Numerical investigation of ALSTON turbine generator foundations using different finite element model

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Abstract: ALSTOM turbine generators have been used in the power plant all over the world. The previous turbine generator foundations were mainly designed and analyzed by the professional design software. In this paper, FE models using frame element in the finite element software of SAP2000 and solid elements in the finite element software of ABAQUS were built to simulate the ALSTOM turbine generator foundation, respectively. Model analysis and forced vibration analysis were conducted and the simulation results were validated against the existing codes and specifications provided by manufactory. The dynamic characteristics of the turbine generator foundation could meet the requirements of the applicable codes and standards. The FE models built with solid element could better simulate the dynamic characteristics of turbine generator foundations.

1. Introduction
Turbine generator is the kernel of power plant and the good dynamic characteristic of the turbine base is the basic conditions for ensuring the stable operation of the Turbine generator [1-4]. Most of the turbine generator foundations in Chinese were all designed according to the code of <ISO10816-2>[5] and GB50040-96 [6]. In the code of GB50040-96 [6], the vibration displacements are limited to ensure the dynamic characteristic of turbine generator foundations. In recent years, ALSTOM turbine generators have been used in some power plant. The design of ALSTOM turbine generator foundations shall satisfy the design specification of HTGD655066 [7] provided by the ALSTOM manufacturers. The requirements of dynamic characteristic of the turbine base in specification of HTGD655066 [7] are as following: 1) The calculated natural frequencies and mode shapes shall in all cases be presented to Alstom, the natural frequencies shall be calculated to the range of 85% ~115 % of the operating speed; 2) the vibration velocity of the foundation shall be less than the value specified in the code of ISO 10816[5].

In this paper, the dynamic analyses of ALSTOM turbine generator foundation were conducted according to the FE (finite element) software of SAP2000 and ABAQUS. The effect of different element types on the numerical simulation results was investigated. The dynamic characteristics were summarize and compared with the existing codes and the specification provided by the ALSTOM manufacturers.

2. Finite element model
In the FE software of SAP2000, the frame element was used to simulate the columns of the structure and the thick shell element was used to simulate the top slab. The thick shell element in SAP2000 is a three or four node formulation that combines membrane and plate-bending behavior. The thick-plate
element could calculate the transverse shear deformation of the slab section. The FE model built in SAP2000 is shown in Figure 1(a). Solid elements of C3D8 and C3D6 were used to build the FE model in software of ABAQUS [8], as shown in Figure 1(b).

![Model in SAP2000](image1)

![Model in ABAQUS](image2)

Figure 1. Finite element model

3. Model analysis

In order to investigate the influence of bottom slab on the structure behaviours of turbine generator foundations, the FE model with the bottom slab was built. The design characteristic value of soil bearing capacity is 400kPa. Refer to the code of GB50040-96 [6], the vertical and horizontal modulus of sub grade reaction was 200000kN/m$^3$ and 140000kN/m$^3$, respectively. The surface spring element was applied to simulate the constraints of the foundation to the bottom slab, as shown in Figure 2. Table 1 lists the results of model analysis. Model A refers to the model without bottom slab and the bottom column are fully constrained. Model B refers to the model with bottom slab and soil stiffness is calculated. As can be seen from Table 1, the differences of frequencies between Model A and Model B can be neglected. It revealed that the assumption of fixed constrain at the end of column was reasonable. The FE model without bottom slab can be used to conduct the dynamic analysis. By comparing the Model A to Model C, the frequencies of Model C was obviously larger than the frequencies of Model A. It was caused by 1) the top slabs in the FE model of SAP2000 were simulated by the thick shell element and the integration points of thick shell located in the middle section of slab, which led to the increasing of the effective length of columns; 2) the top slab and columns (marked in Figure 1) were connected by the concrete chamfering, whereas the connection characteristic was not simulated in the SAP2000 FE model.

The operating frequency of turbine generator was 60Hz, and the frequencies corresponding to 85% ~115% of the operating speeds were ranging from 51 Hz to 69Hz. According to the model analysis, as the natural frequencies of turbine generator foundation increased from 51Hz to 69Hz, the modal participating mass ratios increased by 2%, 1% and 3% in the direction X, direction Y and direction Z, respectively. It reflected that there was not obvious effect on the operation of turbine generator.
4. Forced vibration analysis

The model steady-state analysis was applied to calculate the vibration velocity of turbine generator foundation. The modal steady state dynamics analysis method is based on the modal superposition method to solve the steady state response of the system. The eigenmode of undamped is firstly extracted, and then a set of single-degree-of-freedom equations of motion was expressed by modal coordinates. The steady-state response of the system under the modal coordinates can be obtained according to solve the single-degree-of-freedom equations. Then the steady-state response of the system under physical coordinates can be calculated obtained according to coordinate conversion. It reveals that the calculation results are significantly influenced by the modal analysis results.

The steady-state analysis was conducted according to the detailed calculated operational unbalance loads provided by manufactory. They show the forces amplitude and phase angle at nominal operating speed at each bearing location for a defined standard unbalance case. As the specification provided by manufactory, the peak vibration velocity (RMS value) at the foundation shall be less than the values specified in ISO 10816 [5], and 40 % of the values (2.15mm/s) for zone “A” (for new machines) may not be exceeded, for a rotor speed range of 10 % of the operational speed. The location of unbalance loads is shown in Figure 3

The peak values of the vibration velocities calculated by different FE models under the unbalance loads are listed in Table 2. As can be seen from Table 2, the maximum peak values of the vibration velocities calculated by SAP2000 and ABAQUS all occurred in the Z direction of axis-D. Moreover, the maximum peak value calculated by SAP2000 was 1.7286 mm/s, which is more than the peak values of 1.4296 mm/s calculated by the FE model in ABAQUS. In addition, the peak values all satisfy the requirement of specification provided by manufactory.
5. Conclusion

The FE model of ALSTON turbine generator foundation was built in the software of SAP2000 and ABAQUS. The modal analysis and steady-state analysis were conducted and simulation results were compared with the existing codes and the specifications provided by the ALSTON manufactory. The main conclusion can be summarized as following:

(1) The effect of bottom slab on the dynamic property of turbine generator foundation can be neglected in this paper due to the fine geological conditions. And the FE model without bottom slab could meet the need of dynamic analysis.

(2) FE model built with solid element can accurately simulate the details of foundation and the comparison of the dynamic results show that the results were more accurate than the FE model built with frame element and shell element.

(3) The requirements of ALSTON specification are stricter than the existing codes. The simulation results presented in this paper can provide reference for the similar projects.

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