Case Study On Analysis of Steam Turbine Generator Foundation

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Abstract* - in manufacturing technology has provided machines of higher ratings with better tolerances and controlled behaviour. The increased dependence of society on technology provides no room for failure and demands equipment and systems with higher performance reliability. The design of foundations for such machines requires specialised knowledge. Codes relating to machine foundations provides only general guidance. There are hardly any works of reference which provide detailed information on different types of machine foundations. Turbine generator or turbo-generator is the power generation machinery used in power plants. It is the most vital and expensive equipment of a power plant. In the present study an attempt has been made to show the detailed procedure for the finite element modelling, static and dynamic analysis of the turbogenerator foundation structure. To demonstrate the analysis procedure, both static and dynamic, model of steam turbo generator foundation of a plant in Buxar, Bihar is done using software SAP2000.Free vibration analysis has been carried out for obtaining the natural frequencies of the foundation and forced vibration analysis has been carried out for obtaining the amplitude and velocity of vibrations. Also the attempt has been made for manual dynamic analysis of turbogenerator foundation. For manual calculations and design MS excel sheets are used which saves time and arithmetic mistakes. The design has been carried out as per IS 2974 Part-III (1992) and IS 456:2000 based on the static analysis results.

***Keywords* - Dynamic Analysis, Framed foundation, Machine foundation, Turbo-generator.**

I. INTRODUCTION

Turbo-generator is a vital and expensive part in a power plant complex. The performance, safety and stability of machines depend largely on their design, manufacturing and interaction with environment. 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. Machine transmits vibrations to the structures supporting them. Hence it is important to design and develop such structure which sustains the vibration of machinery. 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.

II. OBJECTIVE

The response of the foundation is then obtained through free vibration analysis (Eigen analysis) and harmonic forced vibration analysis.

- To analyze the turbogenerator foundation for static loads and dynamic loads combinations in accordance with IS 2974(Part 3):1992.
- To study different types loads that are applicable in turbogenerator foundation.
- To check for the resonance conditions of the turbogenerator foundation under free vibration analysis.
- To observe the dynamic behaviour of foundation under time history analysis.

III. LITERATURE SURVEY

Jayarajan [13] 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 [13] highlights dynamic analysis issues related to mathematical modelling of structure, soil and machine. Jayarajan [13] 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 [10] has taken measurements of field vibration on a 200MW turbo generator foundation and studied the dynamic behavior of turbo-generator foundations of various ratings. K. G.Bhatia [10] has concluded that higher level of interaction amongst all the concerned disciplines is required. It is observed that not only the dynamic behaviour of foundation as a whole but also its elements, viz., beams, columns, pedestals,etc., show strong influence on the machine response. Based on detailed seismic analysis, Fleischer [11] 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 [12] 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 [12] evaluates the value of static foundation stiffness and dynamic foundation stiffness and provides the required ultimate limit and serviceability limit state checks. Shasmer Prakash [9] 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. 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.

IV. Input Data

The dynamic analysis of a turbine foundation requires machine input data from turbine & generator manufacturer and soil properties from geotechnical. A check list required for the turbine foundation design is given below.

- Overall dimensions of the machine
- The height at which the centre line of the shaft of the machine is located from top of concrete deck slab.
- Operating speed of the machine.
- The loads and locations of valves and pipes to supported on deck slab.
- Dynamic loads generated during the operation of the machine.
- Different load combinations generated during the operation of the machine.
- Frequency ratio and amplitude of vibration.
- Allowable bearing capacity of the soil.
- Dynamic shear modulus, Poisson's ratio and mass density of soil.

V. Preliminary Sizing Of Turbine Foundation

The preliminary sizing of the top deck beams and columns have been considered based on the recommendations given in 'Design of Large Steam Turbine Generator Foundations', ASCE report and American Concrete institute(ACI 351.3R-04) Foundations for Dynamic Equipment. The following conditions as rule of thumb as given for the preliminary sizing:

1. The ratio of the weight of turbine-generator foundation (excluding the base mat) to the weight of machine shall be minimum 2.44.
2. The weight of the base mat should be atleast equal to the weight of the operating deck plus the turbine generator.

VI. Example

(1) Rated speed of machine = 3000 rpm

(2) Period = 0.02 seconds

(3) Weight of High Pressure Turbine = 18000 kg

(4) Weight of Intermediate Pressure Turbine = 35000 kg

(5) Weight of Low Pressure Turbine = 86000 kg

(6) Weight of Generator rotor = 78700 Kg

(7) Modulus of Elasticity = 37000000 kN/m2

(8) Thermal Coefficient of Expansion = 0.000012 /°C

(9) Change in temperature = 20°C

VII. Modelling

STG Foundation is modelled in SAP2000 for static analysis purpose. The portion above basemat is model in SAP with columns fixed at top of basemat. The column and beams have been model at that centre of gravity by using the frame elements. Proper constraints have been provided at the interface of columns and beams to ensure rigid body behaviour. Appropriate material and geometric properties have been provided. The load of STG equipment as furnished by Equipment supplier have been applied in the model. Different load combinations have been considered for the purpose of analysis. A three dimensional mathematical model has been prepared for dynamic analysis. In order to represent the true behaviour of mass and stiffness of STG foundation elements, the elements in foundation have been modelled using 8 node 3-D solid elements, having 3 translational degree of freedom at each node. The meshing has been regular and proper division of beams, columns, etc. has been ensured to form the entire foundation. Nodes have been provided at each of the bearing locations at center of the shaft. The foundation has been analysed considering base at supported on pile.

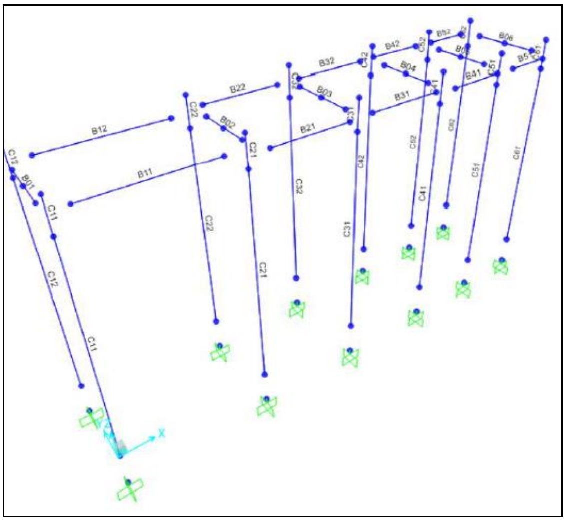

Figure 1: Model for static analysis

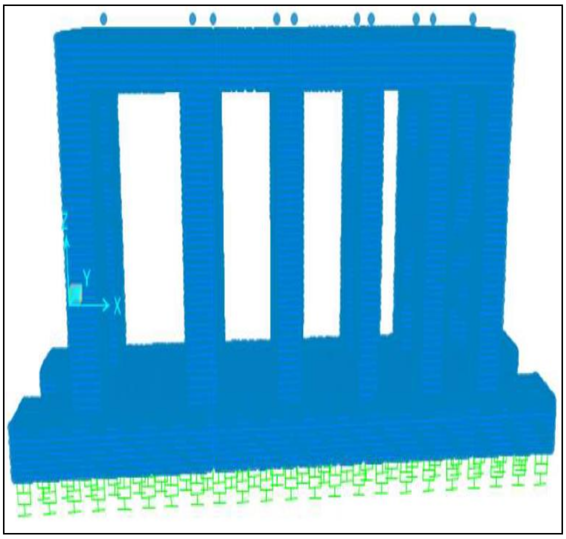

Figure 2: Model for dynamic analysis

VIII. 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.

8.1 Static Analysis

Static Analysis is done to determine forces of each elements Primary load cases includes: (i) Dead load (ii) Static load (iii) Static torque load (iv) Thermal expansion load (v) Dynamic load (vi) Short circuit load (vii) Temperature load (xiii) Shrinkage load (ix) Seismic X (x) Seismic Z.

8.2 Dynamic Analysis

The free vibration analysis have been performed to calculate the natural frequencies of STG foundation. The number of modes will be considered to achieve maximum mass participation and atleast upto 1.3 times the machine operating frequency. In order to avoid any undesirable resonance, the primary natural frequency in each direction shall be kept away 20% lower or higher than the machine operating speed (frequency). The forced vibration analysis have been performed to calculate the amplitude and velocity of vibrations of STG foundation.

IX. RESULTS

9.1 Natural Frequencies

MODE	PERIOD (sec)	FREQUENCY (Hz)
1	0.41	2.45
2	0.40	2.50
3	0.13	7.46
4	0.12	8.08
5	0.12	8.16
6	0.09	10.88
7	0.09	11.56
8	0.08	12.30
9	0.08	12.32
10	0.08	12.66

Direction	Frequency	Recommended Criteria
X	2.45	Either less than 40 Hz or more than 60 Hz
Y	2.50	
Z	12.87	

9.2 Mode Shapes

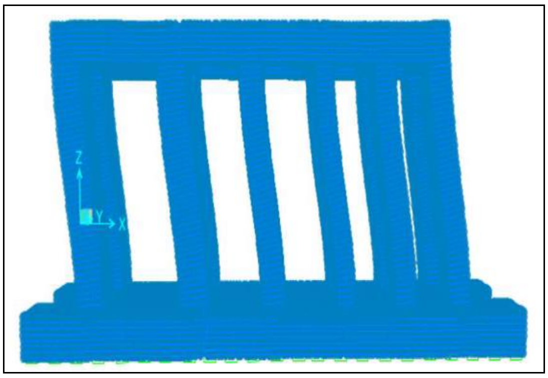

Figure 3: Model-1.

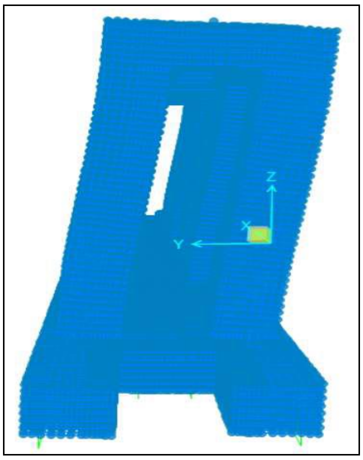

Figure 4: Model-2.

9.3 Amplitudes

The highest value for vibration amplitude of the foundation based on unbalanced forces is 0.00061 mm which has been found less than the preferable vibration amplitude value i.e 0.008mm.Thus this ensures, that these motion of amplitudes will neither endanger the satisfactory operation of the machine nor will disturb people working in the immediate vicinity.

9.4 Dynamic Stiffness

It has been found, that Lowest Dynamic Stiffness based on unbalanced forces is 4.774 x 105kN/cm which has been found more than the allowable value of 4.00 x 104kN/cm (limit by MHPS).This ensures the dynamic stability of turbogenerator foundation and avoids unnecessary rotor vibration.

X. CONCLUSION

The steam turbine generator foundation has been effectively analyzed for static and dynamic condition utilizing SAP2000 software. The natural frequency of the foundation is much lower than the working frequencies of turbo-generator machine and amplitudes are within the limits as specified by the manufacturer. 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 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]. Srinivasulu, P. and Vaidyanathan, V, ―"Handbook of Machine Foundations", *Tata McGraw-Hill Publishing Company*,1980

[2]. "Design of Large steam Turbine- Generator Foundations" – *Task committee on turbine foundations of the fossil power committee and nuclear energy committee of the Energy Division of the American Society of Civil Engineers (ASCE)*, Feb.1987

[3]. 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*.

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

[5]. 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.

[6]. ISO:10816-2:2001: Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 2:Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1500 r/min, 1800 r/min, 3 000 r/min and 3 600 r/min

[7]. ACI351.3R-04,"Foundations for Dynamic equipment", (2004)

[8]. 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.

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

[10]. 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.

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