XA9952613

COMMISSIONING OF QUALIFICATION OF STRUCTURES, SYSTEMS AND COMPONENTS FOR SEISMIC AND ENVIRONMENTAL LOADS OF "CIRENE" NUCLEAR POWER PLANT

A. Bianchi (1), F. De Pasquali (2), F. Gatti (1), F. Muzzi (1), M. Zola (1)

(1) ISMES S.p.A., Bergamo, Italy
(2) ENEL S.p.A., Roma, Italy

SUMMARY

On behalf of the Italian National Electricity Board (ENEL) concerning the commissioning of qualification of structures, systems and components of CIRENE NPP, ISMES performed a technical surveillance on the documentation concerning the environmental and seismic qualification of the safety related systems and experimental activities (dynamic and static tests) on plant buildings. The aims of the work were:

- the evaluation of the qualification carried out (by test, by analysis, by combination of analysis and test) on the equipment and systems, compared with the requirements of the ENEL technical specifications and the most recent international regulations

- the experimental determination of modal quantities (frequencies, damping, mode shapes) of the structures and, in the case of reactor building, the complex impedance of the soil for supporting the analytical work.

The present paper deals with the criteria, the systems and the results concerning the technical surveillance and with the characteristics and the results of the experimental tests.

1. INTRODUCTION

CIRENE was a prototype of a pressure tube reactor, employing a light water direct steam cycle, heavy water moderated; the rating of the unit was 40 MW(e). The site of the plant was Borgo Sabotino, near the existing Latina gas NPP (Central Italy), see photo 1.

During the long period of time since the design phase to the construction of the plant (about twenty years), some international regulations concerning the environmental qualification of safety related systems and components were updated and other ones were conceived and used. A comparison between the actual qualification status of the safety related systems and components (designed, in certain cases, several years before) and the updated regulations was necessary.

ISMES, on behalf of the Italian National Electricity Board (ENEL S.p.A.), performed a technical surveillance on the documentation concerning the environmental and seismic qualification of some safety related systems, in order to evaluate the qualification carried out (by test, by analysis, by combination of test and analysis) on the equipment and systems, compared with the requirements of the ENEL technical specifications and the nuclear standards and regulations consolidated at that time (some of which are reported in Refs. [1]-[13]).

In 1989, several tests on buildings of the plants were carried out, in the frame of various structural research programs. ISMES, on behalf of ENEL, performed a series of static and dynamic tests on some CIRENE plant buildings, in order to tune experimental methodologies on full-scale structures and to determine modal characteristics of these structures.

The paper refers on the criteria of the technical surveillance on the qualification of the safety related systems and on the methodologies and the results of the experimental tests on buildings.

2. TECHNICAL SURVEILLANCE ON QUALIFICATION DOCUMENTS

2.1 Safety related systems subjected to the technical surveillance

The safety related systems subjected to the technical surveillance were:

- Process instrumentation (level switches, pressure transmitters, thermoelements)
- Valves
- Protection system
- Sequences and interlocks system
- Mechanical linking of the process instrumentation to the process
- neutronic monitoring system
- control room and alarms system
- racks of Class 1E instrumentation

2.2 Technical surveillance criteria

The criteria used in the technical surveillance were the following ones:

- verification of the completeness of the Designer specifications in terms of:
** identification of the equipment (safety class, seismic category, QA category, safety functions, boundaries and interfaces)
** seismic, environmental and operational loads
** qualification procedures
- verification of the correctness of the qualification methodology carried out, and of the sequence of the tests and analysis
- verification of the choice of the Representative Sample, if the qualification was performed by test, or modelization adopted, if the qualification was performed by analysis
- verification of the adequacy of the tests methodology, of the instrumentation used and of the methods of analysis of the results
- verification of the adequacy of the computation methods
- verification of the justification of the extension of the results obtained by test and/or analysis, knowing the fault tree of the equipment
- verification that seismic, environmental and operational loads applied to the equipment during the qualification program were greater than those provided by the Designer of the plant
- verification that the results obtained by tests and analysis demonstrated that the equipment was able to perform its safety related functions in the whole design life.

2.3 Results of the technical surveillance

The results of the technical surveillance can be grouped in two main items:
1) results concerning the design documents
2) results concerning the qualification documents

As far as concerns the first item, the main results of the surveillance were the following ones:
i) lack of design data concerning the seismic and environmental qualification: for example, the required duration of seismic tests, relationship between SSE and OBE, required duration and magnitude of LOCA and post-LOCA effects in terms of nuclear radiation, pressure and temperature transients, duration and magnitude of vibration aging, etc.
ii) lack of acceptance criteria on safety functions of equipment which should remain operational during the qualification tests
iii) for some equipment, qualified life (20 years) was not specified

The main results of the second item of the technical surveillance were the following ones:
i) some samples of the components and equipment subjected to the qualification process were not representative of the supplies or was not demonstrated that they were truly representative of the supplies
ii) some components were already qualified for other existing NPPs but the extension of their qualification process to the seismic, operational and environmental conditions of CIRENE plant was not clearly demonstrated
iii) in some cases, the lack of documentation of the Suppliers did not allow the verification of the qualification performed

ISMES compiled reports for ENEL in which, for each system subjected to the technical surveillance, the problems found out during the work were presented and the solutions were suggested, in order to have, from the Suppliers of the equipment and systems, technical report that could demonstrate the adequacy of the qualification carried out.

3. EXPERIMENTAL ACTIVITIES ON CIVIL STRUCTURES

3.1 Introduction

The aims of experimental activities (carried out in 1989) were the following ones:

- to evaluate the dynamic behaviour of the structures in the seismic field of interest in order to support the commissionig of the structures;
- to tune test methodologies on full-scale structures;
- to evaluate the impedance matrix of the soil in order to study the soil-structure interaction problems;
- to verify the behaviour of the upper floor of the turbine building subjected to an accidental overload through a static load test and the comparison with a numerical model.

3.2 Description of the structures subjected to the tests

The buildings subjected to the tests were the following ones (Fig. 1):

- inside the "nuclear island"
  - . building n. 1 "reactor"
  - . building n. 5 "control room"
- in the B.O.P. area (balance of plant)
  - . building n. 6 "turbine"
  - . building n. 10 "off-gas".

The buildings were made of a reinforced concrete basemat and thick walls.

The Reactor building (fig.2) is contained in a metallic vessel; the off-gas building (fig. 3) has a 70 meter-height metallic chimney.

3.3 Dynamic characterization tests

A mechanical vibrator capable of generating sinusoidal forces at various frequencies in the field of seismic interest was used to excite the structures (photo 2).

The exciter was connected rigidly to the upper floor of the buildings. The investigations were performed by exciting the structures along the two horizontal principal directions.

For the Reactor building, more complex tests were performed, in various positions of the building;

For the building "off-gas", the velocity and the direction of the wind were recorded, through an anemometer and a direction transducer installed on the metallic chimney.

The dynamic response of the structures was obtained through a sismometers and accelerometers mesh (see figs. 2, 3 and photo 3); signals were acquired with a digital acquisition system.

3.4 Modal analysis

The analysis of the transfer functions obtained by forced vibration tests made possible to determine modal parameters (natural frequencies, modal shapes and dampings) of the first modes of vibration of the structures.

A synthesis of the results relative to both the reactor and the off-gas buildings are shown in figs. 4, 5 and 6.

From these results, the following remarks can be made:

- considering that about 50% of the structure deformation is due to the flexibility of the soil, the contribution of the foundation soil to the dynamic of the system cannot be neglected, especially at low frequencies. In fig. 4 are shown the experimental transfer functions obtained on the off-gas building in x direction and the corresponding curves computed considering the building as a rigid body capable only to perform rotational and translational rigid displacement on the foundation soil. This comparison shows the importance of the contribution of the rigid mode.
- The high structural damping, in some cases greater than 10%, is due to the great dissipative capacity of the foundation soil, which is involved in a *significant way in all the vibration modes investigated.*
- The interaction between the chimney and the off-gas building is important. In fig. 4 it is shown that the transfer functions of the off-gas building, in correspondence of the resonance frequencies of the chimney, have amplitude reduction in the excitation direction. The first natural frequency of the chimney was found by processing the data of the wind excitation recording.
- The accelerometers, installed on the plant equipment of the Reactor building, measured accelerations lesser than those measured by transducers installed on the reinforced concrete structures of the building at the same level; this demonstrates the filtering action of the supports of the plant equipment.

3.5 Experimental determination of the impedance matrix of the foundation soil

The behaviour of the foundation soil can be described by the impedance matrix of the soil, which can be determined, in the frequency domain, with the following procedure.

The soil and the structure are considered linear elastic systems. The basemat of the building is considered a rigid body with six degrees of freedom, whose motion is described by the vector X(f) where f is the frequency. It is assumed that there is no relative motion between soil and basemat in correspondence of the contact point P_b (Fig. 7) where the impedance matrix of the soil is determined. F(f) is the vector of generalized forces acting on the soil (forces and moments). Then it holds:

$$\{F(f)\} = ([D]\ \{N(f)\} - [T]^T\ [M]\ \{Q_A(f)\}) \qquad (1)$$

where N(f) are the external forces (in our case the mechanical shaker force), [M] $Q_A(f)$ are the inertia forces and the matrices [D] and $[T]^T$ transfer the forces acting on the structure to the soil. [M] is the mass matrix of the structure and $Q_A(f)$ is the vector of the absolute accelerations of the lumped masses describing the structure.

The impedance matrix is given by:

$$\{F(f)\} = [Z(f)]\ \{X(f)\} \qquad (2)$$

where [Z(f)] is the impedance matrix of the soil and is a 6x6 symmetric matrix.

As shown in Fig. 7, the analysis was performed just in the vertical plane containing x and z axes; thus the impedance of the soil was described by a 3x3 matrix so just three independent excitations were used to evaluate it: F_x and F_z applied on the top of the building and F_x' applied at 6,6 m level (level on the sea). The order of magnitude of the soil translational stiffnesses (10^{10} N/m) is in good agreement with the corresponding analytical values computed from the classical model based on the behaviour of a circular disk on elastic half-space.

3.6 Static tests on the turbine building

The main scope of the static tests on the roof of the turbine building was to assess its deformation. The roof was made with prefabricated U reversed beams tighten with a reiforced concrete plate 18 cm thick (see Fig. 8).

During the load steps displacements and strains of the structure were measured (see Fig. 9). The vertical displacements of the structure were measured with LVDT displacement transducers. An automatic data acquisition system was used for signals recording. The static load was reproduced with a water pool in correspondence of the two central prefabricated beams up to a pressure of 400 daN/cm² and simultaneously to the water charging the data acquisition was performed with time intervals of 10 minutes.

The experimental bending displacements were compared with the displacements obtained from a finite element model given by MSC/NASTRAN V.66. The reinforced concrete plate was modelled with rectangular bidimensional elements, whereas the webs were modelled with beam elements; just a quarter of the structure was modelled given the symmetry. To identify the boundary conditions the analysis was repeated in two conditions: structure simply supported and clamped.

Comparing the experimental results with those of the mathematical model in two load cases (dead weight and 400 daN/cm² of water pressure) it is possible to say that the behaviour of the reinforced concrete plate, at low loading levels, can be described by clamped edges.

4. CONCLUSIONS

4.1 Technical surveillance

Many of the problems encountered during the technical surveillance were probably due to the lack of an adequate Quality Assurance Plan at the time in which the NPP was designed: the increment of know-how in this particular field allowed the equipment and systems developped later for other Italian NPPs not to be affected by the same problems.

4.2 Experimental activities on Buildings

The forced vibration tests on the building gave the possibility to get the dynamic characteristics of the buildings and the modal parameters of the main eigenfrequencies in the seismic frequency range were determined.

Due to the big number of transducers, it was possible to get a fine description of the dynamic behaviour of the structure.

An important soil-structure interaction was detected in the frequency range up to 12 Hz; for higher frequencies an important elastic deformation of the structure was observed.

Good results were obtained with low amplitude exciting forces and no damage was produced on the buildings.

REFERENCES

[1] IEEE, 1974, IEEE Std. 323: "IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations"

[2] IEEE, 1975, IEEE Std. 344: "IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations"

[3] IEEE, 1977, IEEE Std. 381: "IEEE Standard Criteria for type tests of Class 1E Modules used in Nuclear Power Generating Stations"

[4] IEEE, 1974, IEEE Std. 383: "IEEE Standard for type test of Class 1E electric cables, filed splices and connections for Nuclear Power Generating Stations"

[5] IEEE, 1980, IEEE Std. 627: "IEEE Standard for Design Qualification of Safety Systems Equipment Used in Nuclear Power Generating Stations"

[6] IEEE, 1983, IEEE Std. 729: "IEEE Standard Glossary of Software Engineering Terminology"

[7] IEEE, 1984, IEEE Std. 730: "IEEE Standard for Software Quality Assurance Plan"

[8] US NRC, 1973, R.G. 1.60: "Design Response Spectra for Seismic Design of Nuclear Power Plants", Rev. 1

[9] US NRC, 1973, R.G. 1.61: "Damping Values for Seismic Design of Nuclear Power Plants", Rev. 0

[10] US NRC, 1974, R.G. 1.89: "Environmental Qualification of Electric Equipment for Nuclear Power Plants", Rev. 0

[11] US NRC, 1976, R.G. 1.92: "Combination of Modes and Spatiale components in Seismic Response Analysis", Rev. 1

[12] US NRC, 1977, R.G. 1.100: "Seismic Qualification of Electric Equipment for Nuclear Power Plants", Rev. 1

[13] ASME, 1983, ASME Boiler and Pressure Vessel Code (SI Edition) Section III: Code for pumps and valves for nuclear power. Subsection NB-3200: design by analysis. Subsection NB-3600: Piping design

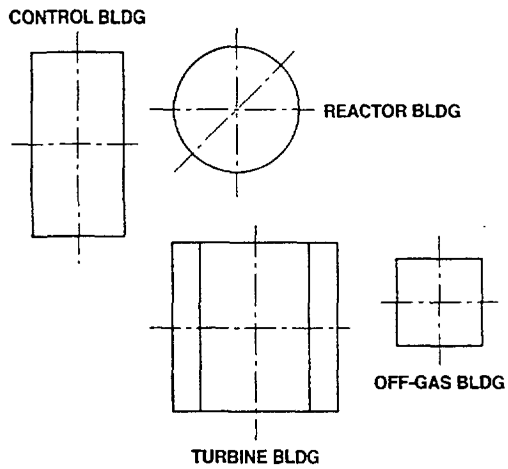


Fig. 1 - Cirene NPP: Building layout.

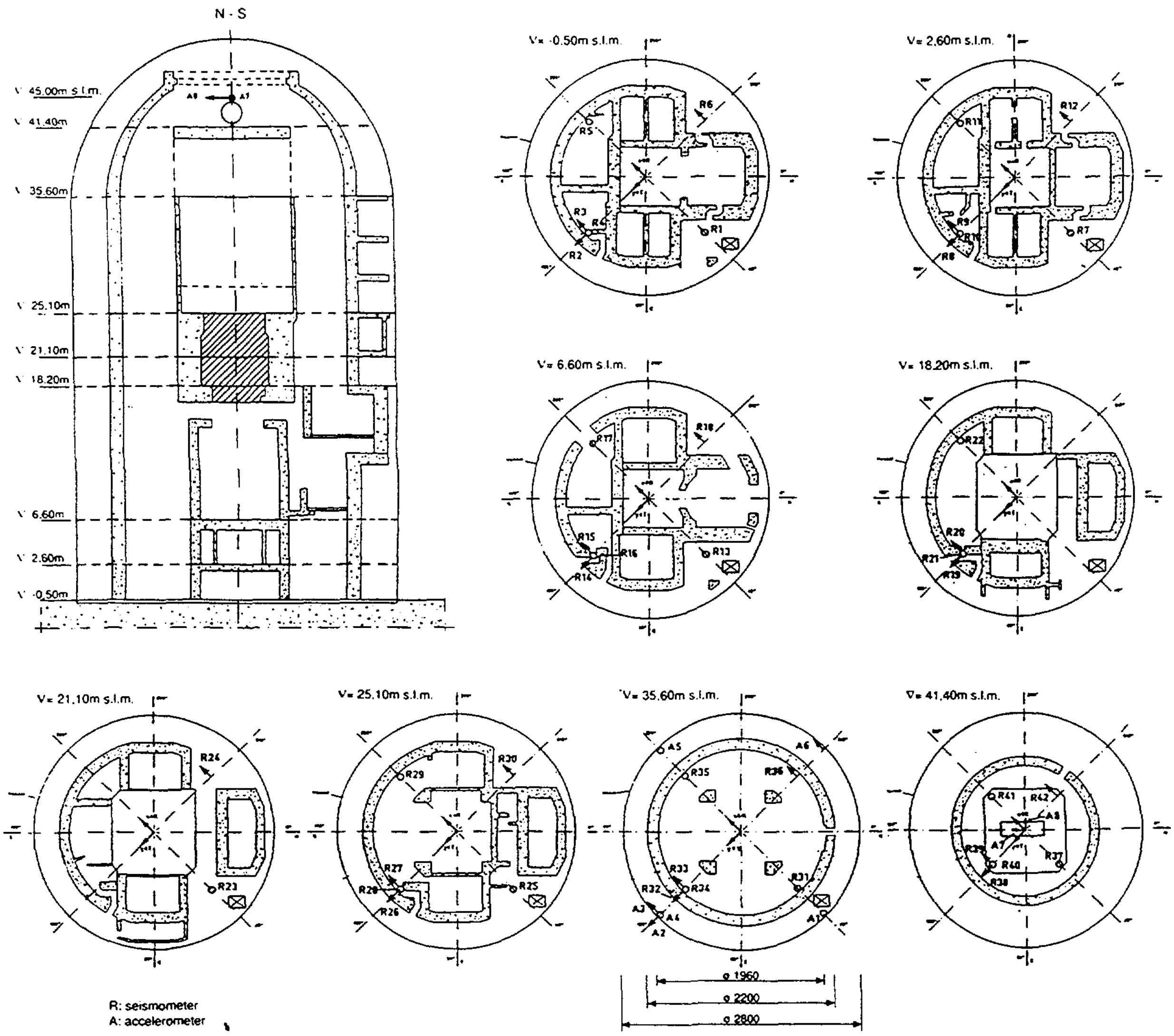


Fig. 2 - Reactor BLDG: Position of the transducers.

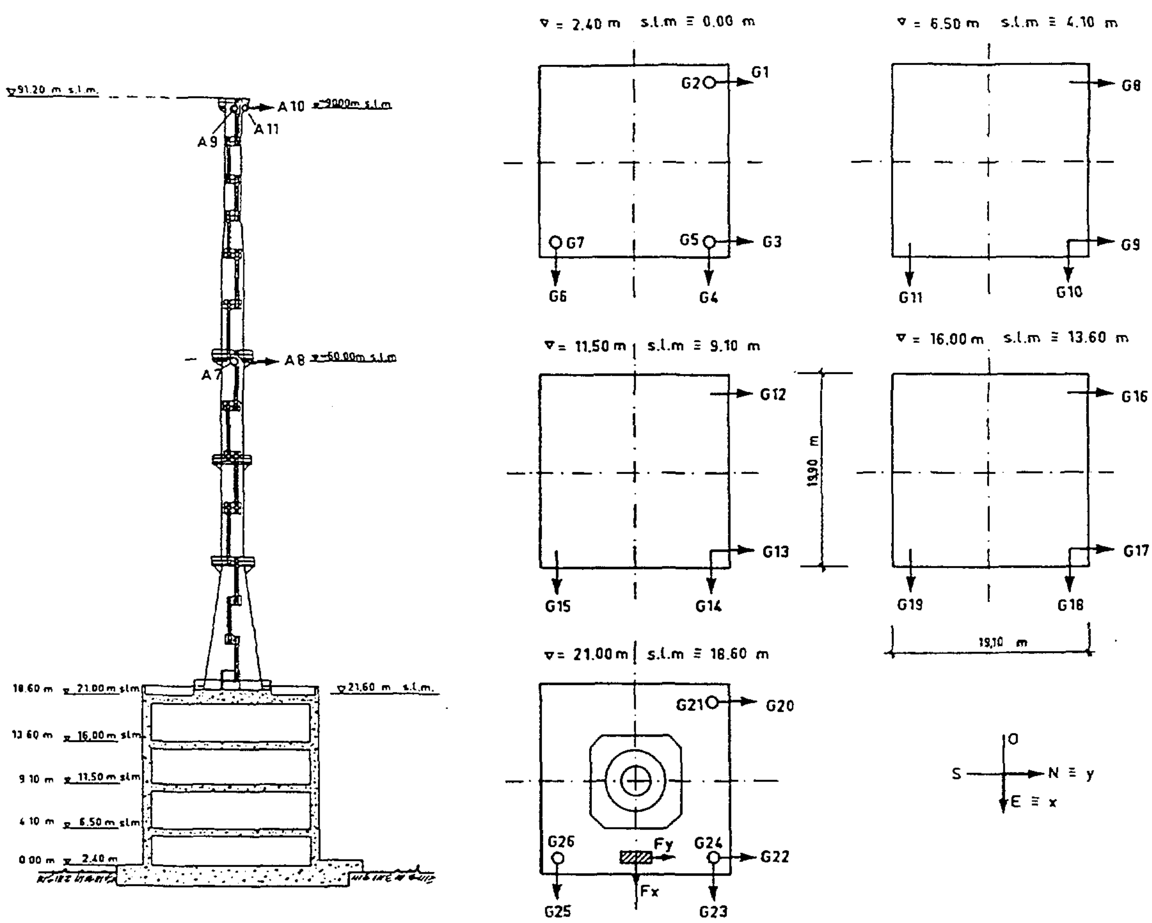


Fig. 3 - Off-gas BLDG: position of the transducers.

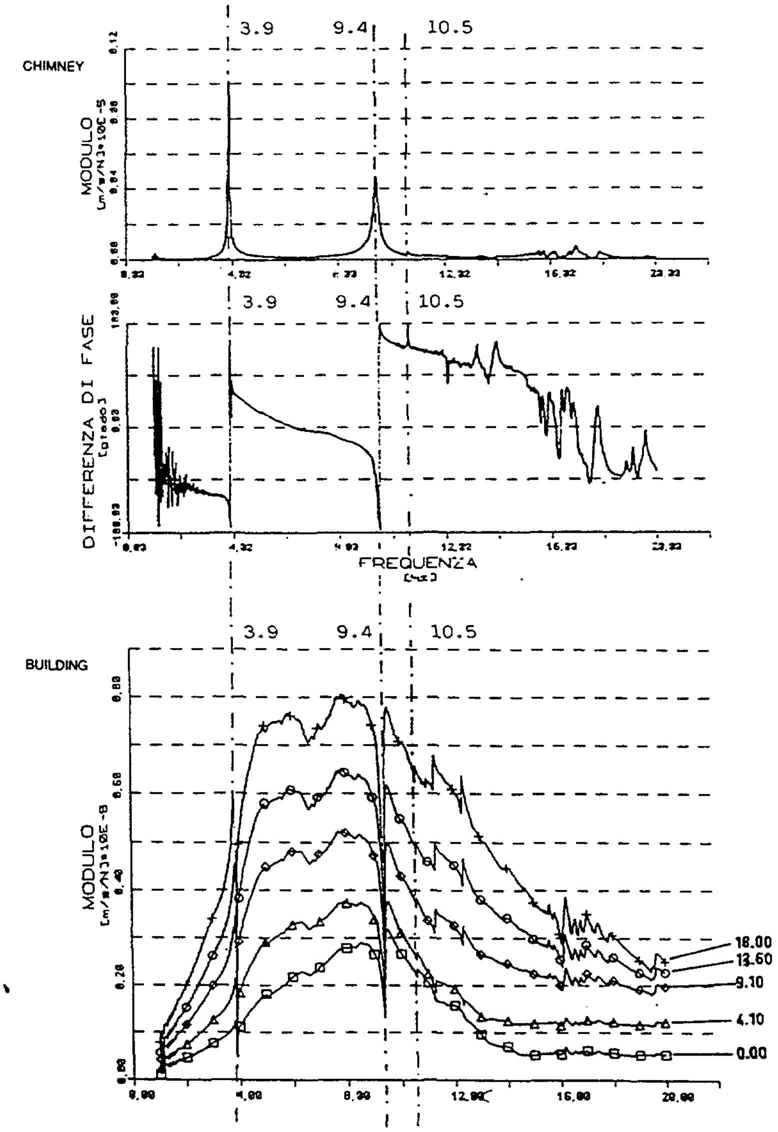


Fig. 4 - Off-gas BLDG: Transfer functions of the chimney and of the building (X-DIR).

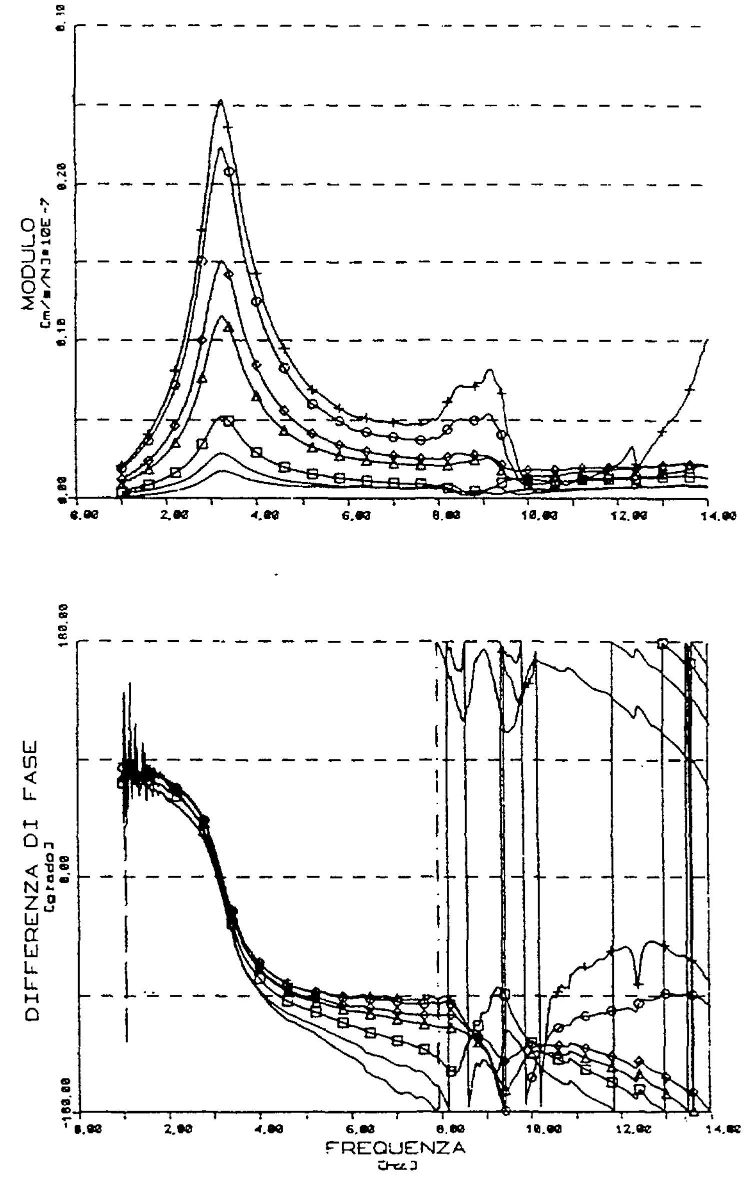


Fig. 5 - Reactor BLDG: Transfer functions (Y-DIR).

$\varnothing_x$	$\varnothing_y$	$\varnothing_z$	$\varnothing_{\varphi x}$	$\varnothing_{\varphi y}$	$\varnothing_{\varphi z}$	QUOTA
52	1000	- 0	- 236	17	- 59	41.90
37	882	- 0	- 264	38	- 40	36.10
35	590	- 0	- 220	-	- 30	25.60
21	480	- 0	- 248	18	- 25	18.70
15	197	- 0	- 173	10	- 9	7.10
11	118	- 0	- 142	7	- 0	3.10
8	79	- 0	- 122	4	6	0.00

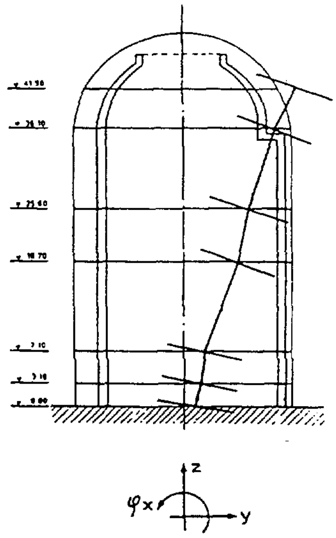
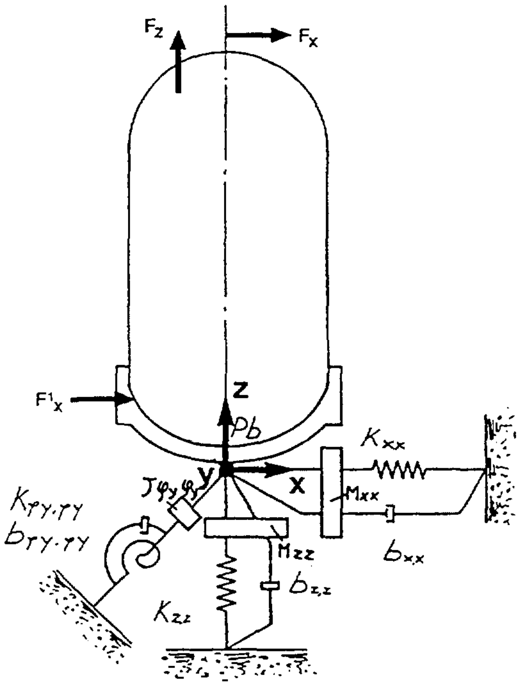


Fig. 6 - Reactor BLDG: First mode of vibration (3,3 Hz;ξ = 15%).



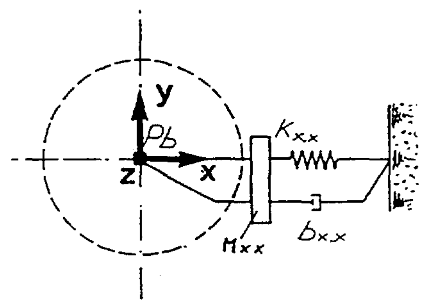


Fig. 7 - Model of the soil impedance.

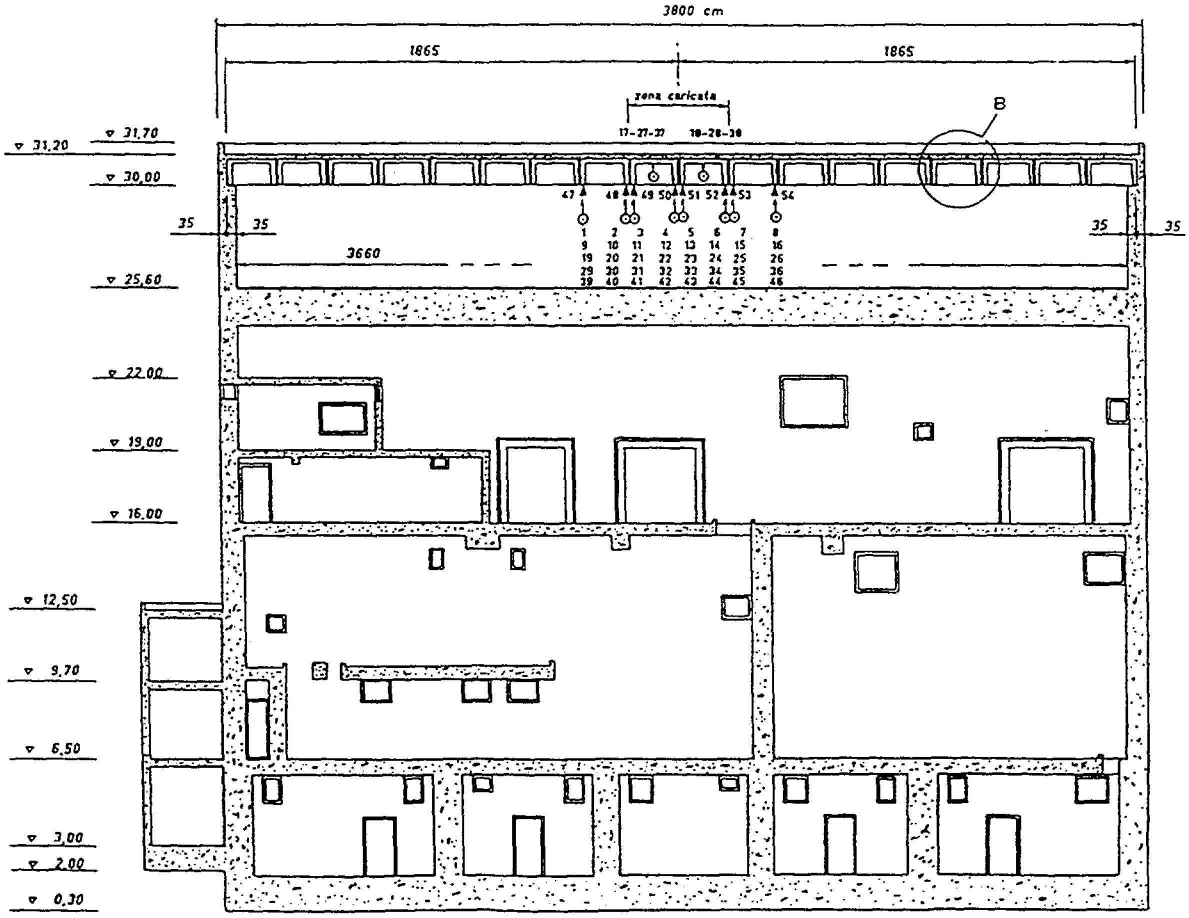
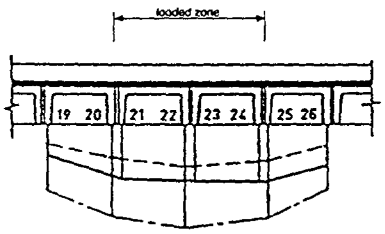


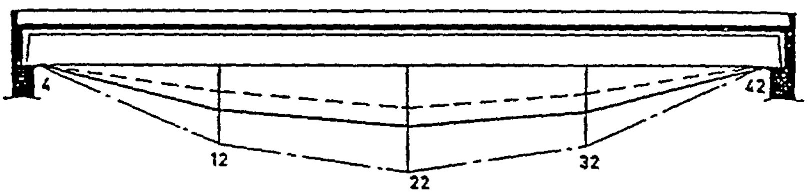
Fig. 8 - Turbine BLDG: Transversal section measurement mesh and geometric data.

a)



Transducer n. (mm)								
19	20	21	22	23	24	25	26	
+0,367	+0,663	•	+0,813	•	•	+0,663	+0,367	— — —
+0,584	+0,934	+1,036	+1,114	+1,092	+1,096	+1,074	+0,806	———
+1,250	+1,800	•	+2,047	•	•	+1,800	+1,250	—·—

b)



4	12	22	32	42	
0,000	+ 0,500	+ 0,813	+ 0,500	0,000	— — —
+ 0,034	+ 0,840	+ 1,114	+ 0,834	+ 0,012	———
0,000	+ 1,458	+ 2,047	+ 1,458	0,000	—·—

- - - - - - Clamped - Clamped beam (numerical data)

——————— Experimental values

——·——·— Hinged - Hinged beam (numerical data)

Fig. 9 - Turbine BLDG:
Compaison between experimental and numerical displacements.
a) Transversal section; b) Longitudinal section.

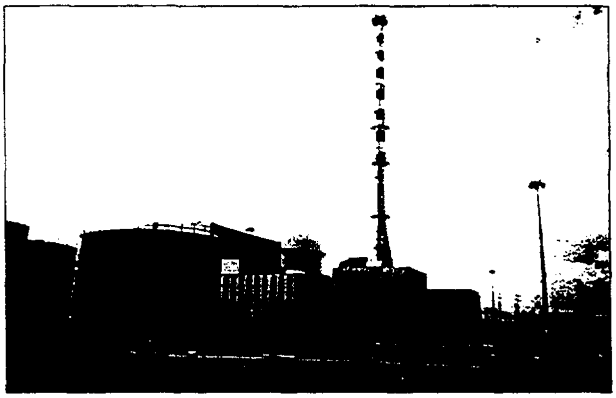


Photo 1 - General view of the CIRENE NPP.

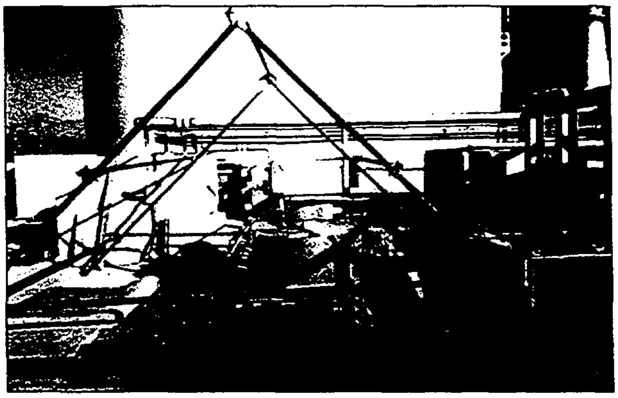


Photo 2 - Mechanical exciter on the top of the control building.

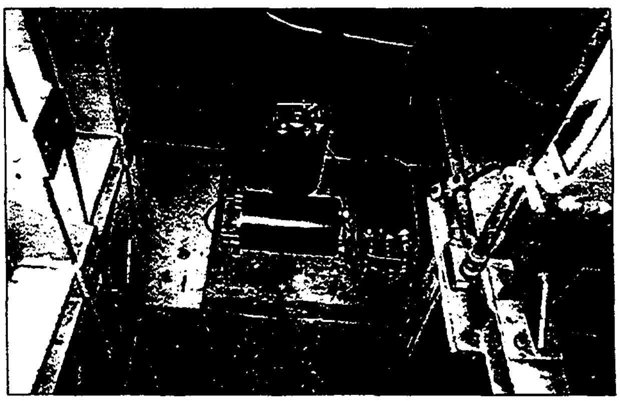


Photo 3 - Seismometers on the foundation floor.