# SEISMIC RESPONSE OF FLOATING NUCLEAR POWER PLANT EQUIPMENT (TURBINE-GENERATOR ON STEEL FOUNDATION)

by

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## SYNOPSIS

Seismic response (maximum accelerations, displacements at critical points) due to a sample shock spectrum in the vertical direction, of turbine-generator-steel foundation equipment designed for a 1200 MW floating nuclear power plant application was obtained. The required dynamic characteristics of the complex total structural system were obtained by using a large general purpose finite element computer program. These characteristics were then used in a seismic response program in order to obtain upper bound values of responses to a sample shock spectrum using the modal superposition technique.

## GLOSSARY

$\gamma_r$ = Modal participation factor for the r$^{th}$ mode

$m_r$ = Generalized mass in r$^{th}$ mode

$N$ = Number of discrete mass degrees of freedom in system

$M_i$ = Lumped mass at degree of freedom i

$\psi_{ir}$ = Motion of i$^{th}$ degree of freedom in r$^{th}$ mode

$X_i$ = Output quantity (acceleration, displacement, force) at point i or element i

$D_r$ = Shock spectrum input for r$^{th}$ mode

## INTRODUCTION

During the last two decades the electric utilities and the turbine-generator suppliers in the United States have witnessed considerable growth of Central Power station units. These power plants (especially the large nuclear ones) require a large body of water for cooling purposes. Due to increasing awareness of environmental concerns, as well as limited availability of suitable sites near high density population zones and concentration of industrial zones along the East and West Coast, the utilities are faced with the ever increasing problem of selecting suitable sites for these (nuclear or fossil) plants. Furthermore, due to differences in site conditions, these land based units do not lend themselves to a standardized plant concept thus, the economy of a standardized design cannot be utilized to its full advantage.

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In response to these problems of the electric utilities, Westinghouse Electric Corporation in late 1971 announced the building of floating, platform-mounted nuclear power plants. These plants would use a standard equipment design and would be located in an ocean, estuary or river along the Eastern and Gulf shore lines in breakwaters where necessary. The floating platform material, being steel, also motivated increasing interest in supporting these turbine-generator sets on steel foundations rather than traditional reinforced concrete structures. Due to floating platform environmental conditions, such applications impose much larger deflections on the turbine-generator foundation system than heretofore experienced. Furthermore, the platform structure being more rigid than the turbine-generator-foundation will impose almost all the cyclic wave motions , seismic loads (particularly in the vertical direction since water cannot transmit horizontal component) and long time dependent (temperature) platform deflections on the foundation deck. These motions are in turn imposed on the tandem coupled rotor bearing system.

Although the size of turbine-generator sets has grown considerably since the mid sixties, there has been little or no change in the foundation design criteria (static deflection limits). These deflection limits for conventional reinforced concrete foundations are primarily based on past successful experience, therefore, the design guidelines tend to be conservative. Furthermore, to allow for any significant changes in these guidelines, it is imperative that the effect of foundation flexibility and mass of the superstructure on the dynamic behaviour of the journal and bearing housings should be thoroughly investigated. Any adverse effect on the journal and bearing housing vibrations could be detrimental to the smooth operation of the unit. Therefore, primarily for the design of turbine-generator equipment for unique application to the floating nuclear power plants and secondarily for land based plants, it was necessary to develop a method of total system structural analysis, which would lend itself easily to determine the effects on journal vibrations due to different load conditions. This paper gives a brief description of the analysis method used to obtain an upper bound of seismic forces generated at the turbine deck level, journals and corresponding bearing housing at the rotor level, due to a typical ground shock spectrum applied in the vertical direction at the foundation column bases. Results of a sample calculation are discussed. The seismic forces developed at the turbine level are then used to determine the structural adequacy of the equipment involved.

## ANALYSIS APPROACH

The total structural system was divided into several major components such as the steel foundation, tandem coupled rotors, bearings and bearing supports, turbine cylinders (stationary parts) and the floating platform. To simplify the calculation procedure as a first approximation, the turbine cylinders were represented by several concentrated masses attached at selected locations on the foundation top deck. In the initial analysis the influence of the platform component was not included, therefore, the foundation column bases were assumed rigidly fixed and the shock spectrum input was applied at these base points. The principal damping in the system is provided by the bearing oil film which was included in this analysis whereas the material damping was neglected. Finite element approach was used to develop the analytical total system model.

## SYSTEM MODEL

NASTRAN[I], a large general purpose finite element computer program for structural analysis, was used for representing the steel foundation and tandem coupled rotors in the total system model. The foundation component approximately 5922 cm long, 1500 cm high and 1074 cm wide consisting of built up box beams was representee by 213 CBAR elements with 198 grid points. The BAR elements have all the stiffness properties of a general prismatic beam. The rotor component approximately 5794 cm long consisting of variable diameter bored forgings including rotating blades & discs was represented by 245 CBAR elements with 246 grid points. The rotor component was connected to the foundation transverse beams at eleven bearing locations through bearing oil film stiffness and damping elements and bearing support stiffness elements. For simplicity in calculations only the vertical and horizontal bearing oil film properties were used. A schematic of the total system model showing foundation and rotor components, typical connection between the two and relative location of bearings 1 thru 11 in the system is shown in Figure 1. Also shown in this figure are other pertinent data points relative to the location of bearings. The bearing supports were connected to the centre of foundation transverse beams through rigid links such as 4"-5" shown in Figure 1.

## SEISMIC RESPONSE OF TOTAL SYSTEM

Figure 2 shows typical spectra for horizontal ground acceleration of 0.1G for various damping values. These spectra were used to develop vertical input shock spectra representing 2/3 of 0.3G horizontal ground acceleration at the site. The input spectra consisted of acceleration vs frequency for various damping values within the frequency range of interest. The response of the total system due to this sample shock spectra was obtained by using a NASTRAN post-processing computer program called NASMIC developed by SDRC[II]. This program utilizes the modal superposition method also called the normal mode method. It uses the total system natural frequencies ($\omega_r$), mode shapes ( $\psi_r$ ), generalized mass ( $m_r$ ) for each of n modes generated in the NASTRAN to obtain modal participation factors ( $\gamma_r$ ) as shown below:

$$\gamma_r = \frac{1}{m_r}\sum_{i=1}^{N} M_i \, \psi_{ir} \qquad r = 1, 2, 3, \cdots n$$

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[I] NASTRAN=(NAsa STRuctural ANalysis)

[II] Structural Dynamics Research Corporation, Cincinnati, Ohio

The following assumptions are made in this analysis.

(1) The system is linearly elastic.

(2) The system is initially at rest.

(3) The shock spectrum consists of rectilinear acceleration at the base.

(4) Modes are viscously damped and uncoupled (Proportional damping).

The results of this analysis give an upper bound for the maximum value of each response quantity (acceleration, displacement) which for most problems are sufficient for obtaining design loads. For obtaining the upper bound response the following superposition approach was used.

$$X_{i\,max} \le \sqrt{\sum_{r=1}^{n} (\psi_{ir}\, \gamma_r\, D_r)^2}$$

## DISCUSSION OF RESULTS

At points of primary interest in the total structural system such as journals, bearing housings and bearing support locations on the foundation transverse beams, upper bound values of response accelerations in G's due to sample vertical shock spectrum input of 0.2G is shown in Table 1. Also included in this table are the amplification factors (maximum response/ input shock spectrum, 0.2G) at these points. As can be seen from this table, Bearing #3 (located at the governor end of Low Pressure Turbine #1) has the maximum response with amplification factors of 2.18 for the journal, 1.89 at the bearing case (point 3') and 1.69 for the corresponding bearing support (point 3"). It was interesting to note that the center of LP #2 rotor had a maximum response of 0.52G (amplification factor = 2.6) and the center of the generator rotor 0.48G (amplification factor = 2.4). These maximum responses in the system can be used to evaluate the structural adequacy of the components involved.

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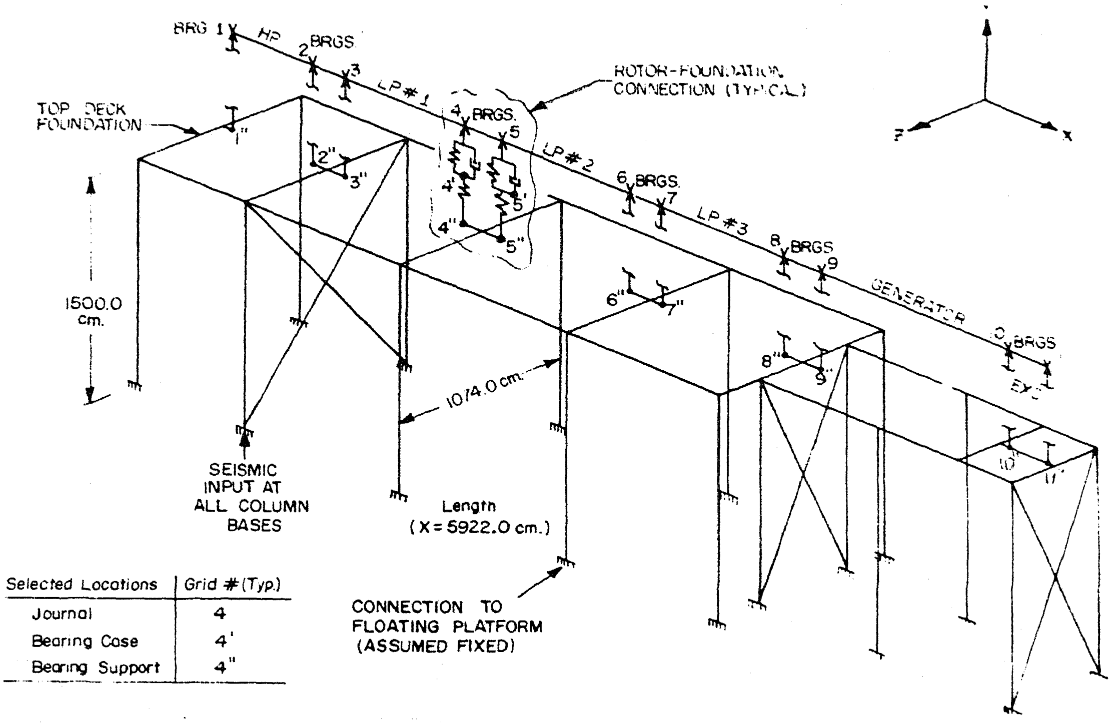
*point locations as per Fig. 1 schematic.

FIG. 1 SCHEMATIC SHOWING TOTAL SYSTEM MODEL



| *Selected Locations* | *Grid # (Typ.)* |
|---|---|
| Journal | 4 |
| Bearing Case | 4' |
| Bearing Support | 4" |

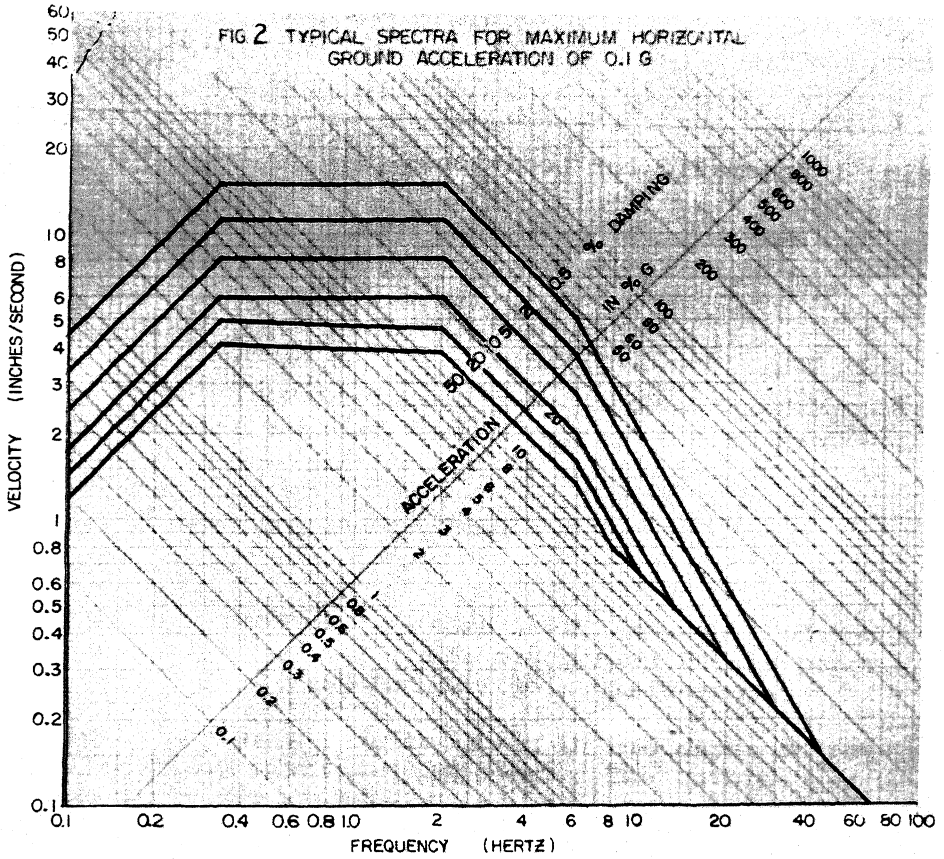


FIG 2 TYPICAL SPECTRA FOR MAXIMUM HORIZONTAL GROUND ACCELERATION OF 0.1 G

TABLE 1. COMPARISON BETWEEN MAXIMUM VERTICAL RESPONSES (G) AT SELECTED* LOCATIONS IN TOTAL SYSTEM

| LOCATION | MAX. VERTICAL RESPONSE (ACCL. IN G) AT | | | AMPLIFICATION FACTORS AT | | |
|---|---|---|---|---|---|---|
| | JOURNAL | BEARING HOUSING | BEARING SUPPORT | JOURNAL | BEARING HOUSING | BEARING SUPPORT |
| Brg. #1 | .26 | .22 | .19 | 1.28 | 1.09 | .96 |
| 2 | .34 | .27 | .22 | 1.68 | 1.37 | 1.12 |
| 3 | .44 | .38 | .32 | 2.18 | 1.89 | 1.61 |
| 4 | .38 | .32 | .26 | 1.91 | 1.59 | 1.28 |
| 5 | .31 | .26 | .21 | 1.53 | 1.28 | 1.07 |
| 6 | .31 | .26 | .21 | 1.57 | 1.30 | 1.07 |
| 7 | .23 | .19 | .16 | 1.15 | .95 | .78 |
| 8 | .21 | .17 | .14 | 1.06 | .86 | .68 |
| 9 | .27 | .22 | .18 | 1.33 | 1.10 | .92 |
| 10 | .33 | .29 | .25 | 1.67 | 1.44 | 1.27 |
| 11 | .22 | .20 | .19 | 1.12 | 1.01 | .91 |

*Refer Fig. 1 Schematic for Locations.

## DISCUSSION

### D.K. Paul (India)

1. The seismic analysis of the system had been carried out by considering only the vertical response spectra recorded on ground i.e. fluid structure interaction has been neglected. In the opinion of writer, the vertical motion at the base of the floating platform will have predominantly long period waves, therefore in the analysis choice of corresponding response spectra would be more reasonable.

2. It is true that water cannot transmit the horizontal seismic load to the platform, but there will be other horizontal load (1) due to wave action and current of water generated by the seismic disturbance in the ocean. This horizontal load unless evaluated, should not be neglected in the aseismic design of such structure.

3. Are the reactor building and turbine building of the proposed plant located on the same platform ?

Reference: (1) Murtha, J.P. and Owen M. Kirkley "Response Spectra for Ocean Structures" Proc. Sixth World Conference on Earthquake Engineering 3-13, Jan. 1977.

### H. Shibata, (Japan)

How do you think about gyroscopic effect for the analysis of turbine-generator system in aseismic design ?

### R.Y. Soni (India)

In view of the fact that your paper discusses Earthquake response of floating Nuclear Power Plant, the discussor would like to know as to how the Earthquake input was applied to the structure ?

### Author's Closure

The author is thankful to Messers Paul and Soni of India and Mr. Shibata of Japan for their discussion on the paper. Following is the brief response on their discussion.

The seismic analysis results given in the paper do not include the floating platform component. The turbine pedestal is assumed rigidly connected to the platform. The author agrees with Mr. Paul that the fluid-structure (floating platform) interaction may significantly alter the response spectra; therefore, in the final analysis this effect is planned to be included.

Regarding the effect of water waves generated by seismic disturbance in the horizontal direction on the floating platform, this has been included in selecting the wave heights and frequencies for generating platform design loads. Incidentally the maximum wave height is approximately 13 meters at 13 seconds intervals.

The reactor and turbine buildings are located on the same platform which is approximately 400 feet square.

The vertical response spectra corresponding to 0.1g acceleration was selected. A table of frequencies vs. g loadings from 0.05 to 33 Hertz was obtained from this response spectra. Modal damping values for the turbine-generator foundation system were generated from a separate finite element analysis. The 'g' loads corresponding to selected frequencies and modal dampings were applied at the fixed column bases of the turbine pedestal. The maximum response at selected locations in the system was obtained due to these loadings.

In the preliminary design of turbine-generator unit gyroscopic effects have been considered. These include loads due to 2° yaw and roll of the platform at its natural frequencies. Similar loads from a selected seismic response spectra can be studied for the final design.