Research on Vibration Characteristics of Urban Substation Building and Transformer

Ma Yuchao1*, Mo Juan1, Nie Meng2, Li Xiang1
1China Electric Power Research Institute, Beijing 100055, China
2Heze Power Supply Company, Shandong Electric Power Corporation, Heze, 274000, China
*Corresponding author’s e-mail: myc2011bjut@163.com

Abstract. The problem of vibration of the buildings and transformers in the urban substation has become more and more socially concerned. The urban substation and its associated building are taken as the research object. The vibration tests and modal shapes of the building and each floor slab were carried out. The transformer vibration and its noise were transmitted with obvious attenuation in the structural floor slab. The vibration transmission into the lower floor slab was higher than that of into the higher one. The further away from the transformer room, the vibration characteristics are weak, and the attenuation is no longer significant. At last, the finite element model was established for the urban substation. The transformer and floor slab vibration went through the simulated analysis and the consistent analysis results were obtained.

1. Introduction
The problem of vibration in the urban substations has becoming more and more socially concerned. With the rapid development of urban construction, the power consumption continues to rise in recent years. Many substations built up deep into the densely populated area of the city. Vibration characteristics and modal shapes of the substation buildings are made important theoretical basis of vibration reduction measures. In the paper, the urban substation and its conjoined buildings were taken as the research object. The vibration tests and modal shapes of the building and each floor slab were carried out. The transmission rules of transformer vibration in building structures were obtained through the simulated analysis of the finite element in the urban substation.

2. Tests of Vibration and modal shapes
2.1. Condition of the substation
The urban substation building designed and installed three transformers. The substation was seamlessly built with the office building. The underground part had two floors. The basement floor 2 (BF2) included a ventilator room, an electric reactor room, a capacitor room, and a warehouse etc. The basement floor 1 (BF1) included the cable inter-layers. The ground floor 1 included 3 main transformer rooms and a switch gear room; the ground floor 2 and 3 included GIS rooms mainly. The ground part of the building included 8 floors (F4-F8) of office area with floor height of 3.8m.
2.2. Test Points of Vibration and modal

In order to obtain the vibration characteristics of the main functional areas, such as the transformer room and office room, the vibration tests and modal tests were conducted according to the structural layout of the urban substation and conjoined buildings. The main vibration within the substation came from 1#, 2# and 3# main transformer rooms located in the first floor. The test points of vibration were arranged in transformer foundation. The test points of vibration were set up in each floor so as to control the vibration characteristics of floor slab in the building structure. The understanding of overall dynamic characteristics of building structure would facilitate the simulated analysis and research on finite element. Therefore, the field modal test was conducted in the urban substation so as to obtain the main dynamic characteristic parameters of the building. In order to make the finite element model of urban substation to truly simulate the dynamic characteristics of actual building structure, in this paper, the structural mode of the substation is tested. Adopt the horizontal speed sensor of the YSV-201 type and adopt medium velocity with frequency range of 1Hz-100Hz, which is suitable for testing the low-frequency weak vibration signal. 3 test points are arranged at the two angular point locations in each floor. Test the horizontal directions in north-south and east-west; adopt environmental excitation method for the load excitation and the sampling time is 30 minutes. Figure 1 and Figure 2 are the distribution of test points and speed sensors.

![Fig. 1 Distribution of Test Points](image1)

![Fig. 2 Sensors](image2)

2.3. Finite Element Model of Urban Substation

Taking urban substation as the research object, ANSYS finite element software was used for simulation analysis. The geometrical parameters of the model structure are based on the structural design drawing of the substation and the field test. The substation belongs to the urban substation and its main body is steel-concrete frame mixed structure. The two basement floors are the reinforced concrete structure and the over-ground 8 floors are the steel frame supporting structure. The floor slab is the concrete composite slab of profiled steel sheet. Therefore, the model structure is also designed into 10 floors including 2 basement floors and 8 over-ground floors. Adopt beam element of beam188 to simulate the beam and pillar, adopt the shell unit of shell63 to simulate the floor slab and adopt the body element of solid187 to simulate the transformer. Divide the beam and pillar based on linear
elements, arrange the floor slab edge according to dividing mode of beam element and adopt the quadrangle for the surface element to divide the gridding. The structure is rigidly connected with the ground and the bottom of the model restricts all displacement. however, the steel structure wall is simplified into the linear load on the frame beam, and the finite element model is established as shown in Figure 3.

![Fig.3 FEM of Urban Substation](image)

3. Analysis on Test Results
The vibration of three main transformer rooms in the urban substation are transmitted and diffused in floor plan and different floor facades by means of steel-concrete floor slab. This section takes the urban substation and conjoined office building as the test object and obtains the basic characteristics and transmission rules of vibration in building structure through the time-domain analysis of vibration signals and Fourier spectrum analysis in the transmission of different floors and the same floor. Select the vibration test points in the floor slab of main transformer room and the floor slab in the upper floors from BF2 to F1 as well as the noise test points in the same position for analysis. List the corresponding the vibration time domain and spectrum value.

| NO. of Test Point | Effective Value (m/s²) | Vibration Level (dB) | 100Hz Vibration Level (dB) | Test Point Position |
|-------------------|------------------------|----------------------|---------------------------|---------------------|
| BF2_Z5            | 0.0078                 | 77.86                | 56.6                      | Basement floor BF2  |
| BF1_Z5            | 0.0234                 | 87.39                | 66.01                     | 2# main transformer warehouse BF1 |
| F1_Z5             | 0.0326                 | 90.67                | 60.99                     | 2# main transformer warehouse F1 |
| F4_Z5             | 0.0019                 | 66.16                | 37.04                     | F4 corridor         |
| F5_Z5             | 0.0015                 | 64.43                | 40.02                     | F5 corridor         |
| F6_Z5             | 0.0014                 | 60.33                | 41.44                     | F6 corridor         |
| F7_Z5             | 8.6E-4                 | 60.27                | 33.65                     | F7 corridor         |
| F8_Z5             | 0.0011                 | 61.87                | 34.47                     | F8 corridor         |
Fig. 4 Vibration Time Domain and Spectrum Diagram in Test Points of the floors

Table 2 shows the modal test results. It can be seen that the first three order frequencies of finite element model are matched well with the tested results and the directions of vibration modes are consistent. The third order torsion frequency of the model is slightly lower than the tested result for the model does not consider the rigidity contribution of the filled wall. The simulation analysis model of urban substation can be thus determined.

Table 2 Modal Analysis Results

| Modal order number | Actually Tested Frequency (Hz) | Model Frequency (Hz) | Error(%) | Description of Vibration Mode |
|--------------------|--------------------------------|----------------------|----------|------------------------------|
| 1                  | 2.201                          | 2.186                | 0.68     | Lateral bending modality in north-south direction |
| 2                  | 2.269                          | 2.267                | 0.09     | Longitudinal bending modality in east-west direction |
| 3                  | 3.248                          | 3.142                | 3.2      | Torsional mode               |

The finite element model of urban substation goes through the transient dynamic analysis to get hold of vibration transmission characteristics of conjoined building structure in the substation transformer. Adopt the load step during loading; each load step is divided into 5 sub-steps and the acceleration time course value in array read-in is adopted and there are totally 1000 load steps. Each load step time is 0.001s, and the total calculation time is 1s. Figure 5 shows the distribution of vibration acceleration in each point of urban substation at a certain time. Figure 6 shows the vibration attenuation curve at test points in each floor slab.
4. Conclusion

Based on testing and analysing the vibration and modal in the urban substation, there are regular attenuation on vibration amplitude in vibration transmission paths of the main transformer. Combined the field test results, the transmission rules of transformer vibration and noise in the building floor slab can be obtained. First, the effective value is calculated according to acceleration response curve and the vibration level is calculated according to test result. The transmission of structural vibration within the building floor slab is attenuated obviously. Second, the test point F1 is the floor where the transformer is installed. The floor slab vibration is radially transmitted in the building structure. The floor slab vibration is the largest if it is close to the transformer. The structural vibration of the basement floor slab is significantly greater than that of in the floor slab above 4 over-ground floors. Third, for the office building (F4-F8), the vibration level has no more attenuation and is basically kept at 60dB-70dB, which indicates that transformer vibration has relatively little influence on the superstructure floor slab. Last, through establishing the finite element model of urban substation, the modal analysis and transient dynamic analysis were conducted and the vibration transmission characteristics of transformer and floor slab were obtained from the urban substation. Compared with the actually tested results, we can use the finite element simulated model of transformer and conjoined
structure in the urban substation and input the transformer vibration excitation, and thus predict the vibration response of the actual transformer and conjoined building.

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