# DYNAMIC ANALYSIS AND STRUCTURAL DESIGN OF TURBO GENERATOR FOUNDATION

**Madhu Priya M [1], JeyaKumar D[2]**

[1] *PG Scholar, Department of Civil Engineering, PRIST University, Thanjavur, Tamil Nadu.*
[2] *Assistant Professor, Department of Civil Engineering, PRIST University, Thanjavur, Tamil Nadu.*

## ABSTRACT

*Development in manufacturing technology has given rise to greater dynamic forces which leads to the development of greater stress. Thereby to ensure better performance and to avoid failures, foundation design plays a vital role. A key ingredient to the successful foundation design for a turbo-generator is the careful engineering analysis of the foundation response to the dynamic loads from the anticipated operation of the machine. This paper highlights a detailed procedure for the structural design of a framed foundation structure along with dynamic analysis of machine foundation design.*

*Index Terms—Dynamic Analysis, Framed foundation, Machine foundation, Turbo-generator.*

## INTRODUCTION

Turbo-generator is a vital and expensive part in a power plant complex. Safety, stability, durability and reliability of structure should be considered while designing the foundation system. The analysis and design of turbo generator foundation is a complicated problem because of the interaction of Structural engineering, Geotechnical engineering and vibration theory. It is essential that the foundation for turbo-generator is designed adequately for all possible combinations of static and dynamic loads. The foundation system may be block type, frame type, frame with isolator. The frame type foundation is preferred for supporting high speed machinery due to saving in space, time and materials, easy accessibility for inspection of machine and less liability to cracking due to settlement and temperature changes. Frame foundation system comprises of a top deck, a set of frames and a base raft.

## LITERATURE SURVEY

Jayarajan [1] focuses on dynamic analysis to calculate natural frequency of vibration under a loaded condition shall not fall within ±20% of operating frequency and critical speeds. Jayarajan [1] highlights dynamic analysis issues related to mathematical modelling of structure, soil and machine.

Since the finite element method provides an efficient tool for dynamic analysis and modelling, Jayarajan [1] uses SAP 2000 to perform free vibration and forced vibration analysis and also studied the finite element modelling of framed foundation structure and concludes that dynamic analysis needs attention to detail both in the interpretation of results as well as modelling of turbine foundation. K. G.Bhatia [2] has taken measurements of field vibration on a 200MW turbo generator foundation and studied the dynamic behavior of turbo-generator foundations of various ratings. Turbo-generator foundation also indicated the importance of soil structure interaction effect on the dynamic response and recommendations, including the soil structure interaction effect for dynamic response calculations based on the results of the analytical and experimental studies. Based on detailed seismic analysis, Fleischer [3] elaborates practical design approach of spring mounted, table mounted and raft type foundation system and given importance to load distribution over the height apart from local parameters such as soil amplifications and ground accelerations.

Peter Nawrotzki [4] presents a systematic overview of the static analysis and dynamic analysis of turbine reinforced concrete foundations and also focuses on the load cases to be applied for foundation. Peter Nawrotzki [4] evaluates the value of static foundation stiffness and dynamic foundation stiffness and provides the required ultimate limit and serviceability limit state checks. Fang Ming [5] performs detailed investigations on dynamic characteristics of the turbine foundation soil system, a highly developed and complex finite element model was constructed to consider soil effect and facility vibration. Considered all major components of the system, including shaft, journal bearing, piers, deck, rotors, piles, foundation mat and soil medium have been included along with the full interaction between the facility, the foundation, and the soil medium is taken into account. Fang Ming [5] analyzed 1000MW turbine foundation soil system under excitations from earthquakes and rotor unbalances. Three dimensional viscous spring boundary elements have been used for exploring the influence of soil structure interaction on the response of the system. Effect on the acceleration and internal force is minimal, the presence of soil does affect the displacements of the system under seismic excitations.

Shasmer Prakash [6] discuss the analyzing methods for determining the response of foundations due to vibratory loads and design of machine foundation is made by idealizing the foundation soil system as a spring mass dashpot model having single or double degrees of freedom. Since most foundations for machine is treated as surface footing, the soil spring and damping values can obtained by following the impedance compliance function approach and also by using the elastic half space analog. Arkady Livshits [7] performed modal analysis for verification of frequency separation, harmonic forced vibration analysis checks limit for amplitude of vibrations at machine bearing. Under seismic excitation, Response spectrum analysis gives an estimation of internal forces and displacements. Structural design turbine generator reinforced concrete foundation requires a series of static analysis of quasi-static loads and various static loads. Bharathi [8] studies the codes/standards includes IS 2974, CP 2012, DIN 4024 and ACI3513R04 and reviews the variation among codes/standards of different countries for the design of machine foundations.

Bhatia [9] carried out that investigation of the dynamics of the machine foundation system is very vital and the consideration of earthquake effects on machines as well as on their foundations adds complexity to the system. The safety, performance and stability of machines depend largely on their design, interaction and manufacturing with their supporting frame. In this case, the machine foundation system should be able to withstand the action of earthquake loading up to the safety limit without collapse. Bhatia [9] described that the suitability of machine foundations depends not only on the forces subjected to act, but also on their behavior of machine foundation when exposed to dynamic loads, which depends on the natural frequency of the foundation and speed of the machine hence vibration analysis becomes necessary. A detailed vibration analysis is done for each and every machine foundation providing dynamic behaviour of foundation and its components for satisfactory performance of the machine. Bhatia [9] recommendations, equates the vertical seismic coefficient with horizontal seismic coefficient in application to machine-foundation in order to get better performance for the systems. Sukanta Adhikari **[**10**]** illustrates the critical aspect in the design of a turbo generator foundation for a thermal power plant with respect to IS 2974 (Part 3)-1992 and other international standards. Due to some contradiction in demands for seismic design, Fleischer [3] put forward an idea for consideration on a simplified method of design principles for large machine foundation and it is preferred to transfer seismic to static equivalent force loads for practical design of pedestals, machine anchorages and foundation supports.

Karthigeyan [11] have pursued harmonic analysis of a finite element model for a steam turbine tabletop using a combination of beam and plate elements to compute the amplitudes of vibration for the out off-balance machine loads and to limit amplitude to a suitable acceptance criterion. They highlights that the amplitudes computed from lumped mass models due to the participation of flexural modes are lower than the amplitude of the detailed finite element model. Ali Ossama [12] compared the study between frame element and brick element models were performed under the effect steady state forces and harmonic excitation forces. In order to identify the problem, the simulation of the model was performed in software for finite element analysis, SAP: 2000.Frame element and brick element models were constructed to study the effect of rigid links distribution and element type on the mass foundation pedestal responses and elastically suspended turbine generator subjected to dynamic loads of reinforced concrete column foundation is optimized. The design objective is to avoid resonance of the natural frequency of foundation columns with first harmonic excitation of the generator.

Ping Jiang [13] uses Staad pro v8i to perform modal analysis and proposes the use of DMF (Dynamic Magnification Factors) to determine the acceptability of mode shapes and natural frequencies. Ping Gu [14] proposes a new DPF (Dynamic Participation Factor) for design and design of structures supporting large turbine generators and rotating machines. Based on the approach on modal synthesis Lakshmanan [15] developed a simplified analytical formulation for computing peak dynamic responses of turbine-generator pedestals and focuses on the effect of the variability on the amplitudes of the various modes and variability of elastic modulus of concrete. For accurate determination of resonant frequencies, Moreschi [16] studied the application of the harmonic analysis technique for resonant frequencies of individual structural members in large steam-turbine generator foundations and proposed a systematic procedure for the accurate determination of the local structural vibration properties and details of the implementation is done using the GT STRUDL software.

Sungyani [17] considered the winkler spring soil model, dynamic analysis of Turbo generator foundation and solid Finite element modelling. The frequency dependent soil impedance, stiffness and damping for various mode shapes are addressed and dynamic response of foundation was analyzed .The soil foundation system were simulated in SAP: 2000 software.

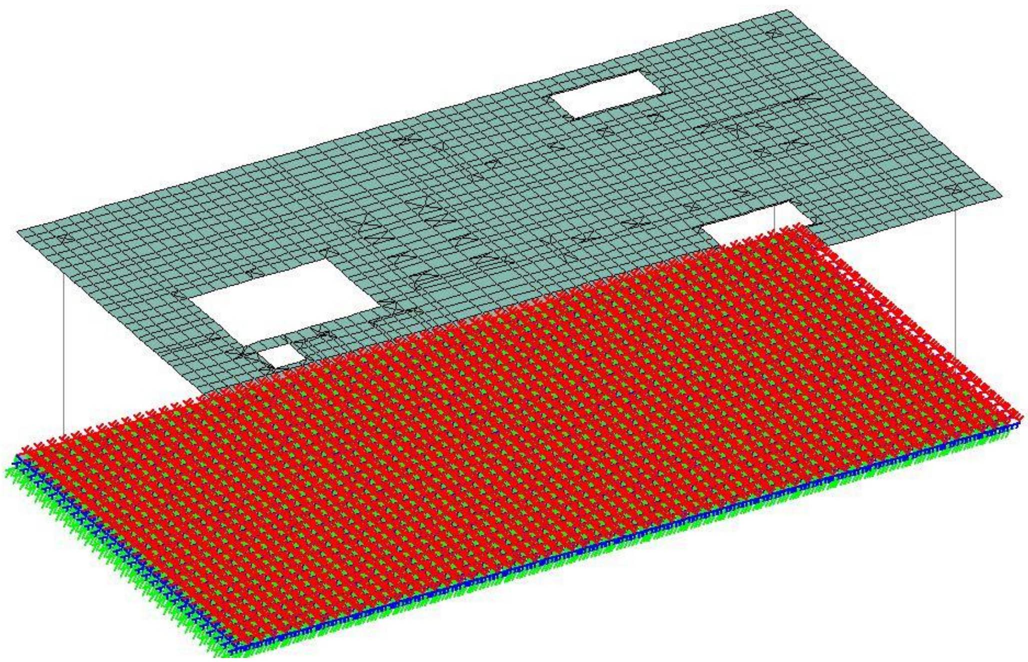
## CODAL PROVISIONS

<table>
<tr><th>Description</th><th colspan="3">IS 2974- 3</th></tr>
<tr><td rowspan="4">Sizing of Foundation</td><td>Top deck</td><td>Girders which support Turbine</td><td>Girders to Support Generator</td></tr>
<tr><td>Clear span to depth ratio</td><td>2 -3</td><td>2.5 – 3.5</td></tr>
<tr><td>Depth to width ratio</td><td>1 -3</td><td>1 -1.5</td></tr>
<tr><td colspan="3">Base Raft<br>Ratio of Bending stiffness of the base and largest column in transverse direction $\geq 2$<br>The thickness of the base raft should not be less than 0.07 $L^{4/3}$, L is the average of two adjacent clear span length.</td></tr>
<tr><td>Eccentricity</td><td colspan="3">Under unavoidable circumstance, a maximum eccentricity of 3% base dimension may be allowed.</td></tr>
<tr><td>Frequency Ratio</td><td colspan="3">$1.2 < \frac{\text{operating frequency}}{\text{natural frequency}} < 0.8$</td></tr>
<tr><td>Limiting Amplitude</td><td colspan="3">Amplitudes $\leq$ 0.07 mm in horizontal direction.<br>Amplitude $\leq$ 0.12 mm in vertical direction.</td></tr>
<tr><td>Description</td><td colspan="3">IS 2974- 3</td></tr>
<tr><td rowspan="2">Minimum Reinforcement</td><td>Top Deck</td><td>Column</td><td>Base Mat</td></tr>
<tr><td>Top and bottom=0.25% of $A_g$ (each)<br>Side = 0.1% of $A_g$</td><td>Longitudinal= 0.8% of $A_g$</td><td>Top and bottom=0.12% of $A_g$ (each)<br>Intermediate = 0.06% of $A_g$ (if raft thickness >2m)</td></tr>
<tr><td>Fatigue factor</td><td colspan="3">For dynamic analysis use Fatigue factor = 2</td></tr>
</table>

## MODELING

Turbo generator foundation has been modeled as a space frame where top deck and base raft as plate elements and columns as beam elements using STAAD. Pro software. Foundation has been provided with fixed-but supports with spring constant.

| S.No | Description | Dimension/Data |
|---|---|---|
| 1 | Top Deck and bottom raft | 15.5 m x 7.5 m |
| 2 | Depth of base raft | 2 m ($0.07L^{4/3}$=$0.0711.5^{4/3}$=1.) |
| 3 | Size of columns | 1.2 m x 1.2 m |
| 4 | Material | M-30 , Fe-500 |
| 5 | Seismic Inputs | Z = 0.16 (zone III) |
| 6 | Live load | 20 kN/$m^2$ |
| 7 | Pressure on base plate due to soil | 17.95 kN/$m^2$ |



**MODEL OF TURBO GENERATOR FOUNDATION**

## ANALYSIS

Static and dynamic analysis has been performed and design of top deck slab, base raft and columns using the results of analysis. Dynamic examination has been performed to find the displacement, natural frequency and maximum amplitude of vibration.

(IJAER) 2017, Vol. No. 13, Issue No. III, March **e-ISSN: 2231-5152, p-ISSN: 2454-1796**

**DYNAMIC ANALYSIS**

Dynamic analysis consists of both free vibration analysis and forced vibration analysis. Free vibration analysis is carried out to calculate natural frequencies and modal shapes of foundation. Forced vibration analysis is used to determine the displacement due to amplitude unbalanced force.

| | | |
|---|---|---|
| Balance grade quality | G | = e ω mm/sec |
| Eccentricity | e | = 6.3 / ω mm |
| Amplitude of exciting force | | = m e $\omega^2$ |
| Time Step | | = e / 10 |

**STATIC ANALYSIS**

Static Analysis is done to determine forces of each elements Primary load cases includes (1) Static load (2) Dead load (3) Live load (4) Short circuit + load (5) Short circuit – load (6) Thermal Expansion load Longitudinal (7) Thermal Expansion load Transverse (8) Loss of blade + load (9) Loss of blade – load (10) Static load at Torque (11) Dynamic vertical + (12) Dynamic vertical – (13) Dynamic horizontal + (14) Dynamic horizontal – (15) Dynamic Axial + (16) Dynamic Axial – (17) Temperature load (18) Shrinkage load (19) Seismic X (20) Seismic Y ( 21) Seismic Z

Load combination to be considered for design

a) Operating condition
   DL+OL+NUL+TLF
b) Short circuit condition
   DL+OL+NUL+TLF+SCF
c) Loss of Blade condition/Bearing failure condition
   DL+OL+TLF+LBL/BFL
d) Seismic condition
   DL+OL+NUL+TLF+EQL

DL Dead Loads
OL Operating Loads
LBL Loss of Blade condition
TLF Temperature Loads
SCF Short circuit Loads

## RESULTS

**AMPLITUDES OF VIBRATION**

| | | | |
|---|---|---|---|
| Maximum Horizontal Displacement | 0.0215 mm | Maximum Vertical Displacement | 0.0181 mm |
| Amplitude of vibration (Microns) | 21.5 µ | Amplitude (Microns) | 18.1 µ |
| Allowable Amplitude | 40 µ | Allowable Amplitude | 20 µ |

The amplitude of vibration of machine from STAAD. Pro are within limits.

## CALCULATED FREQUENCIES

| MODE | FREQUENCY (CYCLES/SEC) | PERIOD (SEC) |
|---|---|---|
| 1 | 0.000 | 0.00000 |
| 2 | 5.076 | 0.19701 |
| 3 | 9.045 | 0.11055 |
| 4 | 12.412 | 0.08057 |
| 5 | 17.727 | 0.05641 |
| 6 | 32.242 | 0.03102 |

## FREQUENCY RATIO

Natural frequency of Turbo Generator foundation shall be 20% away from operating frequency.
For the Static STAAD model frequency and period of 5.076 cps and 0.19701

| Frequency (Cycles/per second) | RPM | 20 % of RPM | +20% of RPM | -20% of RPM |
|---|---|---|---|---|
| 5.076 | (5.076 x 60) = 304.56 | (6800 x 0.2) = 1360 | (6800+ 1360) = 8160 | (6800-1360) 5440 |

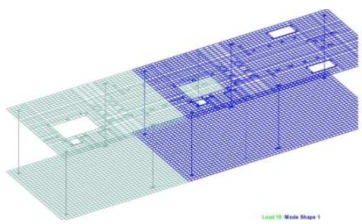
Frequency is not in the range between 5440rpm – 8160 rpm. The natural frequency of the foundation is 304.56 rpm which is much lower than the operating frequencies of turbine and machine.

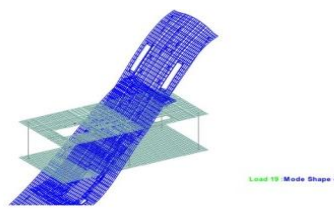
## REINFORCEMENT DETAIL

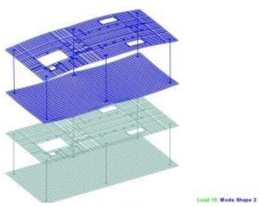
| TOP DECK REINORCEMENT | | | |
|---|---|---|---|
| **Mx/My** | **Required $A_{st}$** | **Provided $A_{st}$** | **Provided Rod Details** |
| $M_x$ | 7095.14 $mm^2$ | 7311 $mm^2$ | Provide Y32 at 110 mm c/c (2 layers bundled rods) |
| $M_y$ | 6516.74 $mm^2$ | 6702 $mm^2$ | Provide Y32 at 120 mm c/c (2 layers bundled rods) |
| Provide Side reinforcement of Y 20 at 110 mm c/c<br>Provide Shear reinforcement of Y 12 at 220 mm c/c | | | |
| **BOTTOM RAFT REINORCEMENT** | | | |
| **Mx/My** | **Required $A_{st}$** | **Provided $A_{st}$** | **Provided Rod Details** |
| $M_x$ | 8966.06 $mm^2$ | 8976 $mm^2$ | Provide Y40 at 140 mm c/c (2 layers bundled rods) |
| $M_y$ | 8460.00 $mm^2$ | 8976 $mm^2$ | Provide Y40 at 140 mm c/c |

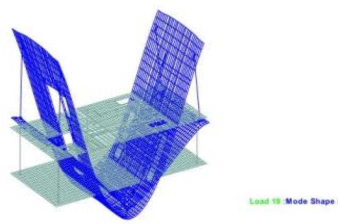
| | | | |
|---|---|---|---|
| | | | (2 layers bundled rods) |
| Provide Shear reinforcement of Y 12 at 140 mm c/c | | | |
| **COLUMN REINORCEMENT** | | | |
| **COLUMN SIZE** | **Minimum $A_{st}$ Required** | **Provided $A_{st}$** | **Provided Rod Details** |
| 1.2 m x 1.2 m | 11520 $mm^2$ | 12867.96 $mm^2$ | Provide Y32 – 16 Nos |
| | 11520 $mm^2$ | 12867.96 $mm^2$ | Provide Y32 – 16 Nos |
| Provide Stirrups of Y 10 at 100 mm c/c | | | |

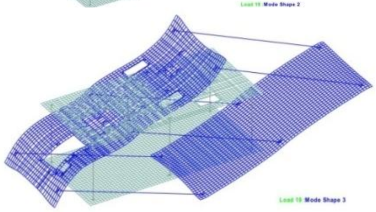
**MODE SHAPES**

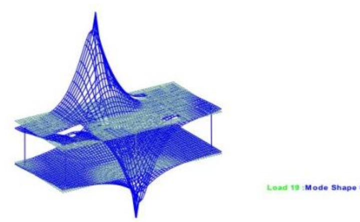



# CONCLUSION

An extensive study about the dynamic loads and static loads, frequency, amplitude, eccentricity and code/standards of machine foundation is carried out and observed the procedure for the design of machine foundation. A very less Research work has been done on turbo generator foundation. It has been concluded that the dynamic analysis of turbine generator foundations needs attention to detail both in modelling and interpretation of the results and also to consider the issues on mathematical modelling of structure, soil and machine for dynamic analysis. The Turbo generator foundation has been successfully analyzed using STAAD. Pro. The design of top deck, column, base raft has been done according to IS 2974(part 3):1992 and it has been found that the dimensions of top deck and base raft are safe.

## REFERENCES

[1] Jayarajan P., Kouzer K.M, "Dynamic analysis of turbo-generator machine foundations", Journal of Civil Engineering and Environmental Technology, Volume 1, Number 4; August, 2014, pp. 30 – 35.

[2] Bhatia K.G, "Foundations for Industrial Machines and Earthquake Effects", ISET Journal of Earthquake Technology, Vol.45, No.1-2, March-June 2008, pp. 13-29.

[3] P. St. Fleischer, P.G. Trombik, "Turbo generator machine foundations subjected to earthquake loadings", The 14th World Conference on Earthquake Engineering,2008.

[4] Peter Nawrotzki, Gunter Huffmann and Timur Uzunoglu, "Static and Dynamic analysis of concrete turbine foundations", Structural Engineering International, Volume 18, Number 3, August 2008, pp. 265-270.

[5] Fang Ming, Wang Tao , "Dynamic behavior of turbine foundation considering full interaction among facility", structure and soil,15thWCEE,2012.

[6] Shasmer Prakash, Vijay.K.Puri, "Foundation for vibrating machines, Journal of structural engineering", SERC, Special Issue, April-May, 2006.

[7] Arkady Livshits, "Dynamic analysis and structural design of Turbine generator foundations", European built environment CAE conference.

[8] Bharathi M, Dhiraj Raj and Dr. R.N. Dubey, "Codal Provisions for Design of Machine Foundations", International Symposium Geohazards: Science, Engineering and Management, November 20-21, 2014, pp 459-464.

[9] Bhatia K.G. "Foundations for Industrial Machines—A Handbook for Practicing Engineers", D-CAD Publishers, 2008.

[10] Sukanta Adhikari , "Turbo generator foundation", Unpublished

[11] Karthigeyan V., Prakhya, G. K. V. &Vekaria, K., "Dynamic Analysis of a Steam Turbine Support Structure", Eighth International Conference on Civil & Structural Engineering Computing, September, 2001, pp. 299-300.

[12] Ali Ossama, "Effective Modeling of Mass Concrete Foundation Under Dynamic Loads", Master Thesis, The American University in Cairo, 2006

[13] Ping Jiang, " Modal Analysis for Steam Turbine/Generator Machine Table Top Foundation", ASCE,May 12-15, 2010, pp. 2684-2691

[14] Ping Gu, "New Dynamic Participation Factor for Turbine-Generator Foundations", May, 2009, pp. 54-62.

[15] Lakshmanan N, Gopalakrishnan N., "New Design Approach for Computing Peak Dynamic Response of Turbo Generator Pedestals Using Modal Synthesis", ASCE, February, 2006, pp 31-37.

[16] L.M.Moreschi and F.Farzam, "Determination of Local Structural Vibration Properties for the Design of Machine Foundations", ASCE, April, 2005, pp.1-10.

[17] Sungyani Tripathy, A.K Desai, "Dynamic analysis of turbo generator frame foundation using SAP: 2000 v 17.1 software" , 50th Indian Geotechnical Conference,2015

[18] IS: 2974 (Part III)-1992, Code of Practice for Design and Construction of Machine Foundations - Foundation for Rotary Type Machines (Medium and High Frequency), BIS New Delhi, India.

[19] Srinivasulu, P. and Vaidyanathan, V, " Handbook of Machine Foundations", Tata McGraw-Hill Publishing Company,1980

[20] ISO 1940-1, "Mechanical Vibration – Balance Quality Requirements of Rigid Rotors – Part 1: Determination of Permissible Residual Unbalance",1993.

[21] Staad pro v18, Structural design program, Computers and Structures Inc., Berkeley, California. www.csiberkeley.com.

[22] Madhu Priya M, "Dynamic Analysis And Structural Design Of Turbo Generator Frame Foundation – A Review" INTERNATIONAL JOURNAL OF ADVANCES IN ENGINEERING RESEARCH e-ISSN: 2231-5152/ p-ISSN:2454-1796 in Vol 12, Issue 3, September, 2016