Shaking Table Test and Factor Influencing Seismic Performance of Overhead Catenary System

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Abstract

Overhead Catenary system (OCS) is the only part of the traction power supply system for the electrified railway without standby equipment, whose performance directly affects the safety of railway operation. Different from the general civil engineering structure, OCS is a long-span structure connected by the suspension structure and the supporting structure, and the contact line and the catenary wire of the suspension structure have the initial pretension, so the setting of the seismic input direction and the conductor tension has a certain impact on the seismic performance of the overhead catenary system. In the past earthquakes, the catenary system is easy to be damaged, which makes it difficult for the railway to resume operation in a short time. At present, there are few research results on the seismic performance of OCS in the world, but for countries with frequent earthquakes such as China and Japan, it is more urgent to carry out the research on the seismic performance of OCS. Based on the overhead catenary system of electrified railway in a high intensity zone, the vibration table test of 1:1 full scale model was carried out in the vibration table Laboratory of Chongqing University, China. Firstly, the model of OCS is designed according to the similarity theory. Due to the limitation of laboratory span, the similarity ratios of conduct line and catenary wire are taken as 1:10, The artificial mass model is adopted, and the artificial mass is added to the conductor model, which makes up for the deficiency of gravity effect and inertia effect without affecting the structural rigidity. Then by finishing the vibration table test, the dynamic response of each part of the OCS model under three kinds of levels (frequent seismic, fortification intensity seismic, rare seismic) is obtained. At the same time,the influence of the seismic direction and wire tension on the seismic performance of OCS is analyzed by comparing the seismic response results of each component of the OCS model under different earthquake input directions and different wire tension. The results show that: (1) for the pole, the seismic response along the line direction is significantly greater than that perpendicular to the line direction, which means it is more unfavorable for poles under the seismic along the line direction. On the contrary, for the conductor structure, the transverse displacement of the conduct line and catenary wire under earthquake along the line direction is significantly smaller than that along the line direction, while the direction of earthquake input has little effect on the vertical displacement of the conductor. (2) The seismic response of conductor in OCS can be reduced to a certain extent by increasing the tension of contact line and catenary wire properly, as the seismic response of contact line and catenary wire decreases with the increase of conductor tension. However, compared with the seismic perpendicular to the line direction, the seismic response of the pole changes more when the conductor tension is changed under seismic along the line direction. This is because the movement of the pole along the line direction is limited to a certain extent by the cantilever, and the greater the conductor tension, the more stable the cantilever is.

Key words: Electrified railway, Overhead catenary system, shaking table test, Similarity ratio, Seismic response, conductor tension, Lang-span system

1. Introduction

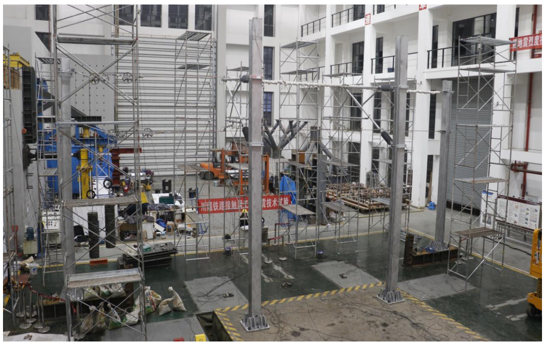
With the development of China's electrified railway construction, many large-scale electrified railways began to be built in high seismic intensity zones. In particular, the Sichuan-Tibet Railway under construction is the first electrified railway to Tibet, which is of great significance for construction; considering the poor environmental conditions and the varied topography of the Sichuan-Tibet railway, its seismic safety is an important problem that must be seriously faced and solved.

Up to now, the research on seismic performance of the catenary system (OCS) is still lacking in the world, especially the shaking table test of OCS is almost blank. Based on the above purpose, a 1:1 full scale shaking table test of 4-pole and 3-span catenary system is carried out, and the corresponding laws of OCS under different seismic levels and seismic directions are obtained, which truly reflects the seismic response characteristics of the system, provides parameters and basis for engineering construction and theoretical research, and also supplies test basis for seismic design of similar structures in the future. At the same time, by changing the working tension of the conductor (contact line, catenary wire) to compare and analyze the dynamic response of OCS under the earthquake, the influence of conductor tension on the seismic performance of the system is studied, which provides a reference for the selection of conductor tension in practical engineering.

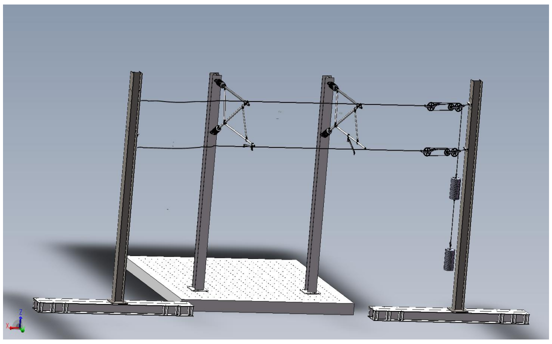
2. Shaking table test design

2.1 General situation of the test model

The OCS in a high intensity area is used as the prototype. There are three spans and four poles in the model, including two suspension poles (one is pull-off support and the other is push-off support) anchored on the shaking table and two anchor masts anchored outside the shaking table. The form of the cantilever is triangle type, and the poles are H-section steel pole. The overhead catenary system model is shown in Fig.1, in which is the physical object and is the schematic diagram.



(a) Panorama of shaking table test for OCS



(b) model 3D diagram

Fig. 1 – Arrangement of shaking test for OCS

2.2 Similarity ratio design

Similarity theory is not only the basis of selecting similarity criterion in physical model experiment design, but also it is the precondition of correctly simulating the basic physical phenomena of the studied object under given conditions. As the S_L of columns and cantilever of the OCS model is 1:1, the height of the suspension poles and anchor masts are 7.2m and 6.2m respectively. The similarity ratio coefficient of the pole and cantilever device is shown in Table 1.

Table 1 – Similarity ratio coefficient of the pole and cantilever device

Physical quantity	Similarity ratio	Physical quantity	Similarity ratio
Geometry size	$S_L = 1$	Time	$S_t = 1$
Elastic modulus	$S_E = 1$	Displacement	$S_r = S_L = 1$
Poisson's ratio	$S_\mu = 1$	Velocity	$S_v = 1$
Density	$S_\rho = 1$	Acceleration	$S_a = 1$
Stress	$S_\sigma = 1$	Frequency	$S_f = 1$

Considering that the maximum width of the shaking table is 6.1m, the length of the contact line and the catenary wire are taken as 4.5m according to the similarity ratio between test model and the prototype which is 1:10. According to the artificial quality model, the similarity ratio coefficient of the conductor model of OCS is determined as shown in Table 2.

Table 2 – Similarity ratio coefficient of the conductor model

Physical quantity	Similarity ratio	Physical quantity	Similarity ratio
Geometry size	$S_L = \frac{1}{10}$	Time	$S_t = S_L^{0.5} = \sqrt{\frac{1}{10}}$
Elastic modulus	$S_E = 1$	Displacement	$S_r = S_L = \frac{1}{10}$
Poisson's ratio	$S_\mu = 1$	Velocity	$S_v = S_L^{0.5} = \sqrt{\frac{1}{10}}$
Density	$S_\rho = 1$	Acceleration	$S_a = S_g = 1$
Stress	$S_\sigma = 1$	Frequency	$S_f = S_L^{-0.5} = \sqrt{10}$

2.3 Seismic wave selection

In this test, a Taft wave and an El-Central wave recorded in the PEER which is widely used in the world are selected as the sources of natural ground motions. At the same time, an artificial wave made by the wave selection software developed by our team is added for comparative analysis according to specific indicators of site condition. The information of the three selected seismic waves is shown in Table 3, and the acceleration time history of the three seismic waves are shown in Fig.2.

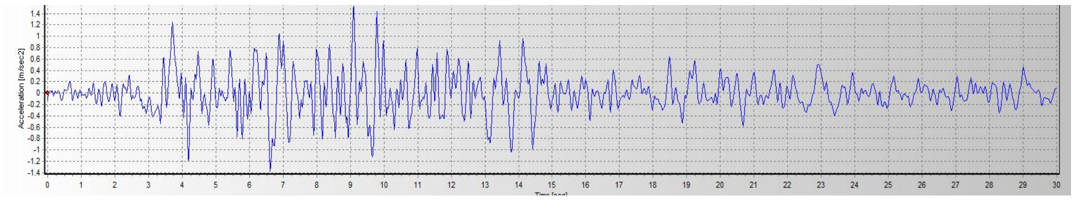
2.4 Arrangement of testing points

There are a total of 63 channels in the test, including 14 acceleration sensors (28 channels), 12 displacement sensors (23 channels), and 6 strain gauges (10 channels). The strain gauges are mainly arranged at the steady arms and the bottom of four poles, the acceleration sensors and displacement sensors are mainly arranged at the middle of the conductor spans, the top of the pillars, the junction of the conductor and the cantilever, and the balance weight of the anchor mast.

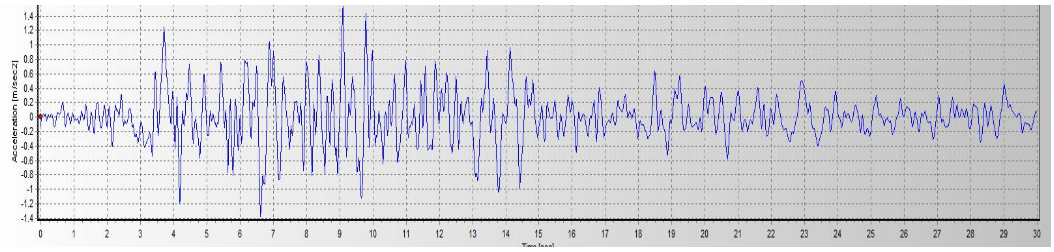
The arrangement of testing points can be seen in Fig.3, for the convenience of description, the X direction is located along the line direction, Y direction is perpendicular to the line direction, and Z direction is vertical. Meanwhile, A represents for accelerometer, B for displacement sensor and C for strain gauge relatively.

Table 3 – The information of the selected natural waves

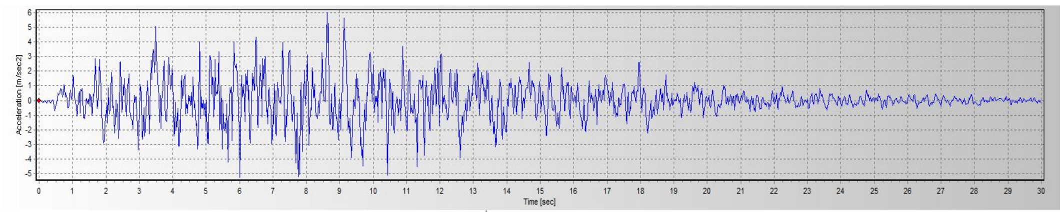
Earthquake events	Year	Seismic Station	Magnitude	Fault mechanism	Site classification
Imperial Valley	1979	El-Central	6.53	Strike-slip fault	II
Kern County	1952	Taft Lincoln School	7.36	Thrust fault	II



(a) Acceleration time history of El-Central wave



(b) Acceleration time history of Taft wave



(c) Acceleration time history of Taft wave

Fig. 2 – Acceleration time history of the tree selected seismic waves

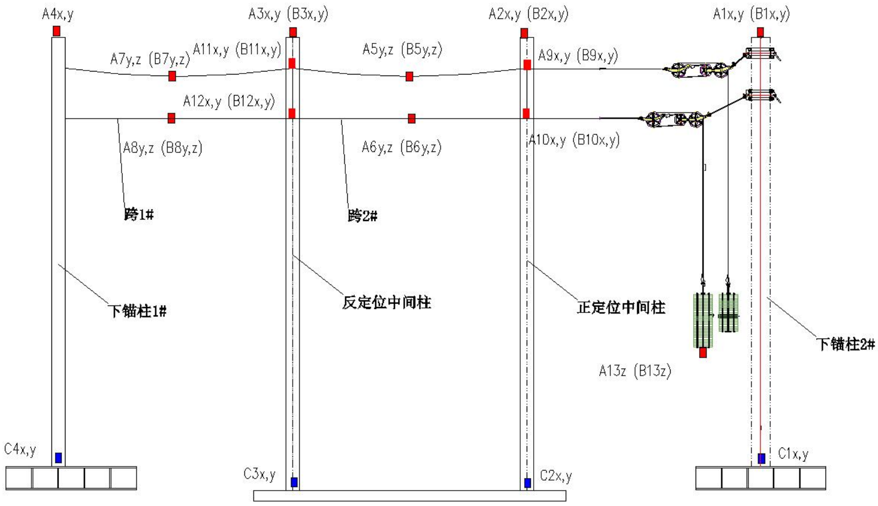


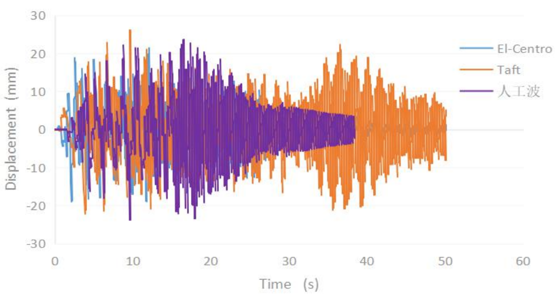
Fig. 3 – Arrangement of testing points

3. Seismic response analysis

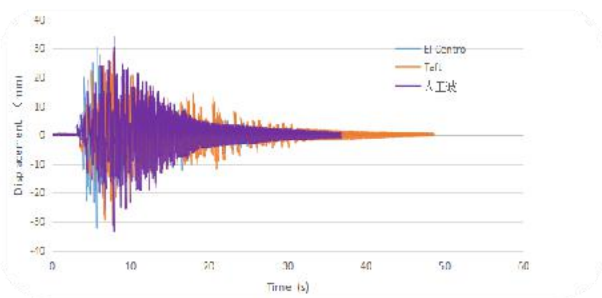
3.1 Under frequent seismic (0.14g)

Fig.4 and Fig.5 show that when the seismic wave transmits along the line direction (x direction), the amplification of the acceleration at the top of the pole is more obvious than that perpendicular to the line direction (Y direction). In the case of earthquake along the line (x direction), the peak value of acceleration amplification coefficient of pull-off pole is 7, and the peak value of acceleration amplification coefficient of push-off pole is 9; while the peak values of acceleration amplification coefficient of pull-off pole and push-off pole are 4.5 and 4 when the direction of seismic wave is perpendicular to the line (Y direction).

In Fig.6, Fig.7,under the action of three seismic waves, the displacement trend in the middle span of contact line and catenary wire is similar. However, the direction of the seismic input has a great influence on the displacement of both contact line and catenary wire. Under the seismic action perpendicular to the line direction (Y direction), the maximum value of the transverse displacement in the middle of the catenary span reaches 27.75mm, and the peak value of the transverse displacement in the middle of the contact line span is 20.84mm, which is far greater than the peak value of 0.83mm in the middle of the catenary span and 0.68mm in the middle of the contact line span under the seismic action along the line direction (x direction).

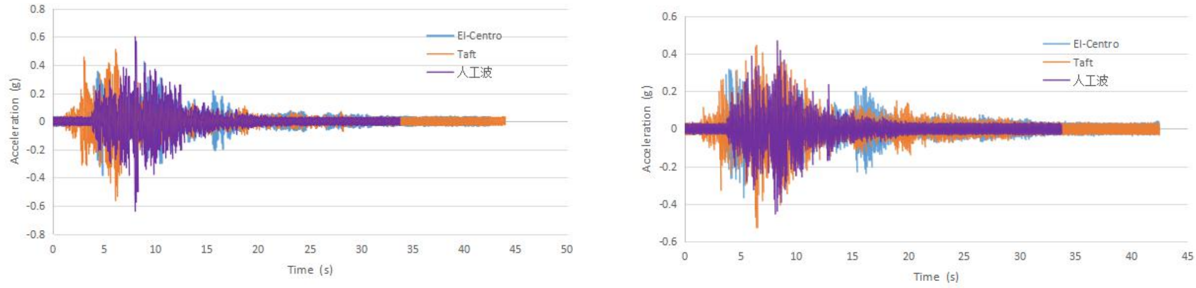


(a) pull-off pole



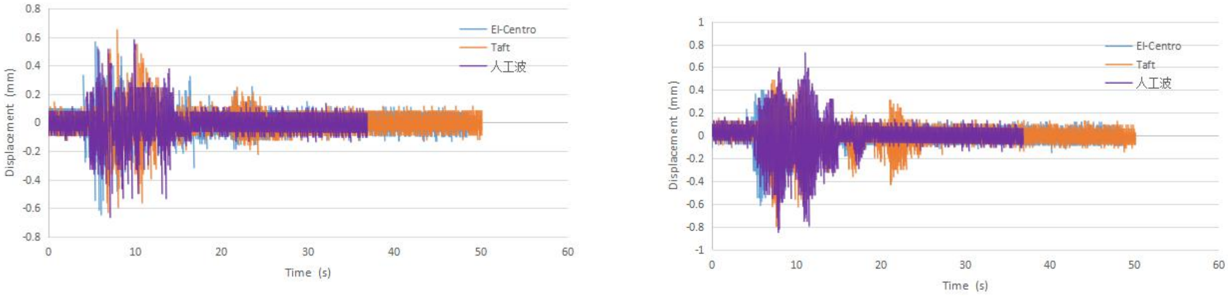
(b) push-off pole

Fig. 4– Acceleration at the top of poles under frequent seismic along the line direction



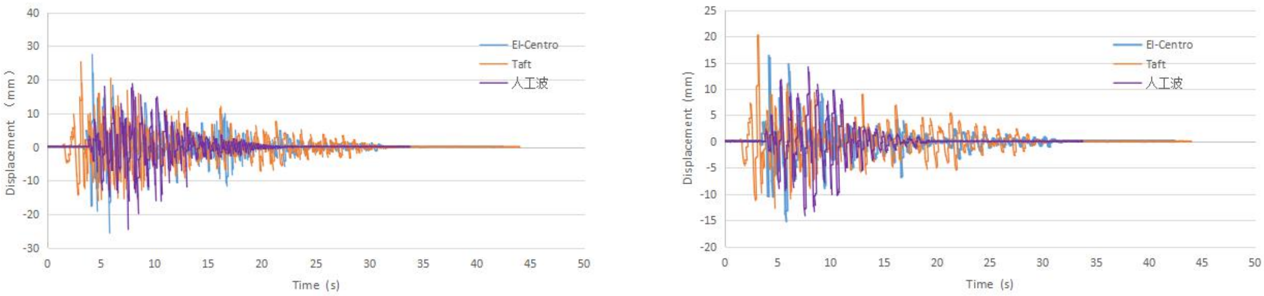
(a) pull-off pole (b) push-off pol

Fig. 5 – Acceleration at the top of poles under frequent seismic perpendicular to the line direction



(a) conduct line (b) catenary wire

Fig. 6 – Transverse displacement in the middle span under frequent seismic along the line direction



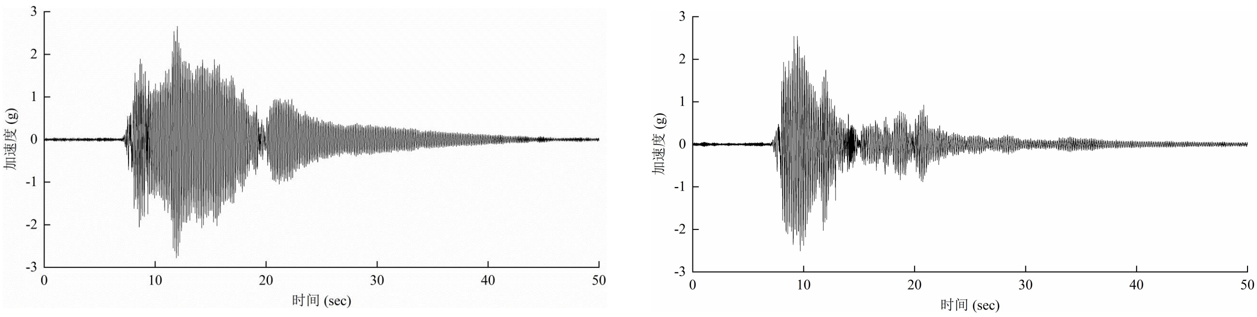
(a) conduct line (b) catenary wire

Fig. 7 – Displacement in the middle span under frequent seismic perpendicular to the line direction

3.2 Under fortification intensity seismic action

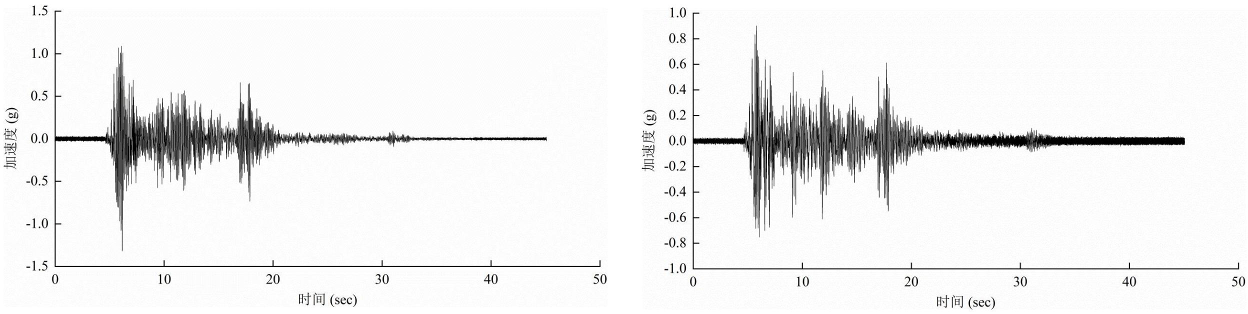
From Fig.8, Fig.9 we can see that the change rule of displacement response at the top of poles under fortification intensity seismic is the same as that under frequent seismic. When the seismic wave transmits along the line direction (X direction), the amplification of the acceleration at the top of the pole is more obvious than that perpendicular to the line direction (Y direction). The peak value of acceleration amplification coefficient of pull-off pole is 10, and the peak value of acceleration amplification coefficient of push-off pole is 8, while the peak values of acceleration amplification coefficient of pull-off pole and push-off pole are 5 and 2 when the direction of seismic wave is perpendicular to the line (Y direction). From the aspect of displacement response, under the same directions of seismic, the peak displacement at the top of the push-off pole is always slightly greater than that at the top of the pull-off pole, while the displacement at the top of poles under the earthquake along the line (X) is significantly greater than that under the earthquake perpendicular to the line (Y).

Fig.10, Fig.11 shows the change rule of displacement with time in the middle of the conduct wire span. Under different seismic directions, the horizontal and vertical displacement in the middle of the catenary wire span is greater than that in the middle of the contact line span. When the seismic action is perpendicular to the line direction (Y direction), the maximum values of the horizontal and vertical displacement of the catenary wire are 75.51mm and 27.85mm, respectively; while the maximum values of the horizontal and vertical displacement of the contact line are 44.83mm and 23.92mm.



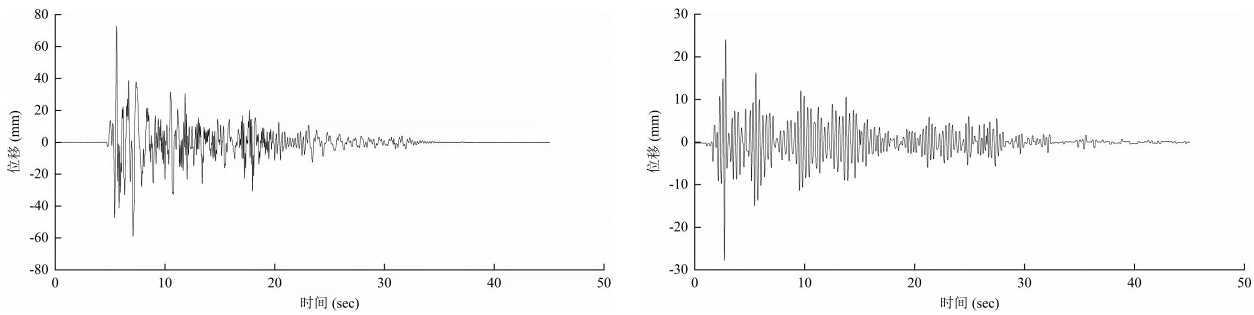
(a) At the top of pull-off pole (b) At the top of push-off pole

Fig. 8 – Acceleration response under fortification intensity seismic along the line direction



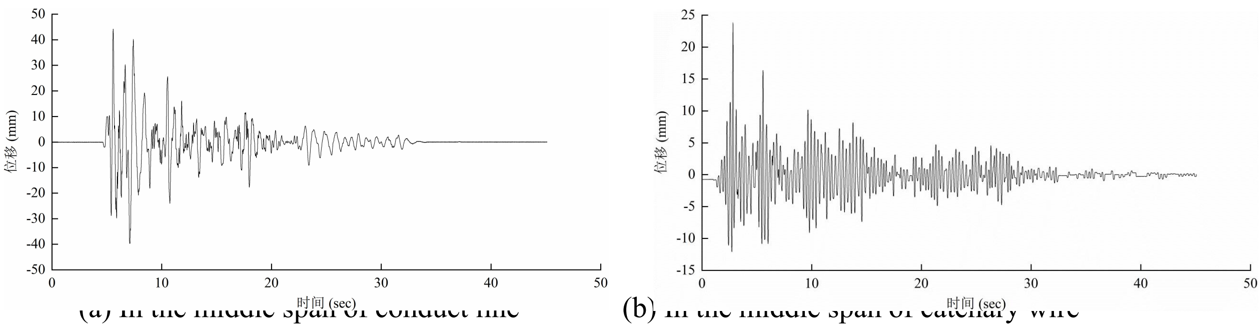
(a) At the top of pull-off pole (b) At the top of push-off pole

Fig. 9 – Acceleration response under fortification intensity seismic perpendicular to the line direction



(a) In the middle span of conduct line (b) In the middle span of catenary wire

Fig. 10 – Transverse displacement under fortification intensity seismic perpendicular to the line direction



(a) In the middle span of conduct line (b) In the middle span of catenary wire

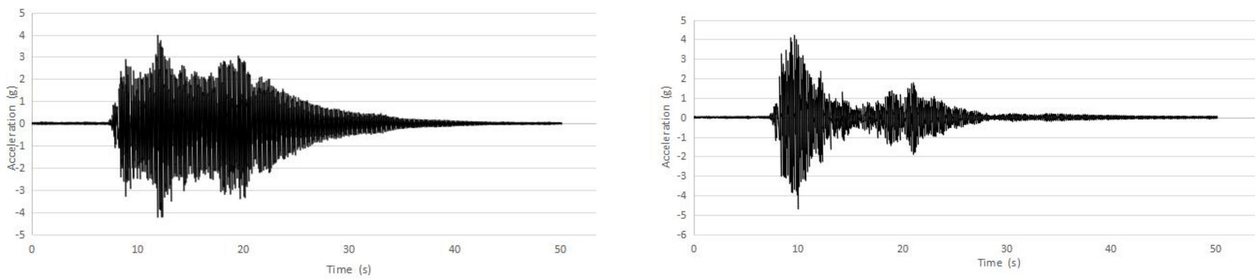
Fig. 11 – Vertical displacement under fortification intensity seismic perpendicular to the line direction

3.3 Under rare seismic action

Similar to the previous two conditions, in the rare earthquake (0.64g), when the earthquake along the line direction (x direction), the amplification effect of the acceleration at the top of the poles is more obvious than that perpendicular to the line direction (Y direction). In Fig.12, we can see that when the seismic direction is X, the peak value of acceleration amplification coefficient of the top of poles reaches 6.5, while the peak value of acceleration amplification coefficient is only 3.5 when the seismic direction is Y in Fig.13. But when it comes to seismic response of anchor mast, the change rule of the acceleration is just the opposite, when the seismic action along the line direction (X direction), the acceleration at the top of the anchor mast is significantly smaller than that in the vertical direction (Y direction). It shows that the effect of the earthquake action perpendicular to the line direction is greater than that along the line direction.

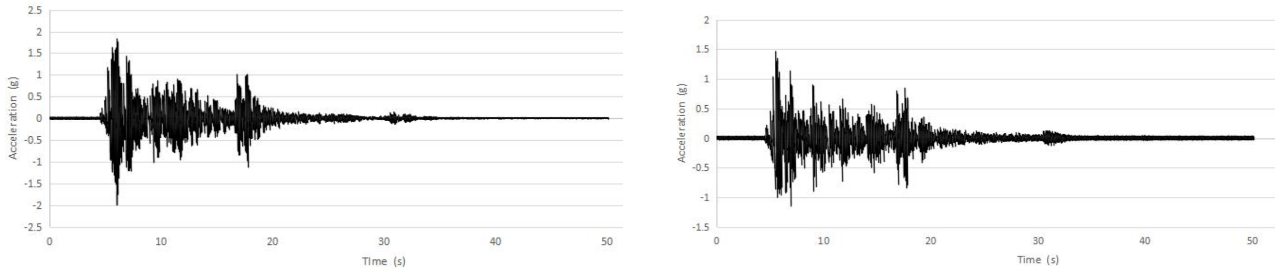
In Fig 14 and Fig.15, under the rare earthquake (0.64g), it is similar to the two previous conditions that the displacement of catenary wire in the middle of span is greater than that of contact line no matter which direction the earthquake is.

It is worth mentioning that under both X and Y seismic directions, the peek value of the vertical acceleration of the balance weight is 0.2g as shown in Tabe1, resulting in the tension deviation of 20%, which has a great impact on the working state of the catenary system.



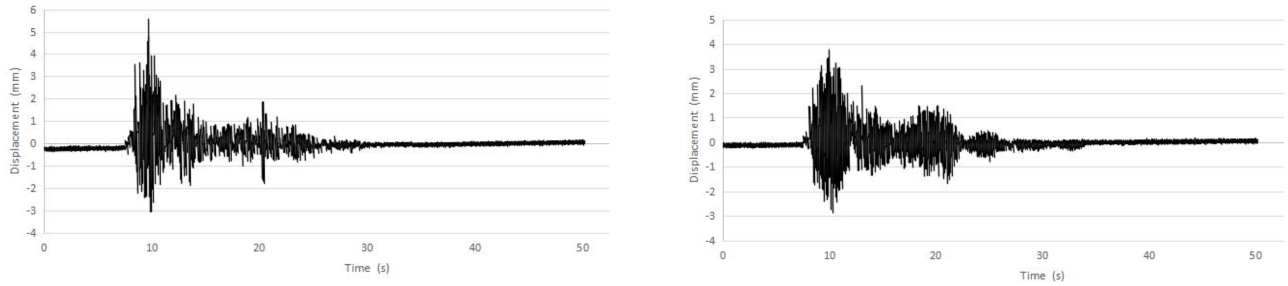
(a) pull-off pole (b) push-off pole

Fig. 12 – Acceleration at the top of poles under rare seismic along the line direction



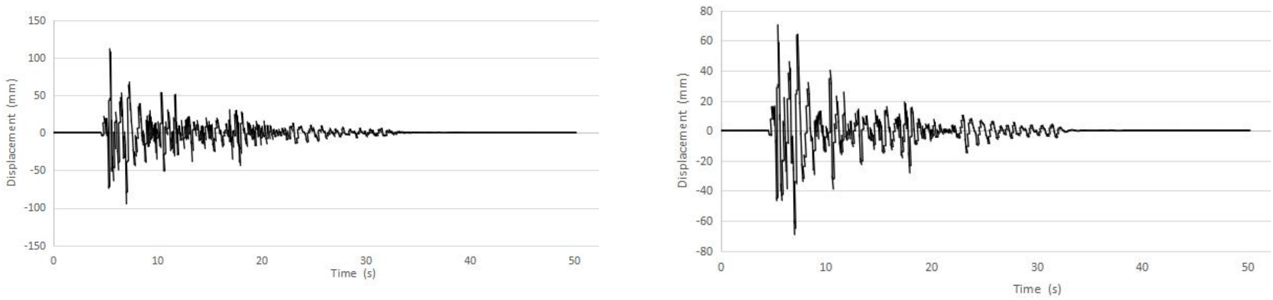
(a) pull-off pole (b) push-off pole

Fig. 13 – Acceleration at the top of poles under rare seismic perpendicular to the line direction



(a) conduct line (b) catenary wire

Fig. 14 – Transverse displacement in the middle span under rare seismic along the line direction



(a) conduct line (b) catenary wire

Fig. 15 – Transverse displacement in the middle span under rare seismic perpendicular to the line direction

3.5 The influence of conductor tension

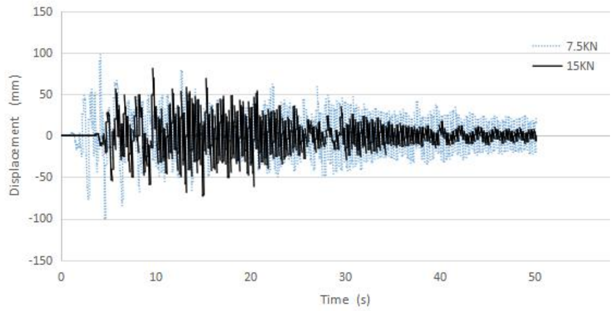
In this study, shaking table tests were carried out under the conditions of contact line, catenary wire tension of 15kN and 7.5kN respectively. By comparing the seismic response of the two conditions under the same seismic wave, the influence rule of contact line and catenary wire tension on the seismic performance of OCS was obtained.

In the two conditions, we use the EL-Central wave as the input of seismic motion, which direction is along the line direction and perpendicular to the line direction (Y direction), under fortification intensity seismic action.

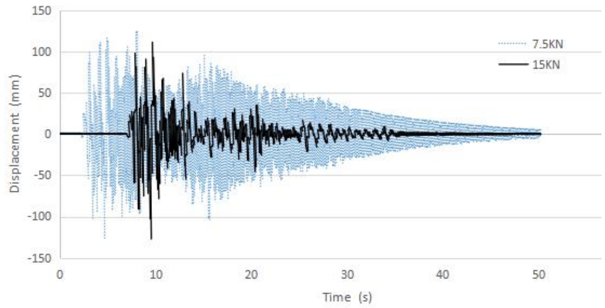
The compared result of seismic responses is shown in Fig.16, when the tension of catenary wire is 7.5kN, the relative displacement at the top of poles are significantly greater than that of catenary wire is

15kN. However, compared with the seismic action perpendicular to the line direction, the seismic response of the poles changes more when the conductor tension is changed under the line direction seismic action. This is because the movement of poles along the line direction is limited to a certain extent by the cantilever, and the greater the conductor tension, the more stable the cantilever.

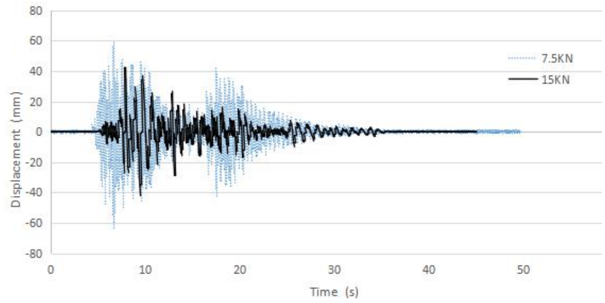
In Fig.17, under the earthquake action perpendicular to the line direction, the displacement in the span of contact line and catenary wire decreases with the increase of the wire tension, but the change is not very obvious , which shows that properly increasing the tension of contact line and catenary wire can reduce the seismic response of wires in the catenary system to a certain extent.



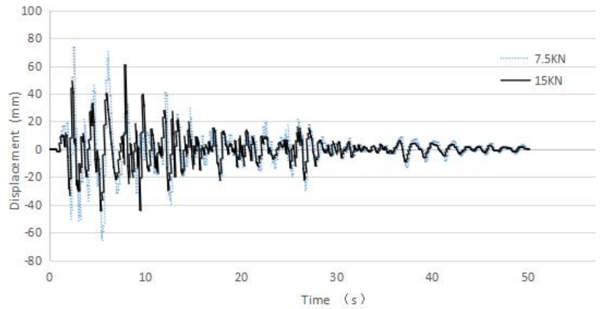
(a) pull-off pole (along the line direction)



(b) push-off pole (along the line direction)

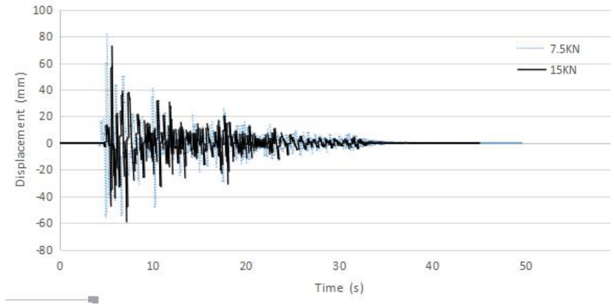


(a) pull-off pole (perpendicular to the line direction)

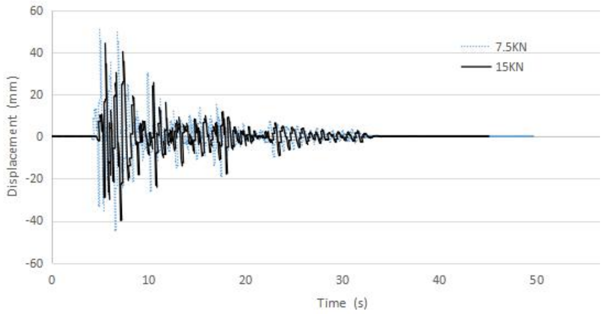


(b) push-off pole (perpendicular to the line direction)

Fig. 16 – Acceleration response at the top of poles under different conductor tension



(a) conduct line (perpendicular to the line direction)



(b) catenary wire (perpendicular to the line direction)

Fig. 17 – Transverse displacement in the middle of the conductor under different tension

4. Conclusion

In this paper, based on the actual engineering of an electrified railway overhead catenary system, a 1:1 full-scale model is used to complete the shaking table test of the dynamic response of the electrified railway OCS which have 4 poles and 3 spans. Under three different kinds of seismic levels, the seismic response of each component of the OCS and the influence of conducting wire tension on the seismic performance are obtained. Through the above analysis, the following conclusions are drawn:

(1) When the seismic along the line direction (X direction), the amplification ratio of the acceleration at the top of pole is more obvious than that perpendicular to the line direction (Y direction). Under the rare earthquake, the shaking of the top of the poles is violent, which may lead to the tilt or even break of the pole.

(2) Under different direction of seismic, the horizontal and vertical displacements in the middle of catenary wire span are greater than those in the middle of contact line span. Compared with the contact line, the catenary wire is more likely to be damaged under earthquake.

(3) The vertical acceleration of the balance weight can reach 0.2g in the case of rare earthquake, resulting in the conductor tension deviation of 20%, which has a great impact on the working state of the OCS.

(4) The change of the conductor tension can affect the seismic performance of the catenary system. The larger the conductor tension is, the smaller the seismic response of the catenary system is, and the more favorable the seismic resistance is. In practical engineering, the tension of contact line and catenary wire can be increased appropriately.

6. References

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