Journal of Material Science and Mechanical Engineering (JMSME)
p-ISSN: 2393-9095; e-ISSN: 2393-9109; Volume 3, Issue 4; April-June, 2016 pp. 303-308

http://www.krishisanskriti.org/Publication.html

Dynamic Response of Machine Foundation Supported on Pile

Ankush Chourasia[1] and M.M. Mahajan[2]

[1]M.Tech student, Department of Applied Mechanics, VNIT, Nagpur, India
[2]Department of Applied Mechanics, VNIT, Nagpur, India
E-mail: [1]ankush.chourasia01@gmail.com, [2]mukundmmahajan@gmail.com

Abstract—*The paper discusses about the effect of piles on the dynamic response of machine foundation system. An attempt has been made to show how pile can be used to control the dynamic response of machine foundation just by changing the normal pile parameters. For this a rotary machine resting on block foundation supported on piles is selected and dynamic analysis is performed. The machine data, soil data & foundation parameters are taken in such a way that they resemble actual field condition. Solutions given by Novak (1974) are used to calculate the pile stiffness & damping values. Spread sheets are prepared in Microsoft-Excel to compute the natural frequencies and amplitudes for different modes of vibration and response of machine foundation system under variable pile diameter, spacing and weight of block are studied and graphs are plotted. From the analysis it is found that the introduction of piles affects both amplitude and frequency of machine foundation, and hence provide better flexibility to the designers in designing machine foundation.*

Keywords*: Rotary machine, Machine foundation, Pile group, Dynamic analysis, Frequency, Amplitude.*

1. INTRODUCTION

With the increasing demand of large machineries in last few decades, the mechanical industries are putting more efforts in standardizing the machine foundations. The increased requirement of machine efficiency have led to a high quality and standardized machine foundation. Although the cost of machine foundation is only a small fraction of the total cost of project they have to be designed properly, because any outage due to foundation failure may result in the breakdown of industrial unit because of non-production causing high economic loss which probably may exceed the total cost of foundation.

A number of machines having wide range of frequencies are operated in mechanical industries. For proper operation these machines are to be mounted on suitable foundation block which is further supported on ground. Depending on site condition or some other unavoidable situation some time these foundation blocks are to be supported on a group of piles. The introduction of piles in machine foundation system affects the stiffness, mass and damping of the system, which result in providing flexibility to the designers to design the machine foundation for a particular value of Natural frequency and amplitude of vibration just by changing the normal pile parameters like spacing and diameter.

2. METHODOLOGY

For analysis the complete system is mathematically modeled as spring mass system (see Fig.1), both machine and foundation block are considered as non-elastic bodies possessing mass and inertia, and piles are considered as mass less springs of stiffness K and damping C. The mass of machine and the foundation block is assumed to be lumped at pile top and dynamic analysis is carried out for all six degrees of freedom. Solution given by Novak (1974) are used for calculation of pile stiffness and damping ratio.

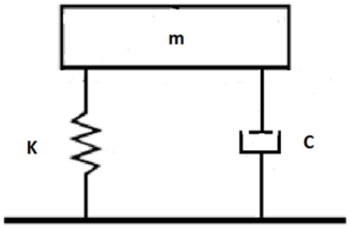

Fig. 1: Mathematical model of machine foundation system.

2.1. Model used for analysis

The foundation used for analysis is that of a rotary machine of G6.3 grade having total mass of 900 KN and operating at a frequency of 10 Hz. The rotary machine system consist of two parts, the drive machine and the driven machine, connected by a coupling. Both the drive and driven machines are operating at same frequency.

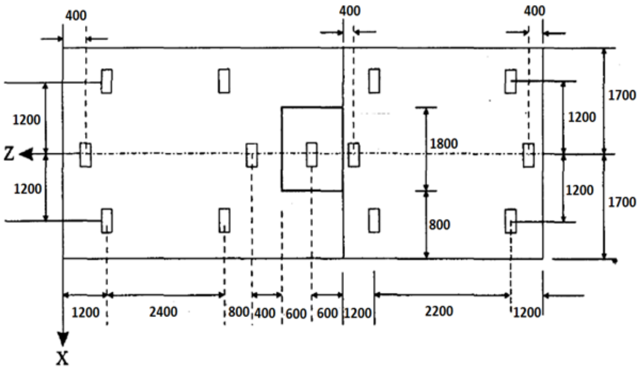

Fig. 2: Bolting arrangement of machine on foundation block.

The foundation consist of a RCC block (Fig. 3) having plan dimension of 10.6m×3.4m. The height of the block is 2.5 m above ground level and 1.5 m below ground level. The total weight of the concrete block is 3197 KN. The whole foundation block is supported on 12 nos driven cast in situ concrete piles having 0.6m diameter and 21m length, symmetrically located along longitudinal axis (Fig. 4). The whole foundation is founded on medium dense sandy silt/ silty sand. The variation of shear modulus of soil with depth is taken to be parabolic.

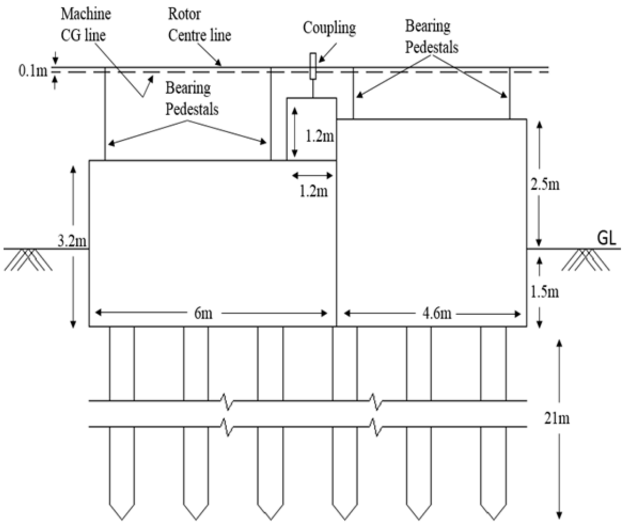

Fig. 3. Elevation of machine foundation taken for analysis.

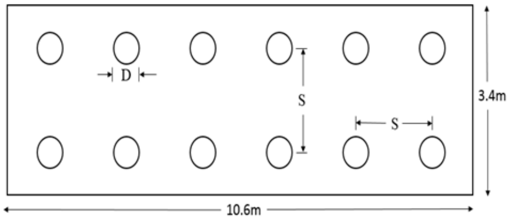

Fig. 4. Arrangement of piles in pile group.

2.2. Loading Specification

2.2.1. Static load. Self-weight of machine is taken as provided by the machine manufacturer and is transferred to the foundation block through the bolted connection. The weight of the foundation block is taken considering density of reinforced cement concrete as 25 KN/m^3. The whole mass is assumed to be lumped on the pile top.

2.2.2. Dynamic load. The dynamic force considered is that produced by the machine during its operation. In case of rotary machine the dynamic force generated is nothing but the centrifugal force produced due to the eccentricity of mass (see Fig. 5) which is generally provided by the machine manufacturer. The dynamic force generated acts in a plane perpendicular to the axis of rotation.

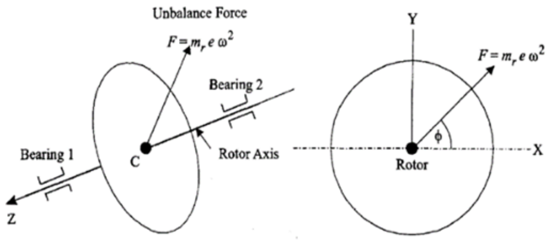

Fig. 5. Unbalance force generated by rotor [2].

The unbalance force generated by rotor acts in all the direction (in a plane perpendicular to axis of rotation) but for analysis we are considering forces in X direction only.

2.3. Assumption in Novak's plane strain model [11]

- It is assumed that the soil is composed of a set of independent infinitesimal thin horizontal layer that extend to infinity.
- It is further assumed that the pile are vertical and do not effect each other.
- The motion of pile is harmonic and limited to vertical plane.

Table 1: Novak's stiffness and damping parameters [4, 8].

VERTICAL MODE - SINGLE PILE	
Stiffness	$K_{yp} = \frac{E_p * A}{r_o} f_{w1}$
Damping constant	$C_{yp} = \frac{E_p * A}{v_s} f_{w2}$
VERTICAL MODE - PILE GROUP	
Stiffness	$K_{yg} = \frac{\sum_1^n K_{zp}}{\sum_1^n \alpha_A}$
Damping constant	$C_{yg} = \frac{\sum_1^n C_{zp}}{\sum_1^n \alpha_A}$
HORIZONTAL MODE – SINGLE PILE	

Stiffness	$K_{xp} = \frac{E_p I_p}{{r_o}^3} f_{x1}$
Damping constant	$C_{xp} = \frac{E_p I_p}{{r_o}^2 v_s} f_{x2}$
HORIZONTAL MODE - PILE GROUP	
Stiffness	$K_{xg} = \frac{\sum_1^n K_{xp}}{\sum_1^n \alpha_L}$
Damping constant	$C_{xg} = \frac{\sum_1^n C_{xp}}{\sum_1^n \alpha_L}$
ROCKING MODE – SINGLE PILE	
Stiffness	$K_{\phi p} = \frac{E_p I_p}{r_o} f_{\emptyset 1}$
Damping constant	$C_{\phi p} = \frac{E_p I_p}{v_s} f_{\emptyset 2}$
ROCKING MODE – PILE GROUP	
Stiffness	$K_{\phi g} = \sum_1^n \left(K_{\emptyset p} + K_{yp} {x_r}^2 + K_{xp} {Z_c}^2 - 2 Z_c K_{x\emptyset p}\right)$
Damping constant	$C_{\phi g} = \sum_1^n \left(C_{\emptyset p} + C_{yp} {x_r}^2 + C_{xp} {Z_c}^2 - 2 Z_c C_{x\emptyset p}\right)$

3. RESULTS FROM ANALYSIS

A spread sheet is prepared in Microsoft excel for different modes of vibration based on the solution given by Novak and other (see Table 1). The following charts were prepared from the results obtained from the spread sheet considering different cases by varying the parameters.

Case 1: When weight of machine and pile spacing is kept constant and pile diameter is varied.

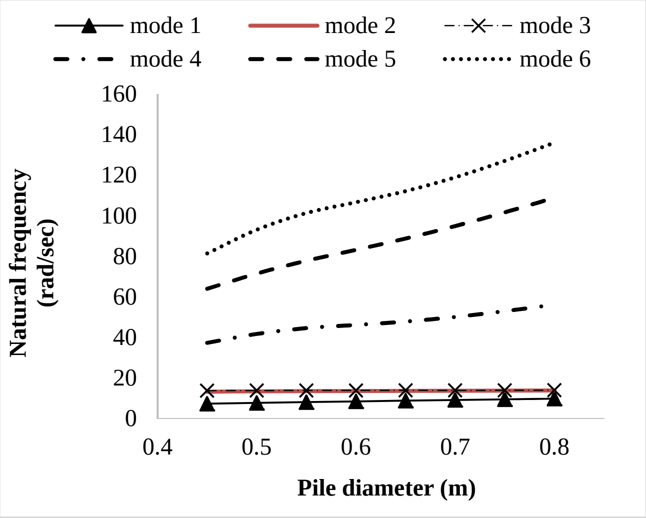

Fig. 6. Natural frequency variation with pile diameter.

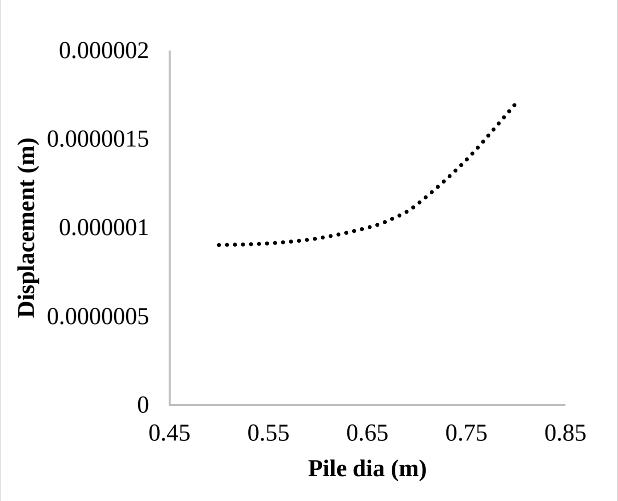

Fig. 7. Variation of displacement in X-direction with pile diameter.

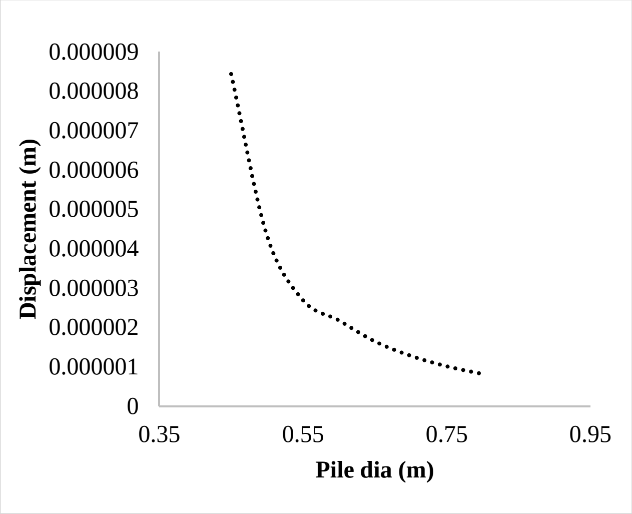

Fig. 8. Variation of displacement in Y-direction with pile diameter.

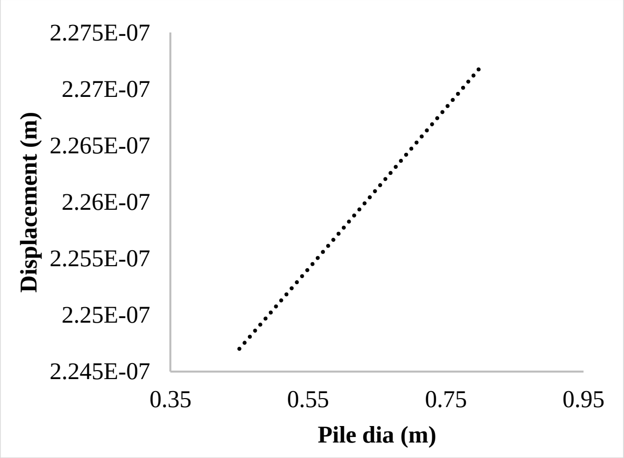

Fig. 9. Variation of displacement in Z-direction with pile diameter.

It is observed from the Fig. 6 that as the diameter of pile is increasing the frequency of the system is also increasing this is due to the increase in stiffness of the system. But the effect of variation of pile diameter is very less in the lower modes as compared to the higher modes. Hence if frequency corresponding to lower modes are under resonance than increasing the pile diameter is of no use.

Case 2: When weight of machine and pile diameter is kept constant and spacing between piles is varied.

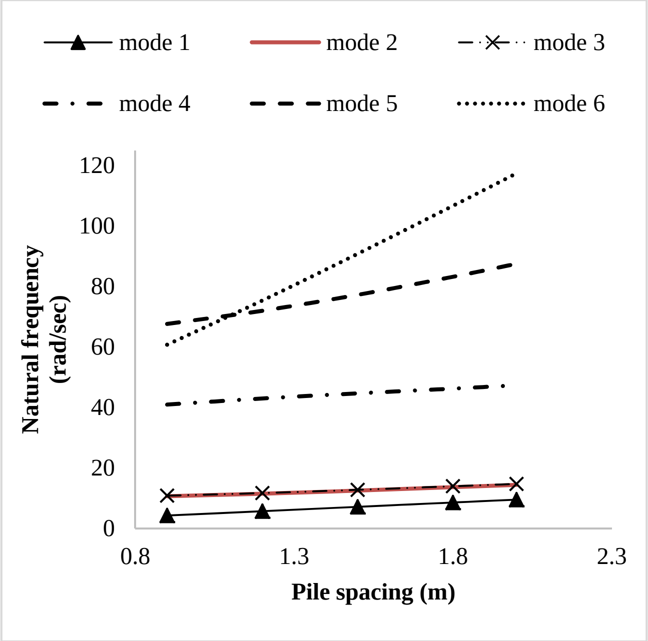

Fig. 10. Variation of Natural frequency with pile spacing.

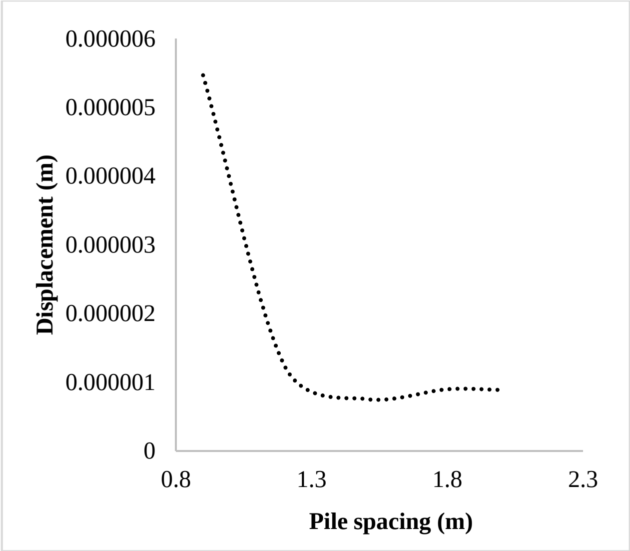

Fig. 11. Variation of displacement in X-direction with pile spacing.

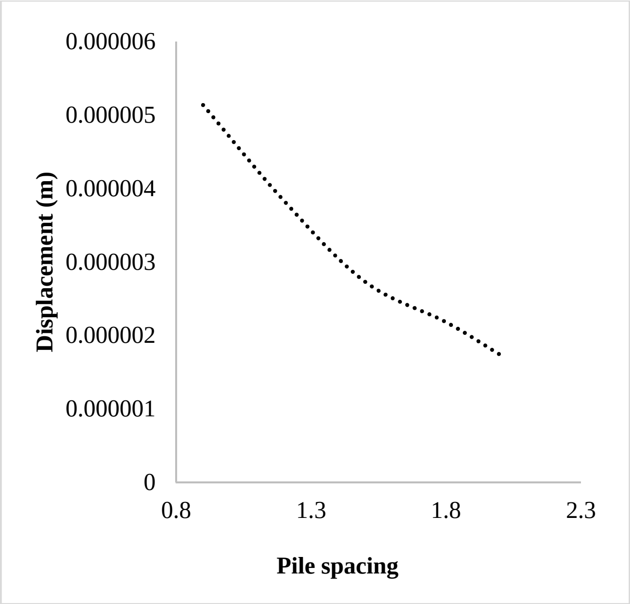

Fig. 12. Variation of displacement in Y-direction with pile spacing.

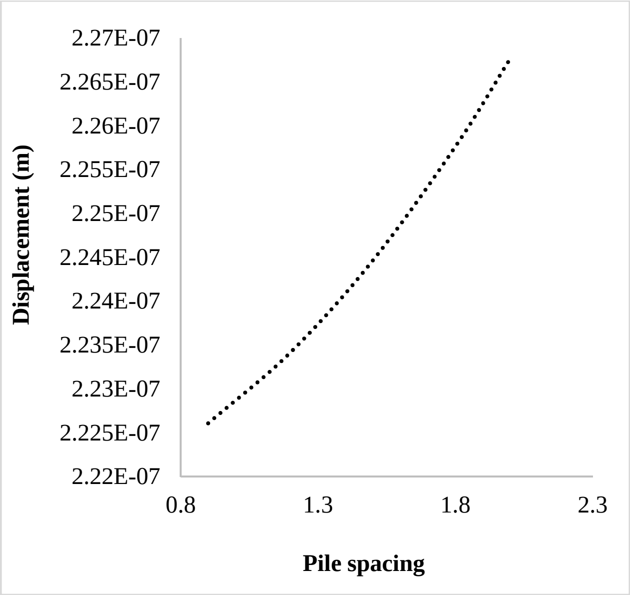

Fig. 13. Variation of displacement in Z-direction with pile spacing.

It is seen from the Fig-10 that as the spacing of pile is increasing the natural frequency is also increasing because stiffness is increasing. This is due to the fact that the elastic resistance of each pile in a group increases with increase in pile spacing and decreases with the decrease in pile spacing. When the pile spacing becomes sufficiently large the elastic resistance of each pile in a group approaches the elastic resistance of single pile. So pile spacing should be kept as large as possible. Further as the natural frequency moves away from the operating frequency the amplitude of vibration goes on reducing since the resonance is eliminated, however converse is also possible.

Case 3: When pile diameter and pile spacing is kept constant and weight of the block is varied.

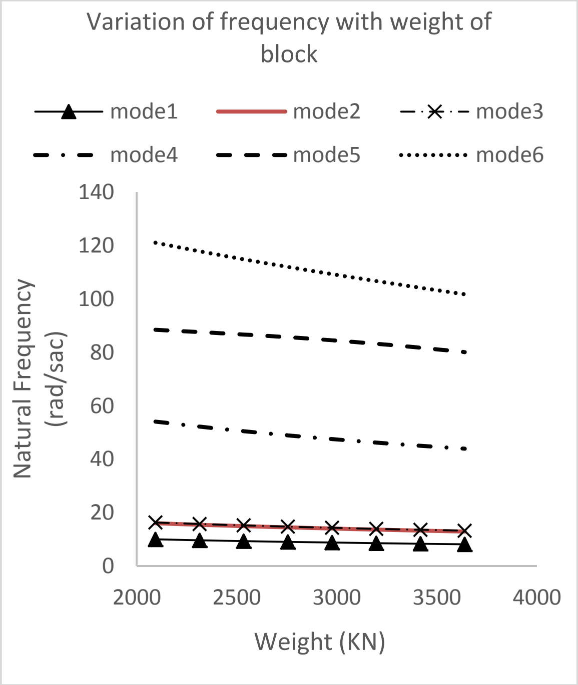

Fig. 14. Natural frequency variation with weight of foundation block.

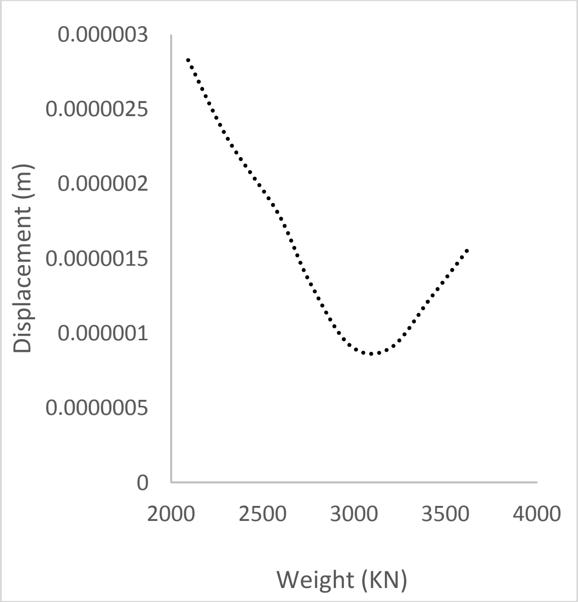

Fig. 15. Variation of displacement in X-direction with weight of foundation block.

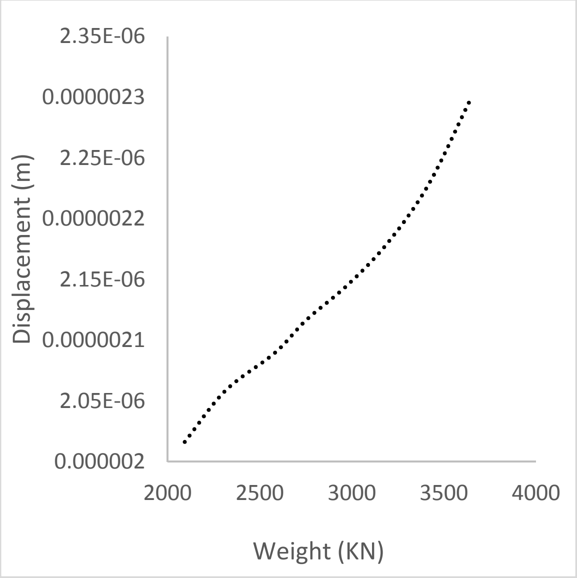

Fig. 16. Variation of displacement in Y-direction with weight of foundation block.

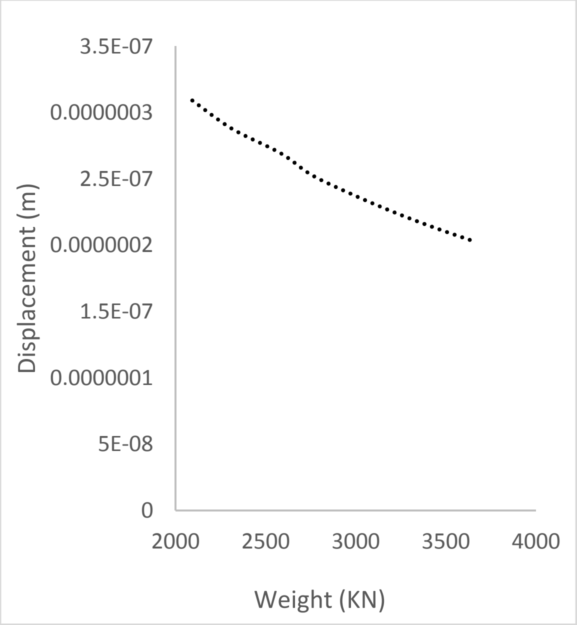

Fig. 17. Variation of displacement in Z-direction with weight of foundation block.

When the pile diameter and spacing between the piles is kept constant and weight of the block is increased, the natural frequency of the system decreases since the mass of the system increases (Fig. 14). The horizontal amplitude also decreases since the natural frequency in horizontal modes moves away from the operating frequency, while vertical amplitude increases because the natural frequency in vertical mode moves near to the operating frequency.

4. CONCLUSION

The following are broad conclusion -

1. It is observed from the graphs that if machine foundation system is close to resonance than increasing the weight of foundation block is more effective than increasing the pile diameter.
2. The spacing of piles is kept as large as possible, so as to utilize the full capacity of pile. It can be seen from the graph that as the spacing of piles increases the natural frequency of system also increases due to increase in effective stiffness of pile group.
3. It is seen from the graphs that variation in pile parameters have a large effect on the response of machine foundation. Hence pile can be effectively used to control the dynamic response of machine foundation.

REFERENCES

[1] Bharathi, M., Dhiraj Raj, Dubey, R.N., (2014). Codal provisions of design of machine foundation. Paper no EQ-17.

[2] Bhatia, K. G., (2008). Foundation for industrial machines. D-CAD publishers, New Delhi.

[3] Bhatia, K. G., (2008). Foundations for industrial machines and earthquake effects. ISET Journal of Earthquake Technology, Paper, (495), 1-2.

[4] Chowdhury, S., & Roy, S. (2015). Application of Novak's method for design of low frequency rotating equipment foundation block on driven cast in situ RCC piles in weak soil – A case study considering specific modification. ICI Journal, ISSN 0972-2998.

[5] Gohnert, M., Luker, I., & Morris, C. (2008). Designing Foundations with Piles for Vibrating Machinery. Open Construction and Building Technology Journal, 2, 306-312.

[6] IS 2911 (part-1/sec-1)-2010, Design and construction of pile foundations-code of practice.

[7] IS 2974 (part-4)-1979, Code of practice for design and construction of machine foundation, Foundation for rotary type machine for low frequency.

[8] Novak, M. (1974). Dynamic stiffness and damping of piles. Canadian Geotechnical Journal, 11(4), 574-598.

[9] Patel, U. S., Mangukiya, S. H., Miyani, L., Patel, H. A., Vora, S. V., Sevelia, J. K. (2015). Dynamic Analysis of Foundation Supporting Rotary Machine. *Int. Journal* of *Engineering Research* and *Applications* ISSN: 2248-9622, Vol. 5, Issue 8, (Part - 2), pp.34-45.

[10] Prusty, S. S. K. (2010). Dynamic response of pile foundations under coupled vibration (Doctoral dissertation, National Institute of Technology, Rourkela).

[11] Saran, S., (2006). Soil dynamics and machine foundations. Galgotia Publications Pvt. Ltd., New Delhi.

[12] Srinivasulu, P., & Vaidyanathan, C. V. (1976). Handbook of machine foundations. Tata McGraw-Hill Education.