APPLICATION OF BASE ISOLATION IN HIGH VOLTAGE ELECTRICAL EQUIPMENT

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ABSTRACT:

The insulation member of high voltage electrical equipment is constitutive of porcelain insulator. The porcelain insulator is made by a kind of brittle material and it has a poor flexural performance. The porcelain insulator endures the considerable bending moment in earthquake, which causes the brittle destroy of porcelain insulator. Especially, the uncoordinated deformation increases the destruction on the connection of porcelain insulator and other materials. In order to solve the damage of high voltage electrical equipment in earthquake and discuss the feasibility of base isolation in high voltage electrical equipment, the seismic response analysis of isolation and non-isolation in high-voltage disconnector is studied in this thesis.

KEYWORDS: high-voltage electrical equipment, high-voltage disconnector, base isolation, time-history analysis

1. INTRODUCTION

The statistical results of earthquake damage show that electric power system has a high seismic vulnerability. The damage of high voltage electrical equipment is one of the main reasons, which causes the failure of electric power network system. High-voltage electrical equipment includes circuit breaker, disconnector, current transformer, voltage transformer, arrester and so on, the damage of electrical equipment is caused by the brittle destroy of porcelain insulator[1]-[3]. Previous research about the aseismic performance of electrical equipment is concentrated on porcelain insulator and supporter. The practical application shows that aseismic performance of high-voltage electrical equipment cann’t be solved by enhancing stiffness of porcelain insulator and supporter, when the transformer substation is located in high earthquake intensity region. Isolation technology is used to improve the aseismic capacity of capacitor bank in Haywards substation of New Zealand[4].

2. PRINCIPLE OF MODEL SIMPLIFICATION

Before finite element analysis, it is very important to simplify the model reasonably. The modeling of high-voltage electrical equipment should consider the components of support, porcelain insulator and flange connection.

The calculation method of sectional inertial moment of porcelain insulator is given by

$$I = \frac{p}{64}(d_1^4 - d_2^4) \tag{2.1}$$

where d_1 is the external diameter of porcelain insulator, d_2 is the internal diameter of porcelain insulator.

The bending rigidity can be calculated by the Chinese Specification (GB 50260-96). The following expression is used:

$$K_c = 6.54 \cdot d_c h_c^2 / t_e \tag{2.2}$$

where K_c is the bending rigidity(N·m/rad), d_c is the internal diameter of cementing porcelain insulator(m), h_c is the cementing height of porcelain insulator and flange(m), t_e is the distance of porcelain insulator and flange(m).

The bending rigidity of porcelain insulator and flange may be produced by the equivalent beam element, the sectional inertial moment of equivalent beam element is given by

$$I_c = K_c \frac{L_c}{E_c} \tag{2.3}$$

where I_c is the sectional inertial moment(m^4), L_c is the length of equivalent beam(m), which is 1/20 of the length of single porcelain insulator, E_c is the elastic modulus of porcelain insulator(Pa).

3. SEISMIC RESPONSE ANALYSIS METHOD

In order to consider the dynamic response of high-voltage electrical equipment in every moment under earthquake, time-history analysis method is adopted in the seismic response analysis. The high-voltage electrical equipment is assumed to be under bidirectional earthquake waves of El-centro and Taft. The seismic characteristics are shown in table 3.1.

Table 3.1 Seismic characteristics

No	Earthquake wave	Site classification	Time interval(s)	Duration time(s)	Maximum peak (cm/s^2)	Predominant period(s)
1	El-centro	II	0.02	30	341.7	0.55
2	Taft	II	0.02	40.02	397.478	0.44

4. ANALYSIS OF EXAMPLE

In order to study the application of base isolation in high voltage electrical equipment, the comparing analysis of seismic responses of high-voltage disconnectors with isolation and without isolation is studied in this thesis. Taking the project of substation in Yunnan Province for example, a 9-degree seismic fortification intensity is considered in the time-history response analysis. Through the large earthquake damage survey on electric power facilities, we can draw the conclusion that one of the main characteristics of high-voltage electrical equipments in damage is the brittle destroy of porcelain insulator. The damage usually focuses on the root of porcelain insulator, so the research emphasis is placed on those positions.

4.1. Calculation Models

The height of high-voltage disconnector is 2.7m. The insulator is made of two-segment porcelains. The length of upper segment is 1060mm and the diameter is 110mm. The length of lower segment is 1060mm and the diameter is 140mm. The bottom of high –voltage disconnector is made of section steel, and the supporter is concrete column of a 4m high. The top of isolation bearings is on the same horizontal plane, and 6 isolation bearings are designed in the project. In order to keep the cooperative work of disconnector and supporter, strip foundation is designed, and the section of beam is 800×600mm. A 100mm-thickness concrete plate is poured on the top of strip foundation considering the ground surface greening. The calculation models are shown in Figure 4.1 and Figure 4.2.

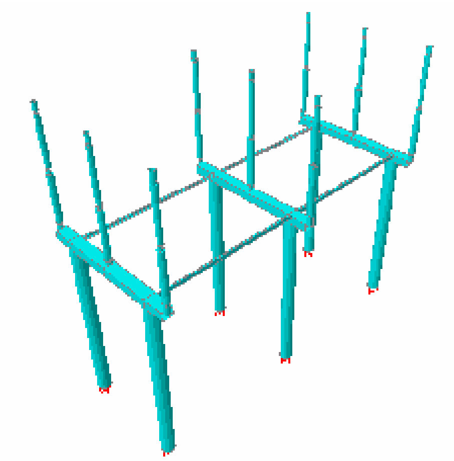


Figure 4.1 Model of Non-isolated disconnector

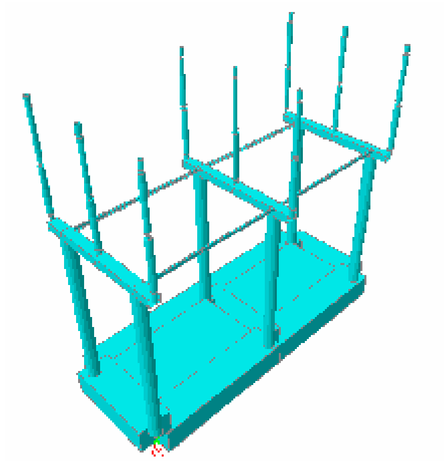
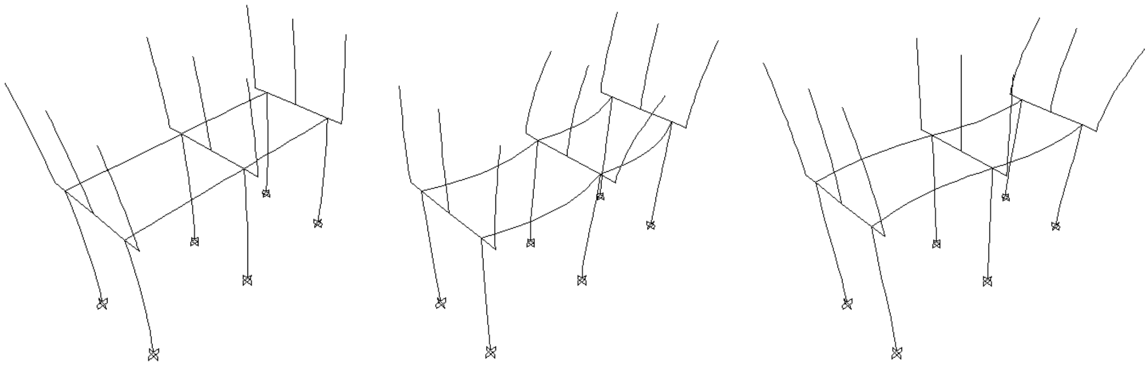


Figure 4.2 Model of isolated disconnector

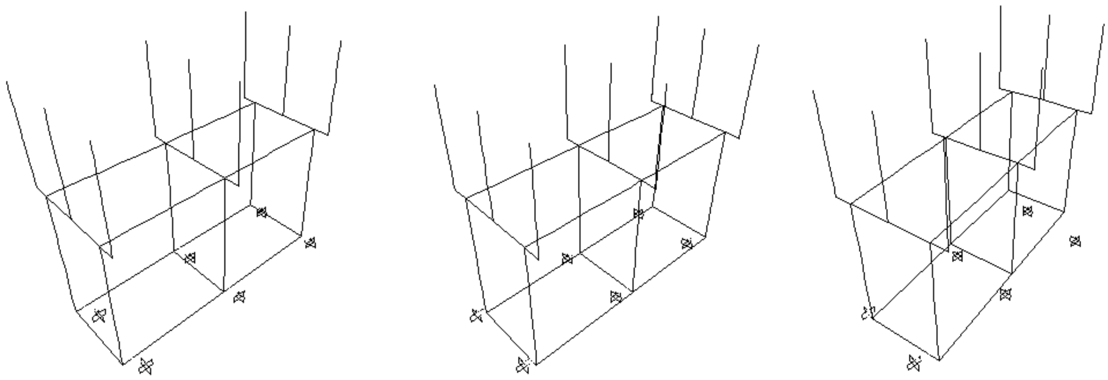
4.2. Modal Analysis

The first three mode shapes of isolated disconnector and non-isolated disconnector are shown in Figure 4.3 and Figure 4.4. The analysis results are compared in Table 4.1.



The first mode shape **The second mode shape** **The third mode shape**

Figure 4.3 The first three mode shapes of non-isolated disconnector



The first mode shape **The second mode shape** **The third mode shape**

Figure 4.4 The first three mode shapes of isolated disconnector

Table 4.1 Natural vibration period

Vibration model	1	2	3	4	5	6
Non-isolation period	0.3902	0.2090	0.2072	0.2066	0.1890	0.1619
Isolation period	1.4040	1.4008	1.3002	0.3724	0.2119	0.2095

These conclusions can be obtained from the modal analysis:

1) The natural vibration periods of isolated disconnector are much larger than the non-isolated disconnector. The base isolation increases the natural vibration period of superstructure.

2) As the figures of mode shapes shows, the basic mode shapes of non-isolated disconnector are the type of displacement amplification from below to above, and the basic mode shapes of isolated disconnector are the type of whole translation. Because the influence of high order mode shapes on structure are very small, the story drifts of superstructure are very small.

4.3. Time-history Curves of Load

Modulating the peak acceleration of earthquake waves to 0.4g (basic design acceleration of ground motion is 0.4g), and modulating the peak acceleration of earthquake waves to 620cm/s^2 (rare earthquake acceleration of ground motion is 620cm/s^2), the seismic response of non-isolated and isolated disconnector is calculated respectively. Under the earthquake waves, the time-history curves of bending moment on the roots of porcelain insulator are shown in Figure 4.5～Figure 4.8.

Where M_2 is the bending moment of global coordinate system in the X-direction and local coordinate system in the 2-direction, M_3 the bending moment of global coordinate system in the Y-direction and local coordinate system in the 3-direction.

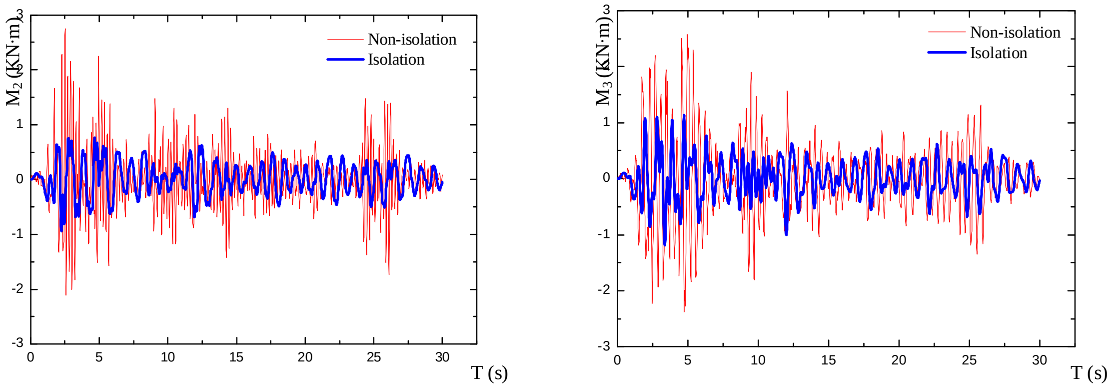


Figure 4.5 Time-history curves of bending moment under the wave of El-centro (0.4g)

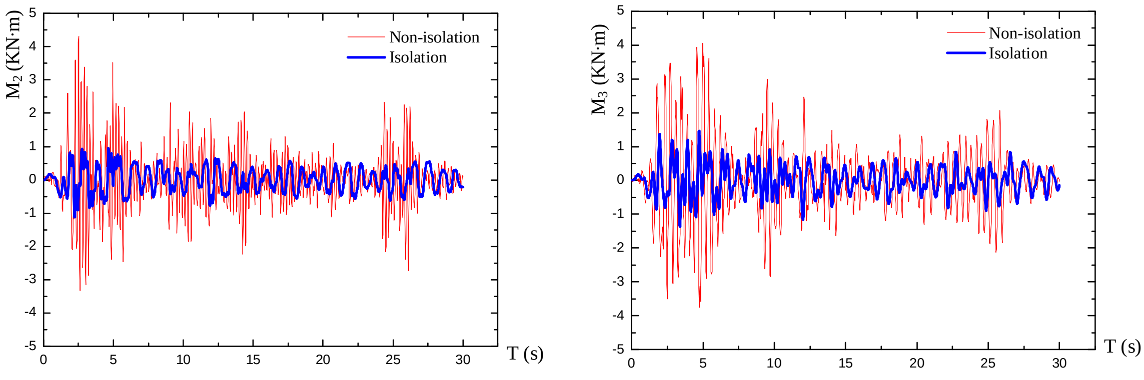


Figure 4.6 Time-history curves of bending moment under the wave of El-centro (620cm/s^2)

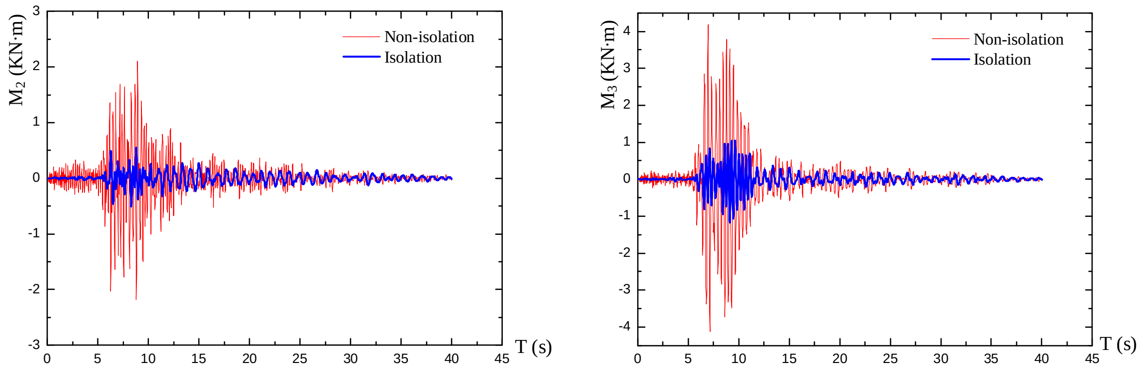


Figure 4.7 Time-history curves of bending moment under the wave of Taft (0.4g)

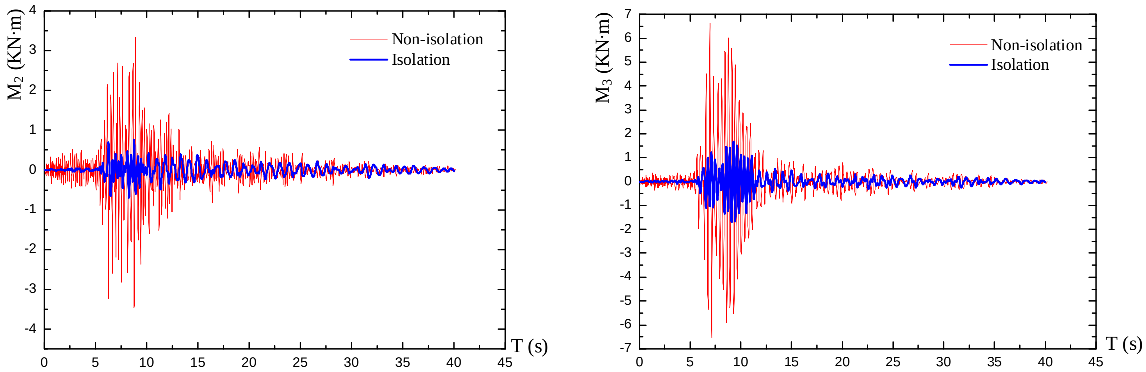


Figure 4.8 Time-history curves of bending moment under the wave of Tafts (620cm/s^2)

In order to compare the damping effect of base isolation, decreasing amplitude ratio is defined, which is the ratio of the difference between the maximum response of non-isolated structure and isolated structure and the maximum response of non-isolated structure. The decreasing amplitude ratio is given by

$$l_e = \frac{e_0 - e}{e_0} \tag{4.1}$$

where l_e is the decreasing amplitude ratio, e_0 the maximum response of non-isolated structure, e the maximum response of isolated structure. The results of decreasing amplitude ratio are shown in Table 4.2.

Table 4.2 Decreasing amplitude ratio of load on the root of lower segment porcelain

Earthquake waves	Decreasing amplitude ratio (%)			
	R_2	R_3	M_2	M_3
El-centro（0.4g）	53.23	64.66	65.69	54.00
El-centro（620cm/s^2）	64.11	73.61	73.99	64.13
Taft（0.4g）	69.67	76.99	74.99	71.90
Taft（620 cm/s^2）	72.41	79.92	78.09	74.41

Though the base isolation increases the natural vibration period, it is different with the main frequency composition of different earthquake wave, so the decreasing amplitude ratio is different with different earthquake wave. On the whole, the base isolated disconnector has an obvious damping effect. The decreasing amplitude ratio of load is more than 50%, some of them even is close to 80%.

5. CONCLUSION

1) Base isolation increases the natural vibration period of superstructure, and increases the frequency ratio of earthquake wave and high-voltage disconnector.

2) The vibration of non-isolated electrical equipment is the type of displacement amplification from below to above.

The vibration of isolated electrical equipment is the type of whole translation, which produces small story drift.

3) The result of comparative analysis shows that the decreasing amplitude radio of shear force on the root of lower segment porcelain is between 53.23% and 79.92%, the decreasing amplitude radio of bending moment on the root of lower segment porcelain is between 54.00% and 78.09%.

4) Base isolation in high-voltage electrical equipment can absorb the earthquake energy through the sliding base isolation bearings, and the finite earthquake energy is transferred to the superstructure. Though the superstructure will be elastic undergoing severe earthquakes.

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