RESEARCH AND DEVELOPMENT ON SEISMIC DESIGN METHOD FOR PRECAST CONCRETE BRIDGE COLUMNS

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Abstract

This paper presents research and development on seismic design method for precast concrete bridge columns (PRE-Columns). Since the PRE-Columns are effective to shorten the construction period at the site because of no need of formwork, placement and curing of concrete to construct bridge substructures, so they are expected to be applied for the construction of overpass crossings in urban areas to minimize the effect on existing traffic.

PWRI has conducted 2-years joint research program with three private companies including Kajima Co., Sumitomo Mitsui Construction Co., Ltd., and P.S. Mitsubishi Construction Co., Ltd. in 2007-2008. In the research program, three types of PRE-Column structural details were proposed and the failure mechanism of the proposed PRE-Columns including the strength and ductility performance and dynamic behavior were experimentally investigated. Based on the experimental studies, design methods including limit states to achieve necessary seismic performance, detailed design methods for segments, joints, PC cables, bending–shear resistance evaluation, and construction methods, were also studied. A series of cyclic loading tests, shaking table tests, and analytical study were made to develop the seismic design guidelines.

Introduction

With a background of the generalization of the performance-based design concept into practices, the applications of new materials, new designs, and new structures have started to be actively employed with necessary performance verifications. PRE-Columns are one of such new applications. PRE-Columns effectively use the combination of high strength materials including steels and concrete. The precast segments, which are produced at factory, for PRE-Columns can be easily achieved to have better-quality. Therefore, PRE-Columns are expected to improve the constructionability at sites and shorten the construction period.

Figure 1 shows the outline of the PRE-Columns. The segments are produced at factory and transported to the construction site. The segments are piled up at the site and connected each other as a column. It is an important advantage to shorten the construction period at the site because of no need of formwork, placement and curing of concrete. So, PRE-Columns are expected to be applied for overpass crossings in the urban areas in order to decrease the traffic jamming and then to minimize the effect on existing traffic.

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The segmental concrete bridge superstructures have a long use at practices. However, there has not been much application for bridge columns. Although one of the key design issues for column applications is the seismic performance, there is not enough data/information on seismic performance and design methods for columns applications. Therefore, the investigation on the failure mechanism, and the strength and ductility performance are necessary.

PWRI has conducted 2-years joint research on PRE-Columns in 2007-2008 with 3 private companies including Kajima Co., Sumitomo Mitsui Construction Co., Ltd., and P.S. Mitsubishi Construction Co., Ltd. Three types of PRE-Column design details were proposed. Research issues were to obtain the data on the failure mechanism, the strength and ductility performance, and the dynamic behavior of proposed PRE-Columns, and to develop the design method including the limit states to achieve necessary seismic performance, detailed design methods for segments, joints, PC cables, bending–shear resistance evaluation, and construction methods. In the 2-years joint research, a series of cyclic loading tests, shaking table tests, and analytical studies were made to develop the seismic design guidelines for PRE-Columns.

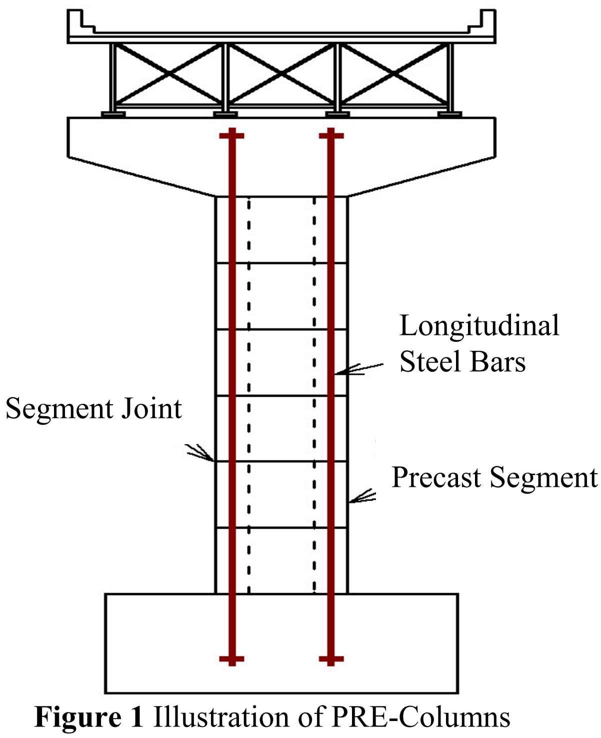


Figure 1 Illustration of PRE-Columns

Outline of Proposed PRE-Columns

Three types of proposed PRE-Columns as shown in **Figures 2-4** were studied. The structural details and properties are shown in the followings.

PRE-Column 1 (Kajima Co.)

Figure 2 shows the outline of PRE-Column proposed by Kajima Co. The segments are piled up at the site. Each segment has the outer and inner steel pipes. Outer steel piles are embedded in the segment when it is produced at factory, and inner steel pipe are installed at the site between the segments. The inner steel pipe is to resist against the shear force acted the joints of segments as a shear key. After the piling up of all segments for columns, the vertical tensioning force is applied for segments by PC cables through the inner pipes, in which the PC cables work as longitudinal steel.

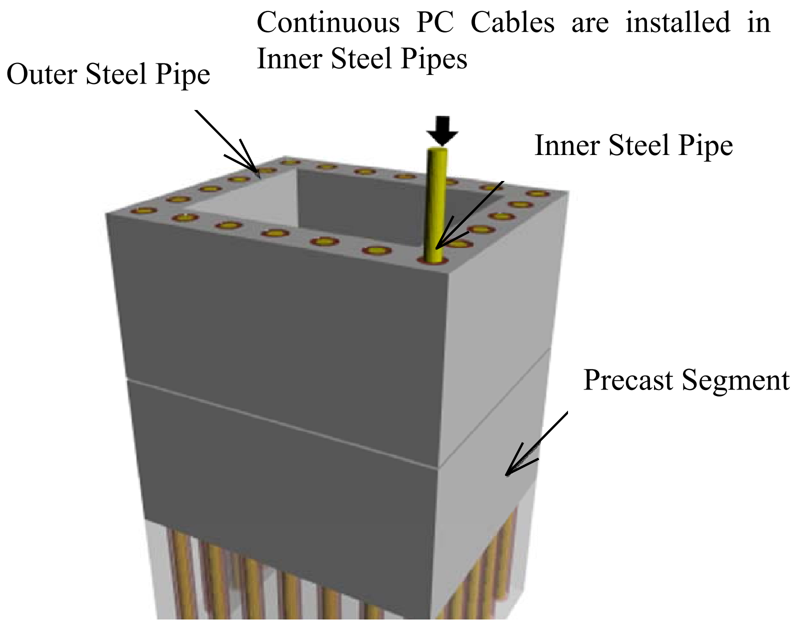


Figure 2 PRE-Column 1 (Kajima Co.)

PRE-Column 2 (Sumitomo Mitsui Construction Co., Ltd.)

Figure 3 shows the outlines of PRE-Column proposed by Sumitomo Mitsui Construction Co., Ltd. The segments are piled up at the site. Each segment is made of combination of inside steel shell and outside concrete. Inside steel shells of the segments are connected by steel bolts. After the piling up of all segments for column, vertical tensioning is applied for segments by inside PC cables. At the joints between segments, shear keys are provided at the edge of steel shell and concrete mortar is placed between the segments outside concrete. Therefore, vertical axial force by dead load and live load is carried by inside steel shell but the earthquake force is carried by steel shells, bolts, and outside concrete. Shear force acted at the joints is carried by the shear keys of steel shell. Steel shells and bolts, and PC cables works as longitudinal steel. The bolts are designed to be firstly yielded when the deformation is exceeding the elastic limit and then the steel shells are not expected to be damaged. It is an important concept for this column that the yielded bolts can be replaceable after the earthquake and then the columns can be easily recovered to the original performance.

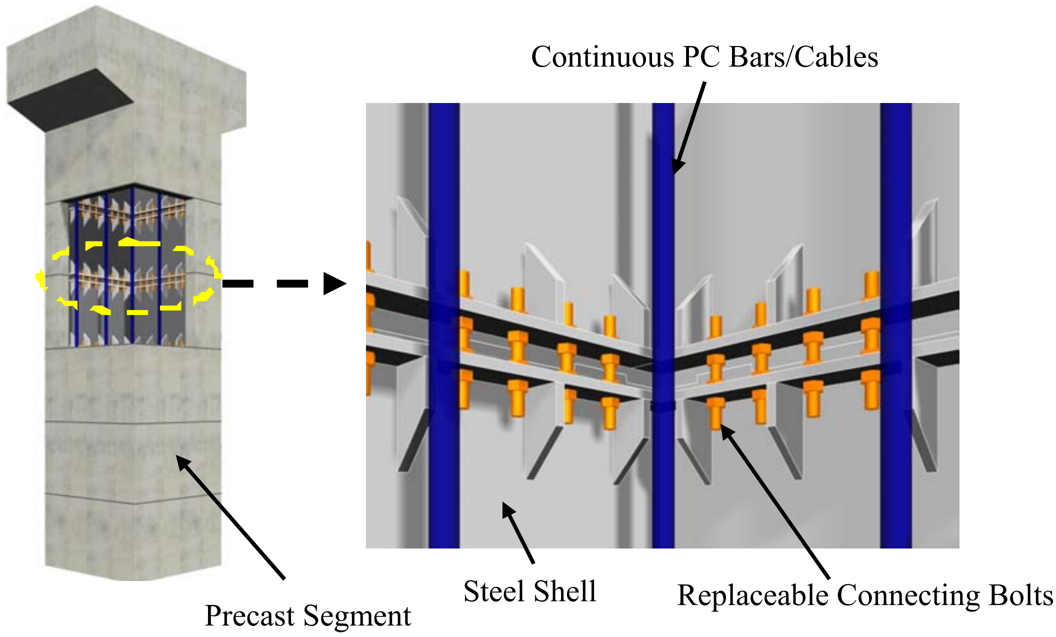


Figure 3 PRE-Column 2 (Sumitomo Mitsui Construction Co., Ltd.)

PRE-Column 3 (P.S. Mitsubishi Construction Co., Ltd.)

Figure 5 shows the outlines of PRE-Column proposed by P.S. Mitsubishi Construction Co., Ltd. The concrete segments are piled up at the site with temporally PC cables. PC cables are provided not for tensioning as longitudinal steel but for just construction to assure the quality of the joint connection between segments by resin. After piling up of all segments, longitudinal re-bars are inserted into the sheathes, which is provided at segments, from the top to the bottom with grout mortar. The columns are made of segments but the design concept is the same as an usual reinforced concrete column. Since the longitudinal steel re-bars are placed inside the sheathe of segments, so the confinement effect to prevent the buckling of longitudinal re-bars is much higher than the usual reinforced concrete columns which is confined by the cover concrete and lateral re-bars.

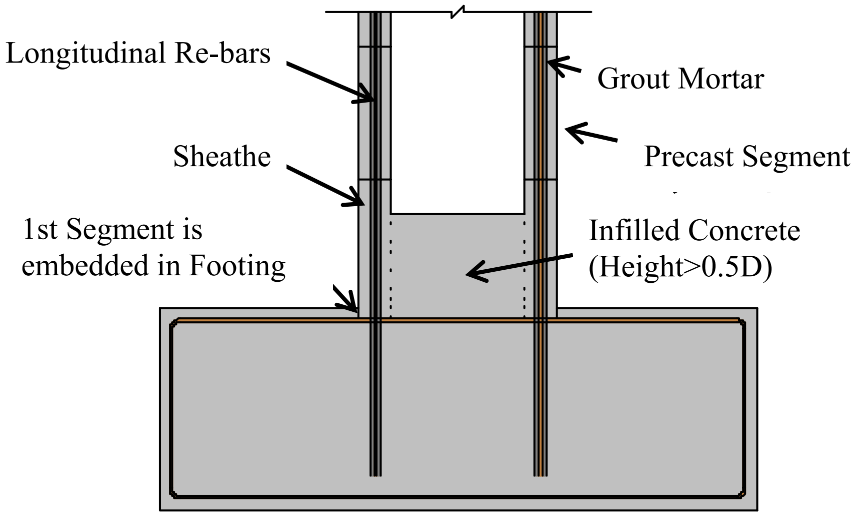


Figure 4 PRE-Column 3 (P.S. Mitsubishi Construction Co., Ltd.)

Research on Dynamic Performance of Proposed PRE-Columns

In order to obtain the data on the failure mechanism, the strength and ductility performance, and the dynamic behavior of proposed PRE-Columns, as well as in order to develop the design method, a series of dynamic loading tests and shaking table tests were made. In this paper, some of the research results are introduced.

Shake Table Tests and the Analytical Simulation

Shake table tests have been made to verify the dynamic performance of PRE-Columns. Objectives of the tests are to have the data on earthquake response characteristics and failure mechanism. Since, in particular, PRE-Columns 1 and 2 use the PC cables as longitudinal re-bars, the effect of PC cables on the dynamic behavior was one of the points. **Figure 5** shows the typical example of the nonlinear force-displacement relation of PRE-Columns with PC tendons. It is of the PRE-Column 2 and was obtained through the cyclic loading tests. The force-displacement relation is different with usual reinforced concrete and the displacement tends to recover toward the origin when the force is released, then the hysteresis energy absorption is relatively smaller than usual reinforced concrete columns.

Photo 1 shows the set up of the shake table tests. PWRI's shake table was used. Scaled models for 3 types of PRE-Columns are tested. Scale factor was assumed as about 1/5. The test columns were subjected to the design level earthquake to know the target performance and the exceeding level to know the failure mechanism. Also, PRE-Column 2 has an important characteristic as the repairability in which the bolts can be replaceable after the earthquake. The dynamic response and the failure mode was also use to verify the design model.

Photo 2 shows the failure modes of each tested columns after the final shaking exceeding the design earthquake level. Tests results show almost the expected behaviors and the performances. Against the shaking exceeding the design earthquake level, the columns behaved very well and the nonlinear column deformation was dispersed to joints and segments.

Based on the dynamic behavior obtained through the shake table tests, design model was also verified through the simulation analyses. **Figure 6** shows the proposed model for PRE-Column 1. Segments and joints are modeled and the joints are modeled as nonlinear rotational spring elements.

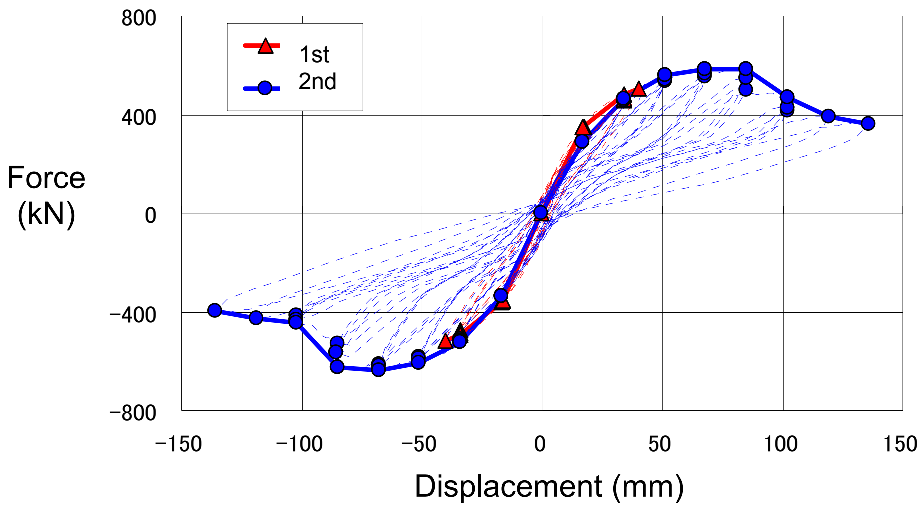


Figure 5 Typical Example of Force-Displacement Relation
(PRE-Column 2; 1st loading and 2nd loading)

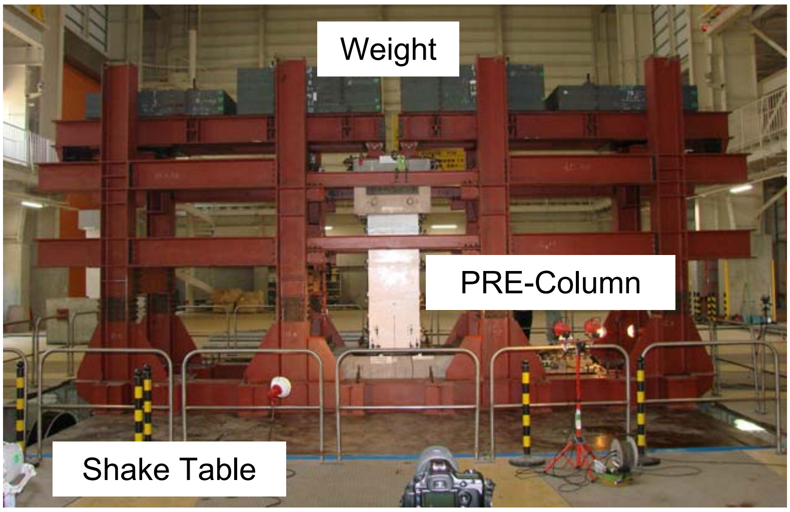
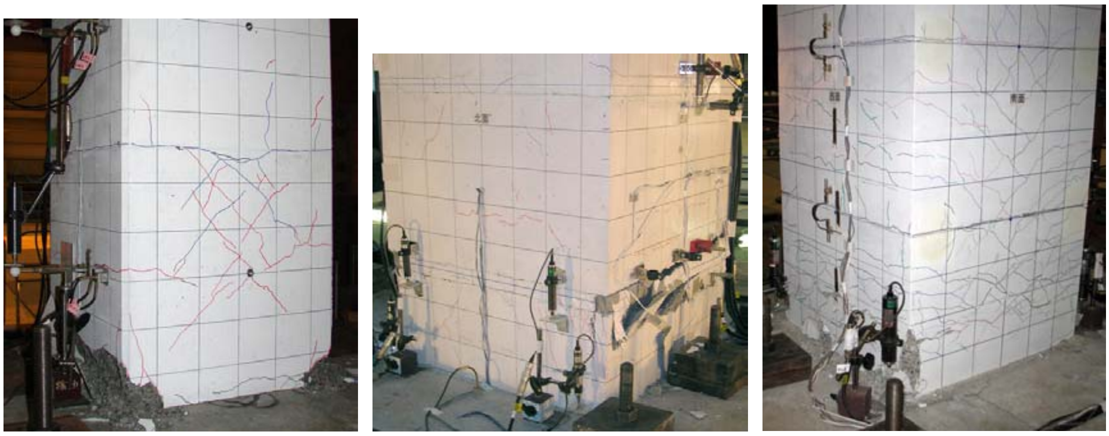


Photo 1 Performance Verification of PRE-Columns through Shake Table Tests



(a) PRE-Column 1 (b) PRE-Columns 2 (c) PRE-Columns 3

Photo 2 Failure Mechanism of 3 PRE-Columns (Column Bottom)

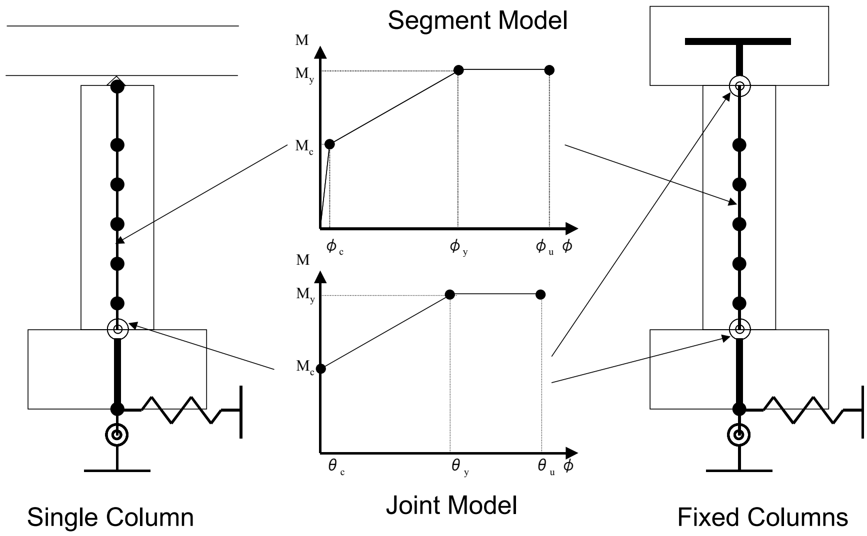


Figure 6 Analytical Modeling for PRE-Column 1

Design Guidelines for PRE-Columns

As one of the outcomes of the joint research, seismic design guidelines is now being developed. It is expected to be published in 2008. The following is the developed table of contents.

Part I. Design Fundamentals

Sec.1. General

Sec.2. Structural Concepts of PRE-Columns

Sec.3. Fundamentals of Seismic Design
Sec.4. Seismic Performance Verification Methods
Part II. Design for PRE-Column 1
Sec.1. Structural Application and Details
Sec.2. Seismic Limit States
Sec.3. Verification of Seismic Performance Level 1 to Level 1 Earthquake
Sec.4. Verification of Seismic Performance Levels 2 and 3 to Level 2 Earthquake
Sec.5. Design Details
Sec.6. Constructions
References (Test Data and Design Example)
Part. III Designs for PRE-Column 2 (the same contents as Part II)
Part. IV Designs for PRE-Column 3 (the same contents as Part II)

Conclusions

The research on the seismic design methods for PRE-Columns was introduced in this paper. A series of cyclic loading tests, shaking table tests, and analytical study were made. The seismic design guidelines for proposed PRE-Columns are now being developed and will be published in 2008.

Acknowledgements

The authors sincerely express great appreciation to all members participated in the joint research from Kajima Co., Sumitomo Mitsui Construction Co., Ltd., and P.S. Mitsubishi Construction Co., Ltd. for their hard work to conduct investigation and to develop the seismic design guidelines.

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