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Autor(en): **Lazzeri, L. / Bozzo, F. / Filippi, G.**

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PROBLEMS FOUND DURING THE SEISMIC DESIGN OF STRUCTURES AND EQUIPMENTS OF A NUCLEAR POWER PLANT

L. LAZZERI, F.BOZZO, G.FILIPPI

(SAIGE SpA , GENOA- ITALY)

ABSTRACT

The aim of this paper is a review of the main points found during the analysis of a nuclear power plant from the seismic point of view .
The main points are :

- soil structure interation
- modelling of structures
- static equivalent models
- floor response spectra
- piping analysis
- electrical cableways
- heavy components

1. INTRODUCTION

The seismic analysis of nuclear power stations structures and components is one of the main problems, the designer has to solve in order to assess the safety of the populations even in the case of extreme earthquakes events. The aim of this paper is a brief analysis of the different problems one has to face , from the soil-structure interaction to sample analysis of different equipments in a nuclear power station.

2. SOIL-STRUCTURE INTERACTION

As it is well Known (see, as an example ref [1]) the soil structure interaction problem is of paramount importance in determining the response of the structures to the seismic excitation. The usual and simplest way of considering the soil-structure problem is by means of a set of springs , which model the stiffness of the ground surrounding the structure . This method, largely based on a method proposed by Whitman [2], [3] , has been widely used in the past and it is quite satisfactory when the soil is relatively uniform and no large embedment is present. Different methods [4], [5], [6] [7] dealing with modifications and corrections of the original half space method have been proposed, however finite element methods (based on the use of the computer code FLUSH and subsequent modifications [8],[9],[10]) are available for an efficient evaluation of the soil-structure interaction phoenomenon . A lot of papers was written to compare the different advantages of the two methods, however in this paper, the authors have simply decided to report their particular experience in this field.

The usual spring methods has large advantages in terms of cost and simplicity, so that many parametric analyses can be performed considering even a large spread of data regarding the soil characteristics [11] and is generally satisfactori. However, many cases exist where a good assessment of the phoenomenon can be obtained by the use of the FLUSH code, as an example with relatively complicated soil profiles , with large embedment phoenomena or when the so called building- soil-building phoenomena may have importance . As far as this last aspect is concerned some runs have been performed in the case of neighbouring buildings on a relatively hard but comparatively not uniform soil (the modulus of elasticity ranging from 20000 to more than 100000 Kg/cmq) . The first example is shown in fig.1 , where two building of relatively similar weight and size have shown a coupled behaviour quite similar to the uncoupled one . The coupling phoenomenon is definitiely more easily discerned in the example in fig.2a,the response spectrum in fig.2b in one building clearly presents a peak corresponding to the eigenfrequency of the other building . However in this case too, while significative effects can be anticipated in terms of the response spectra, no large influence in the building accelerations was detected. Again this is quite possibly due to the relative resemblance of the two buildings, while the building-building interaction phoenomenon should quite possibly be more important for small buildings near much heavier ones.

3. MODELLING OF STRUCTURES

A discussion of the tecniques used in analyzing and modelling the civil structures of a nuclear power stations is given in reference [1] . In many cases, particularelly for stiff buildings on very soft soils, a very simple model of the building (stick model) is adequate to predict the behaviour of the building [12] ; a lumped masses model is used , the masses are generally placed at the floors levels with beam connections, representing the stiffness of the walls connecting subsequent floors. However for panels buildings (box type buildings) the stick model may be not quite adequate and for relatively stiff soil, where influence of the building stiffness may be important, finite elements model may be necessary. In fig.3a an example of a finite elements model is shown and the results of the dynamic analysis is shown in fig.3b ; obviously enough the coupling of the panels vibrations with the over all building vibration, which is visible in the eigen frequency pattern in fig.3b, is not detectable with a stick model. On the other end box type buildings can be quite complicated and an efficient model can be very expensive due to its size, sothat substructuring and condensing tecniques are to be used.

4. STATIC EQUIVALENT MODELS

For obvious economical reasons the dynamic models are relatively of small size and their use can be not quite adequate to compute the inertial forces for the subsequent stresses evaluation. Again huge (thousands degrees of freedom) finite elements models have been used [12] , but their use is very expensive sothat simplificative assumptions have to be used. To test different methods some runs have been made by the authors and their colleagues in SAIGE [13][14] . In fig.4a a simplified model is shoun; it has been loaded by constant inertial forces in the horizonthal plane and by vertical forces on the floor simulating a rotation effect. The displacements pattern is shown in fig.4b,c . While the simplifications in the model may be relatively important (only the lower portion of the building has been modelled, while the influence of the stiffness of the upper portion may have some importance) some general conclusions may be drawn :

- the shear is absorbed only by the walls parallel to the direction of the seismic excitation and it is relatively constant in them
- the bending moment is not absorbed by the structure as a whole, rather the normal stresses are concentrated mainly in the corners or where two normal walls are present
- the floors are not rigid as regards the out of plane bending and are not consequently adequate to transfer the stresses from one end of the building to the other one
- some deformations take place even due to in plane forces, however this effect is much more limited than the previous ones, so that a relatively uniform shear stress distribution takes place

- the vertical forces consequent to rotational accelerations are taken directly by the floors where they are applied and transfered locally to the vertical frames.

Particularely for low and wide buildings the shears seem to be absolutely predominant and the floors are generally adequate to act as rigid frames so that the seismic shears are taken by the vertical walls between subsequent floors independently from the distributions over and under the connected floors. The behaviour is quite opposed to the one usually Known as typical of "shear type buildings' and represents consequently the other extreme.

However there are buildings where both bending and shears may play an important vale so that finite elements models only can be used for a relatively exact evaluation of the seismic stresses.

5. FLOOR RESPONSE SPECTRA

As it is well Known , the modelling of the structures is limited to the main components , while the minor ones are neglected . However there are many components (piping , valves, pumps, electrical components , etc.) which are important for the safety of the plant and whose seismic analysis has to be performed. For relatively light components it is comparatively accurate to assume that no feedback action takes place from the component,so that the seismic time history due to the earthquake and filtered by the building can be directly assumed by it. This procedure is generally Known as 'calculating a floor response spectrum" and it is used even for relatively heavy components even if in this case the procedure may be relatively pessimistic [15] . Many tecniques have been proposed using both stochastic [16] or semistochastic methods [17], [18] ; the use of these methods has large advantages in terms of cost and time as they are based on the use of the response spectrum analyses for the buildings . On the other end time histories analyses have been proposed and used even if they are relatively expensive. The first problem to be solved is the generation of a time hystory compatible with the given ground response spectrum ; starting with a paper by Nih Chien Tsai [19] tecniques have been proposed [21] an an earthquake time history representation by means a Fourier series . Both the SIMQKE program [20] and a home-made program THAMS [22] , [23] based on reference [21] . In fig.5 the time history compatible with the standard USA Regulatory Guide 1.60 is shown as generated by THAMS program is shown.

Much discussion has been made abaut the relative merits of the simplificative and time history methods, it is the authors' opinion that the use of the time history methods are quite necessary in many cases (as an example whenever non linear tecniques are necessary ar when time histories are necessary as an example for tests on heavy machinery or electric components) , however defects in the methods (lack in uniqueness in the solution, costs) may make the simplificative ones preferable. As an example , in many cases, it is not quite necessary to know exactly the floor response spectrum rather it is important to know for which frequencies there is the so called peaks region (large amplifications in the accelerations) and which is the minimum frequency for which the floor response spectrum is flat. In this cases the advantages of the simplified methods are obvious.

6. PIPING ANALYSIS

The seismic analysis of piping runs is one of the main tasks for the designer of a nuclear power system , due to the large numbers of components to be analyzed . It should be further mentioned that ASME 3 NB pipes generaly have some problems concerning the thermal analysis and consequent fatique evaluation, so that it is convenient to have pipings as flexible as possible ; obviously enough this necessity is contrary to the seismic one, as it is customary to have eigen frequencies higher than the peak zone ones in order to minimize the accelerations in the pipe [24] . Then the use of viscous or inertial snubbers has been found particularely useful in solving this problem . However the costs of these equipments is comparatively large so that there is a strong necessity for the limitation of their number , besides the dynamic analyses themselves are relatively expensive and time consuming so that some predesign criterion is very useful indeed [25] .

Some simple predesign criteria (based on a hypothetic independent behaviour of each span of pipe between successive supports) are used for the sizing of the snubbers and a preliminary evaluation of their collocation. Then a final dynamic analysis is performed for a final appraisal of the solution ; an example is given in ref. 5.

It should further mentioned that a huge number of piping in a nuclear power station do not have dilatation problems and their minor importance does not require particular dynamic analysis, hence the simplified analysis are particularely interesting . Two criteria are generally considered,

- each span is considered in an indipendent way so that the fundamental eigen frequency is larger than the one corresponding to the beginning of the flat region in the FRS ,
- the maximum stresses are very low so that the seismic excitation does not contribute to a substantial increase in the stresses.

7. ANALYSIS OF ELECTRICAL CABLEWAYS

Most of the safety related components are electromechanical, whose energy comes via electric wiring ; then they must be analyzed from a seismic point of view. The problem does not present substantial difficulty from a theoretical point of view, however the huge number of components to be analyzed represents a difficulty in itself. Normalization and the use of computerized procedures is then absolutely necessary in order to perform these analyses within reasonable time and costs. ASDIC [26] is an answer to these necessities; the code is capable of analyzing the support structures of cableways and electric wirings, determining the maximum loads (dead load and seismic loads specified under the form of support structures) compatible with each geometric configuration (as an example see fig.6) Then the use of ASDIC together with a normalization makes these analyses quite easy.

8. ANALYSIS OF HEAVY COMPONENTS

The analysis of heavy components is a necessary step in assessing the safety of the plant from the seismic point of view . While many analyses have been performed for important mechanical components such as pressure vessels,pumps etc., few analyses have been reported about electrical equipments such as motors, alternators etc. From a theoretical point of view many problems seem to exist as relative displacements between the stators and rotors could cause heavy consequences on the normal service of the machinery. For this reason some analyses have been performed (see fig.7) on typical machinery by means of finite elements models (approximately 1000 degrees of freedom). The results have been quite good showing that the normal working necessities claim for heavy rigidity necessities, so that the machines are generally rigid . Partial vibrations of some panels might take place, without any loss of functionality of the machine itself. Besides no large relative displacements among the different parts of the structure take place as due to the seismic excitation, so that no large electrical problems are anticipated.

9. ACKNOWLEDGRMRNTS

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FIG.1

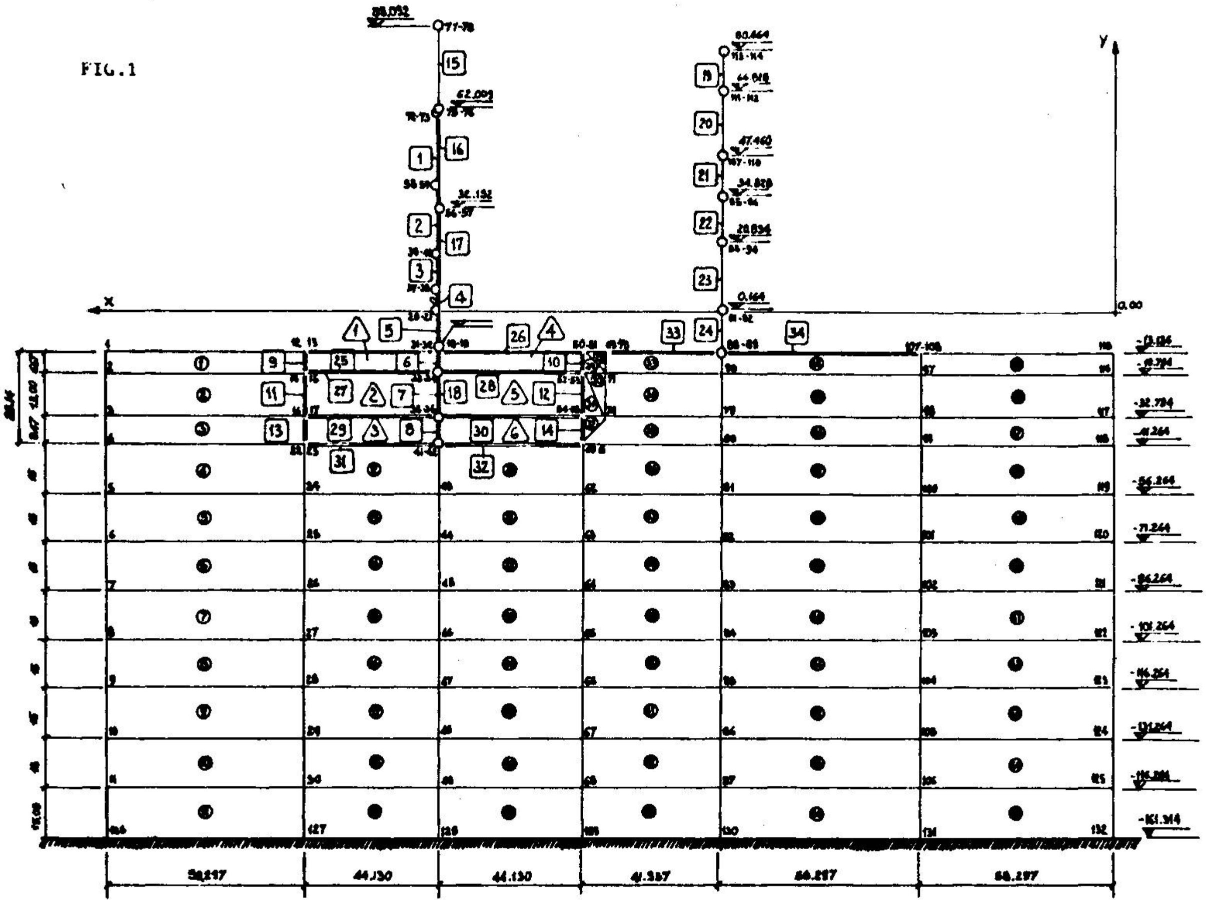


FIG.2a

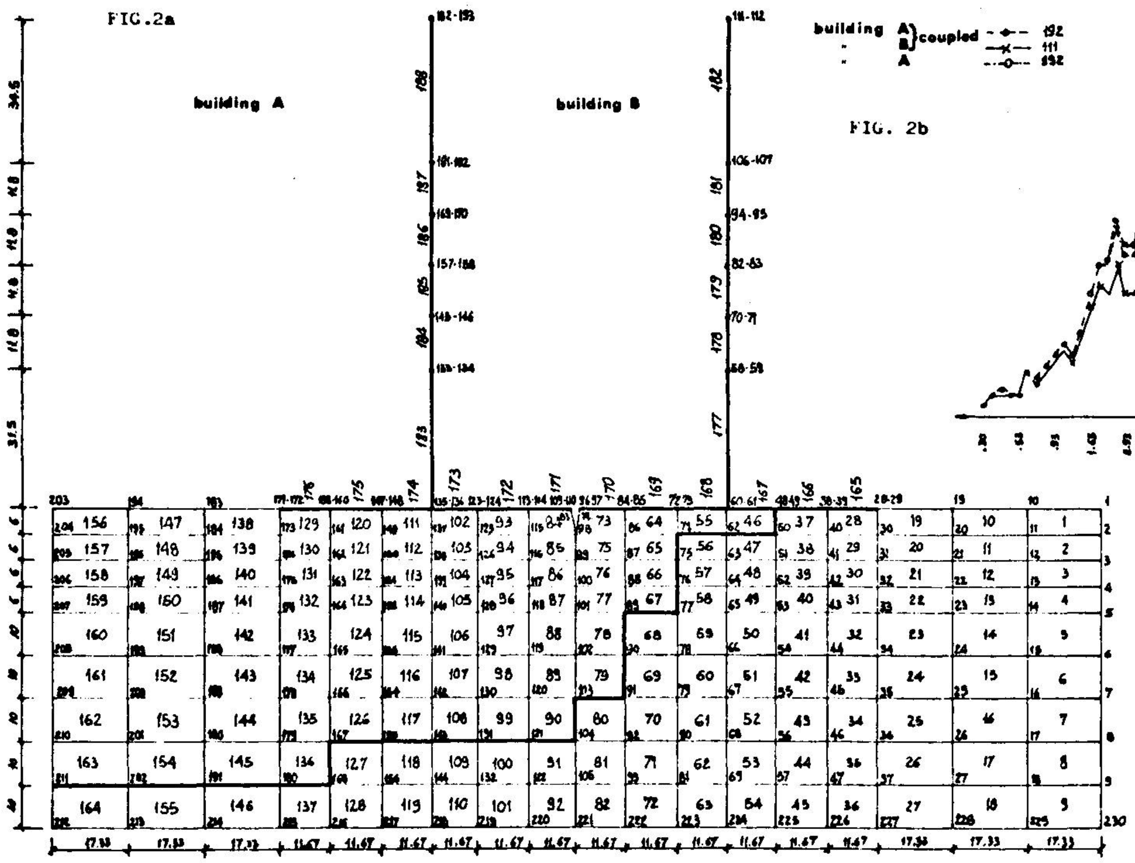
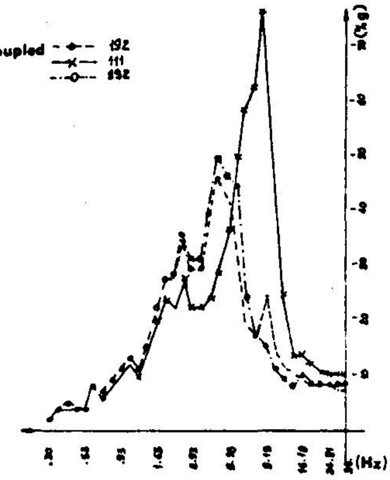


FIG. 2b



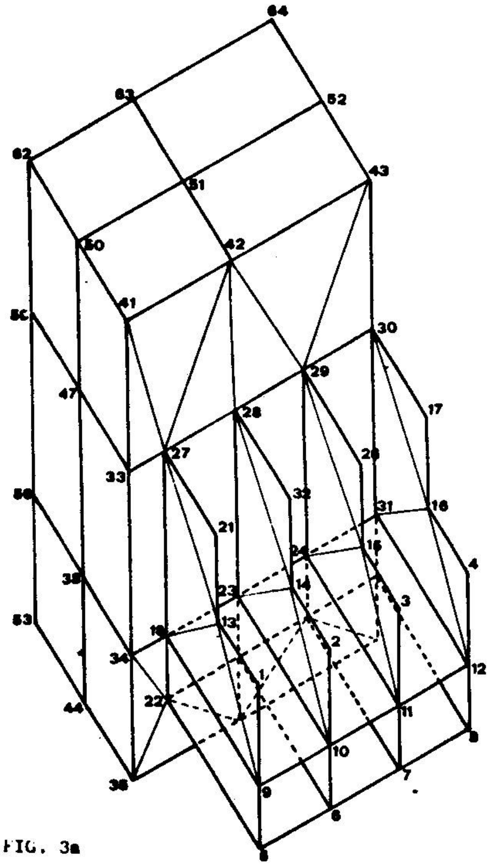


FIG. 3a

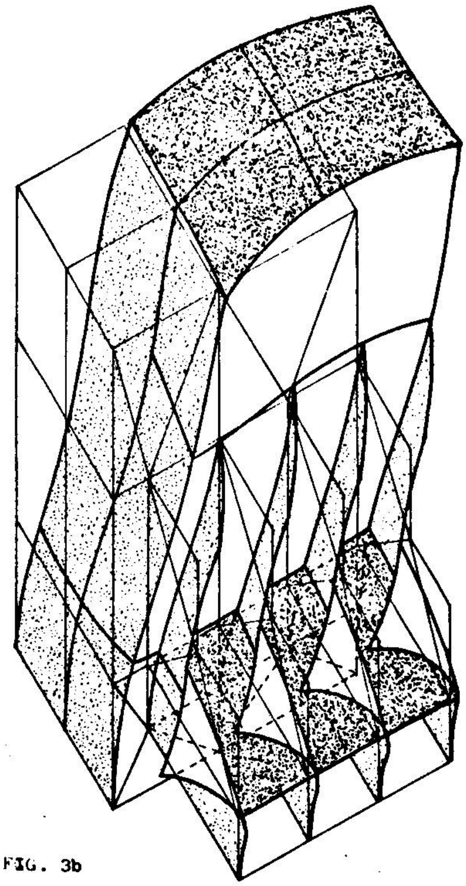


FIG. 3b

MODEL

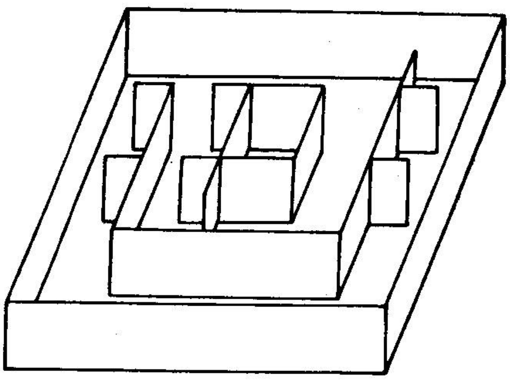


Fig. 4a

HORIZONTAL DISPLACEMENTS

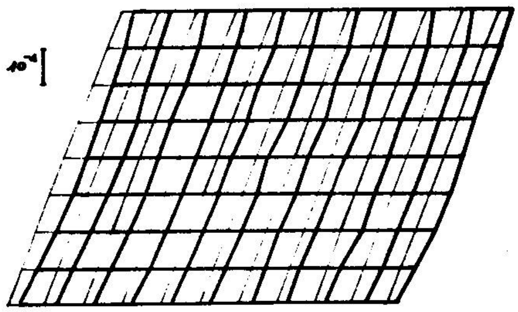


Fig. 4b

SHEAR STRESS

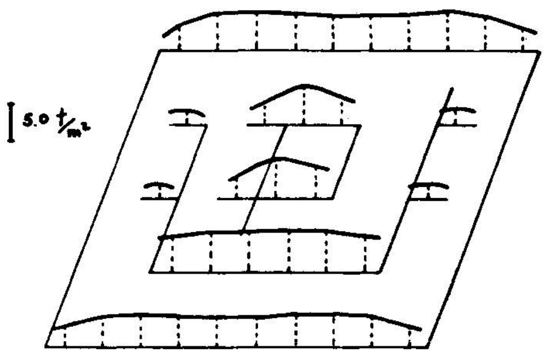


Fig. 4c

VERTICAL STRESS

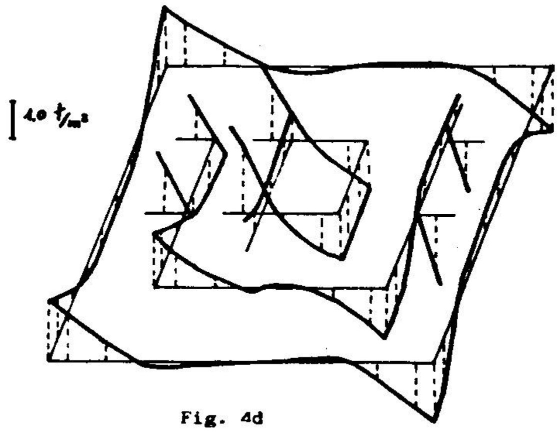


Fig. 4d

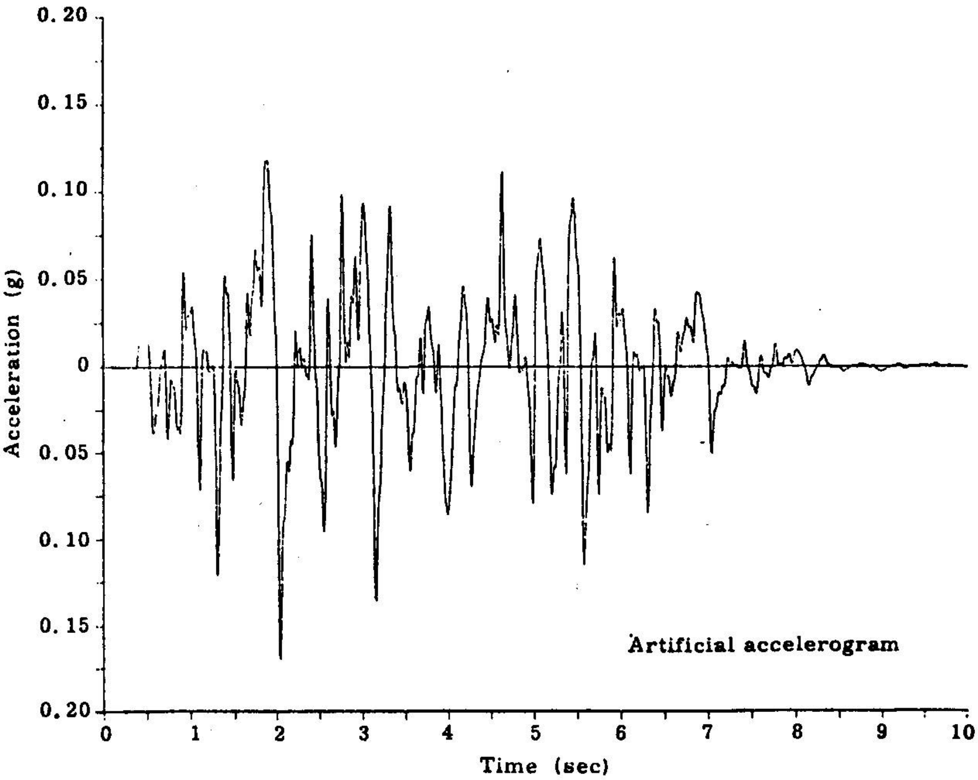
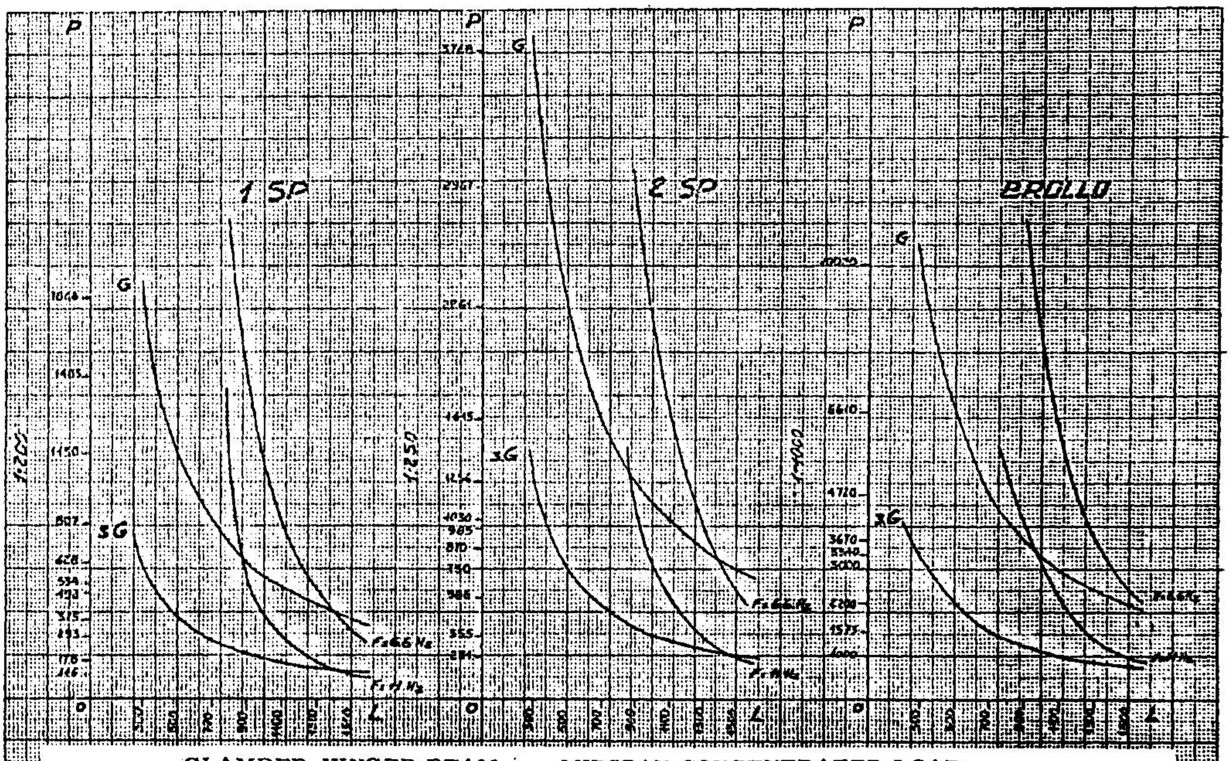


FIG. 5



CLAMPED-HINGED BEAM - MIDSPAN CONCENTRATED LOAD

FIG. 6

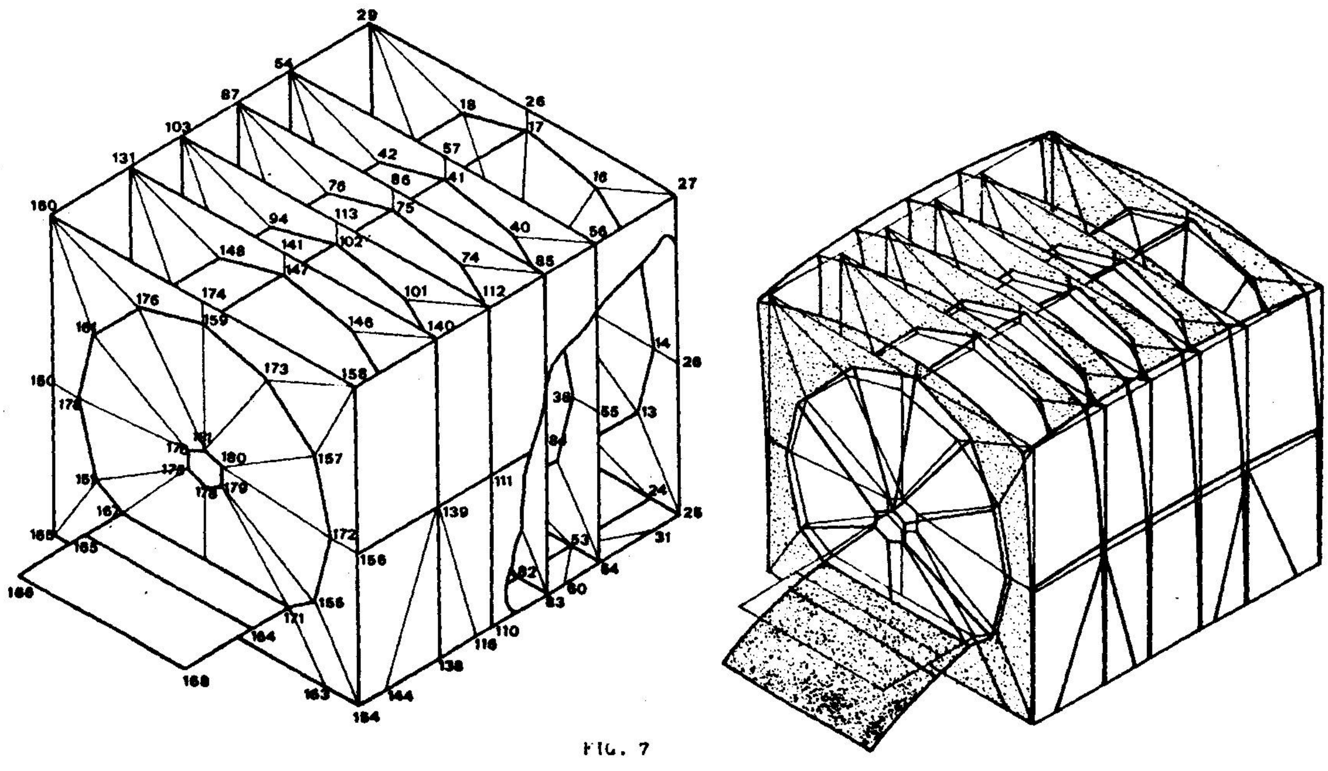


FIG. 7