IMPROVING SEISMIC PERFORMANCE OF POST-TENSIONED COLUMN TO BASE CONNECTION

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ABSTRACT

Post-tensioned precast structural systems are considered efficient structural forms for building constructions. The validity of such designs is justified only when adequate seismic performance is achieved. In order to develop desirable structural performance, the column base connections must possess sufficient stiffness and strength. This study investigated the feasibility of adopting rubber pad in the seismic design of post-tensioned precast column to base connection. Test results show that the self-centering mechanisms of the connections were effectively sustained. The energy dissipating device also added significant stiffness to the system and exhibited stable hysteretic behavior under various magnitudes of post-tension, which justified its applicability to the seismic design of post-tensioned column to base connection.

Keywords: Post-tension, Base connection, Seismic performance

INTRODUCTION

Post-tensioned precast structural systems possess high construction speed and self-centering capability to reduce residual deformation, as shown in Figure 1, thus are considered efficient structural forms for building constructions (Annamalai and Brown, 1990; Harris and Muskivitch, 1980; Koskisto and Ellingwood, 1997; Priestley and Tao, 1993). However, for concerns in seismic designs, such systems must also possess adequate mechanism so that effective energy dissipation can be achieved. In order to achieve adequate seismic performance, the connections between precast structural components must be adequately detailed. Current studies on the precast member connections are mostly focused on the beam-column joints. Information on the performance of precast column to foundation connections, particularly those subjected to earthquake-induced repeated load, is still limited. For effective seismic designs of post-tensioned structural systems, concerns in the performance of the column to base connections are extremely important, because the base connections govern the effective load transmission mechanism.

In general, the seismic effectiveness of post-tensioned column to base connection can be evaluated by two major parameters: the connection’s effective rigidity due to post-tension, and the energy dissipation capability, if any (Lee and Kim, 2003). Effective connection rigidity incurs high structural stiffness and is advantageous to structural deformation control. However, extremely stiff boundary conditions in such systems limit the structural deformation capability, which is essential to the energy dissipation mechanism, thus hamper the seismic performance of the system. Unlike the beam-column joints, the energy dissipation mechanism of post-tensioned column to base connection must be

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designed not to hamper the column integrity, because the post-tension on the column will deteriorate the connection effectiveness if precast member is damaged. To accomplish this goal, a simple and effective approach, by using economic rubber pad as energy dissipating medium to improve the performance of the connection, was adopted. System stiffness as well as energy dissipation capability was evaluated by cyclic loading tests to validate the feasibility of the design. Finally, an analytical model for response estimation was proposed for engineering application.

![Figure 1. Load–deformation relationship for post-tensioned connection](image)

**EXPERIMENTAL PROGRAM**

A set of precast reinforced concrete column and foundation was fabricated for testing. These components were assembled by post-tension to form the column-to-base connection. The specimen is shown in Figure 2. Cross-sectional dimensions for the column were 650mm x 650mm. Length of the column was 3900mm. Four ducts were embedded in the column to allow high strength rod installation for post-tension application. Spiral reinforcements were added to the duct location on both sides of the column so that concrete burst during load application could be prevented. Diameter for the high strength rods was 36 mm. Ultimate tensile load for the rod was 1099kN. Dimensions for the reinforced concrete foundation were 2500mm(length) x 1500mm(width) x 1000mm(height). A square pit with strengthened surface was set in the middle of the foundation. Precast column and the foundation were connected by the four high strength rods. In order to investigate the influence of post-tension to the connection behavior and the effectiveness of the mechanism, four levels of post-tension were applied to the base connection. Test specimens were labeled by the magnitude of applied post-tension and the energy-dissipating medium. For example, a SN15 indicated a specimen with 150 kN post-tension on each high-strength rod and no energy-dissipating device. Similarly, a SR15 represented a specimen with 150 kN post-tension on each high-strength rod and additional rubber pad as energy-dissipating device. The system was tested under increasing cyclic displacements, as shown in Figure 3. The test setup is shown in Figure 4.
Figure 2. Test specimen

Figure 3. Loading history

Figure 4. Test setup
TEST RESULTS

Figure 5 shows the load-displacement relationships and their comparisons for specimens with various level of post-tension. It can be found from the figure that higher system stiffness and strength was achieved when the magnitude of post-tension was increased. It is also observed that the column returned to its original position when the external load was removed. Such self-centering characteristics prevented the occurrence of residual deformation which minimized the inconvenience after earthquake. During the loading process, the connection first reached a decompression point when the tensile force induced by lateral load exceeded the prescribed post-tension. Resistance of rubber pad developed and effectively sustained the system stiffness when the contact surface between column and the foundation opened. Efficiency of the base connections could be further evaluated by the loss in post-tension after systems were subjected to prescribed excitation. It can be found from Figure 6 that specimen with larger initial post-tension maintained higher degree of residual post-tension, which sustained higher system efficiency.

![Figure 5](image_url)

Figure 5. Load-displacement relationships: (a) specimens with various level of post-tension; (b) comparisons
Relationship between connection details and the system responses must be adequately established so that structural analysis model can be defined. It can be found from the test results that the system stiffness can be divided into three stages: pre-decompression stage, decompressed stage, and unloading stage, as shown in Figure 7. They are defined by the stages when post-tensioned connection is still intact; connection is opened, and the load releasing stage.

Stiffness at various stages can be defined by the following expressions:

Pre-decompression stage stiffness ($K$):

$$K = K_c + K_r$$  \hspace{1cm} (1)

Decompressed stage stiffness ($K_d$):

$$K_d = K_b + K_{rc}$$  \hspace{1cm} (2)

Unloading stage stiffness ($K_u$):

$$K_u = K_b + K_{ru}$$  \hspace{1cm} (3)

In which $K_c$ is the stiffness of column, $K_r$ is the compressive stiffness of rubber pad, $K_{rc}$ is the strain-dependent compressive stiffness (Yamagishi and Kawashima 2004), $K_{ru}$ is the stiffness of rubber at unloading stage, and $K_b$ is the stiffness due to high strength rods. The calculated and measured stiffness for specimens with or without rubber pad is shown in Figure 8.
As mentioned above, the column must remain intact during the loading process to prevent post-tension-induced deterioration in member strength. Furthermore, the high strength rods must also stay in elastic range so that connection rigidity can be maintained. To meet these restraints, the energy dissipating mechanism is governed by the added rubber pad. Energy dissipation is evaluated by the area of the hysteretic loop. Figure 9 shows the ratio of energy dissipated by the rubber pad. It can be observed from the comparisons that the effect of the rubber pad in dissipating energy is higher when the displacement is larger. It is also demonstrated from the test results that the efficiency of the energy dissipating medium is reduced when the magnitude of post-tension increased. This phenomenon, in conjunction with the sustainable post-tension discussed above, suggested that the magnitude of post-tension be adequately proportioned so that design efficiency could be optimized.
CONCLUSIONS

This study investigated the feasibility of adopting rubber pad in the seismic design of post-tensioned precast column to base connection. Test results show that the self-centering mechanisms of the connections were effectively sustained. The energy dissipating device added significant stiffness and exhibited stable hysteretic behavior under various magnitudes of post-tension, which justified its applicability to the seismic design of post-tensioned column to base connection.

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REFERENCES


