Application of spatial lateral constrained loading feedback control method in pseudo-static testing

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Abstract. In seismic performance testing of structures, the accurate boundary condition is the key to guarantee the accuracy of testing results. The one-way pseudo-static testing is the most common loading method in civil engineering seismic testing. However, the structures are all spatial structures in practice, therefore, the lateral constraints on specimen are necessary in one-way pseudo-static testing. The reaction devices are used to constrain the specimen laterally in traditional loading method, but the traditional loading method has some disadvantages such as high cost, large occupation of space and so on. In order to avoid those disadvantages of traditional loading method, a spatial lateral constrained loading feedback control method is proposed in this paper. In this method, the main direction loading and lateral constrain of the specimen are realized by the actuators, and the accurate control of the constraint boundary can be achieved by adjusting the position of the lateral constrained actuators. In order to verify the accuracy and feasibility of the proposed method, a pseudo-static testing of a full-scale two-story three-span single concrete frame is conducted. The experimental results show that the proposed method is reliable, and the experiment accuracy can be guaranteed.

1. Introduction

The serious loss of life and property to human society are often caused by earthquake disaster [1]. With the development of large-scale and complex civil structures, the various new structural forms have been abroad applicated in practical engineering, hence, the demand for large and full scale seismic test is becoming more and more pressing [1]. In order to achieve the test results more precise, the more advanced testing technology is needed [1-7]. Based on the above reasons, the various new test methods and equipment are used in seismic performance testing of structures [1-7]. In seismic performance testing of structures, the accurate boundary condition is the key to guarantee the accuracy of testing results [8-9]. The one-way pseudo-static testing is the most common loading method in civil engineering seismic testing. However, the structures are all spatial structures in practice, therefore, the lateral constraints on specimen are necessary in one-way pseudo-static testing. The reaction devices are used to constrain the specimen laterally in traditional loading method, but the traditional loading method has some disadvantages such as high cost, large occupation of space and so on. In order to avoid those disadvantages of traditional loading method, a spatial lateral constrained loading feedback control method is proposed in this paper. In this method, the main direction loading and lateral constrain of the specimen are realized by the actuators, and the accurate control of the constraint boundary can be achieved by adjusting the position of the lateral constrained actuators. In order to
verify the accuracy and feasibility of the proposed method, a pseudo-static testing of a full-scale two-story three-span single concrete frame is conducted. The experimental results show that the proposed method is reliable, and the experiment accuracy can be guaranteed.

2. Experiment

2.1. Specimen
The specimen is a precast full-scale two-story three-span single concrete frame [10]. The heights of the first and second floor of the specimen are 4100mm and 3500mm, respectively. The spans of the specimen are 7500mm, 8500mm and 7500mm, respectively. The cross sections of the columns and beams are 600mm×600mm and 450mm×600 mm respectively. And the detailed dimensions of the specimen are shown in figure 1.

![Test specimen](image)

Figure 1. Test specimen.

2.2. Layout of loading and measuring devices
In this experiment, six different actuators are used to implement the test task, and the maximum force output and stroke of the loading actuators 1 and 2 are ±200t and ±1000mm, respectively. In addition, the maximum force output of the constrained actuators 1, 2, 3 and 4 are 100t, 200t, 200t and 100t respectively, and the maximum stroke of constrained actuators 1, 2, 3 and 4 are ±500mm. The layout of loading and measuring devices of the experiment is shown in figure 2.
2.3. Loading spectrum
In this experiment, displacement loading is used and all actuators are controlled by displacement method. The loading spectrum is shown in the figure 3. The geometric analysis is used to realize the constraint of specimen lateral displacement in proposed method. According to the information of the loading direction displacement sensors and lateral displacement sensors, the actual deviation of lateral displacement of each constraint point can be obtained, and the motion target of lateral constrained actuator can be realized using the proportional integral (PI) control method. During the experiment, each lateral constrained actuator executed its own position revision command while the loading of the specimen is conducted, and the displacement information of the specimen is collected to calculate the next loading correction command. The boundary correction and high precision loading can be completed using this method. Based on the above methods, the experiment has been successfully completed in China State Construction Engineering Corporation Technical Center (CSCECTC) engineering structural laboratory.

3. Experimental results
3.1. Main direction loading actuators response
The displacement response and feedback force curves of loading actuators are shown in the figure 4.
As can be seen from the figure 4, the displacement response and feedback force of loading actuator 1 are found to be in good agreement with loading actuator 2. Therefore, there is no obvious eccentricity in this experiment, and the movement direction of the specimen is strictly along the loading direction.

3.2. Lateral constrained actuators response

The displacement response and feedback force of the four lateral constrained actuators are shown in the figure 5 and figure 6, respectively.
3.3. Test result

Based on the above control method, the lateral displacement of the specimen is shown in the figure 7. And the whole test photograph is shown in the figure 8. In addition, according to the feedback of each actuator and displacement sensor, the hysteretic curve of the precast full-scale two-story three-span single concrete frame is obtained by geometry analysis method as shown in figure 9 [10].

Figure 6. The feedback force of lateral constrained actuators.

Figure 7. The lateral displacement of the specimen.

Figure 8. Test photograph.

Figure 9. The hysteretic curves.
3.4. Result analysis
As can be seen from the figure 6, it is indicated that the each output force of lateral constrained actuator is very small, and the maximum is not more than 15kN. And from figure 7, the each lateral displacement of the four lateral constrain points is very small, and the maximum is not more than 0.4mm because the allowable error of lateral displacement loading is set to 0.5mm in the test software. In summary, the lateral force and displacement of the specimen are very small, therefore the high precision loading of the test can be achieved by the proposed method.

4. Conclusions
In this paper, a spatial lateral constrained loading feedback control method is proposed to avoid those disadvantages of traditional loading method such as high cost and large space occupied for large-scale test in one-way pseudo-static testing. In order to verify the accuracy and feasibility of the proposed method, a pseudo-static testing of a precast full-scale two-story three-span single concrete frame is conducted. According to the experimental results, the conclusions can be drawn as follows: (1) the each feedback force of the lateral constrained actuator is very small using the proposed method, hence the test accuracy will not be impacted. (2) the lateral displacement control requirements of the one-way pseudo-static testing can be satisfied by the proposed method because the lateral displacement of the specimen is very small. In summary, the experimental results show that the proposed method is feasible, and the experiment accuracy can be guaranteed.

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