Review on Parametric Study on Analysis and Design of Turbo Generator Foundation

Mr. Sujay D. Narwade[1], Prof. Dr. Swati D. Ambadkar [2]
[1]Student M. Tech. (Structural Engg.) Dept. of Civil Engineering, G. H. Raisoni University, Amaravati, Maharashtra, India
[2]Associate Professor, Dept. of Civil Engineering, G.H.Raisoni University, Amaravati, Maharashtra, India
[1]sujaynarwade@rediffmail.com

***Abstract* - Turbo generator foundations are critical structural systems designed to safely support heavy rotating machinery subjected to continuous dynamic loading. The performance, stability, and operational safety of turbo generators largely depend on the behaviour of their foundations under vibration and dynamic forces generated during machine operation. Improper foundation design may lead to excessive vibration, resonance, structural cracking, settlement, and premature failure of machine components. Therefore, dynamic analysis and vibration control are essential aspects in the design of machine foundations.**

The present study focuses on the parametric analysis and design of turbo generator foundations with different footing geometries using ANSYS software. Various foundation configurations such as square, rectangular, circular, and oval footings having the same volume are considered to evaluate their structural and dynamic behaviour under machine-induced loading. The study investigates important response parameters including natural frequency, displacement, vibration amplitude, stress distribution, stiffness characteristics, and resonance behaviour.

A detailed review of previous research indicates that the seismic and dynamic performance of turbo generator foundations is significantly influenced by foundation geometry, soil-structure interaction, embedment depth, machine mass elevation, and damping characteristics. Advanced analytical approaches such as finite element analysis, modal analysis, harmonic analysis, response spectrum analysis, and time-history analysis are widely used to evaluate the realistic behaviour of machine foundations under static and dynamic loading conditions. The literature also highlights the importance of avoiding resonance by maintaining sufficient separation between machine operating frequency and foundation natural frequency.

The study further emphasizes the role of modern computational tools such as ANSYS, STAAD.Pro, and other finite element software in accurately predicting the dynamic response of machine foundations. Comparative analysis of different footing shapes is carried out to identify the most efficient geometry in terms of vibration control, structural stability, and load distribution while maintaining equal footing volume. The findings of the study are expected to provide a systematic understanding of the influence of footing geometry on turbo generator foundation performance and contribute toward the development of safer and more economical machine foundation design practices.

Keywords: *Turbo Generator Foundation, Dynamic Analysis, Machine Foundation, Vibration Analysis, ANSYS, Footing Geometry, Resonance, Finite Element Analysis.*

I. INTRODUCTION

Machines are the most important equipment in the industry. The load produced within the machine is dynamic in nature caused due to vibratory motion, impact of hammer, earthquake or wind, pile driving, etc. Repetitively acting load over a long period of time the performance, safety and stability of machine is very important and are largely depends on its foundation which makes foundation one of the important component of that machine. Machine foundation is designed for static and dynamic loading generated by machine supported on top of the foundation.

Design of machine foundation has been associated with the civil engineering discipline as soil mechanics specialist or structural design specialist gives the knowledge of the structural behaviour and design soil parameters but at the same time it is associated with the mechanical engineering discipline as to know data about the forces which are generating within the machine and how they are transferring to the foundation. To get the machine to desired performance level, it required the better interaction amongst all the concerned disciplines which are usually foundation designer and machine manufacturer from the planning stage till the installation of the machinery on the foundation.

The design of machine foundation is very complex than that of normal foundation which only supports static load. Bhatia says that machine foundations should be designed such that the dynamic forces of machines are transmitted to the soil through the foundation in such a way that all kinds of harmful effects are eliminated. The various types of heavy machinery require a much heavier support of foundation that can resist dynamic forces and vibrations. Those vibrations of machine may create harmful deformation and Resonance. Hence the design of machine foundation required to avoid the resonance and foundation will be safe.

Frame Foundation

Machine is supported on the deck slab which in tum is supported on base raft through columns and base raft rests directly over soil or on group of piles shown in Fig 1 4. In this case machine is treated as non-elastic inertia body whereas deck slab, and columns are considered as elastic inertia bodies and soil is considered as elastic media. In certain specific cases, base raft is also considered as elastic inertia body.

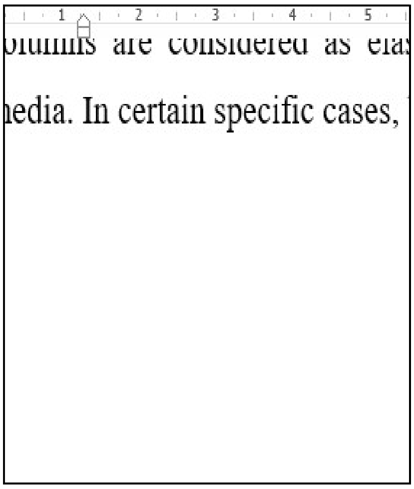

Fig 1 Typical Frame type Foundation

II. NECESSITY OF DESIGN OF TG FOUNDATION

TG foundation is very important structure and need special consideration while analysis and designing because of following reasons.

a) Superimposed load coming on the TG foundation is very huge and can cause shear or crushing failure.

b) Huge mass can cause settlement more than permissible limits.

c) Torsion (or Twisting) may occur if centre of gravity of machine and foundation is not in the same vertical line.

d) There are chances of resonance when machine operating frequency matches with natural frequency of the foundation and can cause premature fatigue of machine parts and damage of engine.

e) Amplitude of foundation may exceed permissible amplitude value and can cause huge cracks in the foundation or can damage adjacent structure.

f) There is possibility of losing of machine parts while operating and can cause unbalance force or moment on the foundation.

g) There are stream or hot air pipes, embedded in the foundation must be properly isolated otherwise can cause temperature effect on the foundation.

h) Foundation need to be coated with acid-resisting coating or suitable chemical treatment to avoid from machine oil and other chemical reactions.

III. STATE OF DEVELOPMENT

Mainak Mallik et. al. (2025) [1] The dynamic analysis of turbine foundations needs attention to detail in both modeling and interpretation of the results to examine the deficiency, if any, in design that may be the cause of excessive vibration in the machine and foundation system. The paper presents the results on various issues related to the mathematical modeling of the structure, machine, and soil for dynamic analysis as well as static analysis of the foundation system. The finite-element method provides an efficient tool for the modeling and dynamic analysis of TG foundations. Structural analysis and design (STAAD) connect provides a real computational environment for the modeling of the structure, machine, and soil in a single model and to perform free and forced vibration analysis. Investigation shows that the design of the TG foundation satisfies all the codal provisions and the requirements of the equipment supplier. Also, the test results show that the vibration amplitudes of the TG deck and the columns are well within the permissible limit. Hence, it can be concluded that the design is adequate for the proper operation of the machine. The excessive vibration in the foundation may be due to the misalignment of the shaft at higher power generation state.

Aysha Zaya K. E. N. et. al. (2025) [2] As machinery evolves, designing foundations to handle dynamic loads has become more complex. This study compares two block-type machine foundation models one with reinforced concrete and another with added polyurethane rubber for improved damping. Using STAAD.Pro, both were analyzed for static and dynamic loads at 3570 RPM. The rubber-based model showed better vibration absorption and flexibility. A machine learning model using Random Forest Classifier was developed in Python to predict foundation sustainability based on structural and vibration data. Results show that rubber integration reduces resonance risk, while AI enhances design efficiency and failure prediction.

Fatemeh Sharafi et. al. (2024) [3] Structural health monitoring has been widely used during the past decades to evaluate the safety of structural assets, detect damage at an early stage, and prevent unexpected and costly damages. The research in this field is often concerned with bridges and buildings and little research has been conducted on structural health monitoring of power plant infrastructures such as machine foundations. The turbo generator, also referred to as the heart of the power plant, is supported by massive concrete foundations in the turbine hall of thermal power plants. Most Turbine Generator (TG) foundations in thermal power plants are at or close to their design age. The reports on structural damage in thermal power plants show that cracks are frequently observed on the beams and columns of frame-type TG foundations. It is probably the most appropriate time for developing vigorous methods for health monitoring of power plant structures to extend their reliability and life span. This paper employs the vibration-based approach for damage detection of TG foundations. Analytical mode decomposition (AMD) and experimental mode decomposition (EMD) methods are both used for modal parameter identification. A genetic algorithm is further used for finite element model updating and damage detection. The performance of the method is investigated using a 3-D finite element model of a frame-type TG foundation.

Ameer A. Ahmed et. al. (2023) [4] The present work included the effect of the machine's mass elevation on the response of a high-speed turbo machine's frame foundation. The mass elevations of (12.6, 13.0, 13.3, 13.6, 13.9, and 14.2) m are selected for the dynamic analyses. A verification process is carried out to calculate the three-dimensional frame foundation's natural frequencies and mode shapes using Ansys software. The results show that the machine's masses must be included and applied at its specific elevation to reflect the true dynamic vertical response of the system as far as the mass height to top slab elevation ratio exceeds 5%. The results show a good agreement in calculating static and modal analysis with the study case. When neglecting the machine mass, the difference between the calculated natural frequencies for any mode shape is less than 10%.

Maksim Zubritskiy et. al. (2021) [5] The article considers the multimodal nonlinear static method as a seismic resistance estimation method of existing turbogenerator foundation structures. The object of research is the turbogenerator foundation on the Tom-Usinsk State District Power Station. The article proposes a modified algorithm for the characteristic point search by the nonlinear static method. According to the calculations results, the existing foundation structures after a partial equipment replacement and the construction site increased seismicity are operational.

Piyush K. Bhandari et. al. (2012) [6] The analysis and design of machine foundation requires more attention since it involves not only the static loads but also the dynamic loads caused by the working of the machine. The limiting amplitude and operating frequency of a machine are the most important parameters to be considered in analysis of machine foundation. The Elastic half space analogy method with embedment coefficients can be used for coupled modes of vibration to get the natural frequencies and amplitudes of foundation vibrations. With effect to depth of embedment there has been increase in natural frequency but considerable decrease in amplitude of foundation vibrations.

Shafii Abdullah et. al. (2012) [7] A rigid-moment frame supporting the turbinegenerator was designed according to BS 8110. This structure is subjected to vibrations of turbine-generators and seismic loading. Turbine-generator with its foundation is model as a single degree of freedom (SDOF) using RUAUMOKO program. RUAUMOKO program is employed in this study to analysis non-linear dynamic behaviour of turbine foundation using time-history analysis and Modified Takeda Model. Mode shape, natural period, natural frequency, nodal displacement, member forces and moment of reinforced concrete turbine foundation were obtained by running this program. The result shows that turbine foundation under Imperial Valley earthquakes does not exceed yield drift limit for monolithic connection and remain within the elastic condition. Thus, RC turbine foundation is safe and able to carry gravity load as designed according to BS 8110. Contradictory, turbine foundation experience exceeding yield drift limit but it is not safe and likely to collapse under San Fernando earthquake loading.

Livshits A. et. al. (2010) [8] suggest doing modal analysis for frequencies separation verification and very strict limits for amplitude of vibrations at machine bearings shall be checked by harmonic forced vibration analysis. Internal forces and displacements due to seismic excitation are estimated by Response spectrum Method. Suggest carrying out series of static analyses on various static and quasi-static loads for structural design of the turbine generator foundation, made of reinforced concrete. ANSYS/Civil FEM software provides an effective computational environment to perform all types of the analyses at once and to combine their results during the design process. Different types of finite elements are used for modelling concrete structures of the foundation, supporting piles, machine parts and their connection to the foundation. Design procedure in accordance with the relevant International and German, American and Israeli Codes and Standards is discussed. Description of applied loads is presented. Together with ordinary structural and environmental loads, specific machine loads for normal operation condition as well as emergency loads are detailed. Load combinations for ultimate state conditions as per IEC design practice are described. Numerical results for "Tzafit" gas turbine generator foundation are presented. ANSYS/Civil FEM software provides an efficient tool for dynamic analysis and structural design of the turbine-generator foundations. Analyses features and design procedure have been described in details.

Bhatia K. G. et. al. (2008) [9] Highlights the methods to improve machine performance and the design aids/methodologies for foundation design isolation system for heavy-duty machines. They recommend a higher level of interaction amongst all the concerned disciplines like soil specialist or structure specialist which should result in an improved machine performance. They briefly discussed about issues related to machine, foundation and soil and their modelling in software and analysis of the foundation. Influences of dynamic characteristics of foundation elements, viz. various issues related to mathematical modelling of machine, foundation and soil and interpretations of results. They also observed the elements like beams, columns, and pedestals etc. shows strong influence on the response of machine. Some case studies are also presented. The paper also touches upon the effects of earthquakes on machines as well as on their foundations. Use of commercially available finite element packages, for the analysis and design of foundations, is strongly recommended, but with some caution.

Fleischer, P. St. et. al. (2008) [10] Focuses on the investigations and studies on design principles for large machine foundations and requirements for turbo generators with respect seismic design demands and discuss the Equivalent Static Force Method and dynamic behaviour of the machine foundation. They also discuss local parameters such as ground acceleration and soil amplifications and mainly discussed the load and its distribution over the height. They also discuss for compact raft foundations, the soil-structure-interaction is an eminent attribute, as first eigen frequencies are in strong dependence to the bedding situation, and are often situated within the critical earthquake frequency range with regard to the soil amplification. Modal superposition has to be considered for table mounted machine foundation, as several eigen modes can affect the response of the structure significantly. With the advancement in the field of computer and numerical method, the foundation substructure (piles, soil, columns and springs) can be modelled by spring elements which give accurate dynamic behaviour of foundation. In concluding remark they says that that the global ductility of the foundation has to be set to a low value, and the focus on constructive measures for increasing the plastic bearing capacity. For practicable design of pedestals, foundation supports and machine anchorages, it is preferred to transfer seismic loads to static equivalent forces.

IV. PROBLEM STATEMENT

Study of vibration and dynamic analysis of machine foundation is carried out in ansys for deferent geometry of footing having same volume, the geometry details of the models are as follow.

 ISSN: 3107-6513

Table 1 Parameters to be consider for rectangular geometry analysis

Square	
Top Slab size	6 x 6 m
Top Slab Thickness	0.2 m
Height of Column	1.5 m
Size of column	0.5 x 0.5 m
Size of footing	6 x 6 m
Thickness of footing	0.2 m
Volume of footing	7.2 M^3
Rectangular	
Top Slab size	6 x 6 m
Top Slab Thickness	0.2 m
Height of Column	1.5 m
Size of column	0.5 x 0.5 m
Size of footing	6 x 8 m
Thickness of footing	0.15 m
Volume of footing	7.2 M^3
Circular	
Top Slab size	6 x 6 m
Top Slab Thickness	0.2 m
Height of Column	1.5 m
Size of column	0.5 x 0.5 m
Diameter of footing	8.48 m
Thickness of footing	0.127 m
Volume of footing	7.2 M^3
Oval	
Top Slab size	6 x 6 m
Top Slab Thickness	0.2 m
Height of Column	1.5 m
Size of column	0.5 x 0.5 m
Size of footing	2.8 x 9.6 m
Thickness of footing	0.29 m
Volume of footing	7.2 M^3

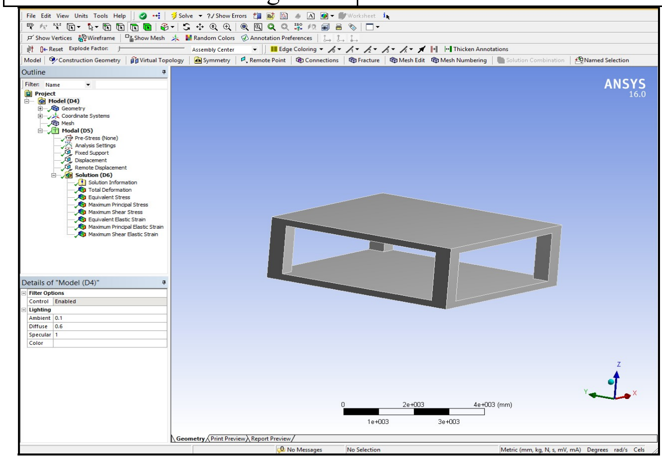
Fig 1 Square Model

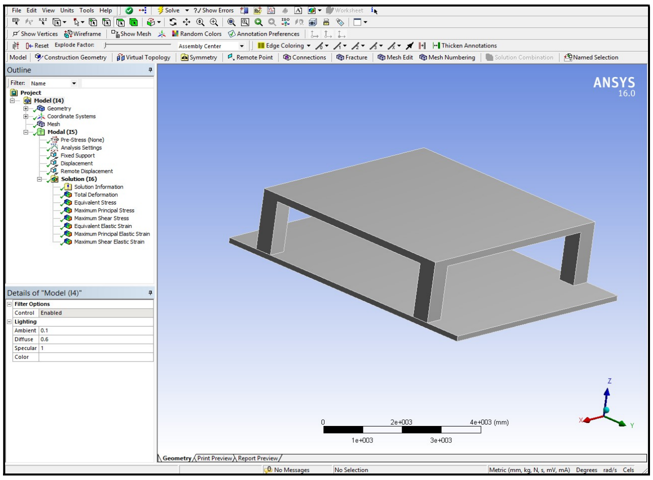
Fig 2 Rectangular Model

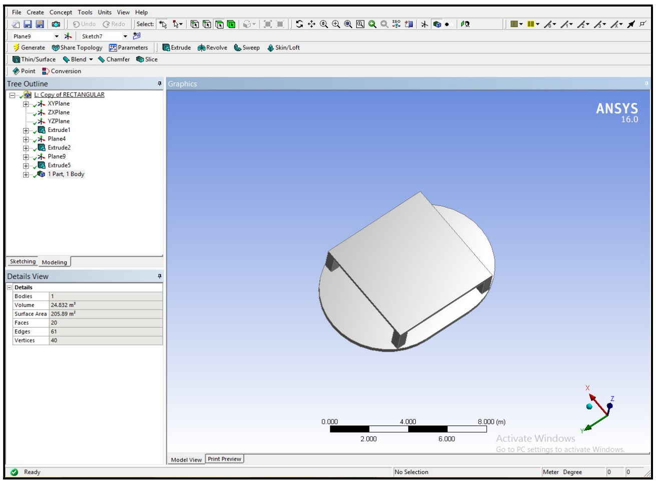
Fig 3 Circular Model

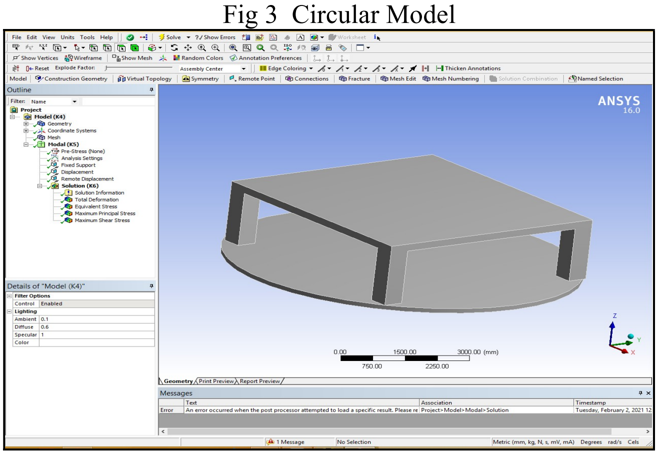
Fig 4 Oval Model

V. FINDING

Above literature survey is carried out for the study of turbo generator foundations subjected to dynamic loading. This study helps to understand the behaviour of machine foundation under dynamic loading and also helps to understand various terminology and definitions and important of machine foundation design. While going through the literature survey it is observed that the limited information is available on the frame foundation and that to scattered form. There is a need to have a systematic design approach including recommendations for selection of the sizes and shape of the frame foundation for turbo generator.

REFRENCES

1) Abdullah, S., and Hamid, N. H. A., (2012). “Modelling of Turbine-generator and Foundation as Single Degree of Freedom Using RuaumokoProgramme.”International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-2, Issue-2, December 2012, pp. 67-76.
2) Bhatia, K. G., (2008). Foundations for industrial machines, D-CAD Publishers, New Delhi, India.
3) Bhatia, K. G., (2008). “Foundations for industrial machines and earthquake effects.” ISET Journal of Earthquake Technology, Paper No. 495, Vol. 45, No. 1-2, March-June 2008, pp. 13–29.
4) Fleischer, P. St., and Trombik, P. G., (2008). “Turbo generator machine foundations subjected to earthquake loadings.” The 14th World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China.
5) IS 1893. (Part I) (2002). Criteria for earthquake resistant design of structures (Fifth Revision), BIS, New Delhi, India.
6) Livshits, A., (2010). “Dynamic Analysis and Structural Design of Turbine Generator Foundation.” European Built Environment CAE Conference, London.
7) Manohar.D “Dynamic Analysis of Machine Foundation” (IRJET) Volume: 04 Issue: 08 (2017)
8) Piyush K. Bhandari “Dynamic Analysis Of Machine Foundation” IJIRSET, Volume 3, Special Issue 4, 2014
9) Eric Wey ; Silky Wong “Vibratory Machine Foundation Design: When to Perform a Dynamic Analysis” ASCE 2013
10) Panel Mehmet Zülfü Aşık “Dynamic response analysis of the machine foundations on a nonhomogeneous soil layer” Elsavier Volume 24, Issue 2, March 1999
11) Panel Z.Huang S.Hinduja “Shape optimization of a foundation for a large machine tool” Elsavier Volume 26, Issue 2, 1986.