International Journal of Civil Engineering and Technology (IJCIET)
Volume 10, Issue 03, March 2019, pp. 1617-1625, Article ID: IJCIET_10_03_160
Available online at http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=10&IType=03
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

MACHINE FOUNDATIONS FOR POWER PLANT: SOME DESIGN ISSUES WITH REAL TIME EXAMPLES

Nidhi R. Somkuwar
Post Graduate Student, Civil Engineering Department,
Guru Nanak Institute of Engineering and Technology, Nagpur, India

ABSTRACT

The power generating industry is undergoing an unprecedented reform. Improvement in power plant has provided machines of higher rating with better stability and increased running life. Proposed soil characteristics represent the most important physical-mechanical parameters for foundation engineering purposes. The use of historical data, improved designed techniques with provisions for earthquake condition by Civil Engineers can enhance durability and running time of heavy machineries. This paper highlights some design issues with real time examples, need for a better interaction between foundation designer and machine maintenance engineer to ensure improved machine performance. Also provides knowledge about the foundation related problems and its percentage share on the partially or fully non availability of equipments in the overall power plant.

Keywords: Machine foundation, Power plant, Rotary machine, Soil dynamics, Vibration

Cite this Article: Nidhi R. Somkuwar, Machine Foundations for Power Plant: Some Design Issues with Real Time Examples. International Journal of Civil Engineering and Technology, 10(3), 2019, pp. 1617-1625

http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=10&IType=03

1. INTRODUCTION

With the advancement of technology and literature available in the field of industry, high speed machinery has been developed. As the speed of machinery has increased, vibrations also increased. Machines transmit vibrations to the structure supporting them. Hence, it is important to design and develop such structure which sustains the vibrations of machinery. Hence, in this study it has been aimed to execute the study on various design aspects of machine foundations in power plant and its share on non-availability of equipments. There are many heavy equipment in power plant industries where machine foundations are required to design to satisfy various base pressures, e.g. Foundation of Pulverizing mills, Boiler feed pumps, Chemical dosing pumps, HP Ash water pumps, LP Ash water pumps, Ash water recovery pumps, Foundation of Raw water pumps, Clarified pumps, Service water pump, Seal air fan, LDO pump, Coal handling conveyors, etc. These equipments are bearing vertical load, horizontal load, bending stresses, shear loads, etc. Being high capital invested in the industries, it becomes necessity to provide earthquake resistance technology in the machine foundations. Improvement in manufacturing technology has provided machines of higher ratings with better tolerances and controlled behavior. These machines give rise to considerably higher dynamic forces and thereby higher stresses and, in return, demand improved performance and safety leaving no room for failures.

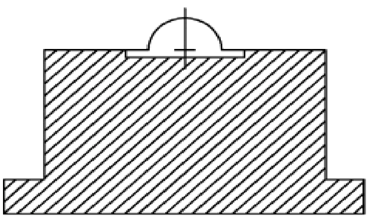
This paper highlights need for a better interaction between foundation designer and machine manufacturer to ensure improved machine performance. It describes the design aids / methodologies for foundation design with real time machine foundation related problems of important running equipments, work done for the improvement and condition of the equipment after work. The paper also touches upon the number of equipments affected due to foundation related problems in the power station. This paper is organized as follows: Section 2 presents a brief literature review on machine foundation, applications and related issues. Section 3 describes foundation design criteria and aspects of design in brief and in section 4 includes results and consequently conclusions in the section 5 reached in this study.

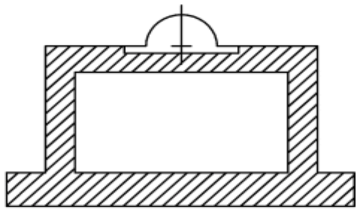
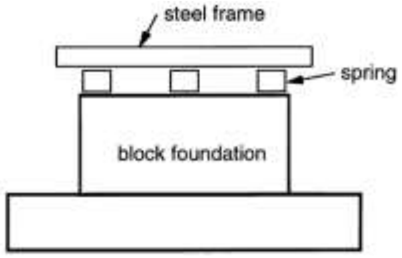
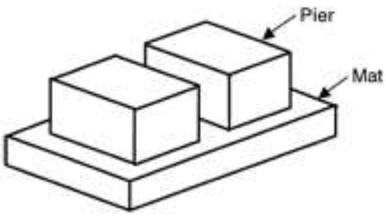
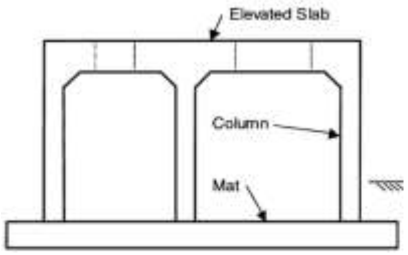
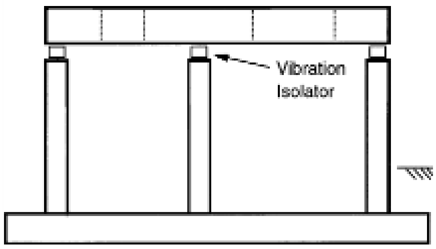
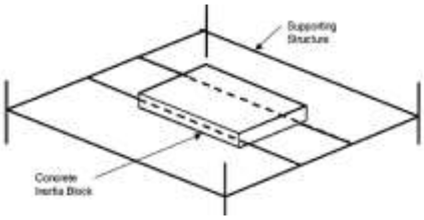
2. LITERATURE REVIEW

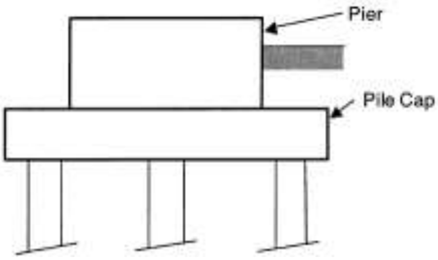
Gazetas G. (1983) [1], Prakash S. et al.[2], Wang ZY et al.[3] and Srinivasulu P. et al.[15] found that with the advancement of technology and literature available in the field of industry, high speed machinery has been developed. As the speed of machinery have increased, vibrations effect increased adversely affecting the condition of equipment.

The superstructure of vibrating and rotating machine for installation is known as machine foundation. It essentially consists of a mass of concrete. Design of machine foundation involves consideration of static load and kinetic forces by Bhatia K.G. et al. [4] and Prakash S. et al. [16] (1988). A brief snap shot ideas about foundation provided is given below in Table 1.

Table 1 Various machine foundations, applications and design aspects

Machine foundation types	Application	Design aspects / concerns
Machine  Footing Block foundation	It is used for machines of large mass and a small natural frequency	The ability to use block foundation primarily depends on the quality of near surface soils and designed as rigid structures. The dynamic response of a rigid block foundation depends only on the dynamic load, foundation's mass, dimensions, and soil characteristics observed by Pradhan P.K. et al. [5]
Machine	It is used in the cases of less mass with higher natural frequency machines.	Due tp hollow concrete block as shown in the figure. The mass of this foundation is less than block type machine foundation as it is hollow. The natural frequency of the box type machine foundation is increased.

 Box machine foundation		
 Spring mounted block foundation	This is used for high vibrating machines and to isolate from thermal forces.	Spring mounted block foundation comprises of vertical columns consisting a horizontal frame at their tops. The machine is laid and supported within the frame. It's very useful to isolate from thermal forces vibrations.
 Combined block foundation	Combined foundation is similar to simple block foundation.	Combined block foundations are used to support closely spaced machines. Combined blocks are more difficult to design because of the combination of forces from two or more machines and because of a possible lack of stiffness of a larger foundation mat.
 Tabletop foundation	It allows for ducts, piping, and ancillary items to be located below the equipment.	Elevated support is common for large turbine-driven equipment such as electric generators. Tabletop structures are considered to be flexible, hence their response to dynamic loads can be quite complex.
 Tabletop with isolator foundation	It is used for high vibrating machines like pumps, blowers, fans, etc.	Springs and dampers located at the top of supporting columns are sometimes used to minimize the response to dynamic loading. The effectiveness of isolators depends on the machine speed and frequency by Richart Jr. et al. [17].
 Inertia block in structure foundation	It is used for small moving blocks, machines, etc.	In this situation, small dynamic machines are usually designed with a supporting inertia block to alter natural frequencies away from machine operating speeds and resist amplitudes by increasing the resisting inertia force.

 Pile supported foundation	It is used in soft ground conditions and excessive Settlement e.g. drilled piers, auger cast piles, and driven piles.	Any of the previously mentioned foundation types may be supported directly on soil or on piles. Piles use end bearing, frictional side adhesion, or a combination of both to transfer axial loads into the underlying soil noted by Kaynia A.M. et al. [6].

Even after sufficient availability of literatures on foundation technology, there is very less data available from the various industries like thermal power plant, coal handling plants, coal washeries, petrochemical industries, fertilizer sector, etc. Therefore, it has been encouraged to carry this study specifically of power plant due to applications of significant rotating, reciprocating, sliding, hammering, etc equipments in the industry.

3. FOUNDATION DESIGN CRITERIA

As per Srinivasulu P. et al. [18] and Gohnert M. et al. [7], the main issues in the design of concrete foundations that support machinery are defining the anticipated loads, establishing the performance criteria and providing for these through proper proportioning and detailing of structural members. It requires the need for careful attention to the interfaces between machine, mounting system and concrete foundation. The loads on machine foundations may be both static and dynamic. Static loads are principally a function of the weights of the machine and all its auxiliary equipment. Dynamic loads, which occur during the operation of the machine, result from forces generated by unbalance, inertia of moving parts, or both, and by the flow of fluid and gases for some machines. The magnitude of these dynamic loads primarily depends upon the machine's operating speed and the type, size, weight and arrangement or position of moving parts within the casing.

The basic goal in the design of a machine foundation is to limit its motion to amplitudes that neither endanger the satisfactory operation of the machine nor disturb people working in the immediate vicinity. Allowable amplitudes depend on the speed, location and criticality or function of the machine. Other limiting dynamic criteria affecting the design may include avoiding resonance and excessive transmissibility to the supporting soil or structure as mentioned by Lee JP [8].

3.1. Soil Exploration

A key ingredient to a successful design is the careful engineering analysis of the soil-foundation response to dynamic loads from the machine operation. The foundation's response to dynamic loads can be significantly influenced by the soil on which it is constructed. Consequently, critical soil parameters, such as the dynamic soil shear modulus are preferably determined from a field investigation and laboratory tests rather than relying on generalized correlations based on broad soil classifications as per Prakash S. (1981) [19] and Bhatia K.G. (1977) [11].

The object of site investigation of industries like thermal power plant, etc. is to obtain reliable, specific and detailed information about the soil/rock and groundwater conditions at a site for enabling engineers in the safe and economic design and execution of engineering works. To meet this objective investigation should be carried out to the required depth and horizontal extent in the region likely to be affected by the proposed constructions. Depth of investigation, in general, is decided based on the intensity of structured loading and the type of foundation contemplated. This depth up to which the increase in stress due to structural loading causes shear failure or excessive settlement of foundation is known as significant depth (Fig. 1). This depth of investigation is generally taken as the depth of pressure bulb of intensity 0.1q to 1.2q where ‘q’ is the intensity of loading at the base of foundation (B-Depth, D-Stressed diameter, σ-Stress). Thumb rules to decide soil exploration (IS: 1892-1979) is shown in Table 2.

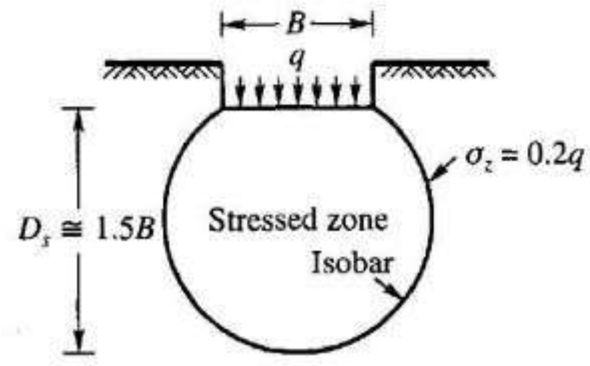


Figure. 1 Significant Depth of Stresses Zone

Various factors affecting significant depth are type of structure, weight of structure, dimension of structure, disposition of the loaded area, soil profile and layer properties. Furthermore, a machinery support structure or foundation is designed with adequate structural strength to resist the worst possible combination of loads occurring over its service life. This often includes limiting soil-bearing pressures to well within allowable limits to ensure a more predictable dynamic response and prevent excessive settlements and soil failures shown by Pitilakis D. et al. [9].

Table 2 Thumb rules to decide soil exploration (IS: 1892-1979)

Sr. No.	Type of Foundation	Depth of Exploration
1	Isolated spread footings or raft or adjacent footings with clear spacing equal or greater than four times the width	1.5 times the width
2	Adjacent footings with clear spacing less than twice the width	1.5 times the length
3	Adjacent rows of footings With clear spacing between rows less than twice the width With clear spacing between rows greater than twice the width With clear spacing between rows greater than four times the width	4.5 times the width 3 times the width 1.5 times the width
4	Pile and well foundations	1.5 times the width of structure from bearing level

3.2. Design Steps

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 is supported over the soil-pile system.

Dynamic forces are internally generated forces by the machine itself, or externally applied forces. The steps required to follow while designing of foundation are given below and followed by Prakash S. et al. (1988) [16] and Svinkin MR [10].

Size of footing to satisfy base pressure
Design of base for bending
Check for one-way shear
Check for two-way shear
Stability against sliding and overturning (earthquake)

4. RESULTS

To study foundation related problems last three years equipment based data collected from the power plant industries. Total approximately 300 numbers (per year) of preventive and corrective data are found on sample basis including vibration, abnormal sound misalignment, etc. The significant equipments with vibration analysis and condition after work are given in Table 3.

Table 3 Real time examples of machine foundation work in Power Plant

Sl No	Equipments of Power Plant	Vibration Reading µ / mm/s	Severity of Vibration	Vibration Analysis / Recommendation	Status of Equipment after Foundation Workdone
1	Raw Water Pump	210 / 9	TRIP RANGE	Pump tripping on high vibration at Non driving end. Structure with foundation to be strengthened	Machine foundation work done by Civil Engineer with pump overhauling by Mechanical Engineer. Trial taken. Pump run with Vibration reduced to normal.
2	Instrument Air Compressor [Dry Fly Ash System]	1905 / 80.9	TRIP RANGE	Compressor vibration was in trip range probable cause loose compressor foundation bolts.	Vibration reduced from 1905 / 80.9 to normal level after compressor foundation bolts tightening.
3	Fluidizing Blower of Ash Handling System	57 / 5.2	ALARM RANGE	Blower vibration was in alarm range. Variation in vibration at blower from 6 to 10 mm/sec with abnormal sound from foundation.	Vibration reduced from alarm range to normal level after foundation work done by Civil Engineer.

4	Transport Air Compressor [Dry Fly Ash System]	165 / 26	TRIP RANGE	Vibration was in trip range suspected loose foundation and pads.	Vibration reduced from 165/26 to normal level after foundation work and anti-vibration pads replacement by Civil Engineer.
5	LDO Pump	110 / 15	TRIP RANGE	Abnormal sound was coming from foundation and improper alignment suspected	After foundation work by Civil Engineer initially Vibration reduced from Trip range to Alarm range. After Motor soft foot work and greasing vibration reduced to normal value.
6	Coal Handling Plant: Conveyor Drive	130 / 10.3	ALARM RANGE	Weak motor foundation, stiffening required.	After foundation work done by Civil Engineer and greasing work by Mechanical Engineer, Vibration reduced from alarm range to normal range.
7	Service Water Pump	617 / 48.0	TRIP RANGE	Soft foot / improper tightening at pump foundation required.	After foundation work done by Civil Engineer vibration reduced from trip range to normal level.
8	Seal Air Fan	56 / 8.4	ALARM RANGE	Loose foundation and motor base frame strengthening required.	After foundation work done by Civil Engineer vibration reduced from alarm range to normal range.

The significant number of equipments affected due to foundation related problems. Study shows about 19% of overall equipments partially or fully affected due to foundation related issues in a year. This data may be significantly affected by plant load factor. Fig. 2 shows yearly variation of total issues including foundation problems. After identifying only foundation related problems of plant equipments, it is observed that there are significant issues, most of which are solvable and preventable. The typical yearly variation of partially or fully foundation related problems are shown in Fig. 3. Still there is a need of extensive study required to refine results.

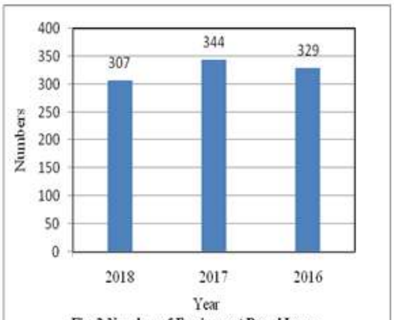


Fig. 2 Number of Equipment Based Issues

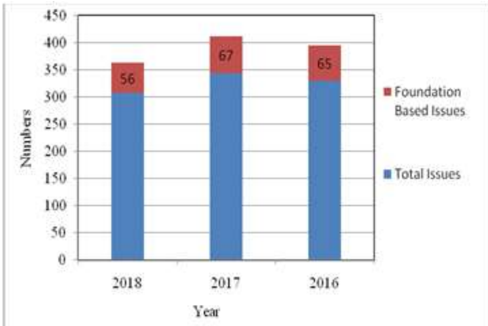


Fig. 3 Share of Foundation Based Issues

5. CONCLUSIONS

Thermal power plants have wide range of heavy machineries and structures in which there is a need of extensive studies with existing data base and history. Machine-foundation design has been associated with the civil engineering discipline with specialization in soil technology and structural engineering. This paper recommends a higher level of interaction amongst all the concerned disciplines, which should result in an improved machine performance. The significant number of equipments affected due to foundation related problems. Study shows about 19% of overall equipments partially or fully affected due to foundation related issues in a year. Out of which approximately 70% of issues solved by rework (partial foundation work) and about 30% of equipments required to make new foundations in the power plant. Use of existing industrial data related to foundation related problems coming in the running equipment with finite element methodologies, for the analysis and design of foundations, is strongly recommended.

ACKNOWLEDGEMENTS

I am grateful to my parents especially my mother Mrs. Bharti and father Mr. Rahul, for showing their continued, unconditional and unfailing love and understanding during the work. My special thanks are extended to my Sisters, Mama-Mami’s and Nana-Nani for always beside me during the happy and sad moments to push and motivate me. My heartfelt regard goes to a very special person and eminent Engineer who come across my life and discovered me with my ability in true sense and inspired to do something unique. Finally thanks to all industries who allowed me to study and refer the data.

REFERENCES

Journal Papers:

[1] Gazetas G., "Analysis of Machine Foundation Vibrations: State of the Art", Journal of Soil Dynamics and Earthquake Engineering, 1983, Vol. 2, No. 1, pp. 2-42.

[2] Gazetas G., "Analysis of Machine Foundation Vibrations: State of the Art", Journal of Soil Dynamics and Earthquake Engineering, 1983, Vol. 2, No. 1, pp. 2-42.

[3] Wang ZY, Liu JB, Pei YX et al. “Theoretical and experimental study on micro-vibration reduction of large dynamic machine foundation” Chinese J Geotech Eng 2002, pp. 363–366.

[4] Bhatia, K.G., “Machine Foundation Design—A State of the Art”, Journal of Structural Engineering, SERC 2006, Vol. 33, No. 1, pp. 69–80.

[5] Pradhan PK, Mandal AB and Aidya DK. “Dynamic response of machine foundation on layered soil” Geotech Geol Eng 2008; pp. 26: 453–468.

[6] Kaynia, A.M. and Kausel, E. (1982), “Dynamic Behaviour of Pile Groups", Proc. of Conf. on Numerical Methods in Offshore Piling, University of Texas, Austin, Texas, 1982, pp. 509-532.

[7] Gohnert M, Luker I and Morris C. “Designing foundations with piles for vibrating machinery” Open Constr Build Technol J 2008; pp. 2: 306–312.

[8] Lee JP, “Dynamic considerations in the design of paper machine foundations” Proceedings of the 2nd international conference on recent advances in geotechnical earthquake engineering and soil dynamics, Rolla, MO, 11–15 March 1991, pp. 1525–1530.

[9] Pitilakis D and Clouteau D. “Equivalent linear substructure approximation of soil–foundation–structure interaction: model presentation and validation.” B Earthq Eng 2010; pp. 8: 257–282.

[10] Svinkin MR. “Dynamic effects of impact machine foundations” Proceedings of the geotechnical earthquake engineering and soil dynamics congress IV, Sacramento, CA, 18–22 May 2008, pp. 1–17.

[11] Bhatia, K.G. and Sinha, K.N. “Effect of Soil-Structure Interaction on the Behaviour of Machine Foundations”, Proceedings of the International Symposium on Soil-Structure Interaction, Roorkee, 1977, pp. 399–404.

[12] “Foundations for Dynamic Equipment” research paper by Reported by ACI Committee 351.

[13] Haldar S and Babu GLS. “Improvement of machine foundations using reinforcement” Proc Inst Civil Eng 2009; pp. 162: 199–204.

[14] Ghosh P. “FLAC based numerical studies on dynamic interference of two nearby embedded machine foundations”, Geotech Geol Eng. 2012; pp. 30: 1161–1181.

Books:

[15] Srinivasulu P. and Vaidyanathan C.V, “Handbook of Machine Foundations”, Tata Mcgraw –Hill Publishing Company, New Delhi, 2003.

[16] Prakash S. and Puri, V.K. (1988). “Foundations for Machines: Analysis and Design”, John Wiley & Sons, New York, USA, 1988.

[17] Richart Jr., F.E., Hall Jr., J.R. and Woods, R.D. “Vibrations of Soils and Foundations”, Prentice-Hall, Englewood Cliffs, U.S.A, 1970.

[18] Srinivasulu, P. and Vaidyanathan, V. “Handbook of Machine Foundations”, Tata McGraw-Hill Publishing Company, New Delhi, 1980.

[19] Prakash S. “Soil Dynamics”, McGraw-Hill Book Company, New York, USA, 1981.