SEISMIC BEHAVIOUR OF FRAMED FOUNDATIONS FOR TURBO-GENERATORS

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ABSTRACT

Turbo-Generator foundation usually consists of a heavy base slab, large supporting columns which carry the top slab on which the machine and other equipments rest. The entire system together with the foundation soil converts itself into a problem of soil-structure interaction when subjected to dynamic loads. The paper examines some aspects of aseismic design of such systems and presents results of a parametric study describing the seismic behaviour.

INTRODUCTION

In view of increased need for generation of power more turbo-generators are being installed in various power plants in the country. Framed foundations are preferred for such high speed rotating machines since such structures provide more space to instal various mechanical equipments and pipe lines. The foundation has to withstand the vibrations caused by running of machines as well as those due to ground shakings while ensuring continuous operation of the machines. So far, attempts were made to analyse such structures for machine operating conditions only. With the experience of damage of structures in past earthquakes, it is necessary to analyse such foundations for earthquake motion also. Such an analysis, is one of soil-structure interaction. In the present study, the turbo-generator foundation is analysed for different soil conditions and the response parameters are computed. These are studied for variations in some of the parameters of the structure also.

THE MATHEMATICAL MODEL

The mathematical model chosen for the analysis of the turbo-generator foundation is shown in Fig. 1. The framed foundation structure is idealised as three degree freedom mass-spring dashpot system. Masses m_1 and m_2 are lumped at the top and bottom slab levels of the foundation structure and I_1, I_2 are the mass moment of inertias of the two masses. K_1 is the stiffness of columns/walls between the two slabs. K_2 and K_θ are translational and rotational spring constants of the soil-pile system.

The dynamic analysis of the above idealised system is carried out when the input ground motion, is given at the base of the foundation structure.

Parameters involved in the analysis:

The seismic behaviour of the system depends mostly on the properties of the soil-pile system and those of the structure. These parameters are described below:

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(i) Spring constants of soil-pile system: Most of the solutions for deflections of laterally loaded piles (1) are based on the assumption that subgrade reaction is constant for cohesive soils and increases linearly with depth for cohesionless soils. The translational and rotational spring constants K_2 and K_θ for this analysis are worked out assuming that the pile system is with cohesionless soil, as follows:

$$K_2 = \frac{C_p}{L + H_o} \qquad \ldots (1)$$

$$K_\theta = \frac{C_p \cdot H_o}{1 + H_o/L} \qquad \ldots (2)$$

in which C_p is a coefficient depending upon the dimensions of pile group and the soil modulus n_h ; H_o is the height of center of gravity of structure above pile cap and L is the length of piles.

(ii) Structure stiffness: The individual stiffness of each column/wall is calculated and then combined to get the equivalent stiffness (K_1) of the entire framed structure. In this, fixity condition is assumed at the two ends of the columns and shear deformations are considered.

(iii) Damping: Damping is an important parameter which affects the dynamic behaviour of the structure. Generally the value of damping factor may be taken as 5% for concrete and 10-15% for soil depending upon the soil type.

PRESENTATION OF RESULTS

Structure Chosen for Study:

In the present analysis the numerical values, required to compute various response parameters, are taken approximately on the basis that they suit a high speed turbo-generator set in a power plant (2). A reference value of n_h, the constant of soil modulus, is taken as 2250 t/m^3 which gives K_2 = 300000 t/m and K_θ = 38000000 t-m/rad. The height between two mass points is taken as 20.0 meters. Assuming the column diamensions to suit the loads (3), the structure stiffness, is computed as K_1 = 110000 t/m. Basic values of lower mass and its mass moment of inertia are taken as 500 t-sec^2/m and 30,000 t.m-sec^2 respectively. Soil stiffness, structure stiffness and mass ratio are varied to study a variety of systems.

Figure 2 shows the variation of fundamental period of the system, Fig. 3 the displacement response and Fig. 4 the rotational component of response to El-Centro motion. Each of the response figures presented consists four sets of curves for four different mass ratios. Again for each set of mass ratio, the four curves represent the variation in structure stiffness. All the response parameters are drawn with soil stiffness as abscissa. The following conclusions are derived from the study:

1. Time period:

i) The fundamental time period of the system decreases with the increase of soil stiffness. For loose soils, the period changes rather rapidly.

ii) It is seen that the time period also decreases when the structure stiffness is increased. However, this change is not much for very loose soils even the structure stiffness varies. For medium and stiff soils, there is significant change.

iii) It is also observed that the period increases with the increase of top to bottom mass ratio.

2. Displacement:

i) Displacement response to ground shaking decreases with the increase of soil stiffness. This change is more rapid for very loose soils. But for stiff soils, the displacements do not change much. It is also observed that for very loose soils, rotational displacement is predominant but not so for stiff soils.

ii) For loose soils, the displacement response does not change significantly with the variation of the structure stiffness. However, for medium and stiff soils these response values do get affected significantly depending upon the structure stiffness.

iii) The peak values of the displacement increase with the increase of top to bottom mass ratio. Also, when this mass ratio increases, the peak values shift towards the region of higher soil stiffness. For very loose soils, rotational displacement increases rapidly with the increase of mass ratio, but for stiff soils this increase is rather small. It is also observed that when the mass ratio is increased, rotational components of displacements are more compared to translational components, irrespective of soil stiffness ratio.

CONCLUSIONS

Soil stiffness plays very important part in determining the dynamic behaviour of framed foundations. If soil is loose, other properties like structure stiffness have almost no effect on dynamic response. This emphasizes the need of a careful assessment of soil properties in aseismic design of such structures.

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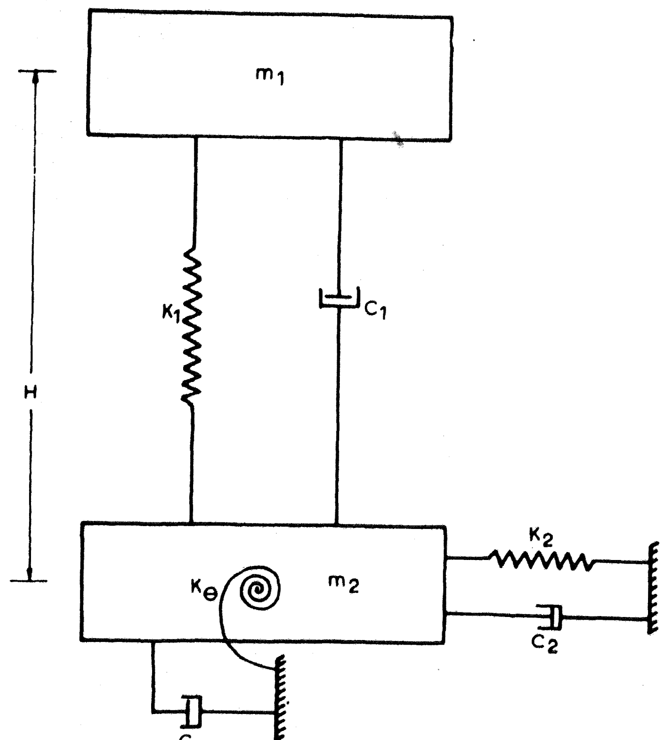

FIG. 1 _ THE IDEALISED SYSTEM OF TURBOGENERATOR FOUNDATION

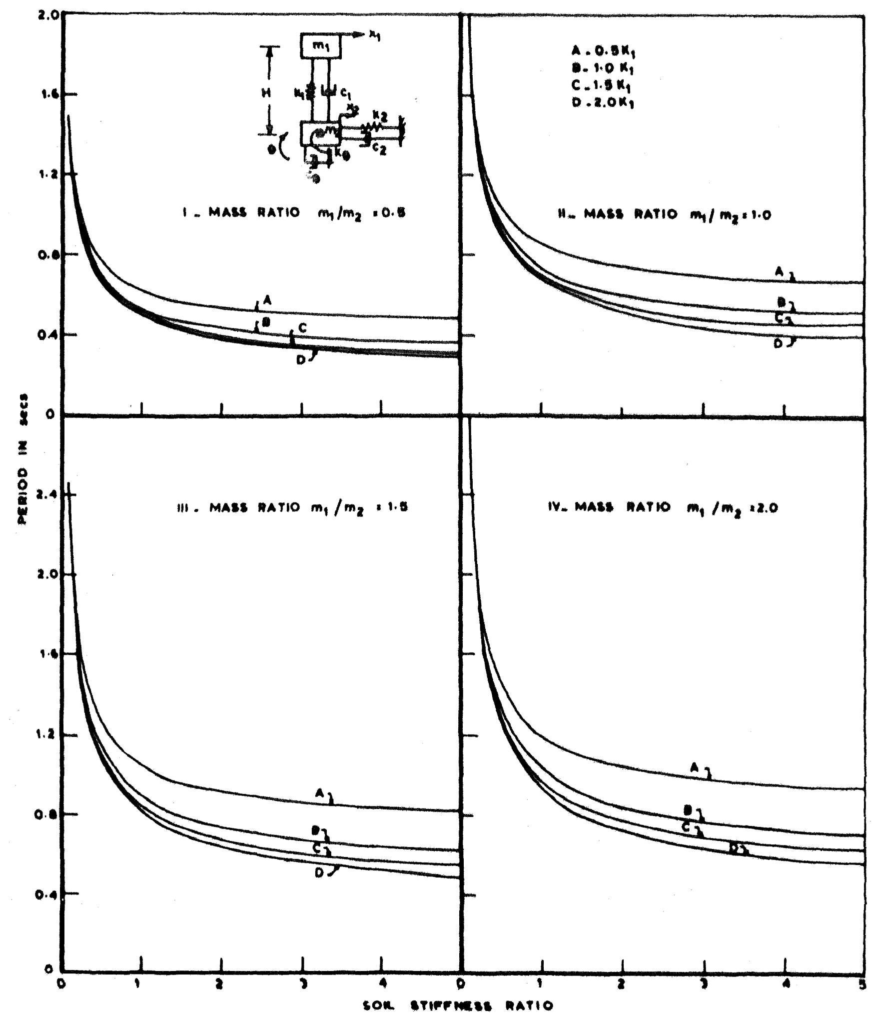

FIG. 2 _ VARIATION OF FUNDAMENTAL TIME PERIOD

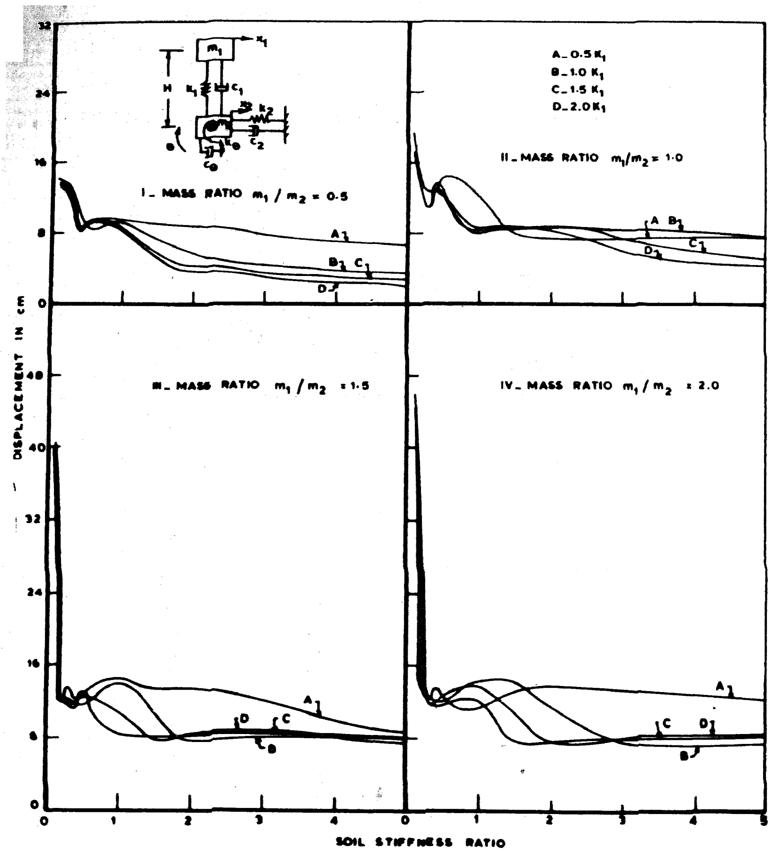

FIG 3 - VARIATION OF MAX. DISPLACEMENT AT TOP MASS LEVEL FOR EL-CENTRO EARTHQUAKE

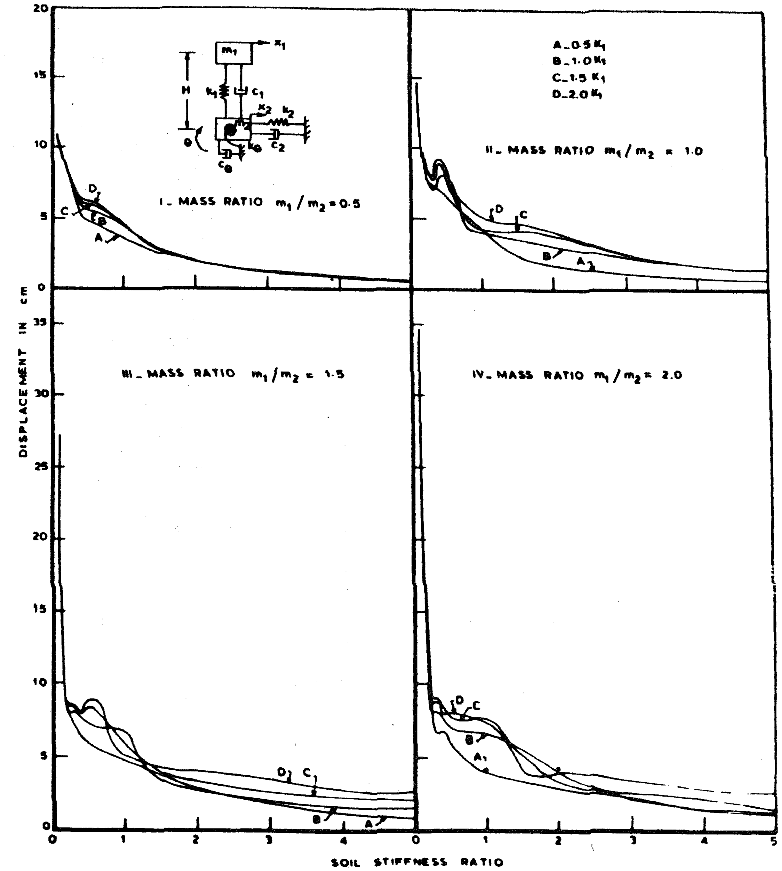

FIG. 4 - VARIATION OF ROTATIONAL DISPLACEMENT AT TOP MASS LEVEL FOR EL-CENTRO EARTHQUAKE

DISCUSSION

P. Srinivasulu (India)

The authors have oversimplified the complex system with interacting elements of the machinery, the foundation structure and the soil below the base slab. The current trend of research in the area is to treat the three dimensional nature of the foundation in real sense considering also the interaction between the machine and foundation structure on one hand and the foundation structure and soil on the other. The discussor and his team have worked out a satisfactory model reflecting the soil structure interaction on the above basis (i), and computed response data has been satisfactorily verified with those observed under normal operating conditions of machinery. The computational procedure adopted in this approach can still be used for evaluating seismic response for a given time history of the ground motion.

It may not be out of place further to refer here to another paper on the same theme (8-14, Page 8-81 by Mr. Ish, K. Aneja) which again deals with seismic response of a turbo-generator unit but on a steel foundation. The computational effort involved in this procedure is indeed very large though the mathematical model does consider the interaction of machine and foundation. Further refinement could be reached by replacing the fixed bottoms of the columns by an analogous soil-spring.

When such improved mathematical models are tried, it would be appropriate first that the steady state response of these structures is verified under harmonic loads caused by the working of the machinery.

In the absence of this, the conclusions arrived at should be viewed with caution.

K.G. Bhatia (India)

The authors have studied the effect of interaction on the behaviour of framed foundation for Turbo-generators. I feel that if the complete structure i.e. T.G. Hall and T.G. Foundation is taken into account, there could be some effect of coupling i.e. the influence from the T.G. hall to T.G. foundation and vice-versa. The discussor would like to know from the authors, whether the effect on the response of T.G. foundation when coupling is considered will remain same or not and if not what could be the variation and since these values are to be used. For the design of T.G. foundation, the variation due to coupling, would be on the conservative side or non-conservative side.

Nuriye Pinar Erdem (Turkey)

The discussor would like to contribute, very shortly, to the paper concerning the terminology used to show engineering properties of soils. In the paper given to theme 3 and other engineering publications the discussor noticed that several terms have been widely used such as: loose soil-stiff soil, soft soil-firm soil, soft soil-stiff soil, hard ground-weak ground, rigid soil, firm ground, solid ground, reclaimed ground.

In the opinion of the discussor, the earthquake point of view, classification of soils should be made in the way shown below to help the choice of a suitable foundation.

In general: Solid ground-weak ground
Solid grounds are: Unweathered firm rocks, hard clay, shales, dense sands and gravels.

Sands, silts, clays could be classified as "Secon degree solid grounds".

Weak grounds are: Alluvium, fills (natural or artificial), wetted sand, muds, weathered rocks.

Apart from these groups the terms shown below could be used in connection with the type of soils.

For rocks	:	solid, firm, weathered
For sands	:	loose, medium dense, dense
For clays	:	hard, stiff, soft
For shales	:	solid, weak

In addition, it would like to draw your attention to the terms "alluvium, dilivium or alluvien, diluvien" mostly used by Japanese engineers.

In geology river deposits belonging to the actual time or to the late Quaternary (Holocene) are named as alluviums or alluvien deposits and those belonging to the early Quaternary (Pleistocene) or to the Tertiary (Pliocene, Miocene) are classified as dilivium or diluvien deposits.

It is known that soil types effect the intensity of earthquake. For example it does not change in rocky grounds although it increases 2 to 4 times in weak and water saturated grounds. The coefficients related to this phenomena are given in the Turkish earthquake-resistant building codes. According to S.V. MEDVEDEV this relation is given:

TYPE OF SOILS	INCREMENT IN EARTHQUAKE INTENSITY
Granite	0
Limestone, sandstone	0-1
Medium solid ground	1

Rubble	1
Sandy soil	1-2
Clayey soil	1-2
Loose fill	2-3

Apart from these, coefficients are given in seismic maps which are divided to four zones according to the intensity of earthquake. The discussor, as a geologist who deals with tectonic, would like to draw engineer's attention to one point; No one can claim that in future a very intensive earthquake will not take place in the third or fourth degree earthquake zone. In Turkey, the discussor has shown that (1,2,3) very intensive earthquakes occurred in areas where no earthquake was known in their history but some young faults were observed in their geological structure. That is to say a young fault may move one day and cause an earthquake if the tectonic conditions are favourable.

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Author's Closure

Regarding the comments of Mr. Srinivasulu it may be mentioned that the model presented in the paper is a two dimensional one and is chosen to highlight the importance of soil parameters in seismic response of such foundations. It would be a good idea to compare the results obtained from those with disscussor's model.

Mr. Bhatia has suggested that the T.G. building and the T.G. foundation should be treated together for such an analysis. In this context, it is pointed out that in most of the situations the T.G. mat has absolutely no structural connection with the T.G. building and therefore there is little possibility of interaction of the two units. Such a coupling was therefore not considered in the present study. It is however difficult to predict whether the coupling through soil structure will be for the good or for the worse as far as the seismic forces on the T.G. foundations are concerned. This can be ascertained only through a detailed dynamic analysis taking into account the feedback which in the opinion of the author would be very difficult to model.

Regarding the comments of Prof. Pinar Erdem on the terminology used in the paper, the authors would like to point out that the various terms used by them are only for relative description of the soil properties and not the absolute identification of the soil type.