurate results. The acceleration levels are far below the design basis conditions for an NPP in operation. By refining the nodal mesh of the shell model predictions will be possible for ranges up to 300 Hz.

REGULATORY LIMITS

The admissible loading of the overall building caused by blasting is governed by the DIN standard 4150. According to this standard, the vibration velocity must not surpass specified frequency dependent limits. The decisive values are the maximum values occurring at the foundation and in the upper floor region. In Fig. 8 the admissible maximum vibration velocities according to DIN 4150 have been compared with the values measured in two experiments. Whereas in the experiment involving 2.5 kg explosive the loading on a slab element is far below the limit values, the margin admitted by the standard has been fully exploited in the blastic involving 14.5 kg explosive in the model shield. However, in case of demolition higher vibration velocities than those admitted by the standard are tolerable provided that evidence can be furnished that the structure is capable of withstanding higher than normal loads.

REFERENCES

/1/ Durchführbarkeit der Zerlegung des Biologischen Schilds mittels Bohrlochsprengtechnik Battelle-Bericht BIeV-R--65.036-4 (1983)

/2/ Zerlegungsversuche an schildspez. Betonplatten bei flächiger Ankopplung an die HDR-Struktur; Quick Look Report, Versuchsgruppe ZER/B, Versuche T53.2-0 - T53.2-4; (May 1987)

/3/ Beton-Zerlegungsversuche in einem geschlossenen Containment Quick Look Report, Versuchsgruppe ZER, Versuche T53.1.0 - T53.1.9 (July 1986)

/4/ Sprengtechnische Trennversuche an großen Rohrleitungen im HDR zur Erprobung von Verfahren der KKW-Stillegung Auswertebericht Versuchsgruppe ZER-R, Versuche T54.1 und T54.2 (July 1988)

/5/ Sprengtechnische Zerlegeversuche an stahlbewehrten Betonschildwänden zur Erprobung von Verfahren der KKW-Stillegung PHDR-Arbeitsbericht No. 05.43/88, 1988.

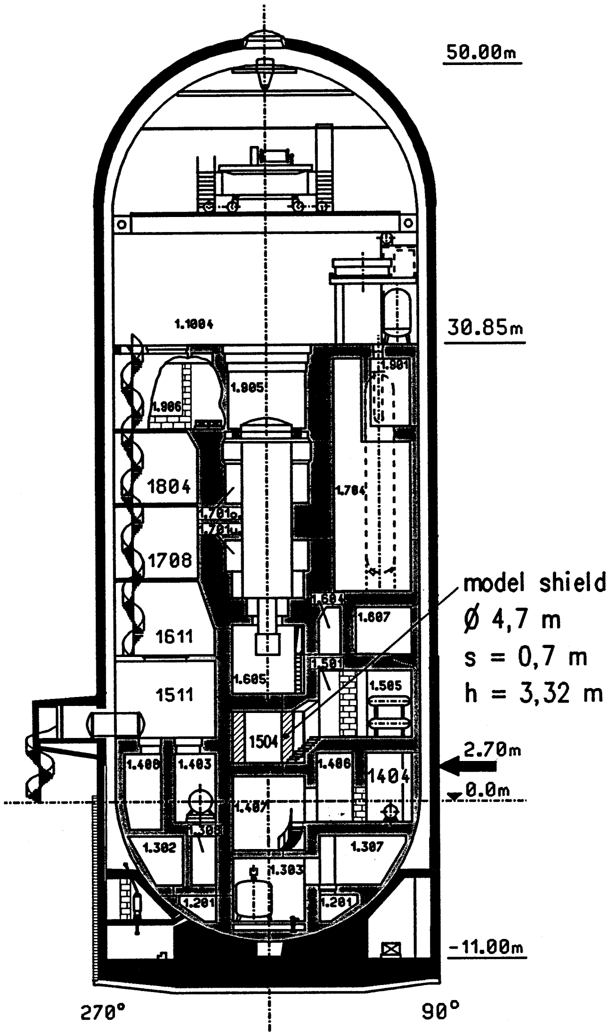
/6/ C.v. Exel, R. Zinn, F. Rischbieter:
Bauwerkserschütterungen bei sprengtechnischer Zerlegung von Betonstrukturen zum Abbruch von Kernkraftwerken, Reaktortagung 1987

/7/ H.U. Freund, H. Wegener:
Abbruchsimulation des Biologischen Schildes mittels Sprengung am HDR, Reaktortagung 1987

/8/ H.U. Freund, T. Rischbieter, C. Schmitz:
Loading Functions Generated by Solid Explosive Detonations Inside Concrete Containment Structures, SMIRT 10, Los Angeles 1989.

Acceleration in $\frac{m}{sec^2}$		Experiment filter		Calculation
		~700Hz	80Hz	
Crane support	horiz.	18	2	2,8
	vert.	35	9	2,4
Floor +31m	horiz.	16	3	4,2
	vert.	100	3,5	10,8
Rotunda	horiz.	5000	-	570
	vert.	900	-	32

table 1



Model shield inside HDR-Containment fig. 1

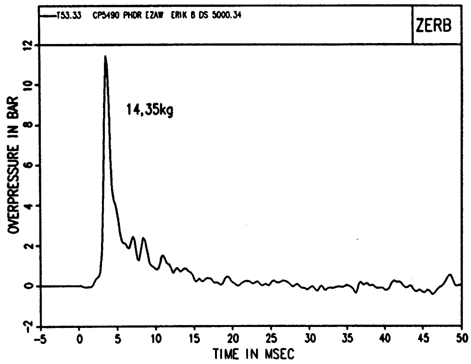


fig. 2

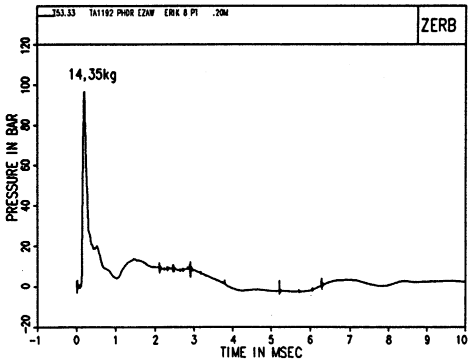


fig. 3

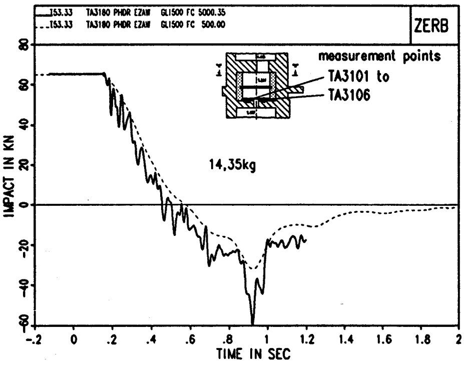
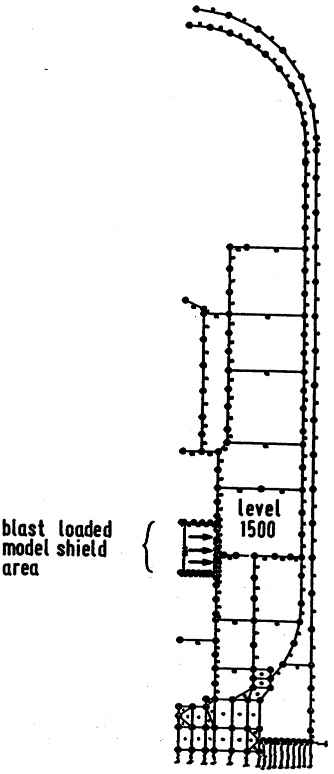
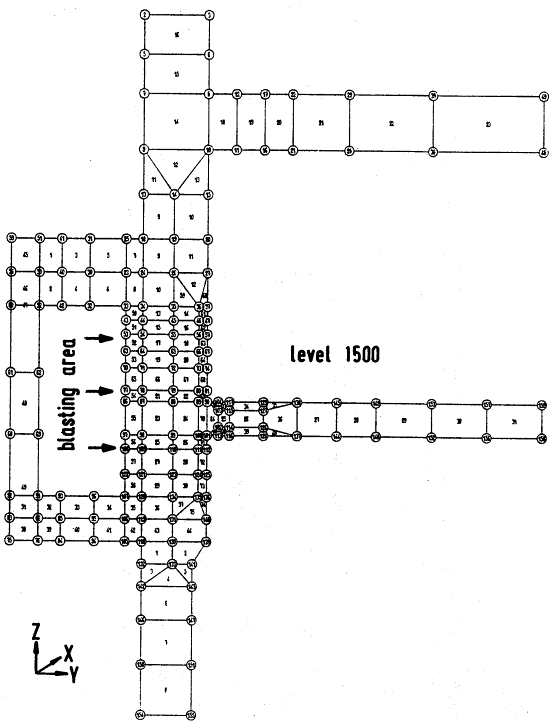


fig. 4



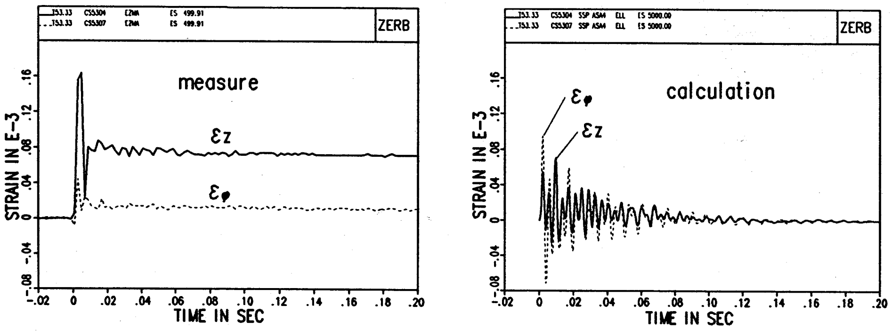
HDR-plant with model shield (global nodalisation)

fig. 5



HDR-plant with model shield (local nodalisation)

fig. 6



Comparison of strains to outside rotunda wall

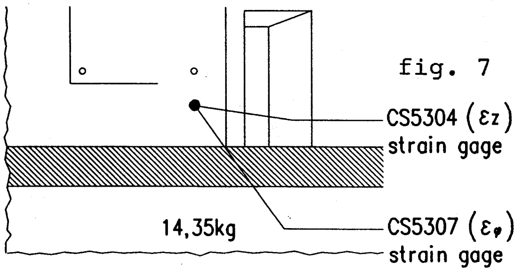


fig. 7

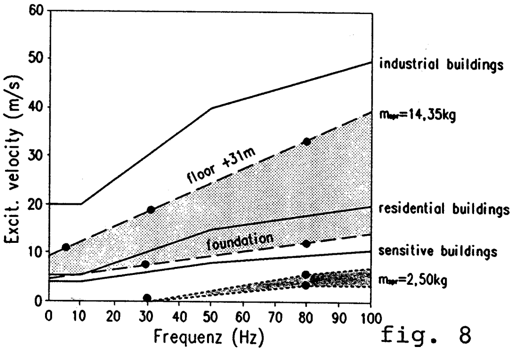


fig. 8