Experiment on Seismic Behaviour of Damaged Cable-Suspended Structure

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Summary

Three damage modes of cable-suspended structures are summed up on the basis of experiences. A model scaled to be one eighth of a real cable-suspended bridge is established. The dynamic tests of the model in non-damage mode and the three damage modes are carried out respectively by applying white-noise and El-Centro waves of different intensities to the model. The structural systems keep stable and the members of the model are not damaged, even though the maximum longitudinal and transverse accelerations applied exceed an equivalent of 0.4*g* for a real structure. It means that the cable-suspended structures of pipelines, even in the three damage modes, have a good seismic resistant capacity in earthquake of intensity IX in China.

Keywords: Long-distance pipeline; cable-suspended structure; experimental study; natural frequency; earthquake response.

Introduction

Cable-suspended structures are usually used for long-distance oil and gas transmission pipeline projects when railways, highways or valleys locate in the way. Large numbers of seismic disasters show that the earthquake not only destroyed the oil and gas transmission pipelines directly, but also led to a certain extent of secondary disasters, such as fires and explosions. So far studies on seismic responses of the cable-suspended structures are rarely carried out. Towers and stayed-cables are the key members that keep the system stable in the structure. After synthetically analyzing all the factors that could bring damages to the cable-suspended structures, three basic damage modes are considered: (1)Damages on the towers; (2)Damage on the hangers; (3)Damage on the stayed-cables.

In this paper, a model scaled to be one eighth of a real structure is established, and the dynamic tests of the model in non-damage mode and the three damage modes above mentioned are carried out respectively.

Fig. 1: View of the test model

1 The model experiment

The test model (Fig.1) is based on a cable-suspended bridge across Wei-Hui channel, a section of the natural gas transmission pipelines from Xianyang to Baoji, in Shanxi Province of China. The test model is scaled to be one eighth of the real structure. The model, which is 9m long and 1.4m high, has main cables of 6.78m each and stayed-cables of 1.25m each, and the arch height of the model is 25mm.

Vertical and transverse responses are the main responses of the cable-suspended structure. 21 accelerometers, 11 displacement sensors, and 36 strain gauges are installed on the test model.

https://doi.org/10.2749/222137908796293901

2 Test results and analysis

The dynamic tests of the model are carried out in 4 different modes: (1) Non-damage mode; (2) Loosen one ground bolt of a tower purposely to simulate the damage of the tower; (3) Fix the ground bolt again and take out one hard hanger to simulate the damage of the hanger; (4) Take out one stayed-cable to simulate the damage of the stayed-cable. Measured accelerations of white-noise and El Centro waves are input into the system from three directions.

The test results indicate that: (1) Although both the maximum transverse and vertical ground accelerations input into the test model in three different damage modes exceed an equivalent of 0.4g of the real structure, the model members keep stable without damage. It shows that the cable-suspended structure could keep running when the ground acceleration corresponds to earthquake intensity IX. (2) Compared with the non-damage mode, modal parameters of the structure in the three damage modes have changed. Though natural frequencies are still discrete, the average values decrease a little, and the fundamental transverse frequency and the secondary vertical frequency decrease markedly. The maximum ground acceleration input is $0.68g$ in damage modes, which is 50% more than that in non-damage mode. However, the maximum acceleration of the test model decreases a little bit. The maximum longitudinal acceleration on the top of the tower is $1.71g$, while the maximum transverse acceleration of the pipe is $1.19g$. The maximum transverse relative displacement of the pipe is 5.27mm, which is 11% bigger than that (4.76mm) in non-damage mode, while the maximum vertical relative displacement of the pipe is 5.27mm, which is a little smaller than that (9.78mm) in non-damage mode. (3) The maximum transverse accelerations of the tower and the pipe as well as the transverse displacement response of the pipe in hanger damage mode are smaller than those in tower damage mode. It indicates that transverse seismic responses of the structure system can be greatly affected by the looseness of ground bolts of the tower, whereas the same effect would not happen when a hanger is invalidated. Compared with those in tower damage mode, the fundamental and secondary transverse frequencies and the secondary vertical frequency are bigger, while there's no noticeable change in the fundamental vertical frequency. The ratio of horizontal frequencies increases, but the ratio of vertical frequencies decreases. It shows that characteristics of the frequencies in hanger damage mode are close to those in non-damage mode. (4) The vibration modals of the system change a lot in stayed-cable damage mode. Compared with non-damage mode and the former two damage modes, both the fundamental vertical frequency and the ratio of vertical frequencies are smaller, while horizontal frequencies are a little greater. As the longitudinal and vertical restrictions are weakened by the invalidation of a stayed-cable, longitudinal acceleration of the tower and vertical acceleration of the pipe are greater than those in the former two damage modes, but there are no noticeable changes in the acceleration and displacement responses at other places. It is the strain that differs most in stayed-cable damage mode. The maximum strains in stayed-cables and pipes are $775\lozenge 10^{-6}$ and $318\lozenge 10^{-6}$ respectively, both of which are the maximum values among those measured in stayed-cables and pipes.

3 Conclusions

(1) The three damage modes described in this paper would not lead to the instability of the structure system under static loads. Even under the simulated earthquake of great intensity, the structure system could run and keep stable as well. It indicates that the cable-suspended structures of pipelines have strong seismic resistant capacity.

(2) The influences on the dynamic characteristics of the cable-suspended structure brought by various damage modes are different. Modal parameters and dynamic responses of the structure system are different in the three damage modes. Because of the environmental complication and the structure complicacy, the values of dynamic responses of the structure vary a lot from place to place; Contrastively, modal parameters, such as natural frequencies and frequency ratios, could reflect the general characters of the structure. The modal parameters are synthetically calculated according to multi-spot testing data, so they would be more stable.

Acknowledgements

The authors would like to acknowledge the financial supports from the National Natural Science Foundation of China under grant number 50578109 and 90715034.