SEISMIC PERFORMNACE AND STRUCTURAL DETAILS OF PRECAST SEGMENTAL CONCRETE BRIDGE COLUMNS

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Abstract

The precast segmental concrete bridge column would be one of the options for the accelerated bridge constructions because the construction period at site can be shorten due to no need of formwork, placement and curing of concrete. Thus, those columns are expected to be applied for the bridges for overpass crossings in urban areas to minimize the effect on existing traffic. Additionally, high quality of the concrete members would be ensured because the concrete segments are fabricated at factories. This paper briefly introduces the state-of-practice of the segmental concrete bridge columns in Japan. Furthermore, recent research activities in PWRI for the precast segmental concrete bridge columns are summarized.

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 initiated to be actively employed with necessary performance verifications. The precast segmental bridge columns are one of such new applications, and effectively use the combination of high strength materials including steels and concrete. The precast segments are fabricated at factory, so that the precast segmental bridge columns can be easily achieved to have better-quality. Therefore, the precast segmental bridge columns are expected to improve the constructionability at sites and shorten the construction period.

Public Works Research Institute conducted 2-years joint research program for the development of the new precast segmental concrete bridge columns with three private construction companies. In the research program, three types of structural details of precast segmental concrete bridge columns were proposed and the failure mechanism of the proposed columns was investigated through a series of shake table test. Based on the experimental studies, the limit states for the required seismic performance are discussed in this paper. Structural details for those columns were also introduced.

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Structural Concept of Precast Segmental Bridge Columns

Figure 1 shows the outline of the precast segmental bridge columns which have been designed and constructed in the past in Japan. The precast segments are produced at factory and transported to the construction site. These segments are piled up at the site and connected each other through the steel bars, to be a column. It would be an important advantage to shorten the construction period at the site because of no need of formwork, placement and curing of concrete. Therefore, the precast segmental bridge system would be 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.

Structural details of the conventional precast segmental bridge columns are shown in **Figure 2**. There are two types of the precast segmental columns. The precast PC columns are built with the segments connected through the high strength steel bars columns, as illustrated on the left side section in **Figure 2**. Each segment is post-tensioned by all high strength steel bars, to integrate with column structure. After post-tensioning, the following segment is piled up on the lower segment and the high strength steel bars are installed into the section through the ducts. These bars are coupled with the lower high strength steel bars and the grout is injected to the duct to be bonded. Details of the segment connection are shown in **Figure 3**. These processes are repeated up to the column height.

On the other hand, the precast RC columns are built with the segments connected basically through the nominal strength steel bar, as illustrated on the right side section in **Figure 2**. A few high-strength steel bars are installed and minimum post-tension required for setup of the segment is applied to these bars. The steel bars are coupled and grouted with the same procedure as the precast PC column.

Construction samples of the precast segmental concrete columns or piles are shown in **Photos 1** and **2**. **Photo 1** shows connection of the precast segmental PC piles with the cast-in-place footing. **Photos 2** shows the precast RC oval column constructed very close to existing bridge column.

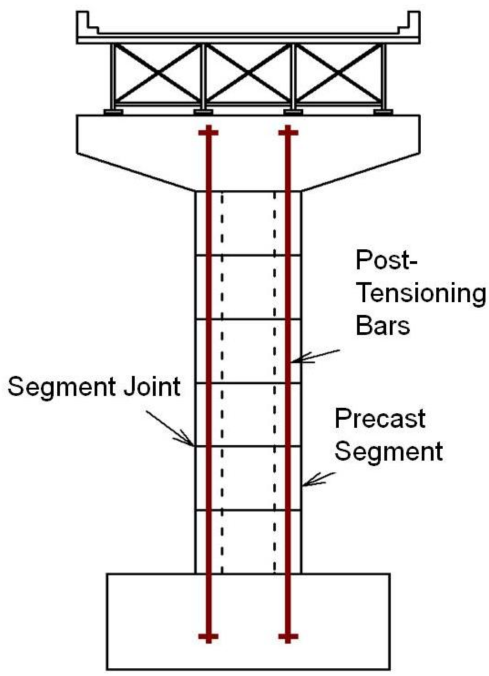


Figure 1 Illustration of Precast Segmental Concrete Columns

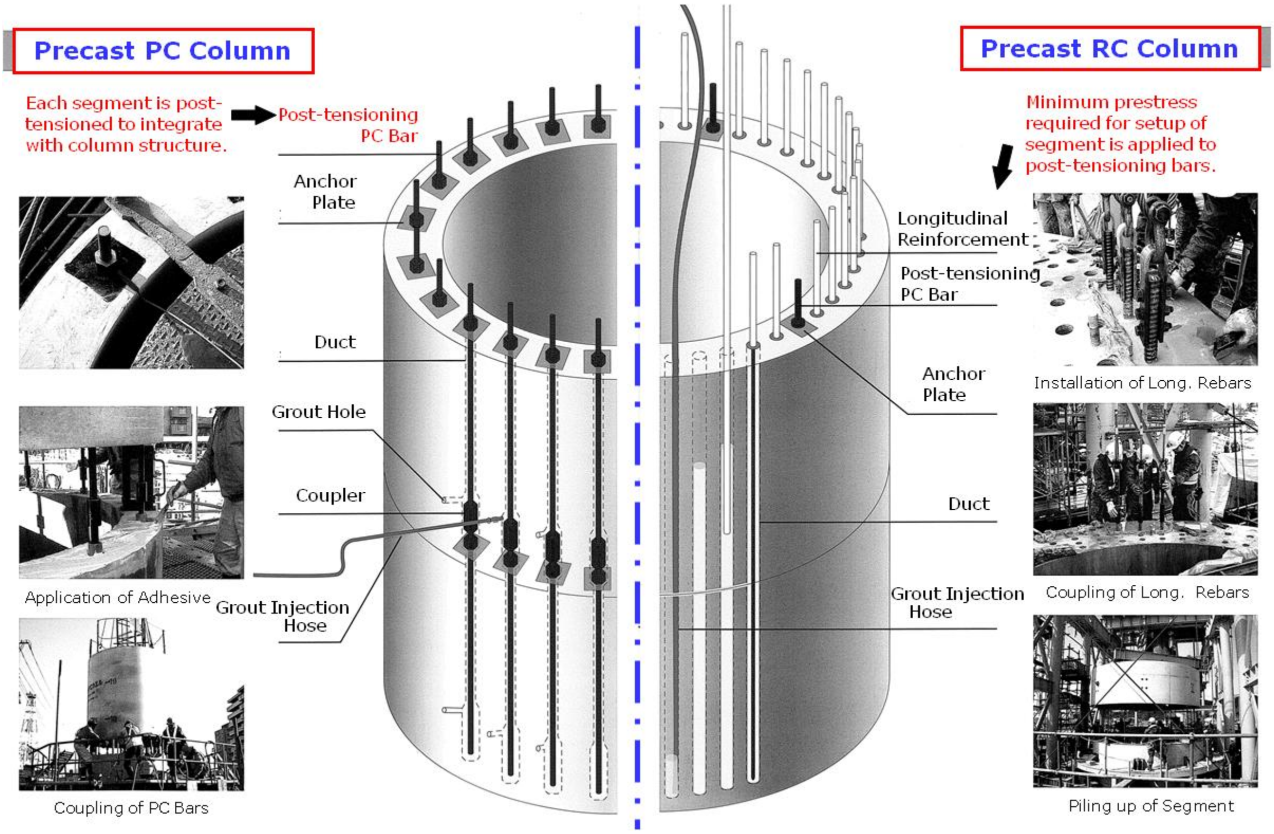


Figure 2 Concepts of Connection Details in Conventional Precast Segmental Concrete Columns

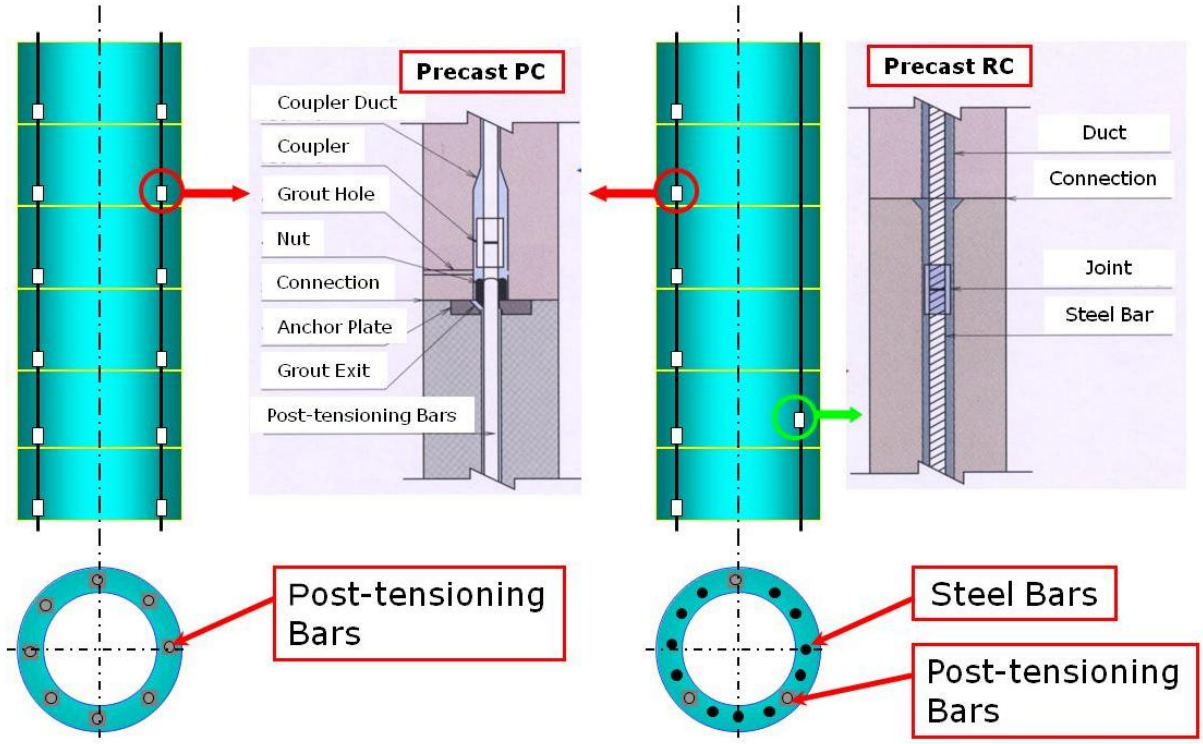


Figure 3 Connection Details of Steel Bars in Segment

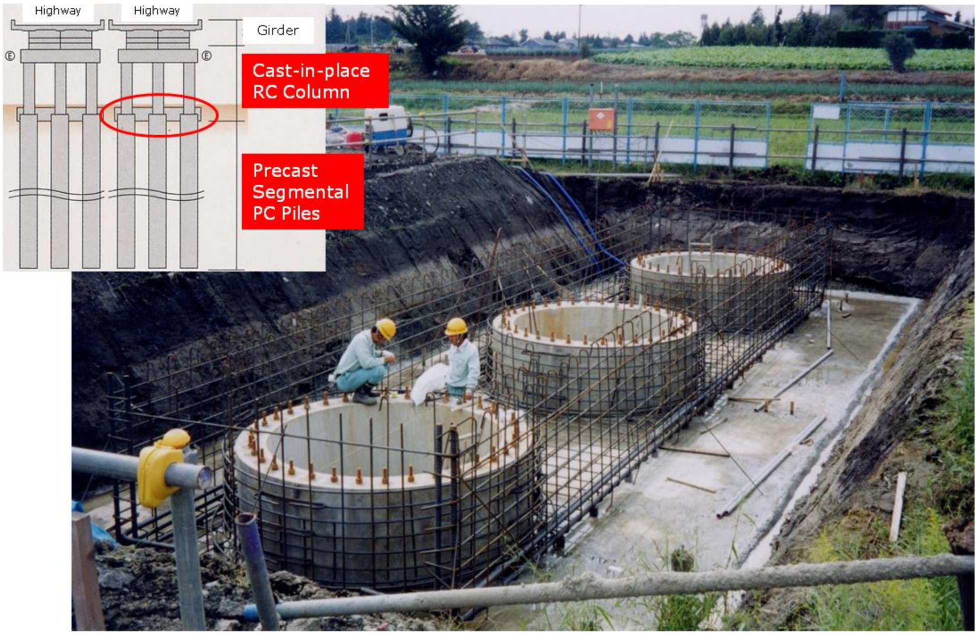


Photo 1 Connection of Precast Segmental PC Piles with Cast-in-place Footing

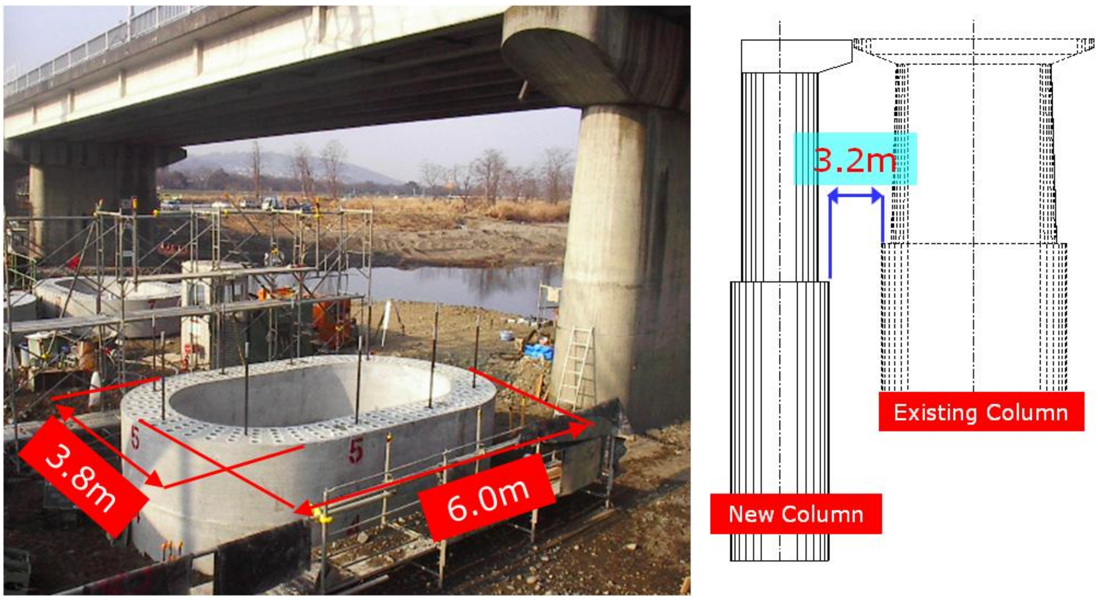


Photo 2 Precast RC Oval Column Constructed Very Close to Existing Column

Recent Research Activities for Precast Segmental Bridge Columns in PWRI

PWRI conducted the joint research program on the new precast segmental concrete columns with 3 private companies including Kajima Co., Sumitomo Mitsui Construction Co., Ltd., and P.S. Mitsubishi Construction Co., Ltd. Three types of the precast segmental concrete column 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 precast segmental bridge 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 joint research program, a series of cyclic loading tests, shaking table tests, and analytical studies were made to develop the seismic design guidelines for the proposed precast segmental concrete columns.

Structural concepts of the proposed precast segmental concrete columns are shown in **Figures 4** to **6**. The structural details and properties are described in the followings. **Figure 4** shows the outline of the precast PC column proposed by Kajima Co. The segments are piled up at the site, and 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 post-tensioning bars through the inner pipes, in which the those bars work as longitudinal steel.

Sumitomo Mitsui Construction Co., Ltd proposed the precast segmental PC hybrid columns as shown in **Figure 5**. 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 external post-tensioning bars. 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 6 illustrates the precast RC column proposed by P.S. Mitsubishi Construction Co., Ltd. The concrete segments are piled up at the site with a few temporally post-tensioning bars. Those bars 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, mild longitudinal steel bars are inserted into the ducts, which are pre-grouted with the mortar from the top to the bottom of the column. The columns are made of segments but the design concept is the same as nominal reinforced concrete column. Since the longitudinal steel bars are placed inside the sheathe of segments, so the confinement effect to prevent the buckling of longitudinal bars is much higher than the nominal reinforced concrete columns which is confined by the cover concrete and lateral steel bars.

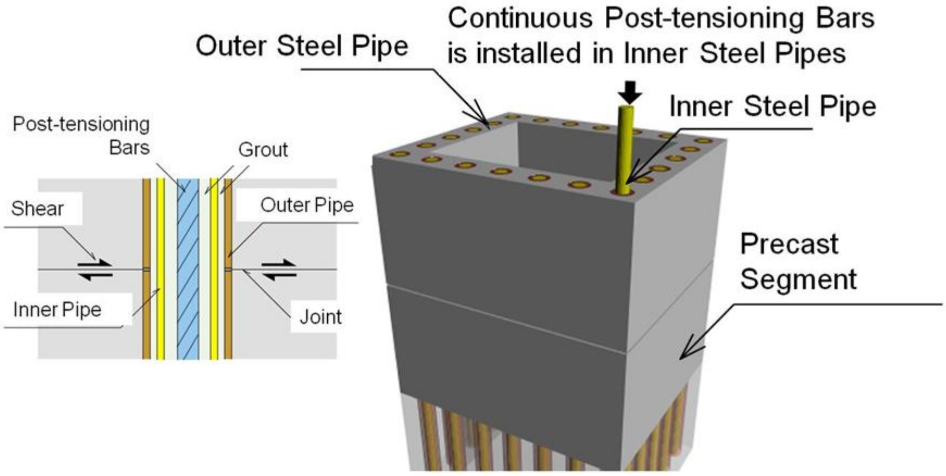


Figure 4 Precast Segmental Prestressed Columns Proposed by Kajima Co., Ltd.

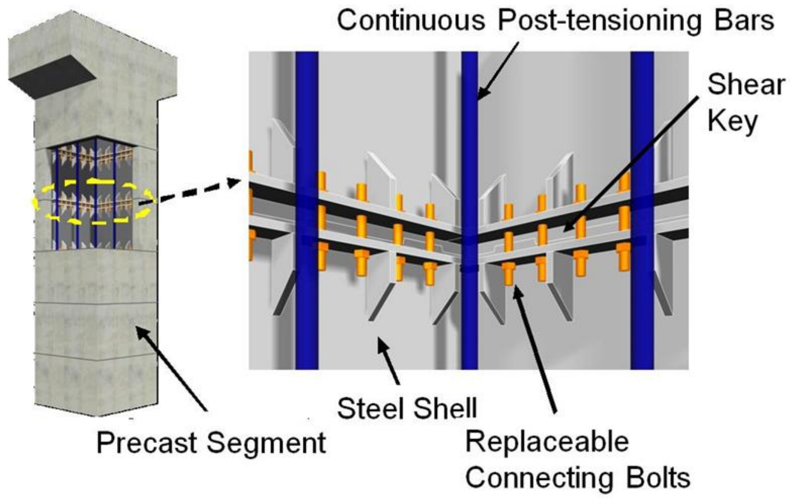


Figure 5 Precast Segmental Hybrid Columns Proposed by Sumitomo Mitsui Co., Ltd.

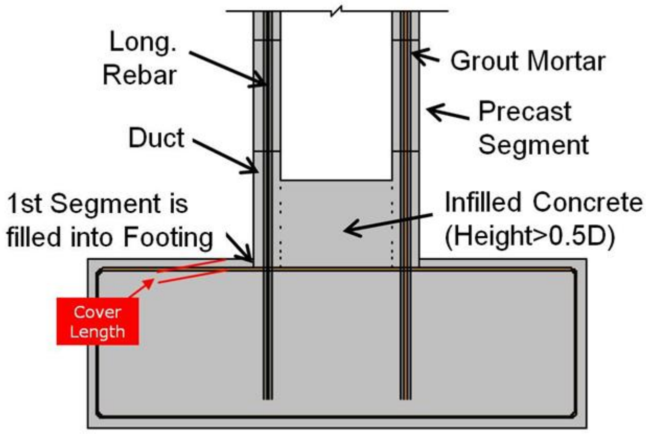


Figure 6 Precast Segmental RC Columns Proposed by P.S. Mitsubishi Co., Ltd.

Limit States of Precast Segmental Bridge Columns

General Concepts of Limit States

It should be essential to determine the limit state for each seismic performance level, to develop the seismic design method. In Design Specifications for Highway Bridges issued by Japan Road Association, three seismic performance levels are specified for intensities of design ground motions and importance of the bridges. The limit states are determined based on the required seismic performance, which are described in terms of the safety, serviceability and repairability. The schematic image of the limit state for the conventional reinforced concrete bridge column is shown in **Figure 7**.

For the seismic performance level 1, it is required to ensure the normal functions of bridges after an earthquake, which means the mechanical properties of the structural members should behave within the elastic ranges. For each structural member, the stress induced by an earthquake shall not exceed its allowable stress. For the seismic performance level 2, it is required to ensure the serviceability and repairability after an earthquake. As the limit state, the structural members in which the nonlinear behavior is allowed deform beyond elastic range but within a range of easy functional recovery. For the seismic performance level 3, it is required to ensure the structural safety during an earthquake. Since neither serviceability nor repairability is required, structural members in which the nonlinear behavior is allowed deform within the ultimate ductility capacity.

Limit States for Proposed Precast Segmental Concrete Bridge Columns

The limit states for the precast segmental concrete bridge columns shown in **Figures 4, 5 and 6** are determined considering the structural properties and nonlinear behavior of each structure. For the seismic performance level 1, the limit states of the precast segmental structures are determined to be same to a conventional reinforced concrete column. For each structural member, the stress induced by an earthquake shall not exceed its allowable stress.
The limit states for the seismic performance levels 2 and 3 are determined based on the nonlinear behavior of each structure, which are introduced in details below.

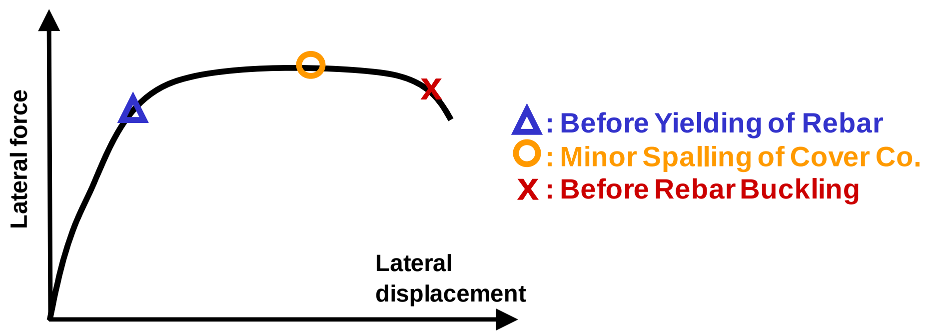


Figure 7 Limit states for Conventional Reinforced Concrete Columns

Limit States for Precast Prestressed Concrete Bridge Column

Because no mild longitudinal reinforcement is provided in the precast prestressed concrete bridge column, the yielding of the post-tensioning steel bar is the important limit state. Once the yielding of the post-tensioning steel bar occur, it is difficult to recover the required functions. Based on these properties of the structure, the limit states shall be determined as shown in **Figure 8**.

For the seismic performance level 2, the yielding of the post-tensioning steel bar is determined as the limit state to ensure the serviceability and repairability. **Figure 9** shows the force-displacement hysteresis and the failure mode obtained from the shake table tests for the precast prestressed columns during the design level earthquake ground motion. The post-tensioning steel bars remained in the elastic range and minor spalling of cover concrete was observed. Although the column model performed well beyond the yielding of the post-tensioning steel bars in the shake table test, the range beyond this point is not considered in the seismic design of the precast prestressed concrete bridge for safety consideration. Thus, the limit state for the seismic performance levels 3 should be determined beyond the yielding of the post-tensioning steel bars. Further research may be needed for consideration of the behavior after yielding of the post-tensioning steel bars.

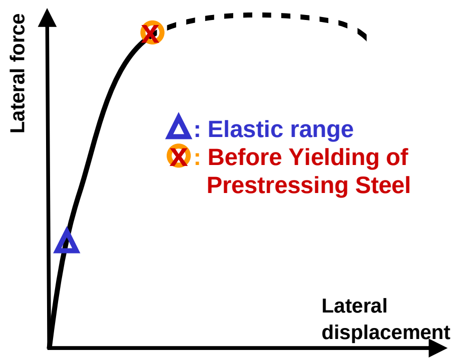


Figure 8 Limit states of precast prestressed concrete columns

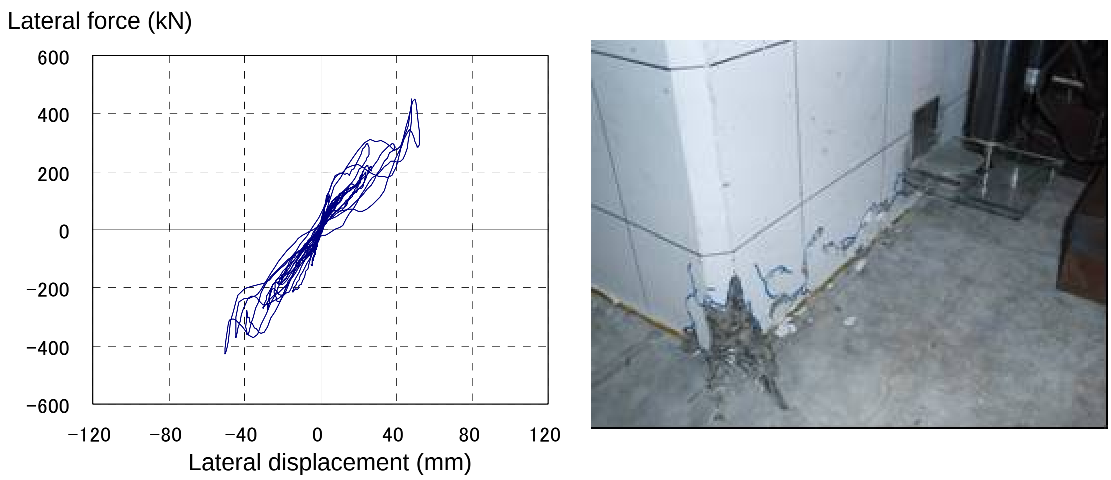


Figure 9 Seismic Response and Failure Mode after Design Ground Motion Level Test for Precast Prestressed Column

Limit States of Precast Hybrid Bridge Column

The schematic image of the limit states of the precast hybrid bridge column is shown in **Figure 10**. Since the key feature of this column is the repairability by replacement of the connecting bolts, the limit states of the seismic performance level 3 should be determined to be same as those of the seismic performance level 2. The replaceable limit of the connecting bolts is determined as the limit state for the seismic performance level 2. The allowable strain of the bolts is estimate to be 2% based on the low-cycle fatigue tests and the shake table tests. The other structural members should remain in the elastic range. **Figure 11** shows the force-displacement hysteresis and the failure mode obtained from the shake table tests during the design level earthquake ground motion. The results from as-built series (case 1) and post-repair series (case 2) are compared. After the design level tests in the post-repair series, the response displacement was still smaller than the design displacement while about 2% strain was induced in the connecting bolts and minor spalling of cover concrete was observed.

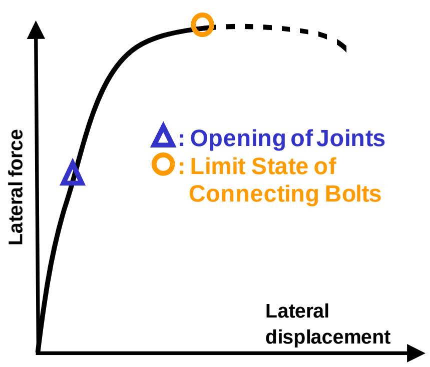


Figure 10 Limit states of precast hybrid concrete columns

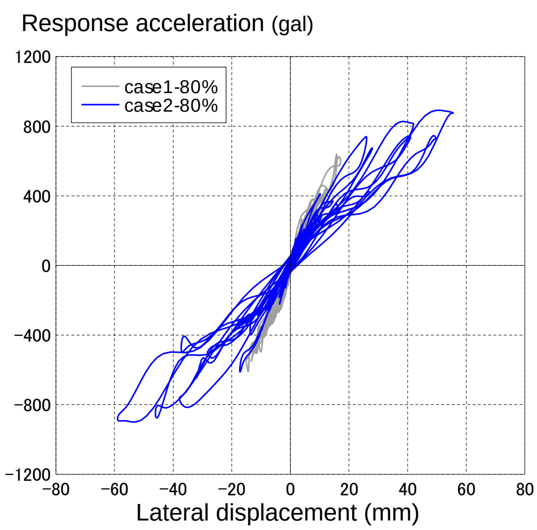
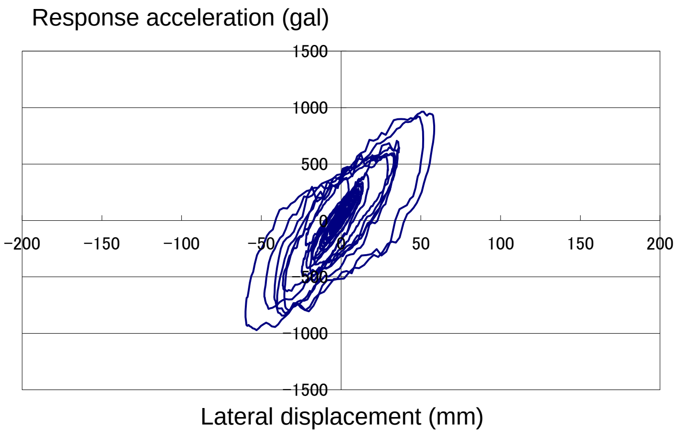


Figure 11 Seismic Response and Failure Mode after Design Ground Motion Level Test in Post-repair Series for Precast Hybrid Column

Limit States of Precast Reinforced Concrete Bridge Column

It was confirmed that the nonlinear behavior of the precast reinforced concrete bridge column was similar or even better than the conventional reinforced concrete bridge column because the longitudinal reinforcing bars inserted into the mortal-grouted ducts have better performance on anti-buckling. The limit states of this column can be determined to be the same as those of the conventional reinforced concrete columns, which is shown in **Figure 7**. **Figure 12** shows the force-displacement hysteresis and the failure mode obtained from the shake table tests during the design level earthquake ground motion. Only flexural cracks were observed, and the stable hysteresis loop was obtained.



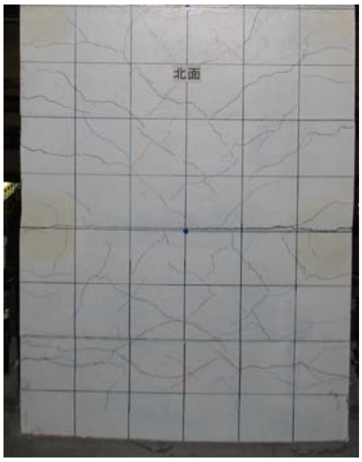


Figure 12 Seismic Response and Failure Mode after Design Ground Motion Level Test for Precast Reinforced Concrete Column

Conclusions

This paper introduces the state-of-practice of the conventional segmental concrete bridge columns in Japan. Also, recent research works for the development of the new precast segmental concrete columns were introduced in this paper. Design Guidelines for the seismic effect of the precast segmental concrete columns is scheduled to be published in 2010. The seismic performance and the seismic limit states of the precast segmental columns will be described in the guidelines based on discussion of the test results. Furthermore, connection design details of those columns will be specified.

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