Parametric Study on Analysis and Design of Turbo Generator Foundation

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Abstract - 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. The object of the project is to Study of vibration and dynamic analysis of machine foundation in ANSYS for deferent geometry of footing having same volume.

Keyword: Dynamic Analysis, ANSYS, Machine foundation,

I. INTRODUCTION

The rapid growth of industrialization and power generation sectors has significantly increased the use of heavy rotating machinery such as turbo-generators, compressors, turbines, reciprocating engines, and large motors. These machines generate considerable dynamic forces during operation due to rotation, vibration, impact loading, and unbalanced motion. Unlike conventional static loads acting on ordinary structures, the loads transmitted by such machines are dynamic and continuously varying with time. Therefore, the design of machine foundations requires special consideration to ensure safety, stability, durability, and satisfactory performance throughout the operational life of the machine.

Turbo-generator (TG) foundations are among the most critical types of machine foundations used in thermal and nuclear power plants. A turbo-generator unit generally consists of a steam turbine coupled with an electrical generator operating at very high rotational speeds. During operation, the rotating masses produce cyclic forces and vibrations that are transferred directly to the supporting foundation system. If these vibrations are not properly controlled, they may lead to excessive deformation, cracking of structural components, settlement of soil, fatigue failure of machine parts, and malfunctioning of nearby structures or equipment. Hence, the analysis and design of turbo-generator foundations demand a detailed understanding of structural dynamics, soil-structure interaction, and vibration behavior.

Machine foundations differ substantially from ordinary foundations because they are designed not only to support static gravity loads but also to resist dynamic forces generated during machine operation. The primary objective of a machine foundation is to transfer these dynamic loads safely to the soil without causing harmful vibrations or resonance conditions. Resonance occurs when the operating frequency of the machine becomes equal or very close to the natural frequency of the foundation system. Under resonance, the amplitude of vibration increases drastically, which may result in severe structural damage and unsafe operating conditions. Therefore, it is essential that the natural frequency of the foundation be kept sufficiently away from the machine operating frequency.

The design of turbo-generator foundations involves the combined application of structural engineering, soil mechanics, and mechanical engineering principles. Structural engineers focus on stiffness, strength, deformation, and vibration characteristics of the foundation system, while geotechnical engineers evaluate soil properties, bearing capacity, settlement, and damping characteristics. Mechanical engineers provide information related to machine weight, operating frequency, unbalanced forces, and dynamic loading conditions. Proper coordination among these disciplines is necessary to achieve an efficient and economical foundation design.

In modern engineering practice, finite element analysis (FEA) has become one of the most effective methods for analyzing machine foundations subjected to dynamic loading. Advanced software such as ANSYS enables engineers to simulate the dynamic behavior of foundations with greater accuracy by considering geometry, material properties, boundary conditions, and vibration characteristics. Numerical modelling helps in evaluating important parameters such as natural frequency, deformation, stress distribution, and mode shapes, which are essential for safe and reliable design.

The geometry of the foundation plays a significant role in controlling the vibration response and structural performance of machine foundations. Different footing shapes provide different stiffness characteristics, stress distributions, and dynamic responses under similar loading conditions. Hence, a comparative study of various footing geometries becomes necessary to identify the most efficient and economical shape for turbo-generator foundations. In this study, four different footing geometries namely square, rectangular, circular, and oval footings having the same volume are analyzed using ANSYS software. The dynamic behavior of these footing shapes is evaluated based on parameters such as natural frequency, total deformation, and equivalent stress.

The present research aims to investigate the influence of footing geometry on the dynamic performance of turbo-generator foundations through finite element analysis. The study helps in understanding how different footing configurations affect vibration characteristics and structural response. The outcomes of the research can assist structural engineers in selecting suitable foundation geometries for heavy machine installations, thereby improving structural safety, operational efficiency, and economic feasibility.

Turbo-generator foundations require special attention during analysis and design due to the following reasons:

- Heavy superimposed machine loads may cause excessive shear stress and crushing failure in the foundation.
- Large mass and continuous vibration may result in differential settlement beyond permissible limits.
- Improper alignment between the center of gravity of the machine and foundation may produce torsional effects.
- Resonance may occur if the operating frequency of the machine matches the natural frequency of the foundation system.
- Excessive vibration amplitudes may cause cracking of the foundation and damage to adjacent structures.
- Unbalanced machine operation may generate additional dynamic forces and moments.
- Temperature effects due to embedded steam or hot air pipes may affect structural performance.
- Exposure to lubricants, oils, and industrial chemicals may deteriorate the concrete surface unless proper protective treatment is provided.

Therefore, the study of dynamic characteristics of TG foundations is essential to ensure safe machine operation, minimize vibration effects, and enhance the service life of both the machine and the supporting structure.

A. 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.

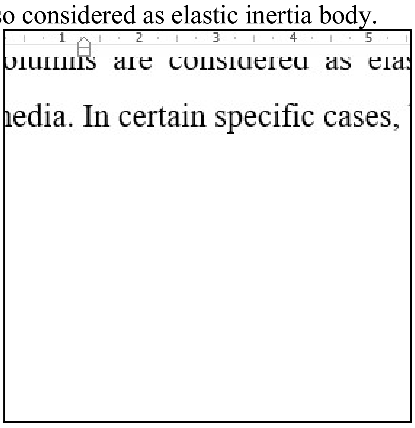


Fig 1 Typical Frame type Foundation

B. 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.

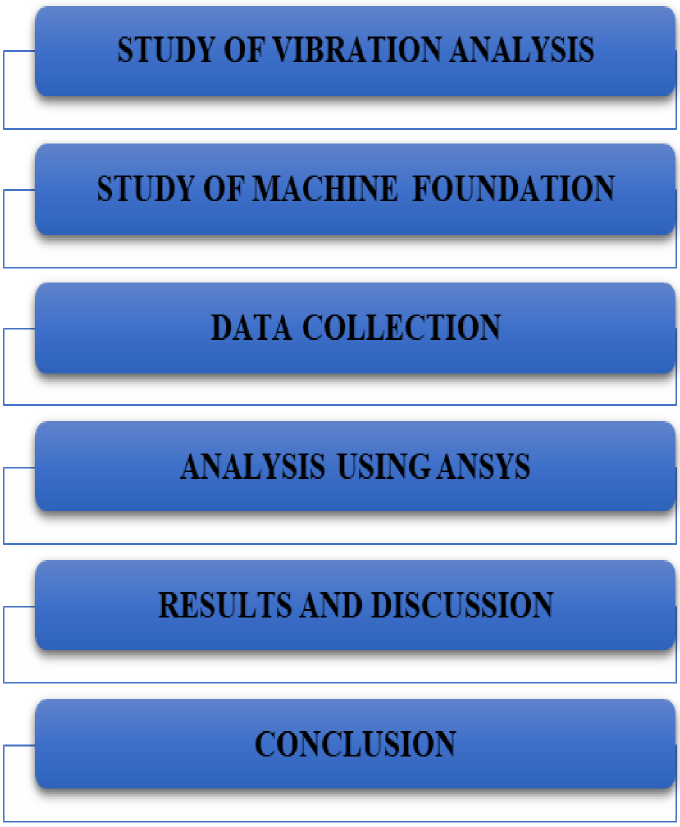
f) There is possibility of losing of machine parts while operating and can cause unbalance force or moment on the foundation.

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

II. METHODOLOGY

The finite element method (FEM) is a widely used method for numerically solving differential equations arising in engineering and mathematical modelling.



A. Problem Statement

Study of vibration and dynamic analysis of machine foundation is carried out in ansys for deferent geometry of

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footing having same volume, the geometry details of the models are as follow.

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

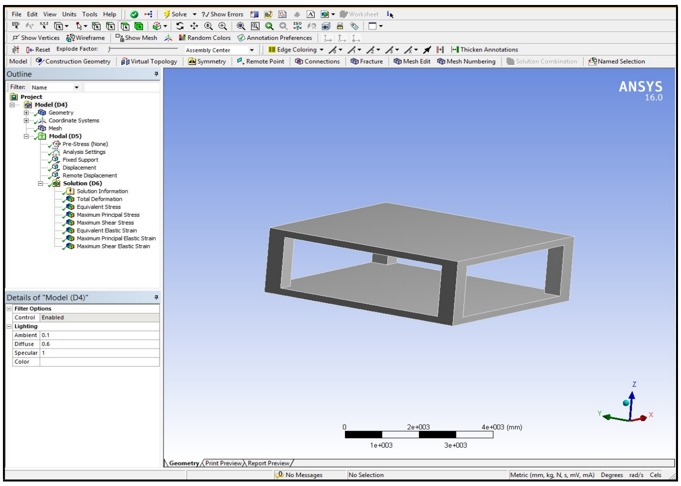


Fig 1 Square Model

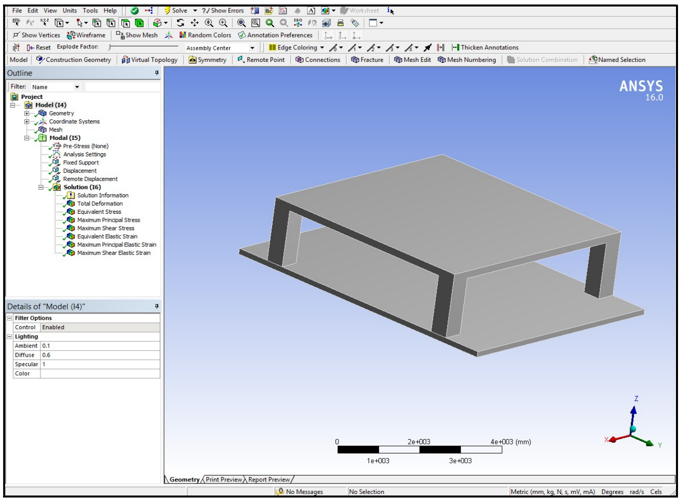


Fig 2 Rectangular Model

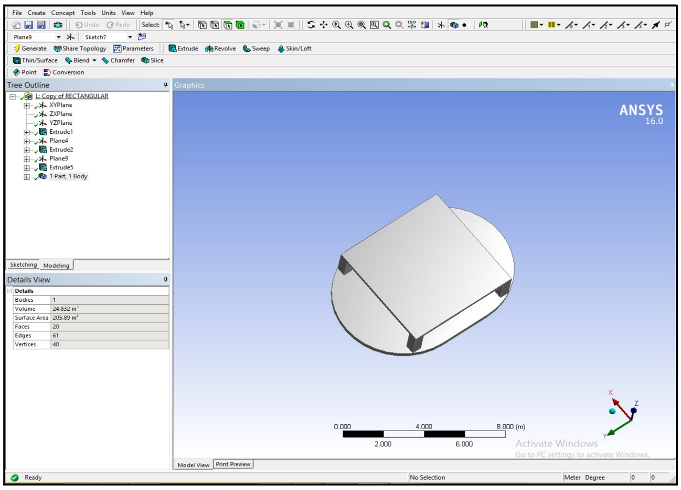


Fig 3 Circular Model

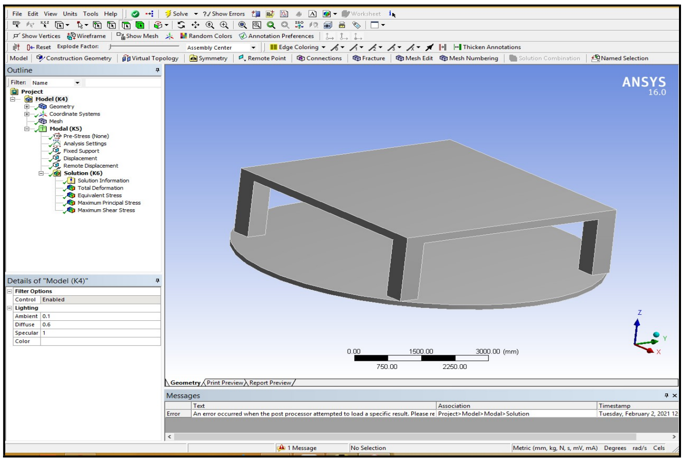


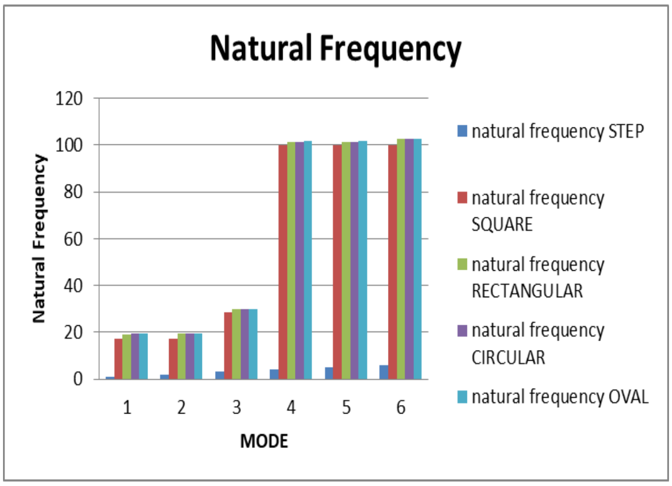
Fig 4 Oval Model

III. RESULTS OF ANALYSIS

A. Natural frequency

Table 2 Natural Frequency

Natural Frequency				
Step	Square	Rectangular	Circular	Oval
1	17.207	19.137	19.323	19.494
2	17.218	19.509	19.349	19.528
3	28.448	29.72	29.715	29.922
4	99.914	101.29	101.33	101.6
5	99.937	101.52	101.45	101.74
6	99.955	102.66	102.61	102.81



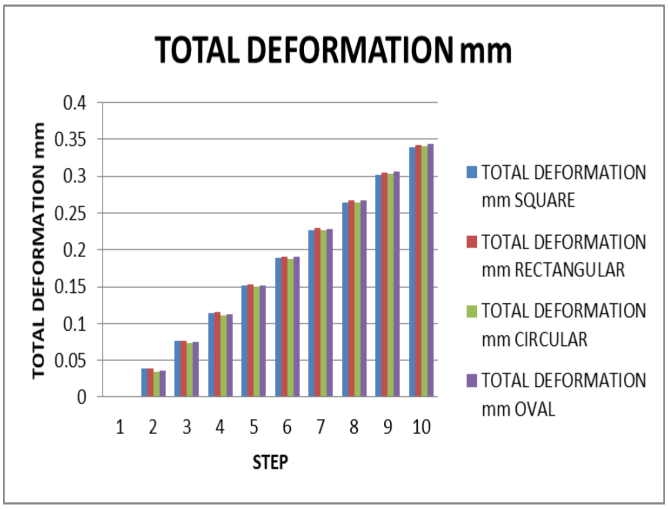
Graph 1 Natural Frequency

In above graph shows the results of natural frequency of all models in ANSYS, the result conclude that natural frequency of the oval shape footing is greater than other shape of footings by 10-15%.

B. Total Deformation

Table 3 Total Deformation mm

Total Deformation mm				
Step	Square	Rectangular	Circular	Oval
1	0	0	0	0
2	0.03945	0.039	0.0351	0.0361
3	0.077	0.077	0.0734	0.0746
4	0.11455	0.115	0.1117	0.1131
5	0.1521	0.153	0.15	0.1516
6	0.18965	0.191	0.1883	0.1901
7	0.2272	0.229	0.2266	0.2286
8	0.2649	0.267	0.265	0.267
9	0.302	0.305	0.303	0.3058
10	0.34	0.343	0.3416	0.344



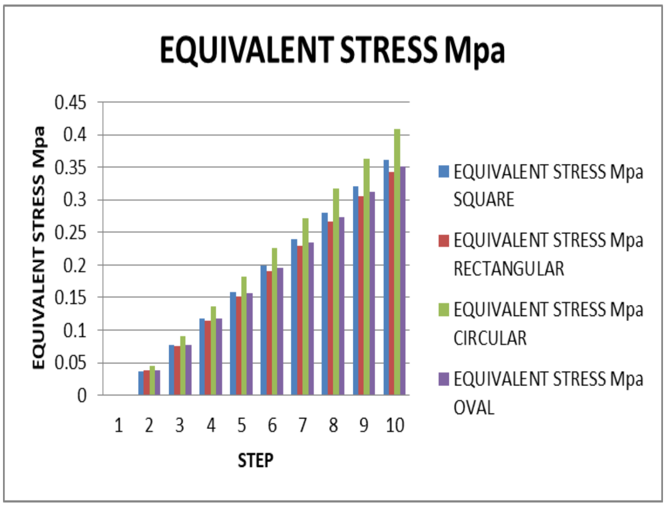
Graph 2 Total Deformation mm

In above graph shows the results of Total Deformation of all models in ANSYS, the result conclude that Total Deformation of the Rectangular shape footing is greater than other shape of footings by 15-20%.

C. Equivalent Stress

Table 4 Equivalent Stress

Equivalent Stress Mpa				
Step	Square	Rectangular	Circular	Oval
1	0	0	0	0
2	0.0368433	0.03783333	0.04483333	0.09
3	0.077393	0.07603333	0.09033333	0.07
4	0.1179433	0.11423333	0.13583333	0.17
5	0.15849333	0.152433333	0.181333333	0.156
6	0.1990433	0.190633333	0.226833333	0.195
7	0.23959333	0.228833	0.27233333	0.234
8	0.28	0.267	0.318	0.273
9	0.32098	0.3053	0.363	0.312
10	0.3611	0.3434	0.409	0.351



Graph 3 Equivalent Stress

In above graph shows the results of Equivalent Stress of all models in ANSYS, the result conclude that of Equivalent Stress the Circular shape footing is greater than other shape of footings by 10-20%.

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VI. CONCLUSION

In the present research work, a detailed parametric study was carried out to investigate the dynamic behavior of turbo-generator machine foundations with different footing geometries using finite element analysis in ANSYS software. Four different footing configurations namely square, rectangular, circular, and oval shapes were considered for the study. All footing models were designed with the same footing volume so that the effect of geometry alone on the dynamic performance of the machine foundation could be evaluated accurately. The comparative assessment was performed on the basis of important dynamic parameters such as natural frequency, total deformation, and equivalent stress.

Machine foundations are highly sensitive structures because they are continuously subjected to dynamic loads generated due to the operation of rotating machinery. Therefore, proper selection of footing geometry is essential to ensure vibration control, structural stability, operational safety, and long-term durability of the foundation system. The results obtained from the numerical analysis clearly indicate that footing geometry has a significant influence on the vibration characteristics and stress behavior of turbo-generator foundations.

The modal analysis results obtained from ANSYS show that the oval footing possesses the highest natural frequency among all the footing geometries considered in the study. The natural frequency of the oval footing was observed to be approximately 10–15% higher than that of square, rectangular, and circular footings. A higher natural frequency generally indicates greater stiffness of the foundation system and reduced susceptibility to resonance under operating conditions. The oval footing therefore demonstrates comparatively better resistance against dynamic vibration effects. However, despite its improved frequency characteristics, the oval footing may not always be the most practical or economical solution because of construction complexity, reinforcement detailing difficulties, and higher execution costs associated with its geometry.

The total deformation analysis indicates that the rectangular footing experiences the maximum deformation among all footing models. The deformation values were found to be approximately 15–20% greater compared to the other footing shapes. This behavior suggests that the rectangular footing possesses relatively lower stiffness against dynamic excitation and may be more susceptible to displacement and vibration effects during machine operation. Excessive deformation in machine foundations may lead to misalignment of machinery, vibration amplification, and possible serviceability problems. Although the rectangular footing may offer advantages in terms of construction simplicity and space utilization, additional design considerations may be necessary to control deformation within permissible limits.

The equivalent stress analysis reveals that the circular footing develops the highest equivalent stress values among all footing geometries. The stress values were approximately 10–20% higher compared to square, rectangular, and oval footings. Higher stress concentration within the footing may increase the possibility of cracking, fatigue damage, and reduction in structural durability under repeated dynamic loading conditions. The stress distribution pattern observed in the circular footing indicates that although circular geometry may provide uniform load transfer characteristics, it may also lead to localized stress intensification under machine-induced vibrations.

Among all the footing shapes analyzed, the square footing demonstrates comparatively balanced and stable performance in terms of deformation, stress distribution, and vibration characteristics. The square footing provides adequate stiffness with moderate natural frequency values and comparatively lower stress concentration. In addition, square foundations are simpler to design, easier to construct, and more economical in practical engineering applications. Due to these advantages, square footing geometry can be considered one of the most suitable options for turbo-generator machine foundations.

The overall comparative study concludes that square and rectangular footing geometries are comparatively more economical and practical for machine foundation applications when compared with circular and oval footings. Although oval footing exhibits higher natural frequency and improved stiffness characteristics, its construction difficulties and cost considerations reduce its practical feasibility. Similarly, the circular footing experiences higher equivalent stresses, which may affect long-term structural performance. Therefore, from both structural and economic perspectives, square and rectangular footings are found to be more appropriate for turbo-generator foundations.

The study also demonstrates the effectiveness of finite element analysis using ANSYS software in evaluating the dynamic response of machine foundations. The numerical modelling approach provides accurate insight into vibration behavior, deformation patterns, and stress distribution of different footing geometries under dynamic loading conditions. Such analysis can assist structural engineers in optimizing foundation design for heavy industrial machinery and improving the safety and reliability of machine foundation systems.

The findings of the present study can be useful for the design and analysis of turbo-generator foundations in thermal power plants, industrial facilities, and heavy machinery installations. Future research may include the effects of soil-structure interaction, damping characteristics, seismic loading, varying machine operating frequencies, and different material properties to achieve a more comprehensive understanding of machine foundation behavior under dynamic conditions.

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