Geotechnical Aspects In Modelling Framed Type Foundation For 210 MW Turbo Generator Using Computer Software

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Abstract— Turbo Generator consists of turbine and generator. It is used for generating Electricity. It is a very heavy machine, inducing large forces due to its self weight & operation on foundation. The Turbo Generator foundation is a vital & expensive part in a power plant complex. It is therefore essential that the foundation is designed adequately for all possible combinations of static and dynamic loads. It is a task of the structural designer to check the adequacy of the foundation under static and dynamic condition. At times it may becomes necessary to suitably alter the dimensions of the foundation as suggested by machine manufacturer so as to satisfy the design requirements. Any alterations thus found necessary must however have the prior concurrence of the Mechanical Engineer to ensure that these changes do not affect the erection operation of the machine. It is desirable therefore to have a close coordination between the foundation designer and the erection staff from the early planning stage until the foundation is completed and the machine is installed.

Keywords— Natural frequency, vibration, damping, elastic modulus, turbo generator

I. INTRODUCTION

In the early stages of development, Turbo Generator were mounted on the so called “wall type foundation” consisting the pair of walls on which were seated the turbine & generator. With the increase in the size & output of the machinery, more sophisticated type of foundation had to be devised for functional reasons. Framed foundation are now popular for supporting high speed machinery, on account of their many advantages, such as they do not limit a designer in the location of the engine & its auxiliary equipments, as do massive foundation e.g. condenser, pipeline, air vents, electric wiring which can be arranged much more conveniently, if the machine are mounted on frame foundation. The use of frame foundations facilitates considerably the inspection & access to all parts of the machine also saving in space, saving in material & less liability to cracking due to settlement & temperature changes.[1]

The common material of construction used for these foundations are reinforced concrete & steel reinforced concrete foundations which are common both in India & abroad. For the analysis of T.G. Foundations, the use of one mass or two mass idealizations has been in vogue for many years. With slender, under tuned foundations, which are commonly used today. These simple methods of analysis cannot be used to satisfy the design criteria. In the last two decades, rapid improvement in the analytical methods have taken place with the introduction of computers & the development of sophisticated techniques using matrix method & finite element techniques. As a result, number of improved mathematical models has been proposed for the analysis of T.G. foundation, comprising of beam elements & analysis is done using standard computer programs, which are commonly available.[1,2]
II. NECESSARY DATA

The machine data & the geotechnical data are necessary for the analysis & design of machine foundation.

2.1. Machine Data
The machine manufacturer shall make the following data available to the designer. Loading diagram of the machine showing the location, magnitude & direction of all the loads, speed of machine, outline dimensions of the foundation, mass moment of inertia of the machine components, details of inserts & embedments, layout of piping ducting etc & their supporting details, temperature in various zones during operation, allowable displacements at the machine bearing points during normal operation.[3]

2.2. Geotechnical Data
Investigation of the site where the foundation is to be located shall be done to evaluate the parameters like allowable bearing pressure, in situ dynamic soil properties as per IS 5249:1992.[4,5]

III. MODEL PREPARATION

For the purpose of analysis of soil structure interaction of T.G. foundation, a model is prepared. For this purpose, the basement is modelled with a plate bending element. The soil below the base mat shall be idealized as spring element i.e. the base mat is discretized into various nodes, each node is given with a spring support. The stiffness of spring is found out to be multiplying modulus of subgrade reaction & area contributed by particular node. The foundation is modelled as a three dimensional space frame in which the columns & beams are idealized as 3D beam elements with a six degree of freedom at each node. An uncracked section is used for calculating moments of inertia of the members.[6]

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Type Of Soil</th>
<th>K (KN/M³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Loose sand</td>
<td>4800 - 16000</td>
</tr>
<tr>
<td>2</td>
<td>Medium dense sand</td>
<td>9600-80000</td>
</tr>
<tr>
<td>3</td>
<td>Dense sand</td>
<td>64000-128000</td>
</tr>
<tr>
<td>4</td>
<td>Claye medium dense</td>
<td>32000-80000</td>
</tr>
<tr>
<td>5</td>
<td>Silty medium dense</td>
<td>24000-48000</td>
</tr>
<tr>
<td>6</td>
<td>Claye sand</td>
<td>12000-48000</td>
</tr>
</tbody>
</table>

Figure 1: Planer model treating the foundation on springs

IV. ANALYSIS OF TURBO GENERATOR FOUNDATION

Analysis of Turbo Generator is done in the following three parts. Part 1 - Static analysis 2) part 2 - Dynamic analysis 3) part 3 - Time history analysis
4.1. Static Analysis
A detailed static analysis of the foundation shall be performed to ensure that the foundation carries all the loads safely. The same model which has been used for dynamic analysis may be used for static analysis.

4.1.1 Load Cases
The following loads shall be considered for the foundation design:
- Dead load which includes the self weight of the foundation & dead weight of the machine (DL).
- Operation loads supplied by the machine manufacturer which includes friction forces, power torque, thermal elongation forces, vacuum in the condenser, piping forces etc. (OL).
- Normal machine unbalance load (NUL).
- Temperature load in the foundation (TLF).
- Uniform temperature change.
- Temperature gradients across members.
- Short circuit forces (SCF).
- Loss of blade unbalance (LBL) or Bearing failure load (BFL).
- Seismic load (SL).

4.1.2 Load Combinations
Operating condition:
- DL + OL + NUL + TLF

Short circuit condition:
- DL + OL + NUL + TLF + SCF
- Loss of blade condition/Bearing failure condition:
- DL + OL + TLF + LBL/BFL

Seismic condition:
- DL + OL + NUL + TLF + EQL

Following are the possible load combinations as per IS-2974 (Part 3) : 1992:

4.1.3 Load Case A
- DL+OL+TLF+NUL +Rotating Static/ Rotating Dynamic
- DL-OL-TLF- NUL +Rotating Static/ Rotating Dynamic

4.1.4 Load Case B
- DL+OL+TLF+NUL+SCF +Rotating Static/+ Rotating Dynamic
- DL-OL-TLF- NUL-SCF +Rotating Static/+ Rotating Dynamic

4.1.5 Load Case C
- DL+OL+TLF+BFL+Rotating Static/+ Rotating Dynamic
- DL-OL-TLF-BFL +Rotating Static/+ Rotating Dynamic

4.1.6 Load Case D
- DL+OL+TLF+NUL+EQL+Rotating Static/+ Rotating Dynamic
- DL-OL-TLF-NUL-EQL +Rotating Static/+ Rotating Dynamic [7,8]

For Static analysis SAP-2000 is used. In this all the elements are considered as beam elements. There are total 152 beam element & 95 nodal points. M25 Grade of concrete is assumed. Value of Modulus of elasticity for concrete = 3 x 10^7 KN/M^2 Density of concrete = 25 x 10^9 KN/mm^3

The self weight of foundation as well as all the forces acting on it is converted into fixed end forces except the forces acting at nodal points. Static analysis is performed in the following steps:

1) Analysis for the self weight of foundation
2) Analysis for static forces of T.G.
3) Analysis for equivalent static forces
4) Analysis for rotating element [9]

4.1.7 Critical Load Combination
From the above load combination it is observed that the critical load combination for load is load 5 most of the times. (i.e. DL+RS+OL+TLF+LBL)
4.2. Dynamic Analysis
Dynamic analysis is performed using SAP-2000. It includes computation of natural frequency for self weight of foundation & Eigen vectors for 14 mode shapes. Natural frequency is also computed manually by Extended resonance method. Frequencies & time period using SAP – 2000 software are shown below.[10,11]

Table 2: Modal Periods and Frequencies

<table>
<thead>
<tr>
<th>Mode</th>
<th>Period (Time)</th>
<th>Frequency (Cycle/Time)</th>
<th>Frequency (Rad/Time)</th>
<th>Eigen value (Rad/Time)**2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.393536</td>
<td>2.5410640</td>
<td>15.965973</td>
<td>254.912293</td>
</tr>
<tr>
<td>2</td>
<td>0.377257</td>
<td>2.6507160</td>
<td>16.654939</td>
<td>277.386984</td>
</tr>
<tr>
<td>3</td>
<td>0.364860</td>
<td>2.7407750</td>
<td>17.220795</td>
<td>296.555778</td>
</tr>
<tr>
<td>4</td>
<td>0.114797</td>
<td>8.7110500</td>
<td>54.733140</td>
<td>2995.71700</td>
</tr>
<tr>
<td>5</td>
<td>0.092605</td>
<td>10.798583</td>
<td>67.849497</td>
<td>4603.55400</td>
</tr>
<tr>
<td>6</td>
<td>0.081454</td>
<td>12.276862</td>
<td>77.137798</td>
<td>5950.24000</td>
</tr>
<tr>
<td>7</td>
<td>0.069334</td>
<td>14.422940</td>
<td>90.622003</td>
<td>8212.34700</td>
</tr>
<tr>
<td>8</td>
<td>0.066399</td>
<td>15.060573</td>
<td>94.6283730</td>
<td>8954.52900</td>
</tr>
<tr>
<td>9</td>
<td>0.060947</td>
<td>16.407676</td>
<td>103.092472</td>
<td>10628.0580</td>
</tr>
<tr>
<td>10</td>
<td>0.059211</td>
<td>16.888776</td>
<td>106.115310</td>
<td>11260.4590</td>
</tr>
<tr>
<td>11</td>
<td>0.057814</td>
<td>17.296824</td>
<td>108.679148</td>
<td>11811.1570</td>
</tr>
<tr>
<td>12</td>
<td>0.057041</td>
<td>17.531333</td>
<td>110.152611</td>
<td>12133.5980</td>
</tr>
<tr>
<td>13</td>
<td>0.056558</td>
<td>17.681014</td>
<td>111.093090</td>
<td>12341.6750</td>
</tr>
<tr>
<td>14</td>
<td>0.054368</td>
<td>18.393267</td>
<td>115.568307</td>
<td>13356.0340</td>
</tr>
</tbody>
</table>

Natural frequencies computed using various methods have been shown in the following table

Table 3: Natural frequencies computed using various methods
Natural frequencies computed using various methods are nearly same. For dynamic analysis the following range of dynamic elastic modulus is used.

Table 4: Range of dynamic elastic modulus

<table>
<thead>
<tr>
<th>Grade of Concrete</th>
<th>Dynamic Elastic Modulus N/mm$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>M20</td>
<td>25590 - 30000</td>
</tr>
<tr>
<td>M25</td>
<td>28500 - 34000</td>
</tr>
<tr>
<td>M30</td>
<td>31200 - 37000</td>
</tr>
</tbody>
</table>

As the dynamic elastic modulus is changes, the natural frequency is also changes. Different values of frequencies for different values of dynamic elastic modulus (E) for first five mode shapes are shown in following table.

Table 5: Different values of frequencies for different values of dynamic elastic modulus (E)

<table>
<thead>
<tr>
<th>Mode Shape</th>
<th>E = 2.559 x 10$^7$ kN/m$^2$</th>
<th>E = 2.85 x 10$^7$ kN/m$^2$</th>
<th>E = 3.0 x 10$^7$ kN/m$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time period(sec)</td>
<td>Frequency (Cys/sec)</td>
<td>Time period(sec)</td>
</tr>
<tr>
<td>1</td>
<td>0.426098</td>
<td>2.3469</td>
<td>0.403759</td>
</tr>
<tr>
<td>2</td>
<td>0.408472</td>
<td>2.4481</td>
<td>0.387057</td>
</tr>
<tr>
<td>3</td>
<td>0.395050</td>
<td>2.5313</td>
<td>0.374339</td>
</tr>
<tr>
<td>4</td>
<td>0.124295</td>
<td>8.0454</td>
<td>0.117779</td>
</tr>
<tr>
<td>5</td>
<td>0.100267</td>
<td>9.9734</td>
<td>0.095011</td>
</tr>
</tbody>
</table>

Therefore from the above table it is clear that as the values of dynamic elastic modulus (E) increases, the time period decreases whereas the frequencies are increases. The standard value of dynamic elastic modulus is 30000 N/mm$^2$ is used.[10,11]

4.3. Time History Analysis
Since rotating element gives dynamic effect, time history analysis is performed for this rotating element. For variation of load sine curve is used. Time taken for the complete cycle is 0.02 sec. This cycle is repeated till the natural period of foundation is reached. Further this one cycle is divided into 13 parts, each of time interval 0.00154 sec. Like this 265 time interval have been considered. Dynamic response for this time intervals have been calculated at every node using SAP 2000.[10,11]
V. CONCLUSION

The fundamental natural frequency shall be at least 20% away from the machine operating speed. The highest natural frequency of foundation is found out to be 1371.60 RPM. Hence difference between machine speed & natural frequencies is 54.28%. Maximum amplitude of vibration are 0.014 mm which is less than permissible amplitude of 0.02 mm. Out of eight load combination, the loss of blade combination is found out to be critical most of the times. From the time history analysis it is observed that maximum forces and displacements occurs at initial period less than 0.08 sec.

The natural frequencies computed by different methods are nearly same. As the values of dynamic elastic modulus (E) Increases, the time period decreases, whereas the frequencies are increases. The natural frequencies increases with the increase in value of sub grade reaction & time period decreases, as the value of sub grade reaction increases.

REFERENCES


