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Effect of High-Strength Precast Concrete Shell on Seismic Performance of Precast Bridge Columns

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ABSTRACT

Bridge substructures are exposed to severe environmental conditions. The cracking and chloride attack across cover concrete are a critical problem to limit the service life of the structure. A precast column with high strength precast shell (PCHPS) is designed to enhance durability and seismic performance. Four precast columns were tested under cyclic load to investigate the structural response. This paper presents the result of an experimental investigation conducted to study the structural response of the precast column according to the existence of the high strength precast shell. The application of precast shell provided greater load-carrying capacity as well as enhancement of the serviceability. The influences of prestress force on precast columns were also discussed. Design recommendation of the precast shell was derived. The experimental results on the precast column with the high strength precast shell showed that the lateral drift capacity is lower than the precast column without precast shell due to the crushing strain of high strength concrete is less than normal concrete. The PCHPS provided an increase of the maximum strength up to 31%. In addition, the PCHPS with the prestress force of 61% showed favorable case because it delayed the yield time until 2.00% drift level. However, the other columns yielded at 1.00% drift level.

1. INTRODUCTION

In recent year, the corrosion is found as the critical problem in the performance of the structure, which is exposed to severe environmental conditions. Particularly, bridge substructures are normally subjected to water, so the effect of corrosion mainly controls the performance of bridge columns and the entire bridge system. Sunshine Skyway Bridge, in Florida is a typical example of the corrosion problem of bridge columns. In bridge column design for serviceability, a design

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engineer allows the concrete cover thickness with approximately 50 – 100mm to project chloride penetration. To ensure the serviceability, a provision of thicker concrete cover or high strength concrete cover shall be recommended. For precast concrete technology, one of the advantages is the concrete cover can be prefabricated with high strength concrete.

A number of precast column has been tested in the literature reviews. (Shim 2008) has conducted his research work on precast bridge columns under cyclic load. The result shows the restoration of deformation, resulting in minor damage, can be obtained by prestress force control. (Shim 2008) has also suggested that the precast column with low steel ratio and well-confined provision response a satisfied and ductile performance under seismic load. For circular prefabricated composite column, the greater flexural strength and energy absorption capacity is achieved by introducing higher prestress force (Shim 2011). (Shim 2012) has conducted the test on precast composite pier cap supported by prefabricated concrete filled tube (CFT) columns. Standardized modular structure, CFT columns, has been found to effective in fast replacement or construction of bridges. In strong earthquake region, (Shim 2015) has not recommended to apply high prestress force, and appropriate prestress force guarantees ductility and fracture prevention of tendon. To assure the structure of precast column, not only the details of precast column shall enhanced, but also the accuracy of geometric control of precast segment shall be achieved. (Koem 2016) has suggested the precast column with combination of continuous mild steel and partially bonded unbonded tendons. The recommended prestress force for the precast columns was 80% of tensile strength of the tendon. Partially unbonded tendons in precast columns provided stable ductile behavior after reaching maximum load capacity of the column. To prevent the possibility of premature crushing of the edge concrete near the precast joint, (Shim 2017) recommends the 3D design and fabrication procedures, including the chamfered edge of the precast segment and machined milled formworks. The target performance level is the criterion to determine the prestressing level.

Precast concrete columns have bonded, partially unbonded and unbonded systems according to required performance. Comparing to the bonded prestressed segmental columns, the unbonded system is advantageous for delaying the yielding of the prestressing tendons because the post-tensioning force was distributed throughout the length of the tendons in the unbonded system (Ou 2007 and Nikbakht 2014). (Hew 2002) performed the tests on unbonded post-tensioned precast concrete segmental bridge columns under lateral earthquake loading [6]. The precast columns withstood without significant or sudden loss of strength up to 4.0% drift ratio. Inversely, the bonded system generates high strength capacity, but limited deformation capacity [Shim 2008, 2015]. Partially unbonded tendon was introduced by (Koem 2017).

The precast columns can be a design option for improving the deficiency of structure. (Palermo 2012) has proposed thesupplemental energy dissipation devices for increasingenergy dissipation capacity. (Ou 2009) has adopted the mild steel bar as a supplemental energy dissipation devices. Mild steel has a function in the formation of plastic hinges at the column base to make the precast column higher energy dissipation capacity. (Kim 2008) and (Shim 2008) have used the internal steel tube for precast columns to maintain the greater energy dissipation capacity.

This paper deals with the experimental studies on precast bridge columns with and without high-strength precast shell. The influence of the proposed composite section of precast column was discussed in terms of the column response under cyclic load.

2. Experiments on precast columns

2.1 Specimens and fabrication

To evaluate the effectiveness the new design concept for precast columns, four precast columns (Fig. 1) were fabricated with a diameter of 800mm and tested under reversal cyclic load. The specimens, named as PT1-TD, PT2TD, TDSHPT1, and TDSHPT2, had the prestress force with 74.46% f_{pu}, 47.26% f_{pu}, 61.53% f_{pu}, and 66.58% f_{pu}, respectively. The distance from the top surface of base footing to the point of load application was considered as the effective length of the columns. The column specimen consisted of two segments, standing on a base footing. The effective length and the aspect ratio of the specimen was 2750 mm and 3.44, respectively. The specimens were reinforced a combination of 32mm mild steel of 400 MPa yield strength and posttensioning tendons of 1860 MPa tensile strength. 6- 32 mm diameter mild steels were used for PT1-TD and PT2TD. For TDSHPT1 and TDSHPT2, the 6-29 mm mild steels were used. 16 mm diameter with 75 mm spacing and 18-15.2 diameter of posttensioning tendon was selected for the design of all columns. The 80 MPa high strength precast shell with the thickness of 70 mm was applied at the first segment of the specimen TDSHPT1 and TDSHPT2. The concrete of 40 MPa compressive strength was used except the precast shell. The main parameters of this test included the application of high strength precast, the amount of non-prestressing steel, and prestressing level.

The fabrication procedure and installation of the precast columns can be referred to (Koem 2016). However, the application of high strength precast concrete is a challenging work for prefabrication technology. To prevent failure of the interface between precast shell and the internal core concrete, mechanical anchors were designed with spacing of 300 mm. The completed fabrication of precast segment with the precast shell consisted of two main steps as shown in Fig. 2. Firstly, the transverse reinforcements were arranged with vertical discontinuous construction reinforcement in the formwork, and the high strength concrete were casted to fabricate the precast shell. It is noted that the half of the enclosed mechanical anchors were embedded in the precast shell. Secondly, corrugated ducts were arranged inside the prefabricated shell before casting the concrete core.

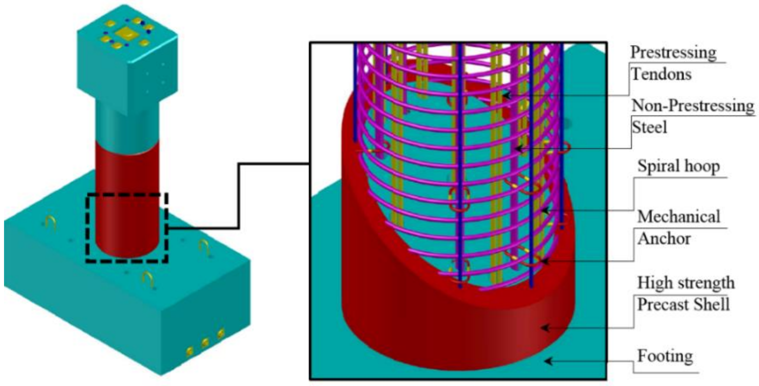

Fig. 1 Precast columns with precast shell

Step 1 Step 2

Fig. 2 Fabrication procedure for segment with precast shell

2.2 Loading and measurements

Fig. 3 describes the test setup plan of the specimen. A pier footing was fixed to the strong floor in the test laboratory with the eight high post-tensioning steel bars. At the top most surface of the column, the axial load was applied by a vertical actuator. For PT1-TD and PT2-TD, the axial force of 1000 kN was applied constantly using two hydraulic jacks which can maintain a constant compressive force even though there is lateral displacement. However, concentrically unbonded tendons were used to represent the axial load of 1000kN and 100kN for TDSHP1 and TDSHPT2, respectively. A hydraulic actuator connected with the top side surface of column was used to apply cyclic load by reacting off the strong wall. To obtain the lateral displacement, a reference frame was set up to support the displacement transducers, which were used to measure the displacement response of the column. During the test, the column drifts were subsequently levelled up to 0.50%, 1.00%, 1.50%, 2.00%, 2.50%, 3.00%, 4.00%, etc., until failure. The stroke capacity of the actuator was ±250 mm, and two cycles of loading were applied for each drift level. The damage inspection of pier specimen was conducted. In order to capture the development of cracks, crushing, and concrete spalling through various stages of the cycle, careful observation was conducted. On the critical location, such as a level of 75 mm, 275 mm from top surface of footing and 200 mm from the connection for segment 1 and segment 2, the strain gauges were placed to measure the longitudinal strain in the reinforcement and concrete strain. Similarly, strain gauges were used to measure the response of the axial steel strain.

Fig. 3 Precast columns with precast shell

2.3 Test Results

The flexural strength of the columns was estimated based on strain compatibility method and design standard such as LRFD and Eurocode 2 before starting the test. The load – displacement of the columns are compared in Fig. 4. The ultimate drift capacity is defined as the limit of the actuator and the time that columns turn to be instable. PT1-TD and PT2-TD have the ultimate drift at 8%, while the TDSHPT2 and TDSHPT1 have the ultimate drift capacity by 6% and 7%, respectively. The sound of tendon fracture was observed during drift 6 % and 7%. The load carrying capacity of the specimens had the range from 532 kN to 698.9 kN, which was a significant increase. The high strength precast shell contributed to the ultimate strength. Initial cracks of all the specimens were observed at a drift level 0.5% as shown in Fig. 5. PT1-TD, PT2-TD and TDSHPT2 yielded at adrift level of between 1.00% and 1.5%. However, the TDSHPT2 yield at a drift level of 3.0%

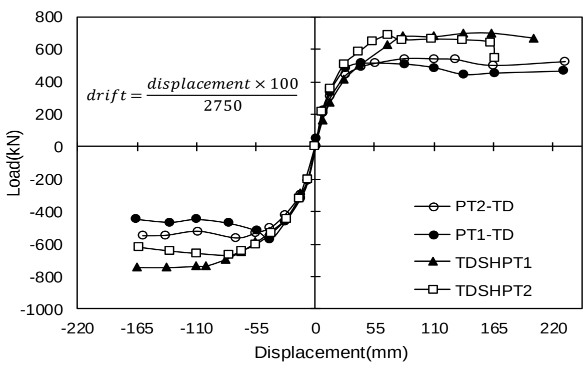

Fig. 4 Nominal bending moment – axial force diagram

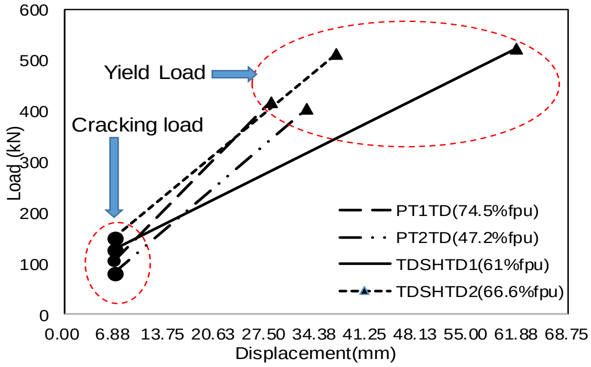

Fig. 5 cracking and yielding of precast column

At final drift level, the accumulative crushing and cracking concrete were observed at the column joint on top of the footing. Fig. 6 shows the columns specimen at end of test. Introducing a high prestressing level to the precast column with precast shell leads the spall off the concrete shell at the joint between segment 1 and segment 2. No buckling of longitudinal and transverse reinforcement in all specimens. However, a prestressing tendon of TDSHPT2 was fractured at a drift level of 6%.

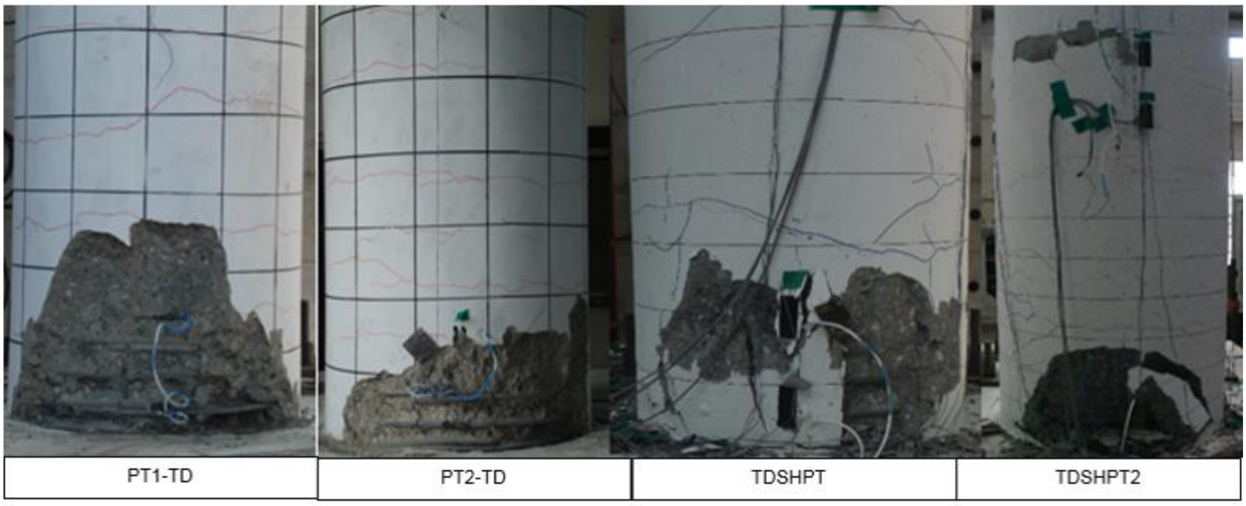

Fig. 6 damage mechanism of precast columns

3. CONCLUSIONS

From the experimental investigation of precast column with precast shell, the following conclusions can be made:

- A precast concrete segmental column with high strength precast shell is proposed to enhance the ultimate strength, which obtaining a good recentering behavior. In addition, the risk of environmental load can be reduced due the characteristic of high strength concrete shell.
- With 70-mm- thickness of 80 MPa precast shell, the 31% of ultimate strength

is improved

- The prestressing level, which is greater than 66%f_{pu}, is not recommended for the design of precast columns with precast shell.

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