AMBIENT VIBRATION SURVEY ON THE CONTAINMENT STRUCTURE OF PEC REACTOR

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SUMMARY

The advent of the digital computer has resulted in an extensive improvement in method of designing earthquake-resistant structures. In fact, the most advanced programming techniques permitted the development of appropriate computer programs based on highly refined analytical models of structures subjected to various load conditions, including dynamic excitation due to earthquakes.

It was soon clear, however, that rather refined calculations were not significant if not supported by experimental tests and data. Therefore, while studies on computer programs for dynamic analysis of structures were carried on, investigations took in consideration also the possibility of verifying these calculations experimentally. A research program was started by CNEN with the purpose of setting up an easily workable method of testing structures under dynamic conditions. Results of tests are the basis of correct calculations and improved analytical models.

In this paper a new experimental method will be described, which has been employed to verify some dynamic calculations for the containment system of PEC (Prova Elementi Combustibili) Reactor near Bologna. This method is named AVS (Ambient Vibration Survey) and has been developed in USA by Teledyne Co. It consists in evaluating the dynamic response of a structure to environmental factors such as wind, earth microtremors, traffic, etc.

The response to the motion caused by all these factors was measured on the structure by means of very sensitive seismometers. Data were stored in a magnetic tape recorder and processed in the computer. The recorded motion was analysed by using spectral techniques; in fact it is known that the direct power spectral density of each recorded motion yields estimates of natural frequencies and modal damping, whereas a cross spectral density between a reference record and all other records yields mode shape estimates.

The results of AVS were compared with those performed on a scale-model in laboratory and those performed on the real structure by means of a vibrodyne. At least all these experimental results were compared with the results of calculations obtained by means of a computer program.

It is clear that this method has a great practical utility. In fact it does not need any complex or heavy apparatus for exciting the structure. Measurements can be repeated later on in occasion of substantial modification in the main structure in order to investigate its influence on its dynamic behaviour.

The tests on the containment system of PEC reactor have demonstrated the practicability of this method.

1. Introduction

An important requirement for licensing nuclear reactors is that structural systems and components closely connected with the safety are designed to withstand seismic loads. This is why any design of a nuclear power plant must take into account all possible considerations to avoid dangerous situations to the public health, including those due to strong earthquakes.

However the possibility of making a reliable aseismic design depends on the knowledge of the dynamic structural characteristics. The advent of the digital computer has resulted in an extensive improvement in methods of designing; the most advanced programming techniques permitted the development of appropriate computer programs based on highly refined analitical models of structures subjected to various load conditions.

However, rather refined calculations are not significant if not supported by experimental tests and data. Therefore CNEN, that is the Italian Authority for Nuclear Power Plants, started some years ago a research program with the aim of setting up an easily workable method of testing structures under dynamical conditions. Results of tests are the basis of correct calculations and improved analytical models.

A preliminar experimental method for evaluating the dynamical characteristics of structural systems is the test on scale models. But only in-situ tests on real structures can give optimum information on their effective dynamical behaviour. This requires first of all that the structures have been built and than that appropriate machines as vibrodynes or other mechanical shakers could be used on the site.

A new in-situ test has been recently developed in USA by Teledyne Co.. This method is named A.V.S. (Ambient Vybration Survey) and consists in evaluating the dynamic response of structures to all environmental factors as wind, earth microtremors, traffic etc. CNEN has used this method to make some measurements on the containment system of PEC reactor. So good engineering data have been easily produced for comparing results obtained from actual mathematical modeling techniques and from other laboratory and in-situ measurements.

2. Preliminar tests on the containment system of PEC reactor

PEC reactor is a fast reactor for testing fuel elements. It is under construction on the shore of Brasimone lake not far more 50 miles from Bologna. At this moment only the external containment structure of the reactor has been built.

The seismicity of the Brasimone lake area implied that all structures important to the safety must be designed to resist to earthquake loading.

In view of the final judgement before the license, the Safety and Control Division of CNEN thought that the most important dynamical parameters of the containment structure could be verified experimentally. Therefore CNEN sponsored a contract to ISMES in Bergamo to build-up two 1:50 scale models of this structure. The first model (see Fig. 1) reproduced the whole structure in the actual conditions, that is leaned on the piers. The second model (see Fig. 2) was derived from the first one after having it cut and fitted in a steel ring rigid with a shaking-table. This model reproduced the whole structure in the final conditions, when its lower part, including the piers, will be drowned in the concrete filled up to the ground level.

Tests on the first model were performed by applying periodic radial forces on its wall in order to excite shell modes of vibration. The amplitude of these forces was kept constant whereas the frequency was changed in agreement with the excited number of lobes. The second model was tested on the shaking table in a similar manner. The peak acceleration of the sinusoidal motion was kept constant whereas the frequency was changed as before. Results of these tests are described in the ISMES report No. 649 (see Ref. 1).

A second contract was sponsored to ISMES with the aim of testing in-situ the real structure in the actual conditions. The shell modes of vibration were excited by means of a vibrodyne which loaded the structure like the model in laboratory (see Fig. 3). Results of these tests are described in the ISMES report No. 728 (see Ref. 2).

A good agreement between the results of the two series of tests, in laboratory and in-situ, was found after having analyzed the data.

3. Ambient Vibration Measurements

3.1 Used instrumentation

Recently CNEN has checked some dynamic parameters of PEC containment structure by using A. V. S. method.

A movable laboratory installed in a small motor-vehicle was carried on the site for the measurements. The measurement system consists in five sismometers S13 by Geotech, one SABRE 3 tape recorder by Sangamo and some auxiliary instrumentation as an oscillograph, a paper recorder and so on. Fig. 4 shows a flow chart of such a system. A simple spring mass vibration pick-up is used as seismometer. Thank to an electromagnetic transducer this instrument generates an electrical signal proportional to the relative velocity between the mass and the external case. The normal damping is about 70%. The output signal is proportional to the input velocity when the exciting frequency is higher than the natural frequency of the seismometer which is about 1 Hz. Fig. 5 shows the instrument response curve. Accelerations can be measured down to 10^{-8} g. The amplifier gain can be adjusted in steps of 6 db from 28 to 70 db for the lpw level output. An additional gain of 30 db, 36 db or 42 db can be used for the high level output which provides the maximum sensitivity of 112 db. The amplifier frequency response is flat up to 100 Hz. Plug-in filter cards are used to select the proper pass band for the measurements.

3.2 Description of A.V.S. measurements

The seismometers were placed directly on the external surface of the containment structure by means of brackets bolted on the wall. Bracket positions were so chosen to put in evidence the most interesting mode shapes of vibration. Fig. 6 describes system configurations used for picking up beam modes (6a), rocking modes (6b) and shell modes (6c and d).

Measurements lasted three consecutive days. They were performed during two or three hours in the night when the background excitation due to environmental factors could not be disturbed by occasional events like the crossing of heavy motor vehicles, local works etc.. The value of 15/16 inch/sec was selected for the recording velocity of the magnetic tape.

3.3 Data reduction

Data stored in the magnetic tape were processed in the LABEN 70 computer. This computer has been programmed by the RASP system for converting analog signals into numerical values, performing the spectral analysis and plotting results. The used play-back velocity for the magnetic tape was 60 inch/sec. The following results were obtained:

1) The power spectral density of all recorded motions shows the presence of a peak frequency at 4.5 Hz. A typical plot of the power spectral density is reported in Fig. 7.
2) Analysis of data obtained by the configuration no. 6a) shows that a beam mode of vibration is excited at 4.5 Hz. Fig. 8 indicates that this mode is due to the piers.
3) The cross spectral density between signals recorded simultaneously at

the positions 1 and 2 of the configuration n. 6b) indicates the absence of twisting modes (see Fig. 9), whereas the same evaluation for the positions 3 and 4 shows a push-pull motion at 4.5 Hz due to the axial elasticity of the piers (see Fig. 10).

4) The cross spectral densities for the configurations no. 6c) and 6d) show shell modes of vibrations. In fact the plot of Fig. 11 indicates peaks at 3.2, 3.4, 3.7 and 4.5 Hz. The respective mode shapes correspond to a pattern of 14, 16, 10 and 20 lobes as shown in Fig. 12.(a;b;c;d;).

3.4 Results evaluation

The containment structure of PEC reactor has been studied by means of a finite element mathematical model in order to determine frequencies and mode shapes. The SHELSO program for axisymetric structures has been used. This rather complex and refined mathematical arrangement allowed to put in evidence many vibration modes. In Table 1 it has been reported a comparison among all theoretical and experimental results. The agreement is pretty good for shell modes. Some differences probably are due to the fact that SHELSO is based on a theoretical schematization while real structures certainly are not axisymmetric.

In addition the following considerations can be done for the beam modes. A.V.S. data reduction showed a beam mode at 4.5 Hz which is essentially due to the piers. This mode of vibration probably is the cause of excitation of the shell mode with 20 lobes which has nearby the same natural frequency. This fact is demonstrated by the presence of a predominant vibration at 4.5 Hz in all A.V.S. signals and is indirectly confirmed by ISMES in-situ tests since a minimum force was required to excite the shell mode at the same frequency.

4. Conclusions and recommendations

Results of A.V.S. for the containment structure of PEC reactor have demonstrated that this method of verifying structural calculations is very practical and efficient. In-situ tests using vibrodynes or other mechanical shakers are very good methods too; but they meet some practical difficulties due to the installation of these machines during the construction of the plant. The A.V.S. method requires only instruments for measurements and recordings. They do not disturb works in the construction yard. Measurements can be repeated later on in occasion of substantial modifications in the main structure in order to investigate their influence on its dynamic behaviour.

The past experience on the PEC containment structure suggested the necessity that instrument configurations are properly studied in order to put in evidence the interaction among all modes of vibration. Also good records of ground microtremors could be used for soil structure interaction analysis in order to obtain additional engineering data for this important part of any structural design.

REFERENCES

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2. "Prove dinamiche sul contenitore del reattore nucleare PEC" - Contratto ISMES-CNEN - Pratica n. 728 - Ottobre 1969.

3. "Ambiente Vibration Survey and Mathematical Analysis of the Carolinas-Virginia Tube Reactor" - Contract n. C-638 T.A. n. 1 Sept. 1968, for Phillips Petroleum Company, Idaho Falls. By Earth Science a Teledyne Company.

4. V.R. McLamore, C.C. Hart, I.R. Stubbs "Ambient vibration of two suspension bridges" - Proceedings of the ASCE Journal of the Structural Division - ST 10- October 1971.

TABLE I

Number of lobes	Experimental results			Calculation by SHELSO
	Scale model	Vibrodyne	A.V.S.	
12	2.79 Hz	-	-	-
14	-	3.06 Hz	3.2 Hz	3.7 Hz
16	3.46 Hz	3.35 Hz	3.4 Hz	3.75 Hz
10	-	3.5 Hz	3.7 Hz	-
18	4.24 Hz	4.22 Hz	-	4.13 Hz
8	4.65 Hz	4.73 Hz	-	-
20	4.82 Hz	4.94 Hz	4.5 Hz	4.76 Hz

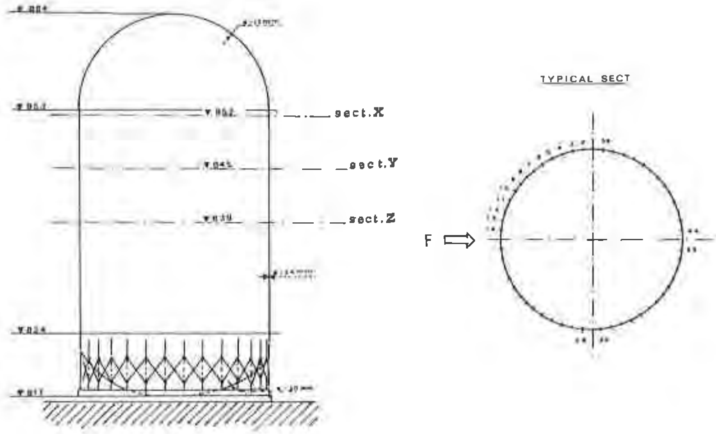

Fig. 1 Dynamical Test on the first Scale Model

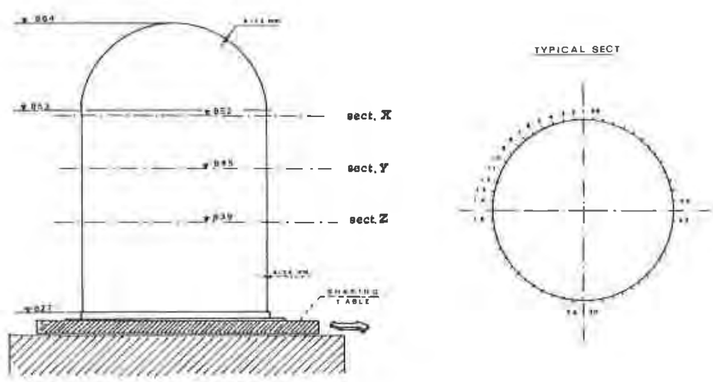

Fig. 2 Dynamical Test on the second Scale Model

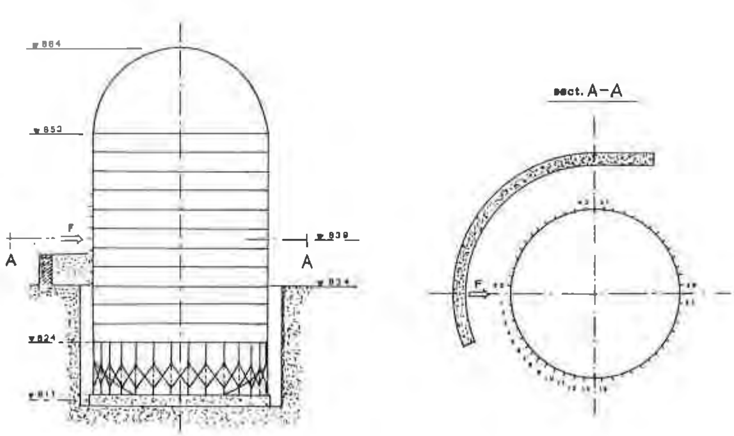

Fig. 3 In situ Test on the real Structure

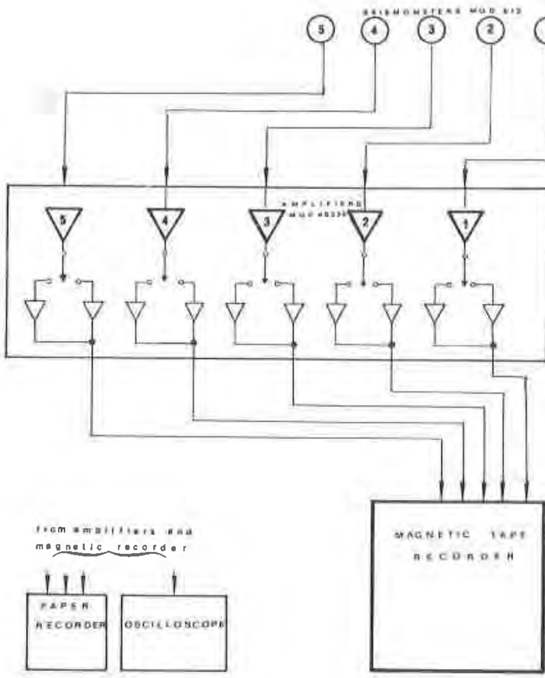

Fig. 4 Flow-chart of A.V.S. instrumentation

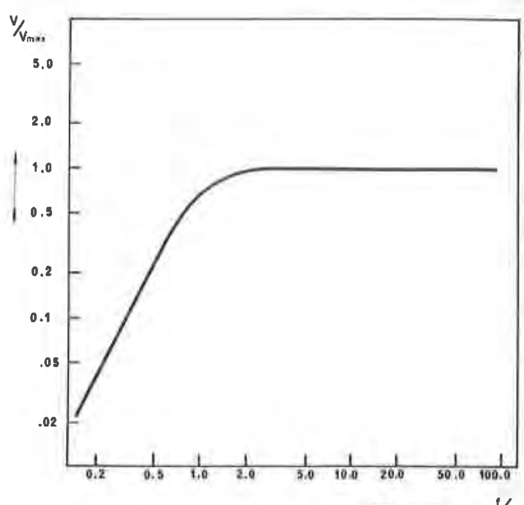

Fig. 5 Seismometer response curve

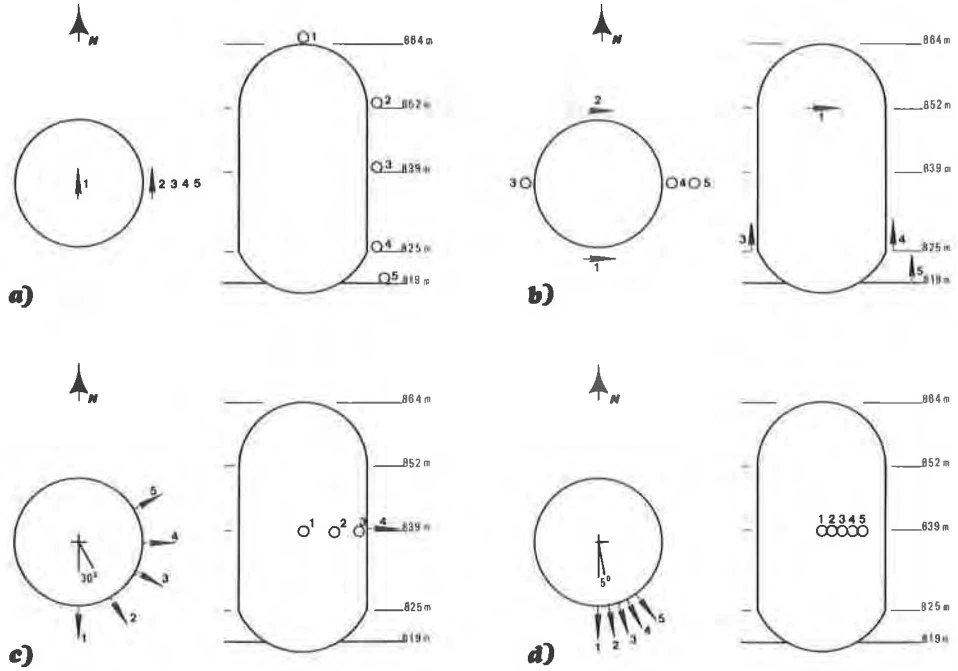

Fig. 6 A.V.S. configurations

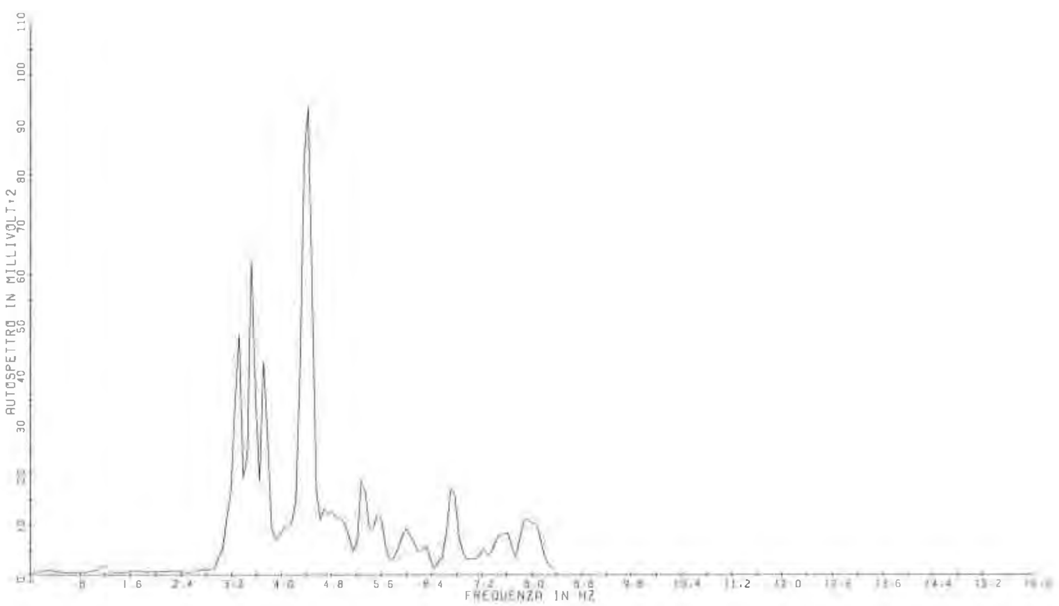

Fig. 7 Typical Power Spectral Density of Recordered Signals

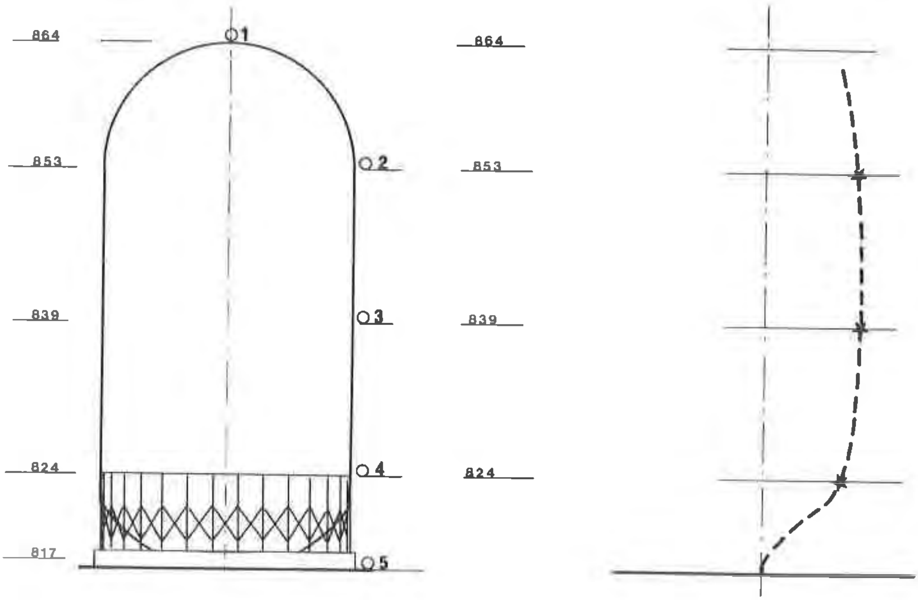

Fig. 8 Beam vibration mode (f = 4.5 Hz)

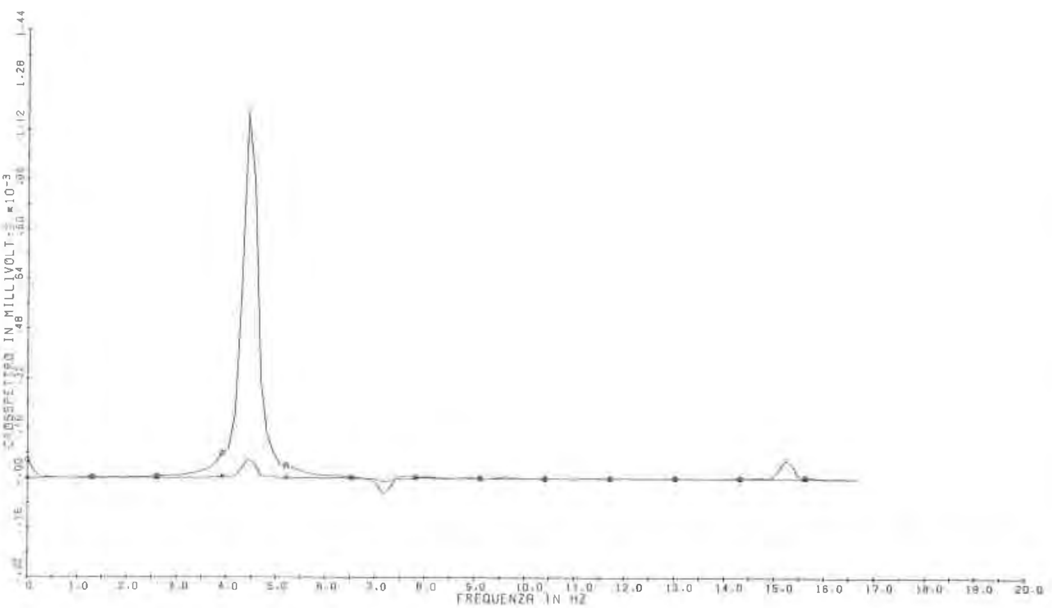

Fig. 9 Cross Spectral Density from Seismometers 1 and 2 in Configuration 6b)

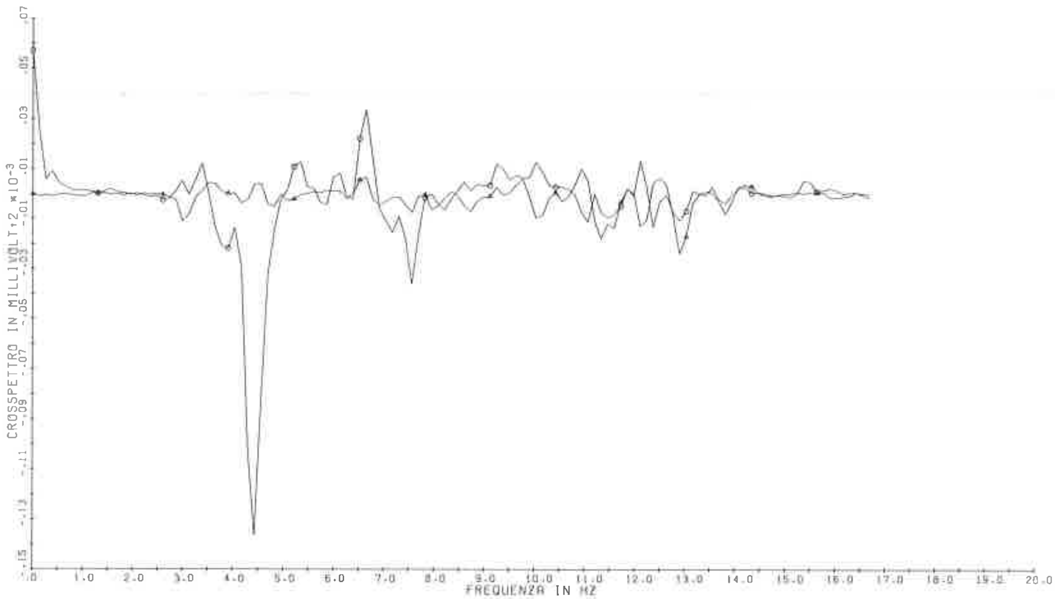

Fig. 10 Cross Spectral Density from Seismometers 3 and 4 in Configuration 6b)

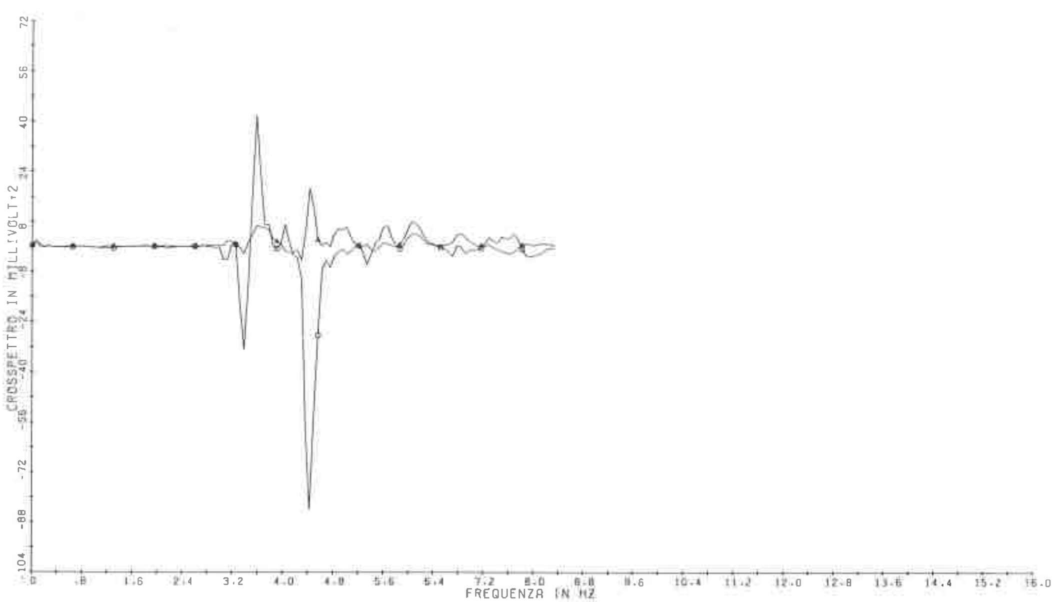

Fig. 11 Typical Cross Spectral Density in Configuration 6c) and 6d)

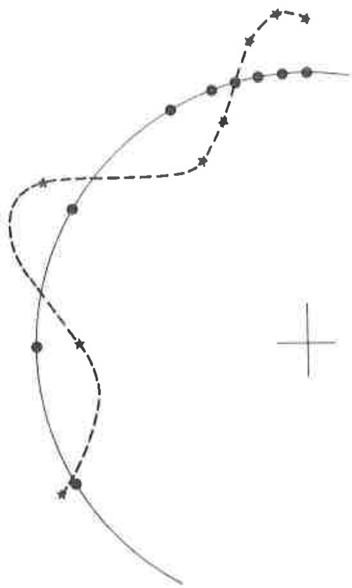

Fig. 12 a) Shell vibration mode ($n = 14$, $f = 3.2$ Hz)

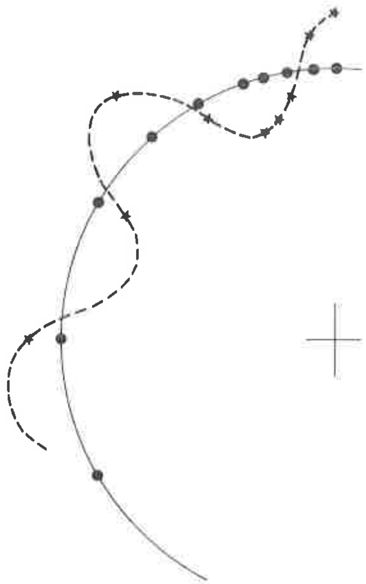

Fig. 12 b) Shell vibration mode ($n = 16$, $f = 3.4$ Hz)

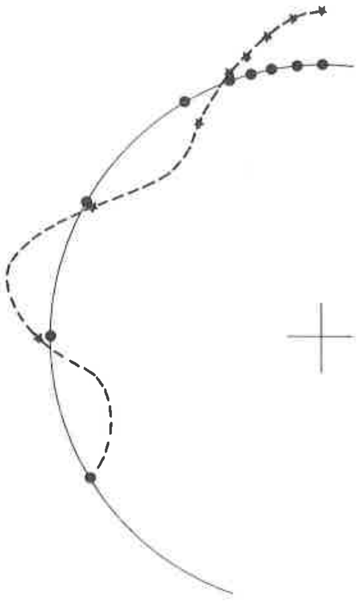

Fig. 12 c) Shell vibration mode ($n = 10$, 3.7 Hz)

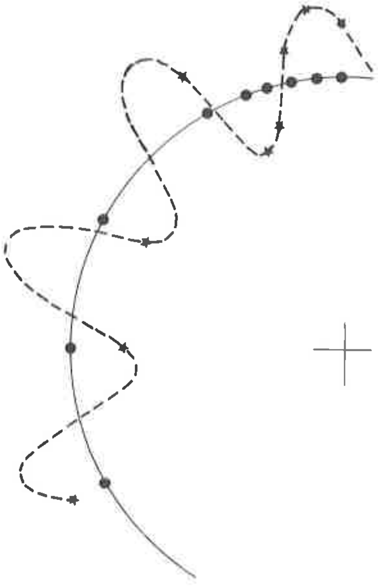

Fig. 12 d) Shell vibration mode ($n = 20$, $f = 4.5$)