Experimental Study on Pedestal’s dynamic amplifying in UHV Electrical Equipment

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Abstract
Simulation earthquake shaking table tests on the system of ultra high-voltage electrical equipment mounted on pedestals are carried out in order to study the dynamic amplifying effect of the pedestal in the system. The relationship between the dynamic responses of the system and main influence factors is studied by means of changing frequencies or stiffness and masses of the system under the driving function of several different earthquake waves. The studied results show that the dynamic amplifying effect of the pedestal in the system or the pedestal amplifying coefficient has close relationship with the stiffness and masses distributing or the frequencies of the system. Some regular and universal conclusions are obtained, and the suggested scale on the dynamic amplifying coefficient of the pedestal in the system is put forward, which provides reference for future design and engineering application on the ultra high-voltage electrical equipment with pedestal.

Keywords: ultra high-voltage electrical equipment; pedestal; dynamic amplifying coefficient; simulation earthquake shaking table experiment

1. Introduction
At present, the ultra-high voltage electrical equipment and pedestal are not often seen as a complete whole structure at time of seismic design, namely earthquake effect of electrical equipment is only considered by multiplying pedestal’s dynamic amplifying coefficient and local seismic fortification peak acceleration. And the pedestal’s dynamic amplifying coefficient value refers to the maximum value 1.2 in literature [1], so its application is limited to electrical equipment of 500 kV and below. Whether the value ranges apply to ultra-high voltage electrical equipment is also worth discussing, while the pedestal is featured with seismic design based on earthquake force posed to electrical equipment.

The research of simulation experiment of shaking table on relations between pedestal dynamic amplifying coefficient and influencing factors of systems of electrical equipment mounted on pedestal is carried out.

2. The experiment
2.1 The design of the experiment
Considering the fact that the existing experimental condition is difficult to fully satisfy with full-scale experiment of ultra high-voltage electrical equipment mounted on pedestal, the design of experiment adopts the system of simulation equipment combing full-scale pedestal and section steel (in table 1) with weight balancing block.

The pedestal uses uniform cross-section lattice, and the pedestal is divided into 4 types. The dimensions of height, root span, principle material and auxiliary material are seen in table 2. Figure 1 is pedestal face.

<table>
<thead>
<tr>
<th>name</th>
<th>Member length/m</th>
<th>section height/mm</th>
<th>flange width/mm</th>
<th>flange thickness/mm</th>
<th>web thickness/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section</td>
<td>3.5</td>
<td>400</td>
<td>142</td>
<td>16.5</td>
<td>10.5</td>
</tr>
</tbody>
</table>

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Table 2. Dimension of pedestal

<table>
<thead>
<tr>
<th>Pedestal type</th>
<th>material</th>
<th>height/m</th>
<th>root span/m</th>
<th>principle material dimension/m</th>
<th>auxiliary material dimension/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20 seamless steel</td>
<td>5.010</td>
<td>1.2</td>
<td>Φ133×6</td>
<td>Φ70×5</td>
</tr>
<tr>
<td>2</td>
<td>6.710</td>
<td>1.0</td>
<td>Φ133×6</td>
<td>Φ70×5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6.710</td>
<td>1.2</td>
<td>Φ133×6</td>
<td>Φ70×5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6.710</td>
<td>1.2</td>
<td>Φ194×12</td>
<td>Φ83×8</td>
<td></td>
</tr>
</tbody>
</table>

2.2 Experimental equipment and loading mode

Basic information of chosen shaking table: table dimension is 3 m x 3 m, under the function of one-way horizontal earthquake wave, maximum acceleration is 1.0 g (full load of 10 tons). The test piece of electrical equipment mounted on pedestal is placed in shaking table, in key parts of test piece is arranged sensing device, and the loading mode is under the function of earthquake wave.

2.3 The experiment content and arrangement of test points

This experiment, using simulated earthquake shaking table under the function of one-way horizontal earthquake wave of IEEE composite wave, El-centro wave (north-south), artificial man-made earthquake wave (response spectrum according to the “code of seismic design of electrical facilities”: II class site, characteristic period of 0.4 s, damping ratio of 2%) and resonance pat wave [2-6], studies dynamic response of system of different electrical equipment mounted on pedestal with changing frequency, stiffness or mass of components (including equipment and pedestal) and finally obtains variation law under power amplifying effect.

Experiment content: test the dynamic characteristics of system and components of electrical equipment mounted on pedestal; test acceleration response, displacement response and strain (or stress) response in key parts of the system.

Arrangement of test points: in table is placed acceleration meter, in pedestal top and section steel (simulation equipment with weight balancing block) top are placed acceleration meter and displacement meter, and at pedestal root and section steel root is decorated with a strain gauge, as shown in Figure 2.

2.4 Experiment process

For system of composite section steel and system of independent section steel, through adjusting weight balancing block on pedestal top, we classify test case into different kinds. In every test case, we test frequency and damping ratio system through cure noise scanning combined with artificial free attenuation test and then input IEEE wave, Elcentro wave, artificial fitting time integration wave and resonance pat wave along the major axis of section steel in Table 3.
3 Experiment results

According to the different forms, we numbered system combing independent section steel and pedestal 1, pedestal 2, pedestal 3, pedestal 4 as system 1.2-133-5.01, system 1.0-133-6.71, system 1.2-133-6.71 and system 1.2-194-6.71, we obtain dynamic response of the system through the shaking table test.

3.1 System dynamic characteristics

So far, the accuracy of cure noise scanning frequency is relatively high, but due to equipment collection precision and other reasons, the error of using half power method to calculate damping ratio is bigger, and using attenuation curve in initial velocity method to determine damping ratio is of higher precision [7-8].

The test shows that first natural frequency of independent section steel is between 1.427-2.592 Hz, first natural frequency of systems combining pedestal and section steel is between 1.349-2.530 Hz, the damping ratio of both the two kinds of section steel is small. Before and after test fundamental frequency of various systems basically does not experience obvious changes, indicating and no significant reduction of stiffness, so these systems basically are not damaged.

3.2 Dynamic response

Through shaking table test of all kinds of systems, we gain dynamic response under different test cases, including acceleration response, displacement response and stress (strain) response. We select dynamic response of seismic fortification intensity of 7 degree (0.1 g) under the function of earthquake wave and resonance pat wave.

(1) Acceleration response
In different test cases under earthquake effect, we use maximum acceleration response on independent section steel top as reference value, compared with maximum acceleration response of other systems, and find out whether the pedestal exerts influence on acceleration amplifying on top of the section steel. In test case 1, acceleration amplifying coefficient on section steel top is 0.97~2.41; In test case 2, acceleration amplifying ratio on section steel top is 0.78~1.41; In test case 3, acceleration amplifying coefficient on section steel top is 1.07~1.57; In test case 4, acceleration amplifying ratio on section steel top is 0.46~1.07.

(2) Displacement response
In different test cases under earthquake effect, we use maximum displacement response on independent section steel top as reference value, compared with maximum displacement response on section steel top relative to section steel root of other systems, and find out whether the pedestal exerts influence on displacement amplifying on top of the section steel. In test case 1, the relative displacement amplifying coefficient on section steel top of other four systems and independent section steel is 0.46~3.67; In test case 2, the relative displacement amplifying coefficient on section steel top of other four systems and independent section steel is 0.44~2.20; In test case 3, the relative displacement amplifying coefficient on section steel top of other four systems and independent section steel is 1.30~7.43; In test case 4, the relative displacement amplifying coefficient on section steel top of other four systems and independent section steel is 0.48~3.09.

(3) Stress response
The test shows that stress response of different systems under the function of same earthquake wave or stress response of one system under the function of diverse earthquake wave.
waves, is not completely consistent. The reason is that the system frequency is highly correlated to dominant frequency and frequency distribution of earthquake wave, thus affecting stress response of the system.

In test case 1, stress amplifying coefficient of section steel is 0.98-2.67; In test case 2, stress amplifying coefficient of section steel is 0.64-1.67; In test case 3, stress amplifying coefficient of section steel is 0.95-1.47; In test case 4, stress amplifying coefficient of section steel is 0.52-1.23.

4. Analysis of influencing factors of dynamic amplifying coefficient of section steel

The influencing factors of the system on dynamic amplifying include mass distribution, stiffness distribution and system frequency, and system frequency overall considers the factors like mass distribution and stiffness distribution, the influence of the system frequency on dynamic amplifying effect is focused on.

4.1 The influence of system frequency on dynamic amplifying effect

Referring to existing researches on frequency of electrical equipment mounted on pedestal with range of 1 Hz-2 Hz, this paper selects frequency range of the five kinds of the system(independent section steel, system 1.2-133-5.01, system 1.0-133-6.71, system 1.2-133-6.71, system 1.2-133-6.71) within 1.349-2.087 Hz under the function of different earthquake waves (IEEE wave, El-centro wave, and artificial man-made wave) and researches the relations between pedestal dynamic amplifying coefficient and frequency change of system. We define dynamic amplifying coefficient of system of independent section steel as 1, and the comparison of dynamic amplifying coefficient of independent section steel with that of other systems is seen in Fig. 3(a), Fig. 3(b), Fig.3(c).

See on the whole: the system frequency is in 1.35-1.60 Hz and change trend of the frequency is diverse under the function of different earthquake waves. Under the function of IEEE wave and Elcentro wave, with system frequency increasing, the dynamic amplifying coefficient shows a trend of increase with the range of 0.55-1.46, as shown in Fig. 3 (a) and Fig. 3 (b), average pedestal dynamic amplifying coefficient is 1.01; while under the function of artificial man-made wave, with system frequency increasing, the dynamic amplifying coefficient shows a trend of decrease with the range of about 2.5-1.0, as shown in Fig. 3 (c), average pedestal dynamic amplifying coefficient is 1.75. We take the average pedestal dynamic amplifying coefficient in increase and decrease trend as 1.38.

Within system frequency range of 1.6 Hz-2.1 Hz, in relation curve between pedestal dynamic amplifying coefficient of systems and their frequencies, with the frequency increasing, pedestal dynamic amplifying coefficient shows a trend of increase with the range of 1.67-0.72, as shown in Fig. 3 (a) and Fig. 3 (c), average pedestal dynamic amplifying coefficient is 1.20; while in a few test cases, pedestal dynamic amplifying coefficient increases slightly within the range of 1.35-1.67, as shown in Fig. 3 (b), average pedestal dynamic amplifying coefficient is 1.51. We take the average pedestal dynamic amplifying coefficient in increase and decrease trend as 1.36.

(a)Function of IEEE wave (b)Function of Elcentro wave (c)Function of artificial man-made wave

Figure 3. Relation curve of systems and their frequencies on pedestal dynamic amplifying coefficient
4.2 the influence of stiffness on pedestal dynamic amplifying effect

From Fig. 3 we can also know: see on the whole, with the pedestal stiffness increasing, that is the dimensions of root span, principle material and auxiliary material increase, pedestal dynamic amplifying coefficient declines. As shown in Fig. 3 (1), 3 (2) and 3 (3), comparing system 1.2-133-6.71 with system 1.0-133-6.71, root span of the former is increased from 1m to 1.2m, but the pedestal dynamic amplifying coefficient is smaller than the latter; and comparing system 1.2-133-5.04 with system 1.2-133-6.71, root span of the former is decreased from 6.71m to 5.04m, in most occasions, pedestal dynamic amplifying coefficient is smaller than the latter.

3.3 the influence of system mass on pedestal dynamic amplifying coefficient

From Fig. 4 we can see: under the function of the same earthquake wave, the change trend of pedestal dynamic amplifying coefficient of different systems with mass change is nearly the same; with the mass increasing, pedestal dynamic amplifying coefficient increases or decreases accordingly, but in most cases pedestal dynamic amplifying coefficient is larger than 1.

Fig. 4 Relation curve between pedestal dynamic amplifying coefficient of systems and their Masses

5 Summary

Based on shaking table test of the five systems in different test cases under the function of different earthquake waves (IEEE wave, Elcentro wave, artificial composite wave, resonance pat wave), the following conclusions are obtained:

(1) In the systems, the full-scale pedestal is simulated by adding weight balancing blocks in section steel, it is found that first natural system frequency of the independent section steel is 1.349-2.594 Hz and damping ratio is small, which is similar to dynamic characteristics of full-scale ultra-high voltage electrical equipment mounted on pedestal.

(2) The pedestal dynamic amplifying coefficient uses the maximum stress ratio with or without pedestal, because it is not only the control condition of seismic capability of electrical equipment, but also more convenient and more comprehensive definition standard.

(3) The pedestal in electrical equipment system can produce dynamic amplifying effect, and acceleration response, displacement response and stress (strain) response in key parts of electrical equipment are also amplified.

(4) The dynamic response(acceleration response, displacement response and stress response) of systems under the function of different earthquake waves are distinct, especially under the function of resonance pat wave, dynamic response is the most intense, this is because the dynamic response of system is highly correlated to site dominant frequency, site frequency distribution, system mass distribution, system stiffness distribution and system frequency, so the above mentioned factors are also influencing factors of dynamic response of systems.

(5) See on the whole: the larger the pedestal stiffness is, the weaker is the dynamic response of electrical equipment mounted on pedestal and the smaller is the pedestal dynamic amplifying coefficient; with the system mass increasing, especially the equipment mass increasing, change trend of pedestal dynamic amplifying coefficient is not the same, featured with increase or decrease, but in most cases pedestal has amplifying effect on equipment and pedestal dynamic amplifying coefficient is larger than 1; System frequency
considers the factors such as the stiffness distribution and mass distribution of itself, so the relations between system frequency and pedestal dynamic amplifying coefficient are featured with regularity and universality: when the system frequency is 1.35-1.6 Hz, the average pedestal dynamic amplifying coefficient is about 1.38; when the system frequency is 1.6 Hz-2.1 Hz, the average pedestal dynamic amplifying coefficient is about 1.36.

In fact, earthquake ground motion and the structure's dynamic responses under the earthquake action are all full of randomicity, so the deep research on pedestal dynamic amplifying under the earthquake action need to combine the intelligent analysis methods such as references [9,10] with the experiment.

References