Research on Seismic Behavior of Double-Column Piers with Anchor Plate

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Abstract: In order to study the seismic performance of double-column piers with anchor plates, a model of double-column pier with anchor plates and a model of double-column pier with hooked anchorage are fabricated with a geometric similarity ratio of 1:5. Through the shaking table test, the experimental phenomena and some other data of the two double-column pier models are analyzed. Experimental results show that: (1) Their failure phenomena are similar, and no failure occurs to the anchorages. (2) The peak displacement, the strain of reinforcement and the curvature of plastic hinge in the transverse direction of the pier with anchor plates are smaller than those of the pier with bending-hook anchorage, which demonstrates that the seismic performance of the pier with anchor plates is improved in the transverse direction. However, the measurements in the longitudinal direction of the pier with anchor plates are increased, indicating that its seismic performance is slightly worse than that of the end-hook anchored pier.

1. Introduction

The reliability of anchorage method is very important to the safety of structure. The types of anchoring methods also directly affect the construction technology and economic benefits. Bending anchorage greatly reduces the anchorage length of reinforcing bar, but it causes some other problems. For example, the bending hook at the end of the reinforcing bar aggravates the congestion at the joints, increases the difficulty of construction, reduces the quality of concrete pouring and also wastes material greatly.

In recent years, with the application of high-strength and large-diameter reinforcement and epoxy resin coated steel bar, structural optimization design and so on. The design and construction problems caused by traditional anchorage methods are becoming increasingly prominent. Anchor plate has been widely used in house structure and other special structures [1] because of its good anchorage performance [2], convenience for construction and good economic [3]. The GB 50010-2010, revised in 2011, has included this anchorage method. The industry standard, JGJ256—2011, has also been issued and implemented. But its research in bridges is relatively scarce. In order to extend the anchor plate to bridge structure, shaking table tests of piers with two anchorage modes are carried out to explore whether the anchorage plate has reliable anchorage performance under earthquake action. It has certain significance for the popularization of anchorage plate in bridge structure and the improvement of the research on seismic performance of anchorage plate.
2. Overview of Shaking Table

2.1 Design of test model
The prototype bridge is chosen as a small bridge on the class-2 highway in Fuzhou. Double-column pier is selected as the bridge substructure and hollow slab beam is selected as bridge superstructure. The factors such as the authenticity of the model, the size limitation of the test site and the loading capacity of the test equipment are considered comprehensively. The similarity ratio of elastic modulus is set at 1/1, geometric similarity ratio is set at 1/5, acceleration similarity ratio is set at 1/1, and other similarity ratios are obtained by dimensional analysis [4].

The test model is a two-span simply supported beam bridge. The bridge deck width of the reduced model is 2.5m, the bridge span is 3m and the bridge deck weight is 7t. The diameter of the pier is 250mm and the height of the pier is 1450 mm. In this paper, the steel end bending anchorage pier is named TRA, and the anchor plate anchorage pier is named ACP. The anchorage length of the pier steel bar in the joint area is determined according to the specifications. The anchorage length of TRA is 320 [5] mm and ACP is $0.4l_a = 130mm$ [6]. The layout of the test model is shown in Figure 1.

![Fig.1 Full Bridge Model of Shaking Table Test](image)

2.2 Working condition design
The loading scheme is designed according to the relevant literature of shaking table test [7]. Wenchuan wave, EI-Centro wave and artificial wave Sitewave synthesized according to geological conditions in Fuzhou are selected to load the structure by appeal method. Taking the longitudinal direction of the bridge as X direction and the transverse direction as Y direction, the two-way loading mode of $X+0.85Y$ is adopted. The structure was loaded from 0.5g to 0.45g at 9 working conditions per wave. Before loading, the structure was scanned by white noise to analyze its dynamic characteristics. Due to equipment constraints, EI-Centro wave and Sitewave artificial waves are only loaded to 0.3g.

3. Analysis of test results

3.1 Experimental phenomena and dynamic characteristics
For space reasons, this paper only lists the data curves of structures under EI-Centro waves. With the increase of PGA (Peak Ground Acceleration), the fundamental frequency of the structure decreases, cracks gradually appear. Initially, short cracks appear along both sides of the pier bottom along bridge in axial direction. Then short cracks extend along the pier body and form annular cracks. With the increase of PGA, cracks also appear in pier body and pier top. The cracks are fine and healing under the action of self-weight after loading. TRA and ACP have similar crack locations and widths. The difference is that the number of annular cracks in ACP is less than that in TRA. The annular crack width at the bottom of ACP pier measured by crack observer is 0.03mm, which is less than 0.05mm of TRA pier.
3.2 Analysis of experimental data

3.2.1 Peak displacement at bent cap
The peak displacements of X-direction and Y-direction at the bent cap of two piers with different anchorage modes show different laws under earthquake action. Because of the large rigidity of anchorage and bearing area, the Y-direction stiffness of the structure is improved to a certain extent. The X-direction peak displacement of ACP is larger than TRA, while the Y-direction peak displacement is smaller than TRA. The small residual displacement of the two piers after each loading condition indicates that the structure has not yet fully entered the plastic state and still has a high safety reserve. The peak displacement diagram at the bent cap is shown in Figure 3.

3.2.2 Strain
With the increase of PGA, the strain increases. The strain of pier bottom is larger than that of pier top, and the strain of longitudinal reinforcement is larger than that of stirrup. The strain diagram is shown in Fig. 4 and Fig. 5.

It is noteworthy that under the action of El-Centro wave, the displacement of the structure decreases from 0.25g to 0.3g. However, it can be seen from the strain of steel bars that the steel bars have not entered the strengthening stage. The displacement response of the structure may be unstable due to the slippage of rubber bearings at different degrees after loading in each working condition and the errors of equipment loading.

The strain of longitudinal reinforcement at pier bottom of ACP and TAR are basically the same. It is noteworthy that the Y-direction strain of stirrups at the bottom of ACP is much smaller than that of...
The results show that the Y-direction bending and the shear deformation of the pier bottom in the plastic hinge region are reduced because of the large anchorage rigidity and the large bearing area of the anchorage plate.

![Graph](image1)

**Fig. 4** Strain of Longitudinal Reinforcement at Pier Bottom Under Different PGAs

![Graph](image2)

**Fig. 5** Strain of Stirrup at Pier Bottom Under Different PGAs

### 3.2.3 Curvature

In this paper, only the curves of curvature of pier bottom in the range of 0 mm to 100 mm are listed. From Figure 6, it can be seen that the curvature values of the two piers are very similar when PGA is less than 0.2g. With the increase of PGA, the curvature of ACP in X direction will be slightly larger than that of TRA while the curvature of TRA in Y direction will be slightly larger than that of ACP. It is noteworthy that the difference of Y-direction curvature of plastic hinge is one of the reasons that the strain of stirrups at the bottom of pier of TRA is much larger than that of ACP. The maximum curvature of ACP in X direction is 150.8% of TRA, and that of TRA in Y direction is 140.4% of ACP.
4. Conclusion

- Through the dynamic test with two models, it can be seen that neither pier has anchorage failure under earthquake, and both anchoring modes have reliable anchorage performance. The anchoring method of anchor plate with buried depth of 0.4l can satisfy the anchorage requirements under earthquake action. It is feasible to adopt anchor plate in the lower structure of bridge.

- It can be seen from the failure phenomena of two kinds of pier that the anchorage form of anchor plate has a certain protective effect on the piers in the joint area. The number and width of annular cracks at the bottom of pier with anchorage plate are less than that of double-column pier with hooked anchorage.

- From the test data, it can be seen that the dynamic characteristics of the two piers are similar. The peak displacement, the strain of reinforcement and the curvature of plastic hinge region of ACP are smaller than those of TRA in the transverse direction. The results show that the seismic performance of the pier with anchor plate is improved in the transverse direction. However, the measurements in the longitudinal direction of the pier with anchor plates are increased, indicating that its seismic performance is slightly worse than that of the end-hook anchored pier.

In summary, the test results in this paper verify that the anchor plate has reliable anchorage performance. As a convenient and economical anchoring method, anchor plate is worth popularizing in engineering.

Acknowledgements

This paper was supported by Fujian Transportation Science and Technology Development Project [grant numbers 201415]. It also thanks for the financial supported by Department of Education Fund [grant numbers JT180046].

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