Computed versus measured response of HDR reactor building in impact test

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1 INTRODUCTION

In the Federal Republic of Germany, safety related buildings and equipment of nuclear power plants are designed to withstand the impact of a crashing airplane. Local failure of the structure at the impact area (penetration) and failure of equipment due to induced vibrations must be prevented. The design provisions are based on dynamic response analyses.

In order to check the accuracy of analysis methods for computing induced vibrations, impact tests have been performed by the Kernforschungszentrum Karlsruhe at the decommissioned HDR reactor building. The tests were funded by the Minister for Research and Technology of the Federal Republic of Germany.

The reactor building has a diameter of 22m and a total height of 64m (Figure 1). The external concrete structure consists of a cylindrical wall topped by a half-sphere dome. It is connected to the complex internal structure by the common base mat and a few walls and floor slabs in the basement. The internal concrete structure is completely enclosed in a steel containment.

2 ANALYSIS

Prior to the experiments, "best estimate" computations of the expected structural response were performed with a simple beam model and an axisymmetric shell model (Figure 1 b, c). For the shell model axisymmetric elements based on the theory of thin shells were used. Its displacement functions are linear for membrane deformation and cubic in bending. In the circumferential direction all variables are expanded into a Fourier series. Due to the orthogonality of the trigonometric functions the solutions are uncoupled with respect to the Fourier order N.

The response analysis was performed by modal decomposition. All modes with eigenfrequencies less than 80Hz were included. The frequencies of the shell model are depicted in Fig. 2a for N = o to N = 9. For N greater 9, no modes exist below 80 Hz.

The modes of the internal structure were included only for N = 1, because other internal modes are not excited by the load applied on the external structure.

The second lowest mode shape for N = 1 with out-of-phase motion of the internal and external structure is shown in Figure 2b. This mode dominates the global response of the structure. A typical higher order shell mode is shown in Figure 2c.

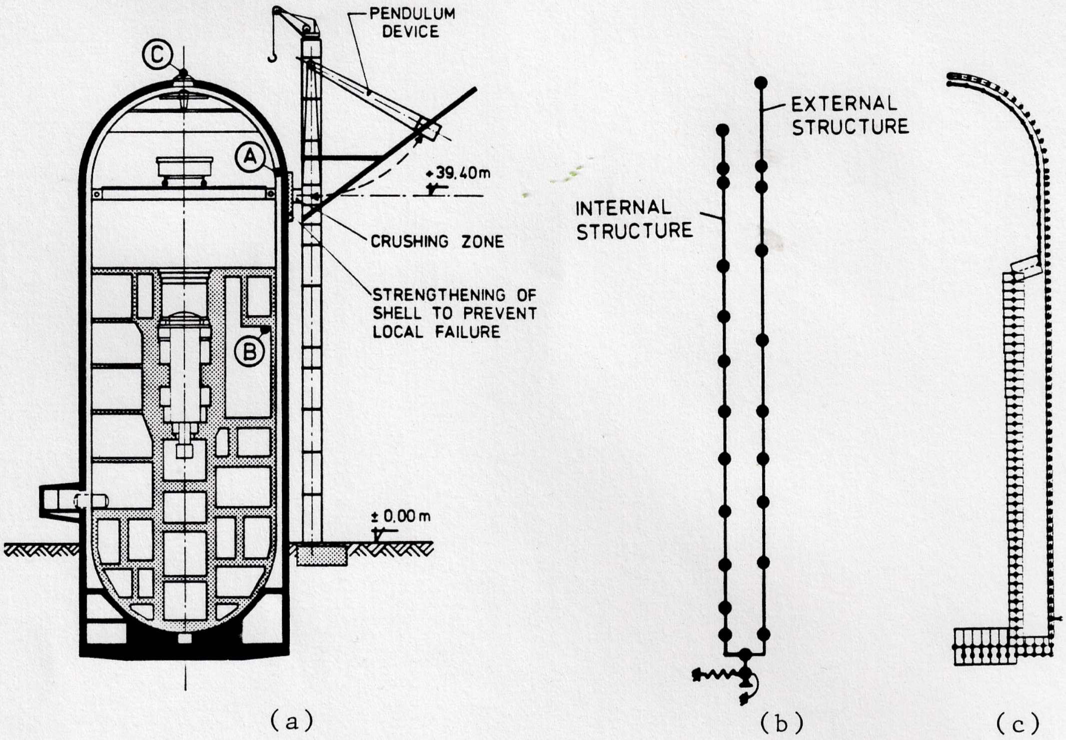


Figure 1. Test arrangement (a); beam model (b); shell model (c).

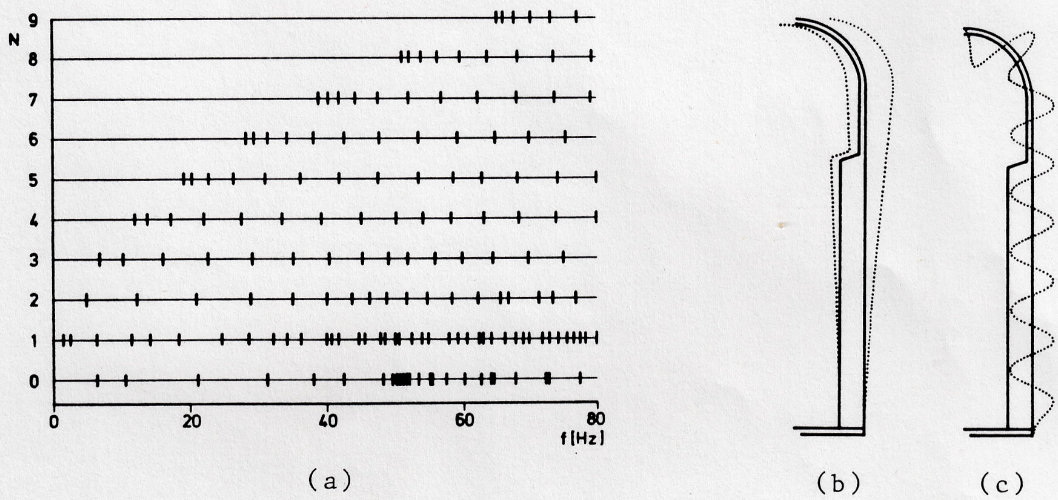


Figure 2. Eigenfrequencies of the shell model (a); mode shape N=1, mode 2, 2.6 Hz (b); mode shape N=2, mode 15, 79 Hz (c).

3 TESTS

The impact load is applied by a pendulum with a mass of 20t and a falling height of 5m (Figure 1a). In order to obtain a force-time-history similar in shape to that of the design provisions for aircraft impact in the F.R. of Germany, an impact cushion is used. It consists of steel pipes which are compressed in transversal direction. (Flade et al. 1985a & b).

The analysis results were submitted before the tests were performed. Hence, the analysis was based on a target time history, Fig. 3. The actually measured time history is in good agreement with it.

Figure 5 shows measured and calculated horizontal accelerations at reference point "A", which is located at the external concrete wall near the impact area. Computed and measured time-histories are in very good agreement in the case of the shell model. The vibrations with large amplitudes and high frequencies at the beginning of the time history are due to local modes of the external wall. The following vibrations with low amplitudes represent the global response of the structure. A phase difference can be noted, which is caused by a slight difference in the measured and computed second eigenfrequency (N=1; 2.6 Hz). The amplitudes, however, are in good agreement. The beam model is well suited to represent the global response of the structure but, of course, cannot simulate local shell vibrations.

The influence of the number of Fourier terms included in the analysis is shown in Figure 4. The acceleration time history obtained with 5 Fourier terms (N=0÷4) has lower amplitudes in the local vibrations of the external shell at the beginning of the time history. If only the term N=1 is considered (which corresponds to the beam model) the local vibrations vanish completely.

The acceleration time histories at reference points B and C in the internal structure are also given in Figure 5. They have a considerably smaller amplitude and are dominated by the global response of the structure. Local vibrations are of minor importance. Both models yield quite similar results, which agree very well with the measured accelerations.

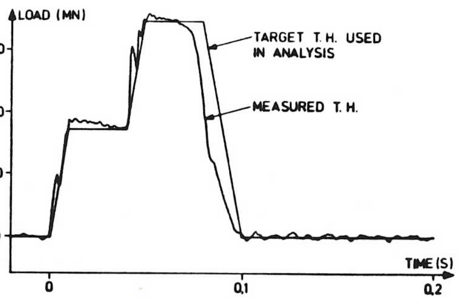


Figure 3. Load time history

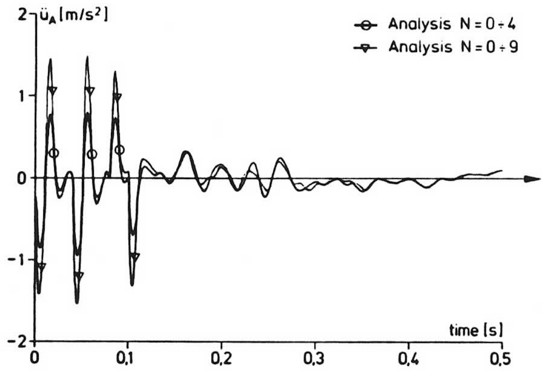
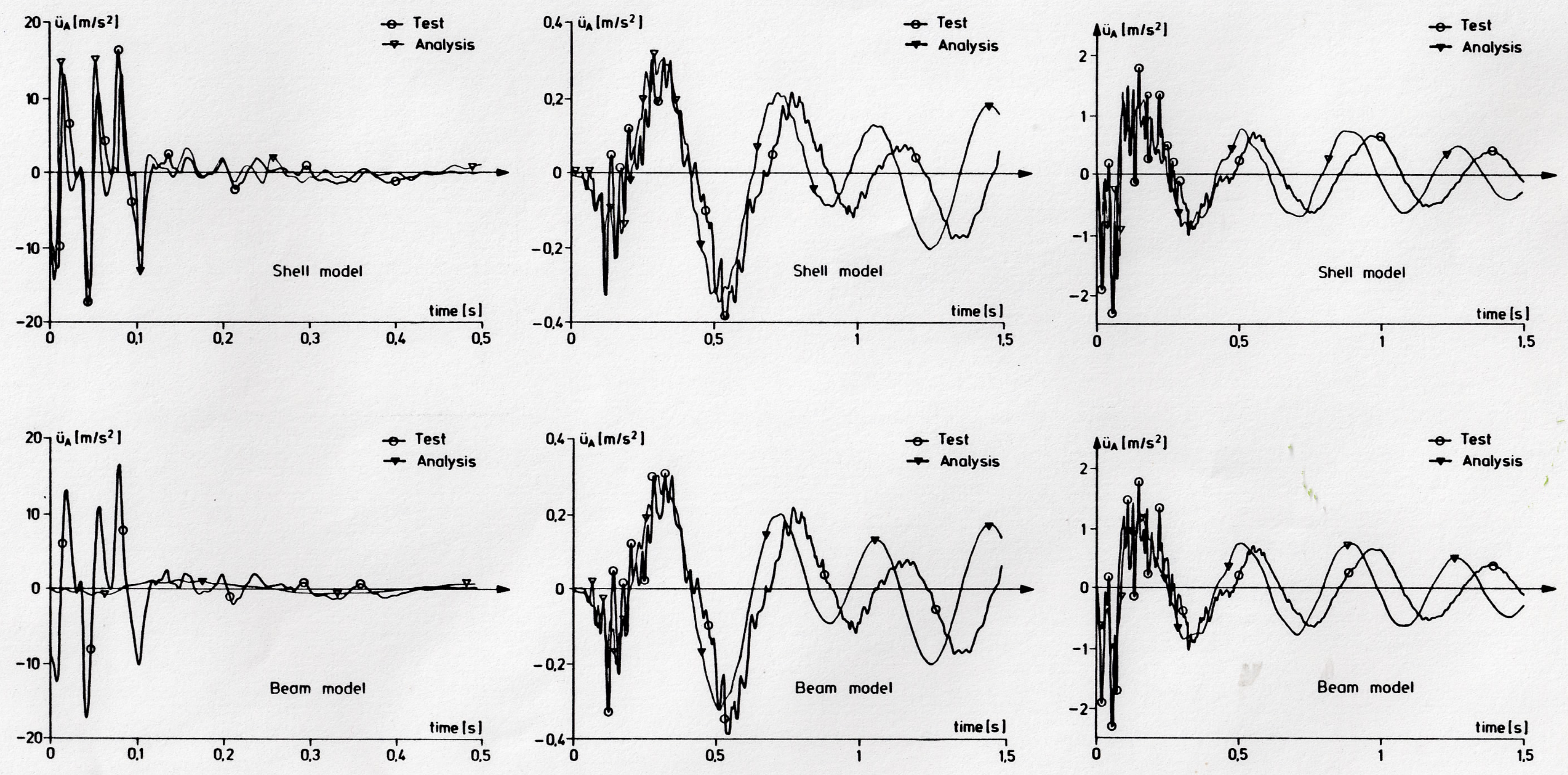


Figure 4. Horizontal acceleration of the shell model at reference point A.



Point A

Point B

Point C

Figure 5. Calculated horizontal accelerations of the beam and shell models versus measured accelerations

4 SUMMARY AND CONCLUSIONS

Structural vibrations caused by an airplane impact were simulated in experiments with a 20t heavy pendulum on an actual nuclear reactor building. Prior to the experiments computations of the expected response of the structure were performed with two different models, a simple beam model and a finite element shell model. Accelerations of the global structural response computed with both models agree well with measured accelerations. The shell model is also able to simulate the local vibrations of the external shell.

The computations and the experiments on an actual reactor building demonstrate that the analysis methods and procedures applied are well suited to predict the response of a complex structure subjected to impact loads.

REFERENCES

Flade D., Malcher L., Schrammel D., Steinhilber H., 1985a, Stoßversuche an der Betonaußenschale, HDR-Sicherheitsprogramm, EV 4000: Strukturdynamische Untersuchungen, KfK, PHDR, Technischer Fachbericht Nr. 55-85, Karlsruhe.

Flade D., Steinhilber H., Malcher L., 1985b, Impulse Excitation of the Outer HDR-Containment with a Pendular Falling Weight, 75/4, SMiRT 8, Bruxelles.