Transactions of the **13th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 13), Escola de Engenharia - Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, August 13-18, 1995

Full-scale vibration test of Atucha II N.P.P. - Part VII: Numerical simulation of steady state response by simplified axisymmetric FEM

Halbritter, A.[1], Krutzik, N.J.[1], Schütz, W.[1], Alvarez, L.M.[2], Capelli, P.[2]
1) Siemens AG, Power Generation Group (KWU), Offenbach, Germany
2) ENACE S.A., Lima, Argentina

ABSTRACT: The aim of this work was to determine the dynamic characteristics of the reactor building of the heavy water reactor Atucha II and to check certain analytical procedures used to validate full-scale vibration tests. Soil-structure interaction effects were incorporated by means of springs and dampers which represented the soil behavior. The full-scale vibration tests were reproduced using a simplified axisymmetric model.

1 INTRODUCTION

Full-scale vibration tests were conducted on the structure of the reactor building of the heavy water reactor Atucha II as described in other papers previously presented.

The aim of the work presented in this paper was to check the accuracy of the numerical methods and axisymmetric mathematical models by trying to reproduce the experimental results.
The main tests comprised application of a sinusoidal force to the structure and measurement of the induced displacements at selected points of the structure.
The frequency of the sinusoidal force varied between 1 and 20 Hz.

From the point of view of the numerical analysis, this structural response of significance comprised the displacement transfer function between the force application point and the measuring points.

2 DESCRIPTION OF THE STRUCTURE

The structure consists mainly of an external concrete containment, an internal concrete structure which supports and separates the reactor components, and finally an internal spherical steel containment (Figure 1). The foundation is a thick circular plate with a diameter of 60 m.

The external concrete structure is formed by a cylindrical shell in the lower part closed by a spherical concrete shell (0.60 m thick) in the upper part, resulting in a 60-m-high structure. This structure has an embedment of approximately 20 m. The internal concrete structure is formed mainly by thick cylindrical and radial walls.

3 FULL-SCALE TESTS

Three full-scale tests were performed:

- Forced vibration tests
  The structure was excited by horizontal sinusoidal forces generated by a load machine. The load machine was located one time at elevation +18.80 m and another time at elevation +0.50 m (Figure 1). These positions are referred to herein as Case 1 and Case 2 respectively.
- Crane tests
  Free vibration was induced by suddenly stopping the polar crane.
- Drop tests
  These tests comprised measuring the vibration in the reactor building caused by dropping a weight on the ground.

4 METHOD OF ANALYSIS

The geometric properties of the reactor building could be well accounted for by choosing axisymmetric modeling for analysis of the dynamic behavior (Figure 2).
The employed model was not based on the present status of the structure but on the final configuration. The effects of soil-structure interaction were accounted for by equivalent springs and dampers which physically reproduced the soil stiffness and damping.
Lateral springs and dampers were also included to reproduce the embedment effects.
As the test loads were applied in the horizontal direction, only horizontal and rocking soil stiffness was considered. The horizontal loads generated by the test machine were applied to the corresponding nodal point of the structure as a sinusoidal force.

Analysis was conducted in the frequency domain. The frequency of the sine function was increased in steps in order to envelop the frequencies up to 20 Hz. Displacements at the measuring points were determined for each frequency. In the present case, only measuring points located in the direction of the force were selected.

The sinusoidal force generated by the load machine was practically a concentrated force, which meant that a large number of harmonics had to be considered.

Emphasis was placed on the results derived for the first harmonic because they represent the global modes of vibration. The influence of higher harmonics was also investigated.

The analysis was performed using the computer program MESY /1/. MESY is a program for static or dynamic analysis of axisymmetric structures having specific capabilities for special load cases that are to be taken into account in the design of nuclear power stations, such as earthquake, external pressure wave or aircraft impact loading. The analysis can be performed in the time domain (modal superposition technique) or in the frequency domain as in the present case.

Additional modal analysis was performed in order to determine undamped natural frequencies of vibration.

5 ANALYSIS IN FREQUENCY DOMAIN

The main results of the tests were the displacement transfer functions. In the analysis a load of 10 kN was assumed in order to be compatible with the units used in the forced vibration tests (tons).

Displacement-frequency curves for sinusoidal forces of 10 kN were determined, considering the first harmonic for the selected nodal points shown in Figure 2. These curves are presented in Figures 3 through 6 and correspond to the global behavior of the structure. Figure 7 presents the results obtained by calculating for harmonic 2.

6 MODAL ANALYSIS

Natural frequencies and mode shapes were determined in order to check and compare the results obtained in the frequency-domain analysis. As expected, a slight shift in the natural frequencies (Table 1) can be seen due to non-consideration of damping in the eigenvalue solution.

Mode shapes were similar to those obtained by plotting the peaks of the transfer functions for all nodal points.

In order to show the influence of higher harmonics, Figures 8 and 9 present a mode shape corresponding to harmonic 2 (F = 11.0 Hz). Figure 10 shows a view from the same vibration mode at elevation +18.80 m where large displacements can be observed at the location of load machine.

7 DISCUSSION OF RESULTS

Certain remarks must be made before comparing the experimental and analytical results. The present model is simplified; it does not consider missing walls, holes and the non-axisymmetric parts of the structure, which are replaced by equivalent axisymmetric ring elements. This simplified model, based on the finished plant, results in a stiffer structure than the present building which is still under construction.

From the experimental results, conclusions were not always directly apparent. In the shock tests [2] the first resonant peak is found to be at 7.3 Hz (Figure 11). This tendency is common to excitation at elevations 18.80 m and 0.5 m; this means that the load machine and the surrounding region were acting as a filter for frequencies which were not close to 7 Hz. Responses at that frequency are amplified. Therefore the global modes of vibration including the soil-structure effects are difficult to identify.

A direct comparison of the calculated and measured results does not provide enough information because the experimental results must be corrected and interpreted considering many factors of influence, and because the analytical results were obtained using a simplified model and a reduced number of harmonics. Nevertheless, the conclusions drawn from the analytical and experimental procedures can be compared.

The forced vibration and crane test results and conclusions were taken from References [2] and [3] respectively.

The natural frequencies and mode shapes were in good agreement, as can be seen from Table 1 and Figures 6 through 19, which show the mode shapes determined experimentally and analytically. Additional modal analysis was performed and the obtained results were included in the comparison.

From the above comparisons it can be concluded that the analytical procedure, despite the simplified model employed, leads to realistic results.

It must be noted, however, that the dynamic characteristics determined in this case are not directly applicable for further dynamic analysis, such as seismic analysis, because the soil properties are not linear with the level of excitation.

8 REFERENCES

[1] MESY, Linear-Elastic Static and Dynamic Analysis of Axisymmetric Structural Systems, User Information Manual Version 1992

[2] Report of the Atucha II Vibration Test, Kajima Corporation, July 1994

[3] Determination of dynamic characteristics of the reactor building complex by means of shock tests, Summary of results, Universidad Nocional de Cordoba - Argentina, December 1994

Table 1

Case	Frequency (Hz)				
Forced Vibration	2.90	4.50	5.90	-	9.2
Shock Tests	2.64	4.48	5.52	6.55	7.36
Freq. Domain Analysis	2.55	4.73	5.59	6.22	7.23
Modal Analysis	2.63	4.75	5.62	6.26	7.25

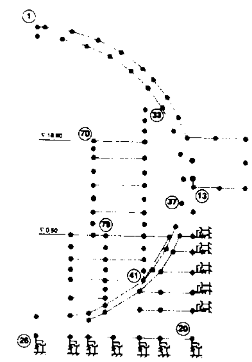

Fig. 2 Axisymmetric Finite Element Model

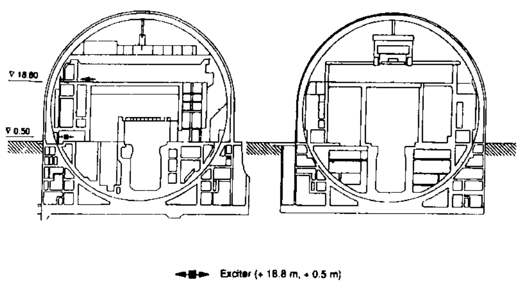

Fig. 1 Sections of the Reactor Building and Location of the Exciter

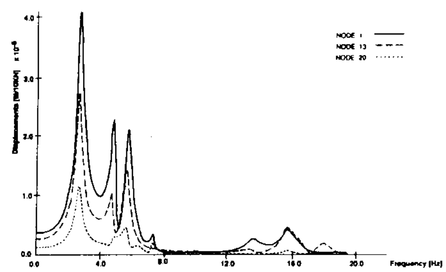

Fig. 3 Displacements Transfer Function - Case 1
Harmonic 1

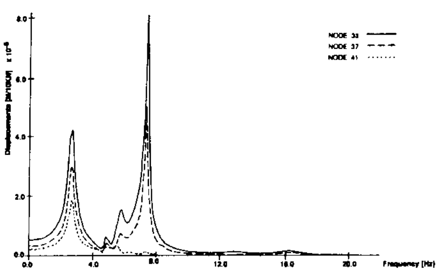

Fig. 4 Displacements Transfer Function - Case 1
Harmonic 1

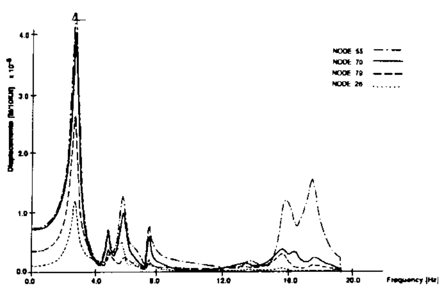

Fig. 5 Displacements Transfer Function - Case 1
Harmonic 1

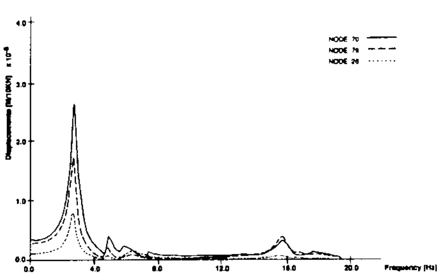

Fig. 6 Displacements Transfer Function - Case 2
Harmonic 1

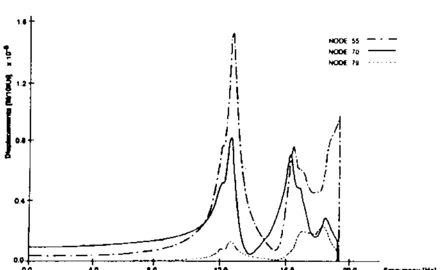

Fig. 7 Displacements Transfer Function - Case 1
Harmonic 2

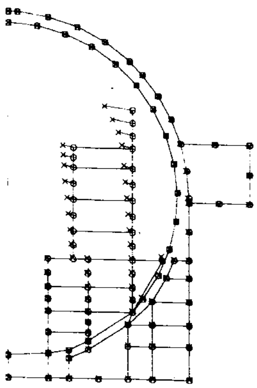

Fig. 8 Mode Shape F = 11.0 Hz
Harmonic 2, Section 0°- 180°

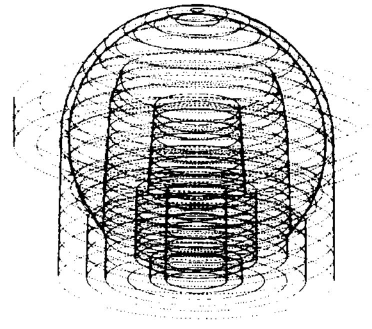

Fig. 9 Mode Shape F = 11.0 Hz
Harmonic 2, 3D View

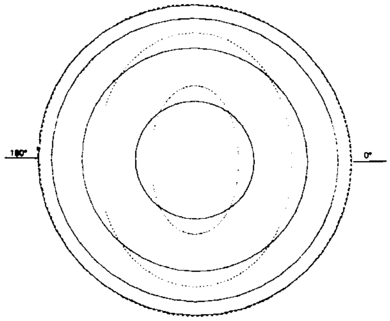

Fig. 10 Mode Shape F = 11.0 Hz
Harmonic 2, Elevation 18.8 m

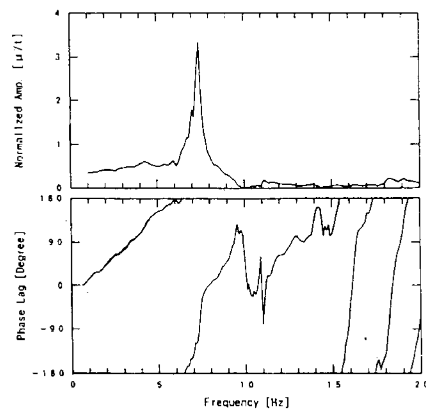

Fig. 11 Experimental Response at the Location of the
Polar Crane - Forced Vibration

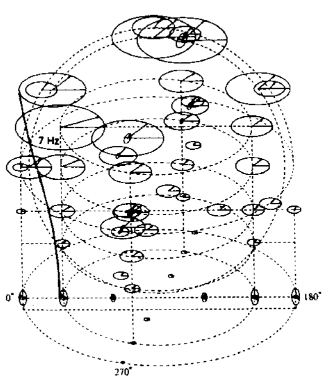

Fig. 12 Mode Shape
Forced Vibration F = 2.9 Hz

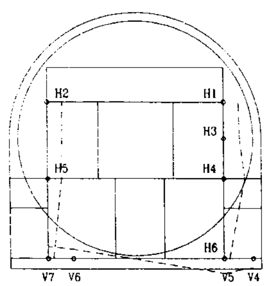

Fig. 13 Mode Shape
Shock Test F=2.64 HZ

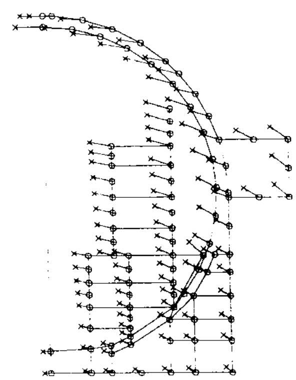

Fig. 14 Mode Shape
Analytical F=2.63 HZ

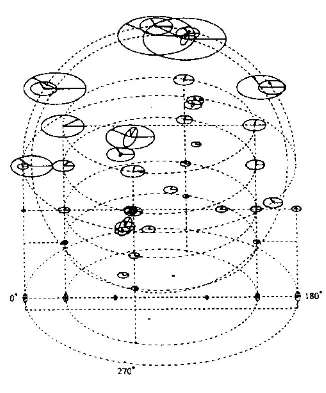

Fig. 15 Mode Shape
Forced Vibration F=4.5 HZ

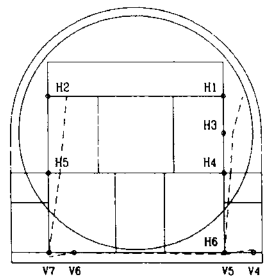

Fig. 16 Mode Shape
Shock Test F=4.48 HZ

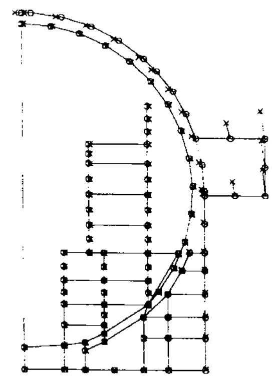

Fig. 17 Mode Shape
Analytical F=4.75 HZ

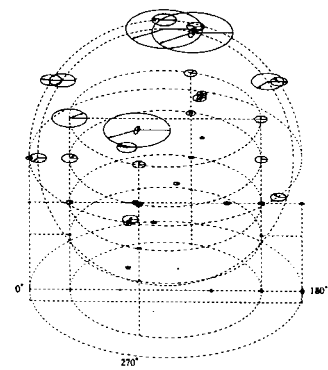

Fig. 18 Mode Shape
Forced Vibration F=5.9 HZ

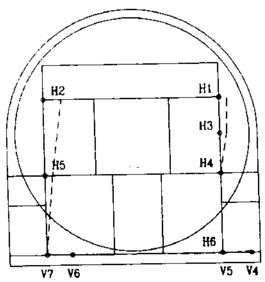

Fig. 19 Mode Shape
Shock Test F=5.52 HZ

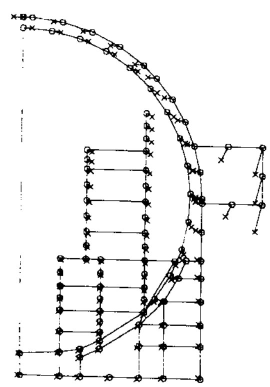

Fig. 20 Mode Shape
Analytical F=5.62 HZ

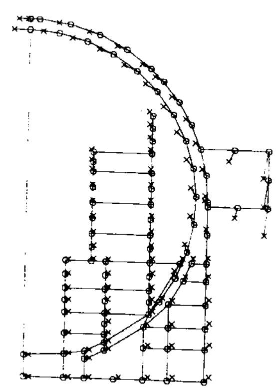

Fig. 22 Mode Shape
Analytical F=6.26 HZ

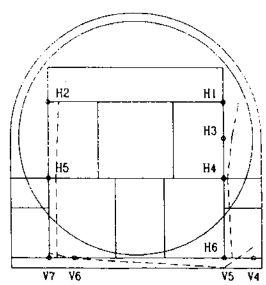

Fig. 21 Mode Shape
Shock Test F=6.55 HZ

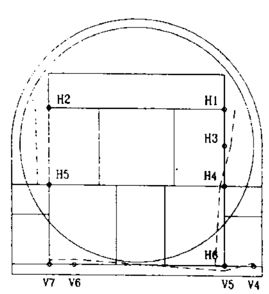

Fig. 24 Mode Shape
Shock Test F=7.36 HZ

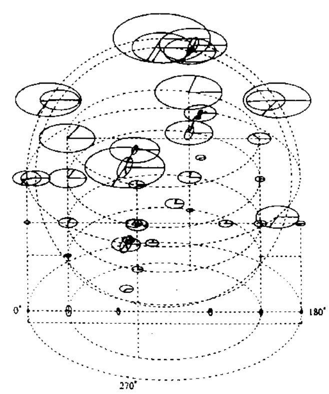

Fig. 23 Mode Shape
Forced Vibration F=7.3 HZ

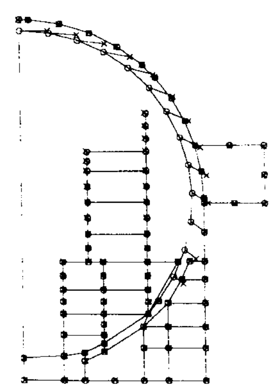

Fig. 25 Mode Shape
Analytical F=7.27 HZ