Experimental and numerical study on thin-walled hollow bridge piers

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Abstract. Research on thin-walled hollow bridge piers is of great importance to the large bridge. To study the nonlinear behavior of the thin-walled hollow bridge piers, two rectangular pier specimens have been tested under quasi-static cyclic lateral displacement and different axial loads. For easier comparison, these two specimens have been tested with constant load and varied load separately. Then an MSC. Marc model is built to compare the skeleton line and energy dissipation properties with experimental results. In consideration of the impact of some important parameters, a parametric numerical model has been built to test its performance with experimental results adopting different axial force and wall height-to-thickness ratio.

1. Introduction
Tall bridges often use thin-walled hollow piers because, in the same situation, thin-walled hollow piers have the feature of less mass, lower seismic inertia forces, and lower foundation forces. However, the performance of hollow piers in large earthquakes needs more study [1][2]. A hollow rectangular column has been chosen from an existing bridge named Niu Lan Jiang Bridge for this numerical analysis. The main objective of this study is to simulate the behavior of the pier in the quasi-static test and then investigate the influence caused by different axial force and wall height-to-thickness ratios.

2. Test specimens and set-up
The properties of the test specimens are briefly shown in Figure 1. The specimen is assumed to be 1:12 scaled, with an aspect ratio of 4. The side length of the hollow square cross-section is 1000mm and its thickness is 70mm. The pier height is 4000mm. The wall thickness ratio of loading direction is 14%. The vertical reinforcement has consisted of 8mm diameter rebars with a yield strength of 406MPa. The transverse reinforcement member is fabricated using a 2.4mm diameter steel stirrup with 50mm interval spacing. The concrete's compressive strength of the standard test cube is 26.3MPa.

The partial test setup is shown in Figure 2. Two different loading conditions have been applied. One specimen is under the constant axial force whose axial force ratio is 0.2. Apply the displacement cycles shown in Figure 3 to the top of the piers using a horizontal actuator. The other specimen is subjected to the same lateral displacement history but has varying axial stress. When reaching the point of maximum positive displacement of every cycle, the axial force ratio is 0.3, and the maximum negative
displacement is 0.1. As the added displacement varies, the axial force ratio can be calculated through the linear interpolation method.

![Figure 1](image1.png)

Figure 1 Design details of the thin-walled hollow bridge piers

![Figure 2](image2.png)

Figure 2 Test set up

![Figure 3](image3.png)

Figure 3 Added displacement history to the top of the pier

3. Experimental results
The basic test results are reported in figure 4. As the test has been conducted and introduced in Sun Zhiguo etc.’s article [3], only briefly results will be stated in this paper. During the test, flexural and shear concrete cracks developed firstly and then can clearly observe the concrete spalling and vertical steel reinforcement bucking in the region close to the bottom of the specimens. The damage mechanism of the specimens is local compression flange bucking of the pier walls and the sharp shear capacity reducing. Also, it has been noticed that there is some different performance between these two comparative specimens. By varying the axial force, the concrete spalling and rebar bucking occurs more seriously in the positive position than that in the negative position. The maximum crack width of the tension side in the negative position is bigger than that of in the positive position.
4. Numerical analysis

The general-purposed Finite Element Method (FEM) software called MSC. Marc is used to numerically investigate the mechanical performance of the specimens. The concrete is simulated using solid elements with eight nodes and a full integration scheme. In this simulation, the concrete constitutive model adopts Buyukozturk concrete with isotropic hardening rule. The compression yield strength is 23.8MPa, the Younger’s modulus is 3e4MPa, and the Poisson’s ratio is 0.2. The steel part is defined as a two-node truss element which is a kind of von Mises material with isotropic hardening rule [4]. Its yield strength is 437MPa, the Younger’s modulus is 2e5MPa, and the Poisson’s ratio is 0.3. The material property of the stirrup is the same as the steel part except for a different yield strength which is 374MPa.

The force-displacement hysteretic curves of two numerical models are shown in Figure 5. The curves indicate that the numerical result matches well with the test result. To get some detailed information, the comparison of the skeleton line and energy dissipation properties as shown in figure 6 and figure 7 has been taken. The skeleton line for the test with varying axial force has a little deviation in the negative position. Figure 8 and 9 shows the equivalent total strain of two specimens. The test performance has been compared with the numerical analysis which coincides with the analysis result, such as the strain in the positive position is larger than that in the negative position.
Figure 6  Comparison of the skeleton lines

(a) the constant axial force specimen  
(b) the varying axial force specimen

Figure 7  Comparison of energy dissipation

(a) the constant axial force specimen  
(b) the varying axial force specimen

Figure 8  Equivalent total strain of the constant axial force model
5. Further study on the numerical analysis
On the basis of the above research, a more in-depth study has been carried out. Through changing one parameter and keeping the other constant, some important information can be gained. In this study, the axial force ratio and wall thickness ratio have been chosen. Figure 10 presents the hysteresis curve with different wall thickness ratios. It can be found that the thinner the wall is, the lower the shear capacity it has and the earlier the damage occurs. Figure 11 shows the hysteresis curve under different axial force ratios. The larger the axial force is, the higher the shear capacity becomes.

6. conclusion
This paper investigated the numerical analysis of thin-walled hollow bridge piers. Major findings are listed as follow:

The results of numerical analysis correspond to the test results. They also have some similar phenomena. Hence, the numerical analysis is credible.

Based on the previous simulation, this research conducted some vertical parameter analysis has been taken in this study. It can be known the high wall thickness ratio is beneficial, and a high axial force ratio can lead to unfavorable results.
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