Dynamic Analysis of Single Cylinder Compressor Block Foundation using SAP: 2000 VS. 16

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***Abstract* — *Dynamics of Machine Foundation is very important for the industrial assets such as, mechanical workshops, paper mills, Gas, Steam, Hydro and Geothermal power plants i.e. producing dynamic load. A few Research work have been done in this area. Safety, serviceability and durability of structure should be considered while designing such machine foundation. In the present work, the foundation system was simulated in SAP: 2000 VS.16 software and dynamic response of foundation was analyzed. The results are compared and validated with the displacement values published in the book "Foundation Vibration Analysis Using Simple Physical Models" published by John P. Wolf.*

Keywords — ***Compressor, Block foundation, Dynamic analysis, SAP: 2000 VS. 16.***

I. Introduction

Machine Foundations require a special consideration because they transmit dynamic loads to soil in addition to static loads. In machine foundation the dynamic load is applied repeatetively over a long period of time and therefore soil behaviour is very important. Also, the amplitude of the vibration of machine at its operating frequency is most important parameter to be determined in designing the machine foundation, in addition to the natural frequency of a machine foundation soil system.

Machines which operate at low to medium operating frequencies are generally supported on rigid block foundations. The main reason behind supporting these low to medium frequency machines on block foundation is to ensure the natural frequencies of foundation sufficiently above the operating frequency of machine because designing these machines by keeping all the preliminary natural frequencies of foundation below operating frequency is very difficult. Hence to keep the natural frequency higher than the operating frequency, the rigid block foundation is generally used to support the low to medium operating frequencies.

In case of machines which run at low operating frequencies, it is very difficult to ensure that the all preliminary natural frequencies of foundation are sufficiently below operating frequency of machine. Means it is difficult to design such low operating frequency machines foundation as under tuned machine foundation. Hence, usual practice for designing low frequency machine is by ensuring all preliminary natural frequencies sufficiently above the operating frequency of machine (over tuned machine foundation), which is generally done by providing a very rigid block foundation. There is no such transient resonance condition in over tuned machine foundation.

In case of block foundations, preliminary natural frequencies of foundation are mostly related to the supporting system because the natural frequencies related to such rigid foundation are very high. The dynamic analysis of a block foundation supporting single cylinder compressor has been performed in this paper.

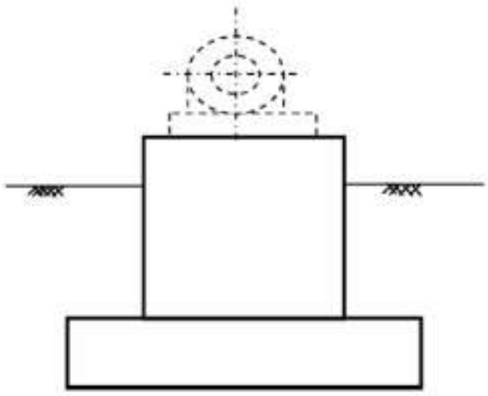


Fig. 1 Layout of Block foundation resting on soil

Many engineers with varying circumstances are engaged in the analysis, design, construction, maintenance, and repair of machine foundations. Therefore, it is important that the owner/operator, geotechnical engineer, structural engineer, and equipment supplier collaborate during the design process. Machines of higher ratings gave rise to significantly greater stresses thereby posing problems with respect to performance and safety. At the same time, a more detailed study became urgent because of the development of machines of higher capacities. Hence it becomes compulsion for development partly in the field of vibration technique and partly in that of soil mechanics. It was in early 1922-23 that I. Geiger carried out investigations to determine natural frequencies of foundation. Latter Ehlers (1925) and Prager (1927-30) studied the theory of vibrations and its practical applications. In 1925 Rausch published a paper on the turbine foundation. After that Timmoshenko (1928), Den Hertog (1934), Jacobson (1958), Norris (1959) and Grade (1961) contributed to very large extent in this field.

J. G. Sieffert discussed about the recent development in the field and also discussed about the dynamic soil-structure interaction. William E. Saul & Thomas W. Wolf (1979) mentioned that the use of piling for machine foundation can add flexibility for designer, It helped to solve special problem and possibly reduce the cost. Z. Huaug & S. Hindiya explained how the cost of an existing foundation for machine can be minimized by optimizing the parameters like thickness of concrete in the machine pit and platform. Payal Mehta stated that dynamic load is not short lived but act over a large period of time. Dynamic force depends upon the machine type & its operation mechanism & frequency. Rohit R Sharma, Prashant V. Muley, Prashant R. Barbude narrated about the machine that creates vibration on foundation due to which higher dynamic forces are generated.

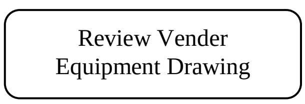
So the designed aids / method for foundation design were suggested. An idea about the characteristics of harmonic force introduced by Cyril Harris in his book "Harris' Shock and Vibrations" was proved to be beneficial while making the mathematical model of the looms machine. M. J. Pender executed a review about the main issues in the design of shallow foundation and deep foundation which may be subjected to earthquake loading.

II. DESIGN PHILOSOPHY OF MACHINE FOUNDATION

The main constituents of a typical machine-foundation system are:

- Machine: rotary machines, reciprocating machines, impact machines;
- Foundation: block foundations, or frame foundations; and
- Support medium: soil continuum, or a soil-pile system, or a substructure that, in turn, is supported over the soil continuum or soil-pile system.

Design methodology of machine foundation contains various stages of analysis which is illustrated by the flowchart shown in figure 2.



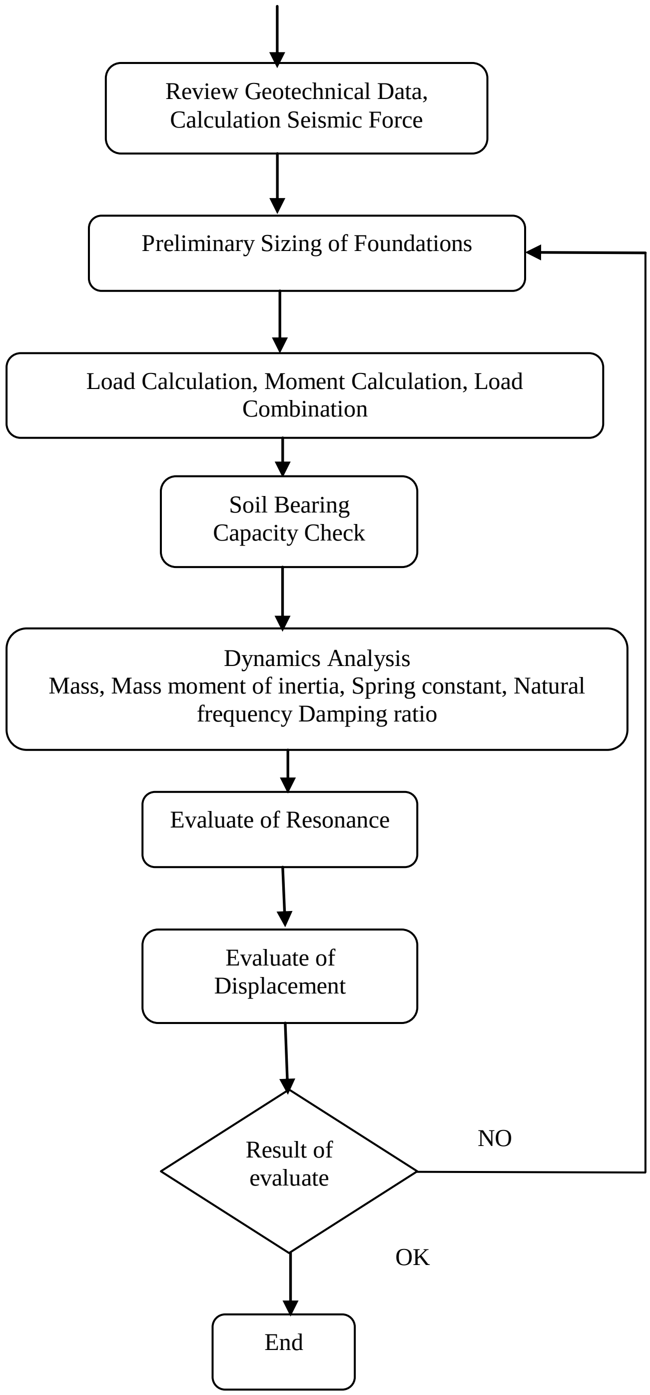


Fig. 2 Schematic diagram of a machine-foundation system subjected to dynamic loads

III. CRITERIA FOR DESIGN

The basic goal in the design of a machine foundation is to limit its motion i.e. amplitudes. Allowable amplitudes depend on the speed, location and function of the machine. Other limiting dynamic criteria affecting the design may include avoiding resonance and excessive transmissibility to the supporting soil or structure.

Machine foundation should insure following criteria to insure its safe and efficient working all over its life period.

[1] It should be safe against shear failure.
[2] It should not settle excessively.
[3] There should be no resonance, i.e. the natural frequency of the machine foundation-soil system should not coincide with the operating frequency of the machine. Frequency ratio should not be within 0.8 to 1.4
[4] The amplitudes of motion at operating frequencies should not exceed the limiting amplitudes, which are generally specified by machine manufacturers.

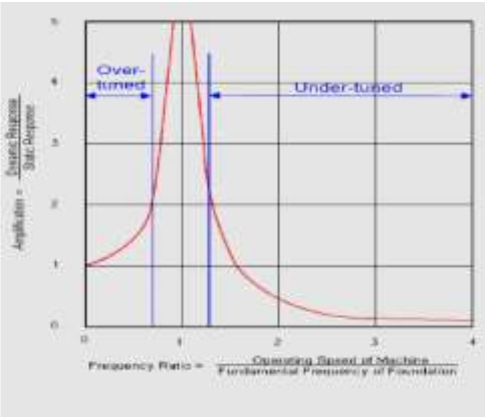


Fig.3 Tuning of Foundation

A. Dynamics of soil

Satisfactory design of a machine foundation needs information of soil profile, depth of different layers, physical properties of soil and ground water level. Dynamic shear modulus of a soil is generally determined from laboratory or field tests.

The soil properties needed in analysis of foundation are:

[1] Dynamic moduli, Young's modulus E and Shear modulus
[2] Poisson's ratio μ
[3] Dynamic elastic constants such as coefficient of elastic uniform compression C_u, coefficient of elastic uniform shear C_τ, coefficient of elastic non-uniform compression C_φ and coefficient of elastic non-uniform shear C_ψ
[4] Damping ratio ξ

IV. MODELLING METHODOLOGY IN SAP: 2000 VS. 16

The software used here for the analysis is SAP: 2000V16. This version is versatile in capability and has the properties like Finite Element Method, Static and Dynamic analysis, Linear and nonlinear analysis, Geometric nonlinearity, including P-Delta and large displacement effects, soil parameters, Soil Structure Interaction, Stress Contour, including earthquake lateral Forces.

A. Problem Validation in SAP: 2000VS.16

A Dynamic Analysis of single-cylinder compressor.

Reference:

[1] Foundation Vibration Analysis Using Simple Physical Models, John P. Wolf, pg. 56, ISBN: 0-13-010711-5 Dynamic Load Type: Periodic Excitation Units: tonnef /m

[2] Clockwork Verification Manual Rev. 12.1-D, Newtonian Machines®, Andrés De Fuenzalida 147, Providencia, Santiago, Chile, pg. 5-6

On a rigid block foundation rests a reciprocating machine composed of a compressor and a driving motor, which generates a vertical unbalanced dynamic load with two components. The first component acts at a frequency of 9Hz and the second component at twice this frequency. The resulting dynamic total load it is represented by P(t).

B. Input Parameters

Compressor and driving motor mass = 2750 kg= 0.28 toneff*sec^2/ m

a) Dynamic Load:
   Total load acts vertically on the foundation block.
   Total Load P(t) :
   P(t)= 3.198cos(56.55t) + 1.066cos(113.1t) KN
   P(t)= 0.326cos(56.55t) + 0.109cos(113.1t) toneff
   Number of terms used in Fourier Series = 20
b) Rigid Foundation Block Size:
   Length = 2.0 m
   Width = 1.5 m
   Height = 1.0 m
c) Soil
   Poisson's Ratio μ = 0.33
   Specific Mass Density ρ = 1700 kgf/ m^3= 1.7 toneff/m^3
   Shear Modulus G =38.25 X 106 M/m^2= 3900.41 toneff/ m^2

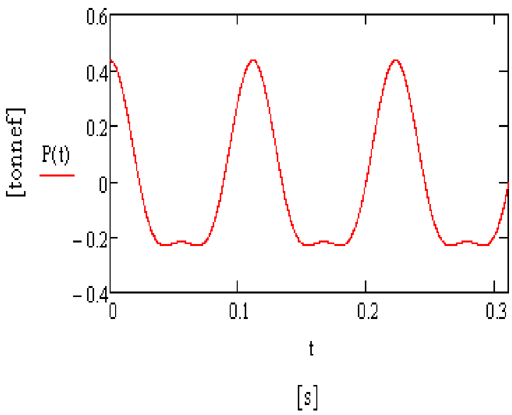


Fig. 4 Dynamic total load from vertical single-cylinder compressor

C. Results Comparison & Discussion

The results of displacements of different modes of referenced book are compared with the model developed in SAP2000 software. The percentage difference is quite law.

Since, both the results are nearly equal, the software SAP 2000 VS. 16 can be validated for the analysis and design of machine foundation for presented work.

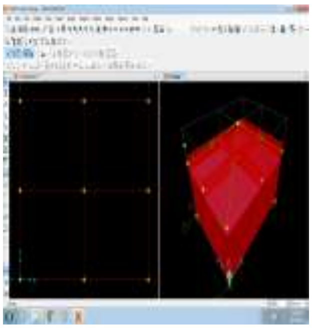


Fig. 5 Modelling in SAP 2000

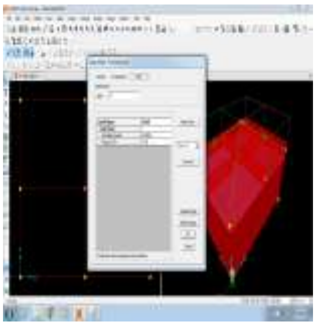


Fig. 6 Assigned Load in SAP 2000

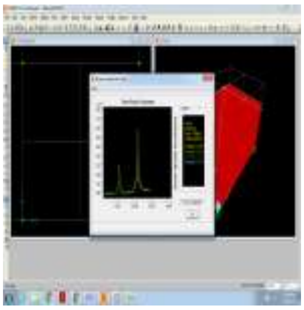


Fig. 7 Response Spectrum Curves

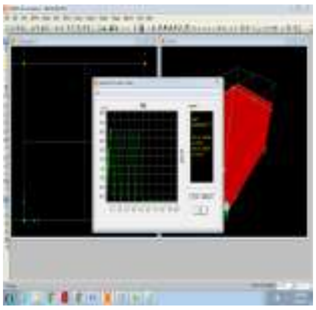


Fig. 8 Plot Function Traces

Table 1: Displacement Comparisons of SAP 2000 and Ref. Book with Percentage Variation

Measured Value	SAP 2000 VS. 16 Displacement [mm]	Displacement Ref[1] [mm]	% Change
Max	0.02086	0.02125 ± 0.00125*	7.7%, 3.6%
Min	-0.01136	-0.01125 ± 0.00125*	9.58%, 9.12%

V. CONCLUDING REMARKS

- In analysis and design of Block foundation, eccentricity check, resonance check, amplitude check, horizontal peak velocity check, ground bearing pressure check has been made and are found to be within the permissible limits.
- It is recommended for Block foundations to include the whole structure and replace the soil / piles by spring elements. Geotechnical parameters are required and have a significant influence on the accuracy of vibratory machinery dynamic analysis. Soil type can have a significant effect on the results of dynamic analysis of vibratory machine foundation. Analysis should consider a minimum range of soil parameters of +/- 20 percent in order to account for uncertainties.
- Increasing the mass ratio of a foundation system will not always bring the natural frequencies of the foundation system out of resonance with the forcing frequency. However, more soil impedance from the foundation system will reduce the vibration amplitude during operation.
- Designing dynamic equipment foundations located in high seismic regions is based on a multitude of factors. Both the dynamic requirements and seismic requirements based on site conditions play a very important role. For finite element analysis, SAP 2000 issued to create a model for static and dynamic analysis.
- It is observed that a resonance condition cannot be avoided but for safety of Foundation to reduce transient resonance condition, the Machine can be speed up during the frequency overlapping.

VI. SCOPE OF WORK

In this paper, a dynamic analysis of single cylinder compressor block foundation has been performed. And the performance can be compared for the worst condition. The foundation system was simulated in SAP: 2000 VS.16 software and dynamic response of foundation was analyzed. The results are compared and validated with the displacement values published in the book "Foundation Vibration Analysis Using Simple Physical Models" published by John P. Wolf. Here, only simple block foundation is modelled on which the machine rests. Another support conditions such as, piles, rafts, pads can also be provided for the different types of soil and seismic conditions and the results can be compared for the worst conditions.

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REFERENCES

[1] Anil K. Chopra, “Dynamics of structures”, Prentice Hall of India Private Limited, New Delhi, 2008.

[2] Arya S., O’Neill M.W.and Pincus G.,“Design of structures and Foundations for Vibrating Machines”, Gulf Publishing Company, Houston, Texas.

[3] Bhandari Piyush K., Sengupta Ayan, “Dynamic Analysis of Machine Foundation”, International Journal of Innovative Research in Science, Engineering and Technology, An ISO 3297: 2007 Certified Organization Volume 3, Special Issue 4, pp- 169-176, April 2014.

[4] Bharathi M., Dhiraj Raj, Dr. R.N. Dubey, “Codal Provisions for Design of Machine Foundations – A Review”, International Symposium Geohazards: Science, Engineering and Management, Kathmandu, Nepal November 20-21, 2014.

[5] Bharathi M., Dr. Saran Swami and Dr. Mukerjee Shyamal, "Analysis of Reciprocating Machine Foundations Resting on Piles", ISET Golden Jubilee Symposium, Indian Society of Earthquake Technology, Department of Earthquake Engineering Building, IIT Roorkee, Roorkee, Paper No. C018, October 20-21, 2012.

[6] Bhatia K. G., "Foundations for Industrial Machines- A Handbook for Practicing Engineers, D-CAD Publishers, New Delhi-2006.

[7] Bhatia K.G.," Foundations for Industrial Machines and Earthquake Effects", ISET Journal of Earthquake Technology, 28th ISET Annual Lecture, Paper No. 495, Vol. 45, No. 1-2, pp. 13–29, March-June 2008.

[8] Clockwork Verification Manual Rev. 12.1-D, Newtonian Machines®, Andrés De Fuenzalida 147, Providencia, Santiago, Chile, pg. 5-6.

[9] Dr. Sevelia Jigar K., Patel Utkarsh S., Mangukiya Siddharth H., Miyani Ankit L., Patel Hardik A., Vora Smit V., " Dynamic Analysis of Foundation Supporting Rotary Machine", International Journal of Engineering Research and Applications ISSN: 2248-9622, Vol. 5, Issue 8, (Part - 2) ,pp.34-45, August 2015.

[10]George Gazetas, "Analysis of machine foundation vibrations: state of the art", Rensselaer Polytechnic lnstitute, Soil Dynamics and Earthquake Engineering, CML Publications, Vol. 2, No. 1, Troy, New York, USA-1983.

[11]Kameswara Rao,, "Vibration Analysis and Foundation Dynamics", N.S.V., Wheeler Publishing, New Delhi-1998.

[12]Kameswara Rao,, "Vibration Analysis and Foundation Dynamics", N.S.V., Wheeler Publishing, New Delhi-1998.

[13]Kaniraj,Shenbaga R.,"Design Aids in Soil Mechanics & Foundation Engineering", Tata McGraw Hill, Publishing Company Ltd, New Delhi,1988.

[14]Srinivasulu,P. and Vaidyanathan, C.V., "Handbook of Machine Fundations", Tata McGraw Hill , New Delhi, 1976.

[15]Tank Yati R., Dhameliya Hitesh K., "A Review on the Dynamic Behaviour of Foundation Supporting Vibrating Machines", International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), ISSN(Online): 2319-8753, ISSN (Print): 2347-6710, pp-11746-50, Vol. 4, Issue 12, December 2015.

[16]Wolf John P., "Foundation Vibration Analysis Using Simple Physical Models", ISBN: 0-13-010711-5, pg. 56.

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