# EARTHQUAKE RESPONSE OF TURBOMACHINERY FRAME FOUNDATIONS

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## SUMMARY

Earthquake response of turbomachinery frame foundations supported by piles is theoretically investigated. The goal is to establish the safety of flexible rotors and to predict the response of the whole system with respect to the effects of soil-pile-structure-machine interaction.

## INTRODUCTION

Turbomachineries such as turbo-generators are not only very expensive but also quite vital for the functioning of basic services. It is desirable that the prediction of seismic effects on such a facility is not limited to the behaviour of its foundation but include interaction with the machinery. In particular, dynamic deflections of rotors relative to the casings should be evaluated. A theoretical approach to such an examination is outlined in this paper. The study compliments the analysis of the foundation response to rotor unbalances presented in (1,2).

## FORMULATION OF SOLUTION

The space frame foundation is supposed to be pile supported and interaction of the whole system is considered. The components of the system are the soil, piles, foundation mat (cap), three dimensional frame, flexible rotors and viscoelastic oil film in journal bearings (Fig. 1).

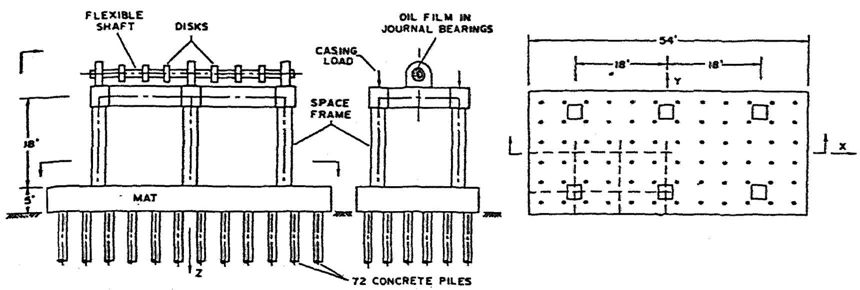


**Fig. 1 – Schematic of Foundation Used in Example (1 ft = 0.305m)**

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The main assumptions are: the soil is composed of horizontal layers; the mat is rigid with two degrees of freedom, i.e. horizontal translation and rotation in the vertical plane. The free field ground motion is given at the level of the mat base, acts in the direction perpendicular to the long side of the foundation and the seismic motions are generated by upward propagating shear waves.

The system is treated by means of dynamic stiffness matrix method in which the overall stiffness matrix of the system is frequency dependent and complex. Therefore, the Fourier analysis technique is used to predict the response.

First, the free field acceleration, $\ddot{V}_g(t)$, is deconvoluted using a shear column to give the free field ground motion at layer interfaces. This free field motion is assumed to be unaffected by the presence of the piles,i.e. kinematic interaction is neglected. Within each layer, linear variation of ground motion is assumed to simplify the calculations. The relative displacement between the pile and the free field ground motion generates soil resistance. This resistance acting per unit length of the pile is derived under plane strain conditions from the equations of an viscoelastic medium (3), and accounts for soil stiffness as well as energy dissipation through wave propagation and soil material damping.

Treating the pile as assembled of elements spanning the distance between soil layer interfaces the end (head) forces $H$ and moments $M$ associated with head relative motion $V_r$ and rotation $\psi_r$ are established (Fig. 2). These forces are added to fixed head forces $HF$ and moments $MF$ due to the applied inertia forces resulting from the free field ground motion. The total end forces acting on

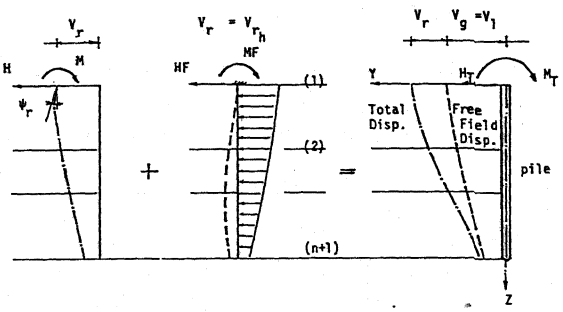
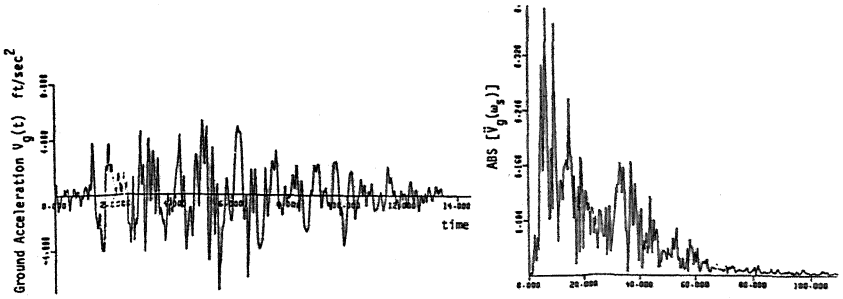



Fig. 2 – Forces Acting of Pile During Earthquake Motion

elements of the space frame and elastic shaft are evaluated in a similar way. Then the overall (structure) stiffness matrix is assembled from the members and piles stiffness matrices and the mat inertia forces. The loads applied on to the system are composed of the fixed end forces of piles, frame and shaft elements (with reversed signs) and the mat inertia forces due to ground acceleration. Because the structure stiffness matrix is frequency dependent it has to be evaluated a great number of times for each frequency separately. The response is obtained using the Fast Fourier Transformation (the complex response method).

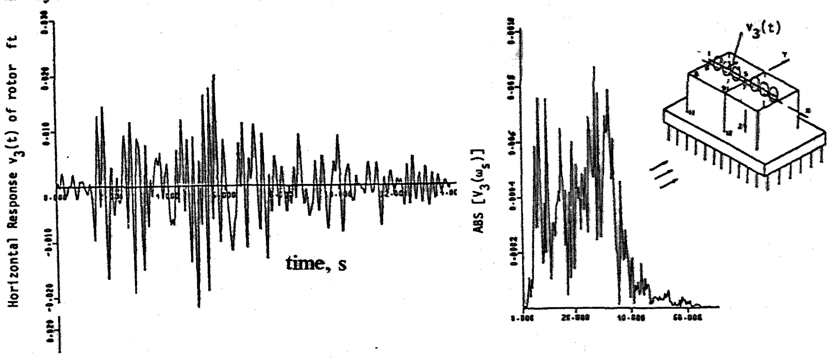
To study the nature of the seismic response of the whole system the two-bay foundation shown in Fig. 1 was analyzed. The space frame foundation is supported by 72 reinforced concrete piles. Symmetry of the system with respect to two vertical planes is assumed in order to save on computing costs. The earthquake input is taken in the form of the horizontal acceleration recorded during the San Fernando Valley Earthquake in 1971. Fig. 3 shows its time history and Fourier transform.




a) b) frequency $\omega$, $s^{-1}$

**Fig. 3 – Ground Surface Acceleration Used in Example: (a) In Time Domain, (b) In Frequency Domain**

The horizontal seismic response of the centre of the shaft relative to the ground is shown in both time and frequency domains in Fig. 4a, b. The response is not as filtered as is usual with buildings because the natural frequencies of the system are high. Although the displacement of the shaft is quite large its deflection is small so that the collision between the spinning rotor and casings is not likely.




a) b) frequency $\omega$, $s^{-1}$

**Fig. 4– Horizontal Seismic Response of Shaft Centre; (a) In Time Domain, (b) In Frequency Domain**

A simplified analysis was also performed in which the effect of free field motion on the piles was ignored and only the inertia forces acting on the mat, super structure and machinery were considered as is common with structures. The results obtained are almost identical to those of the complete analysis as can be seen by comparing Figs. 4 and 5.

## CONCLUSIONS

Seismic analysis including complete interaction of the soil,foundation and machinery indicates that even when large displacements of the superstructure can occur the deflections of the rotor shaft may be small. Sufficiently accurate results can be obtained by means of a simplified analysis in which only the inertia forces acting on the mat, superstructure and machinery are considered.

## REFERENCES


1. Aboul-Ella, F. and Novak, M., "Dynamic Analysis of Turbine-Generator Foundations", Proc. of Intern. Symp. on Machine Foundations, ACI, Houston, Tex., November 1978.

2. Aboul-Ella, F. and Novak, M., "Dynamics of Pile-Supported Frame Foundations", J. Eng. Mechanics, Div., ASCE, 1980.

3. Novak, M., Nogami, T. and Aboul-Ella, F., "Dynamic Soil Reactions for Plane Strain Case", J. Eng. Mechanics Div., ASCE, August, 1978, pp. 953-9.

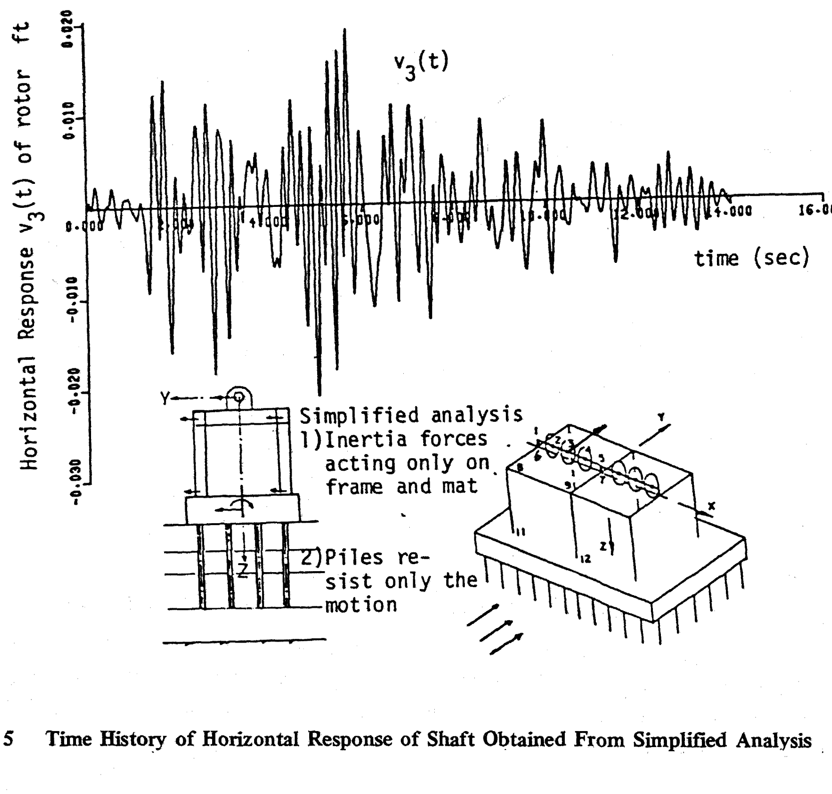




Fig. 5 Time History of Horizontal Response of Shaft Obtained From Simplified Analysis