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CRI TECHNOLOGY DIGEST

RATIONALIZATION OF DESIGN OF MACHINE FOUNDATIONS IN CEMENT PLANTS

PART I RIGOROUS ANALYSIS

CEMENT RESEARCH INSTITUTE OF INDIA

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INTRODUCTION

Foundations for different equipment and machinery in a cement plant constitute about 10 to 12 percent of the total civil engineering cost. Due to this high cost and also in view of the importance of the equipment these foundations support, greater attention needs to be paid to their design.

The major machinery encountered in a cement plant are crushers, grinding mills, kilns, etc. Their foundations are grouped under the category of foundations which support low-frequency machines having operating speeds between 0-300 rpm. For such a type of machinery usually the block foundations are adopted. Framed type of foundations with top and bottom slabs and connecting columns are also sometimes provided for crushers and kilns from practical considerations and the methods of their analysis and design are already well-documented in literature.

This technology digest (Part I) covers computer-based method for rigorous analysis and design of the other type of foundations, ie, block foundations, which have found application for supporting low frequency machines in cement plants. Part II will cover an approximate method of design for block type foundations.

DESIGN PRACTICE

The design includes the following steps: (a) preliminary dimensioning; (b) the computation of natural frequency and amplitudes of vibration of the machine-foundation-soil system corresponding to different degrees of freedom and checking of these values against some pre-assigned permissible limits; (c) checking the stresses exerted by the foundation under static and dynamic loading against the bearing capacity of soil; and (d) designing the critical sections and reinforcements.

The major part of the design process involves the determination of the dynamic response of the machine, foundation and soil system. Different methods have been put forward by various designers towards this end. Table below gives a summary of these methods.

TABLE 1 SUMMARY OF THE DIFFERENT METHODS

METHOD	APPROACH	REMARKS
Empirical methods	a) In this method dynamic loads are taken care of by impact factors (given by machinery manufacturers) which when multiplied by the static load of the machinery gives equivalent static load for design. These impact factors may vary between 1·5 and 5.	It invariably results in heavy foundations and may still lead to harmful deformations.
	b) Another approach is to formulate methods based on the experimental data. It makes use of approximate relation between natural frequency and contact area of a foundation on a given type of soil.	These methods can be used only to check the occurrence of resonance which in itself is not adequate for a satisfactory design.
Barkan's method	This is essentially a lumped parameter approach based on subgrade reaction.	It does not consider damping, depth, of embedment and inphase soil mass.
Richart's method	This is again a lumped parameter approach based on elastic half-space theory.	Effects of inphase soil mass and depth of embedment are ignored.
Ari Danay's method (Ref "vibrations of rigid foundations", Arup Journal, March 1977).	This is also a lumped parameter approach but based on visco-elastic half-space theory. It considers both material and geometrical damping, depth of embedment and inphase soil mass.	It neglects the effects of coupling among different degrees-of-freedom.
IS : 2974 (Part IV)—1979 Indian Standard Code of Practice for design and construction of machine foundations. (Part IV Foundations for rotary type machines of low frequency)	This is based on Barkan's method.	It is a simple method.

The Indian Standard Code of Practice for Design and Construction of Machines Foundations — Part IV: Foundations for Rotary type Machines of Low Frequency [IS : 2974 (Part IV) — 1979] provides a method of analysis for such foundations. This method is based on Barkan's method.

Although Barkan's method is widely used in design offices it suffers from the limitation that it neglects the effect of damping, inphase soil mass and embedment. Due to this, it may sometimes lead to an unconservative design in the case of low frequency machines. In view of the above, a method has been developed by CRI, which takes into account all the above mentioned parameters in the dynamic analysis of machine foundations, in order to study their effect on the total dynamic response. It will help in further rationalizing the design procedure for machine foundations.

RIGOROUS ANALYSIS

The Approach

The proposed method considers simultaneously the effects of damping, effects of coupling between different degrees-of-freedom, effects of depth of embedment and inphase soil mass. Simultaneous consideration of the effects of damping and the coupling makes the solution of the governing differential equations quite involved and the results obtained here are a contribution towards this.

In this method, the dynamic equilibrium equations of the machine-foundation-soil system are formulated based on D'Alembert's principle. The resulting equations of motion are coupled and involve six soil parameters for stiffness and damping co-efficients corresponding to the three degrees-of-freedom. The co-efficients based on visco-elastic half-space theory are used in this analysis. The solutions of these equations are obtained for general type of dynamic forces. The resulting nonlinear equations which are used for the calculation of natural frequency of vibration corresponding to different degrees-of-freedom are solved by an iterative method based on Newton-Raphson technique. The amplitudes of vibration at the operating frequency corresponding to three degrees-of-freedom are determined from these equations of equilibrium.

A computer program based on this method is written in Fortran IV language and developed on IBM-360/44 system. A typical block foundation has been analysed by the proposed method as well as by Barkan's method.

The following are the observations:

i) Barkan's method gives the values of natural frequency which are four to five times the values obtained from the proposed method.

ii) The amplitude of vibration obtained from Barkan's method is almost half of the values obtained from the rigorous method.

Besides the above, computer results indicate that there is scope for reduction in the cost of machine foundations in a cement plant by rationalising the existing design practice through the consideration of parameters, such as damping, embedment and inphase soil mass in design.

Parametric Study

With the help of the computer program the following parametric study has been carried out. The different soil parameters considered are modulus of rigidity, poisson's ratio, density and material damping. The range of the parameters considered are as follows:

Modulus of rigidity	(from $1000t/m^2$ to $8000t/m^2$)
Poisson's ratio	(from 0·25 to 0·5)
Density	(from $0{\cdot}18t\text{-}sec^2/m^4$ to $0{\cdot}25t\text{-}sec^2/m^4$)
Material damping	(from ·01 to ·05)

A number of important observations have emerged out of this parametric study. Within the ranges of parameters considered, the effects on the dynamic characteristics of a rigid foundation in the order of their importance are as follows:

a) An increase of 189% in the natural frequency is observed when the modulus of rigidity is increased from $1000t/m^2$ to $8000t/m^2$ (Fig 1);

b) An increase of 20% occurs in the natural frequency when poisson's ratio of soil is changed from 0·25 to 0·5;

c) A reduction of 7% in the natural frequency is observed when material damping ratio is changed from ·01 to ·05;

d) Insignificant effect is observed in the natural frequency when density of soil is increased from $\cdot18t\text{-}sec^2/m^4$ to $\cdot25t\text{-}sec^2/m^4$.

Further, the following case of a typical rigid foundation (inlet end of a grinding mill) was considered with the following soil data for examining the implications on effects of different design simplifications:

Modulus of rigidity—1000t/m^2
Density of soil—·18t—sec^2/m^4
Poisson's ratio—0·25
Material damping—1%

The results obtained in order of importance are as follows:

i) When damping is ignored the natural frequency is overestimated by 57% (Fig 1).

ii) The natural frequency is increased by 20% for an embedment ratio equal to 1.

iii) The natural frequency is overestimated by 10% when the inphase soil mass is neglected (Fig 1).

iv) The natural frequency is reduced by 2% due to the effect of coupling between the vertical and the rotational motion.

CONCLUSIONS

Based on the above study, the following conclusions may be drawn:

1) The method of analysis which is presented here takes into account the effects of damping, coupling, depth of embedment and inphase soil mass. A feature of this method is that it considers simultaneously the effect of damping and coupling. This method makes use of the soil parameters which are based on visco-elastic half-space theory. A computer program has been developed based on this method for the rigorous analysis of machine foundations.

2) The ratio of the mass of the foundation to the mass of the machine depends on the dynamic soil properties, operational criteria and layout. Computer results obtained from rigorous analysis indicate that there is scope for substantial reduction in the cost of machine foundations in a cement plant.

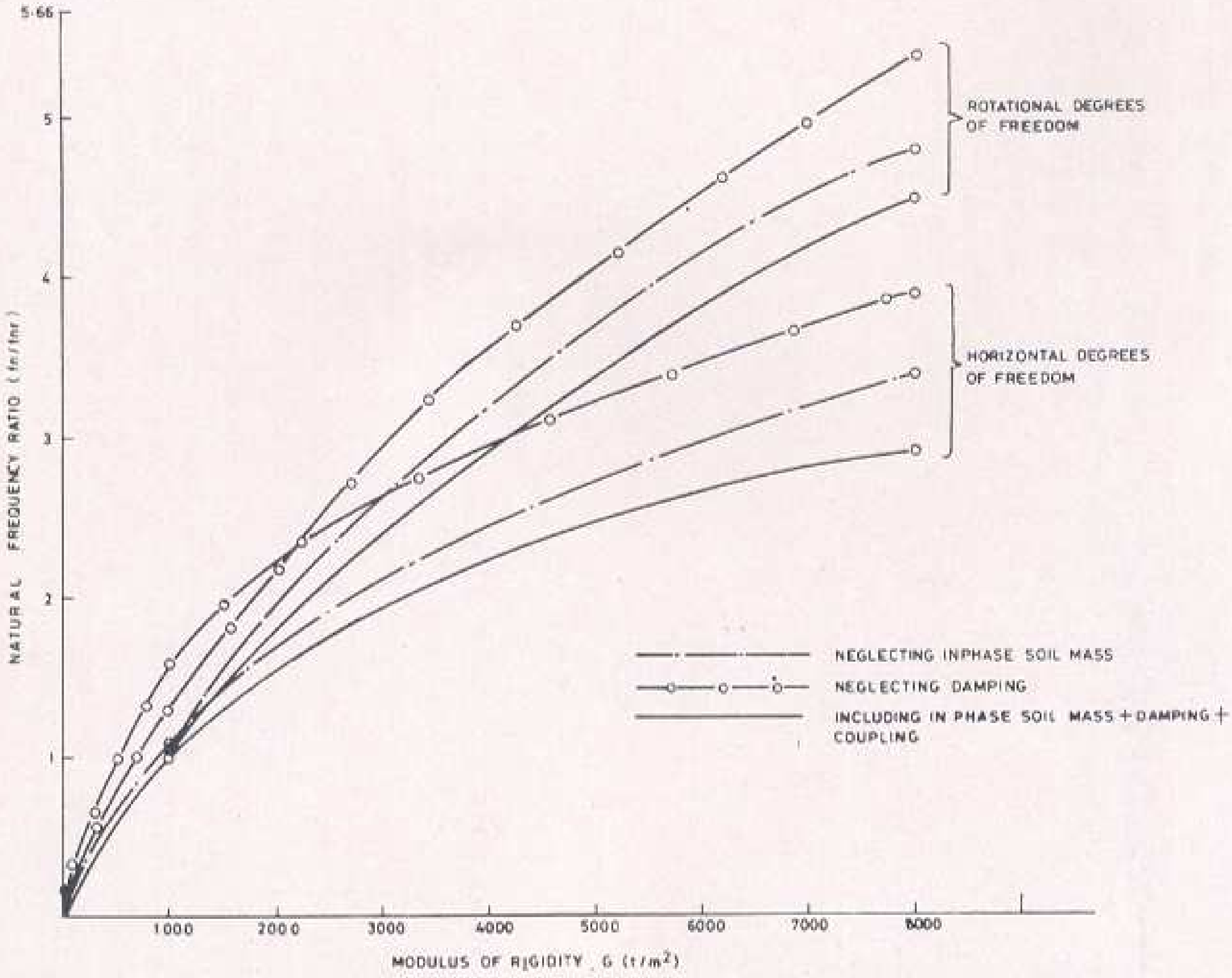

Fig 1 Variation in the natural frequency of vibration with the modulus of rigidity

CRI EXPERTISE

Necessary expertise is available in CRI for dealing with analysis/ design of machine foundations. A computer program is available with CRI for analysis and design of machine foundations. CRI welcomes the cement industry to use the expertise available with the Institute in the area of design of machine foundations.

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