Impact on Nuclear Reactor Building
- Analysis and Experimental Results - *

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Summary

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 "best estimate" computations of the expected structural response have been performed with two different finite element models. The calculated accelerations agree well with the measured accelerations. This applies to the global response of the structure and to the local vibrations of the external shell.

Introduction

In the Federal Republic of Germany, safety related buildings and equipment of nuclear power plants are designed to withstand eartquakes, the impact of a crashing airplane and other rare events. In case of an airplane impact, 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, impact and other dynamic experiments are performed by the Kernforschungszentrum Karlsruhe at an actual nuclear reactor building, which is no longer in operation /1/. The experiments are part of a very comprehensive reactor safety program supported by the Federal Government. This paper is concerned with structural vibrations caused by an impact load.

The reactor building has a diameter of 22m and a total height of 64m (Fig. 1). The external concrete structure consists of a cylindri-

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cal 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.

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 (Fig. 2). For the shell model axisymmetric elements based on the theory of thin shells were used /2/. 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. In case of the shell model, this implied 10 terms of the Fourier expansion in the circumferential direction. The eigenfrequencies of the higher terms exceed 80Hz. The second lowest mode shape for N=1 with out-of-phase motion of the internal and external structure is shown in Fig. 3a. A typical higher order shell mode is shown in Fig. 3b.

Tests

The impact load is applied by a pendulum with a mass of 20t and a falling height of 5m, Fig. 1. 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.

The analysis results were submitted before the tests were performed. Hence, the analysis is based on a target time history, Fig. 4. The test time history, measured later, is in good agreement with it.

Fig. 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 acceleration time histories at reference point B in the internal structure are given in Fig. 6. 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.

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

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/2/ Zienkiewicz, O.C., "The Finite Element Method", McGraw Hill, London, 1977.

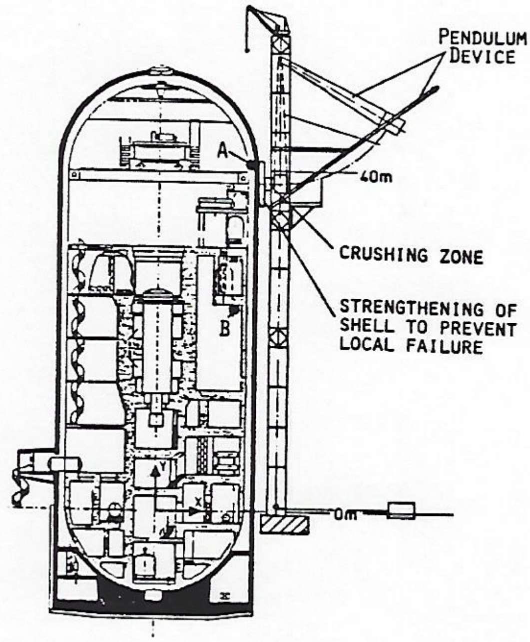
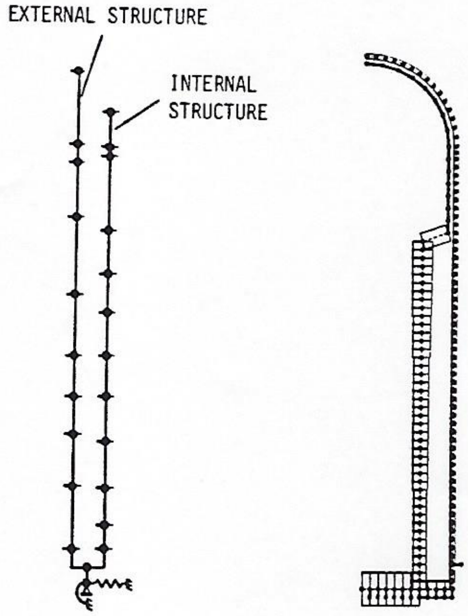
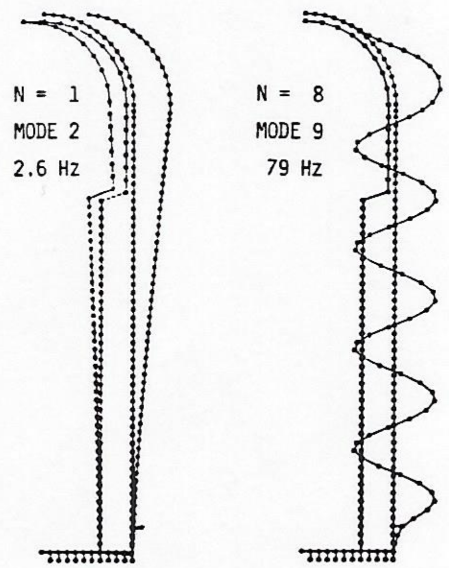


Fig. 1: Test arrangement



a: Beam model b: Shell model

Fig. 2: Finite element models



a) b)

Fig. 3: Mode shapes

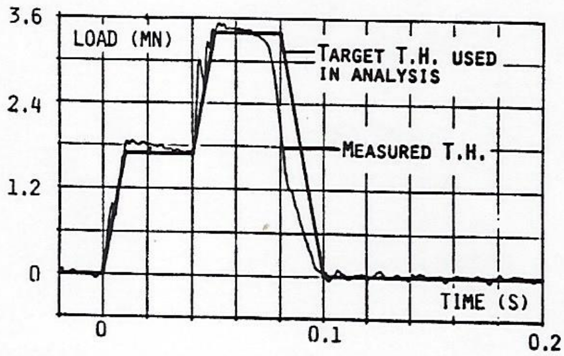
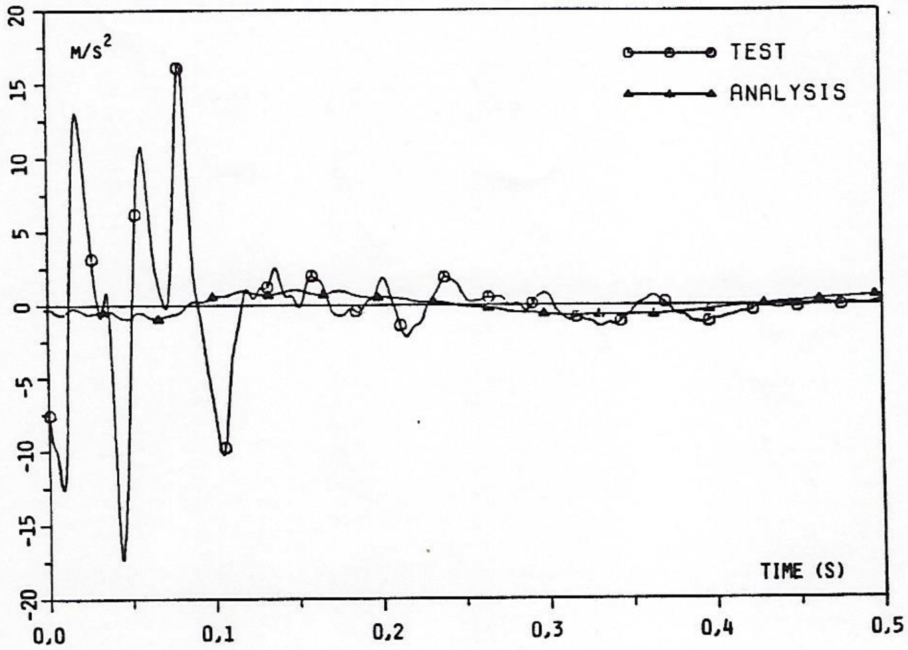
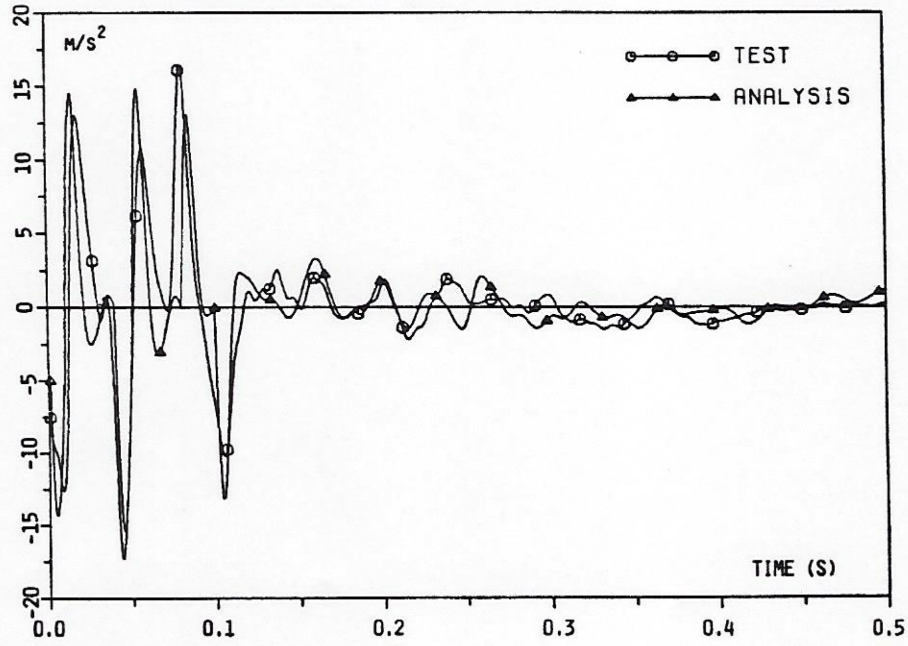


Fig. 4: Load time history

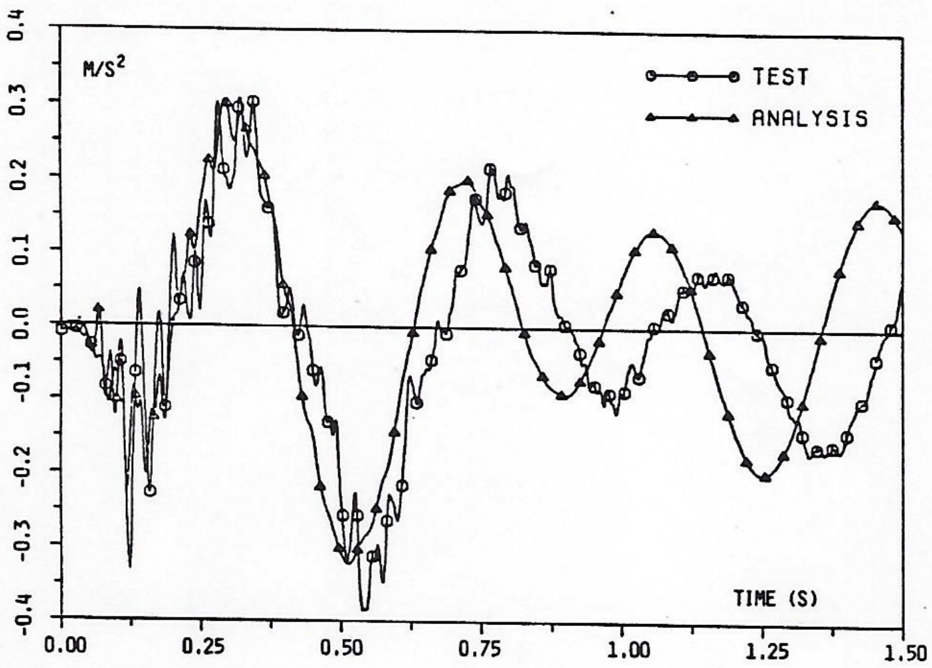


a: Beam model

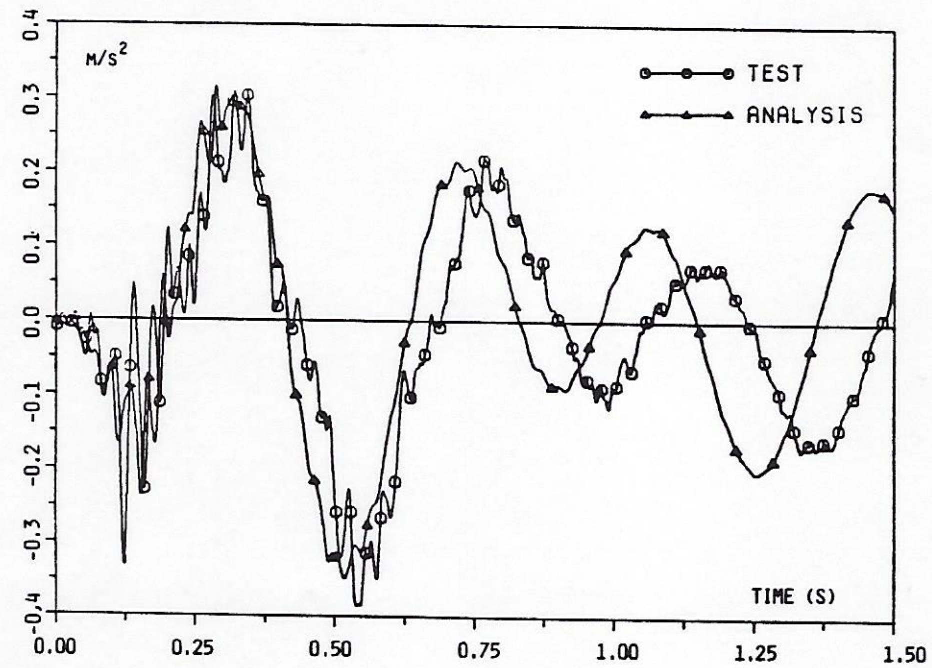


b: Shell model

Fig. 5: Accelerations at reference point A



a: Beam model



b: Shell model

Fig. 6: Accelerations at reference point B