

Development and Practical Application of Slab Connection System for PC Girders Using Low-Elasticity High-Ductility Fiber-Reinforced Cementitious Composite

Kei Muroda¹, Yoshihiko Taira², Yoshikatsu Nabetani³, Motohiro Iijima⁴, Sejiro Uchida⁵ and Takeshi Oshiro⁶

¹Osaka Branch, Sumitomo Mitsui Construction Co., Ltd., 4-7-28 Kitahama, Chuo-ku, Osaka 541-0041, Japan. kmuroda@smcon.co.jp

²Civil Engineering Designing Department, Sumitomo Mitsui Construction Co., Ltd., 2-1-6 Tsukuda, Chuo-ku, Tokyo 104-0051, Japan. ytaira@smcon.co.jp

³Osaka Branch, Sumitomo Mitsui Construction Co., Ltd., 4-7-28 Kitahama, Chuo-ku, Osaka 541-0041, Japan. ynabetani@smcon.co.jp

⁴Civil Engineering Designing Department, Sumitomo Mitsui Construction Co., Ltd., 2-1-6 Tsukuda, Chuo-ku, Tokyo 104-0051, Japan. mijima@smcon.co.jp

⁵Osaka Branch, Sumitomo Mitsui Construction Co., Ltd., 4-7-28 Kitahama, Chuo-ku, Osaka 541-0041, Japan. suchida@smcon.co.jp

⁶West Nippon Expressway Company Limited, 1-6-20 Dojima, Kita-ku, Osaka 530-0003, Japan. t.oshiro.aa@w-nexco.co.jp

ABSTRACT

Construction of Tanabe Parking Area is a project of erecting prestressed concrete girder bridges of three or four spans and connecting them together to create a spacious parking area. The girders in this project varied in span length and girder height due to location restrictions on piers. Connection of prestressed concrete girder bridges is commonly made by reinforced concrete connection system in which adjacent girders are connected with each other by using cross beams. However, this conventional connection system was not appropriate for this project because of the difficulty in design and construction of the connecting cross beams. To solve this problem, the authors developed and adopted a new connection system using slabs for increased ease of construction as well as reduced maintenance requirements after completion. This paper provides an overview of the slab connection system and reports the structural performance test carried out before practical application to this work.

Keywords. Fiber reinforced cementitious composite, Low elasticity, High ductility, Connected structure, Slab

1. SLAB CONNECTION SYSTEM

The slab connection system is a technique to connect adjacent prestress concrete (hereinafter referred to as "PC") girders with each other using slabs for construction of a connected girder bridge.

The loose connection between the PC girders achieved by this system reduces the sectional force acting on the connecting members, which makes it possible to improve construction efficiency and reduce maintenance requirements of the parking area. Two different materials were used for the connecting members, depending on the locations. Normal concrete mixed with vinylon short fibers was used for the slabs under relatively small sectional force, with the span length made to 1.0 to 1.5 m. Newly developed low-elasticity high-ductility fiber-reinforced cementitious composite was used for the slabs under large sectional force, with the span length increased to 2.0 m to reduce the sectional force acting on them. The new material has a compressive strength equivalent to normal concrete, a modulus of elasticity of about two-thirds that of normal concrete, and improved ductility and crack distributing effect due to the added vinylon short fibers (Photo 1). Details of this material are to be presented in a separate report (Ooyagi et al., in submission). Figure 1 shows general structural drawings of the Tanabe Parking Area.

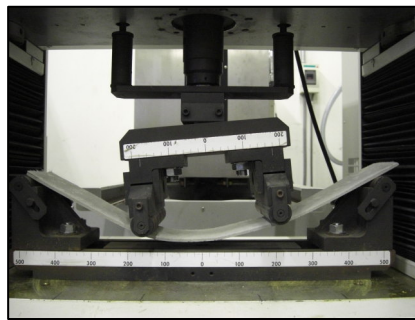


Photo 1. Performance of the Low-elasticity High-ductility Fiber-reinforced Cementitious Composite

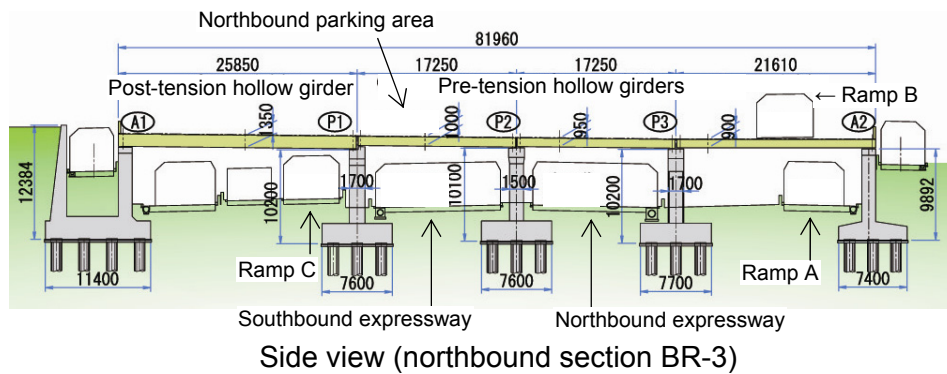
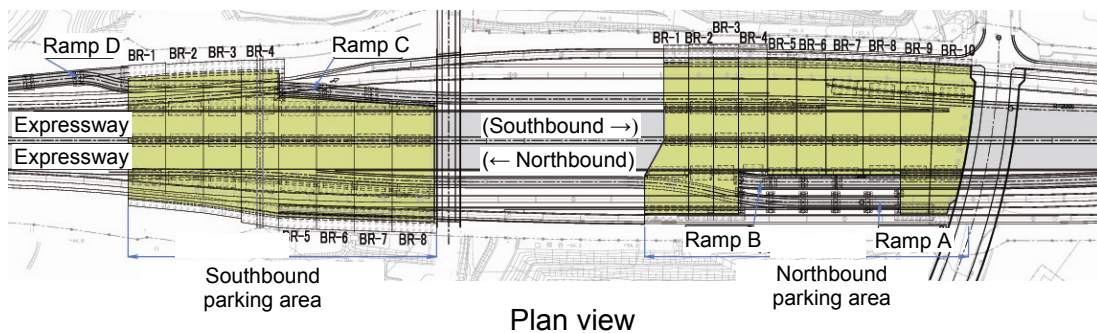


Figure 1. General Structural Drawings

A connected PC girder bridge is commonly constructed by erecting PC girders and connecting them with each other using cross beams as shown in Figure 2-(a). However, construction of the cross beams requires complicated operation in narrow spaces. In addition to the construction difficulty, maintenance problems were suggested because the variation in girder height and cross-sectional shape between the girders could result in broken continuity in reinforcement in the bottom at the cross beams. The other concern about using the conventional connection system was seismic resistance because a large sectional force was expected to act at the middle supports not only in normal state but also during an earthquake because of the high rigidity of the connection [Figure 3-(a)]. In order to solve these problems, a new connection system was developed in which the PC girders were connected with each other only by slabs as shown in Figure 2-(b). The loose connection achieved by the slab connection system reduces the sectional force acting on the connecting members [Figure 3-(b)]. The new system also improves ease of maintenance of the parking area as well as ease of construction of the connection.

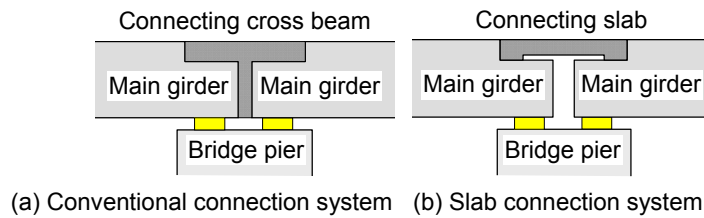


Figure 2. PC Girder Connection Systems

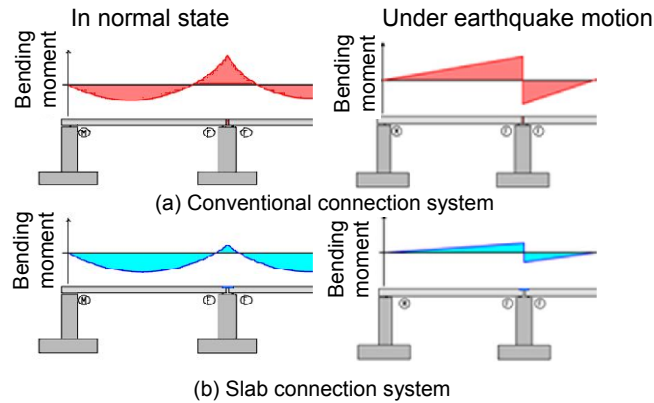


Figure 3. Schematics of Bending Moment

The girders in this project varied in span length and girder height, which was expected to cause variation in sectional force acting on the connecting slabs. For that reason, structural specifications and materials were varied depending on the sectional force. Normal concrete containing vinylon short fibers was used where small sectional force was expected, with the slab span length being 1.0 m or 1.5 m according to the expected sectional force (Type 1; Figure 4). Where large sectional force was expected, the newly developed low-elasticity high-ductility fiber-reinforced cementitious composite material was used, with the slab span length being 2.0 m for a reduced sectional force acting on the connecting slabs (Type 2; Figure 5). Design strength was 30 N/mm^2 for both types, and reinforcing steels of D22 were

spaced at intervals of 125 mm or less in the slabs. The slabs were designed as normal reinforced concrete members to provide an adequate safety margin (in compliance with the Specifications for Highway Bridges of Japan), ignoring tensile resistance of concrete and that of short fibers and having tension to be resisted only by reinforcing steels.

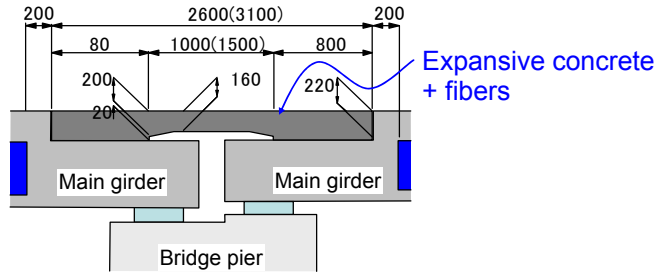


Figure 4. Side View of Type 1

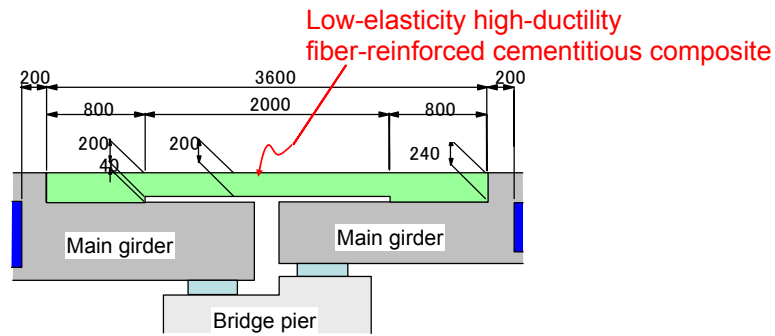


Figure 5. Side View of Type 2

2. STRUCTURAL ANALYSIS

The sectional force in a whole bridge connected by the slab connection system proposed in this study can be calculated by two-dimensional frame analysis using a combination of centerlines of the members. Figure 6 shows the whole system model, and Figure 7 shows the details of a support region.

FEM analysis was carried out for verification, using the same boundary conditions with those in the frame analysis. The frame analysis values were found to be equivalent to or larger than the FEM analysis values, showing the adequate safety margin of the design (Figure 8).

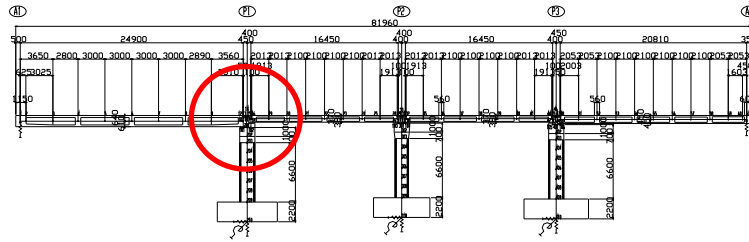


Figure 6. Two-dimensional Frame Analysis Model (Whole System)

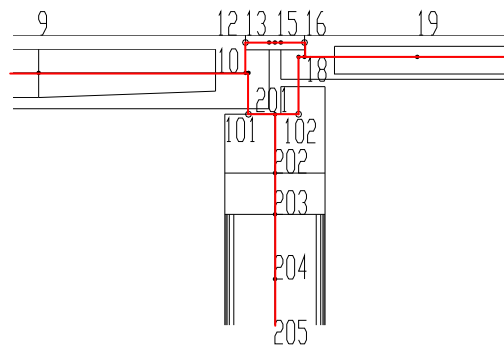


Figure 7. Details of the Support Region of the Two-dimensional Frame Analysis Model

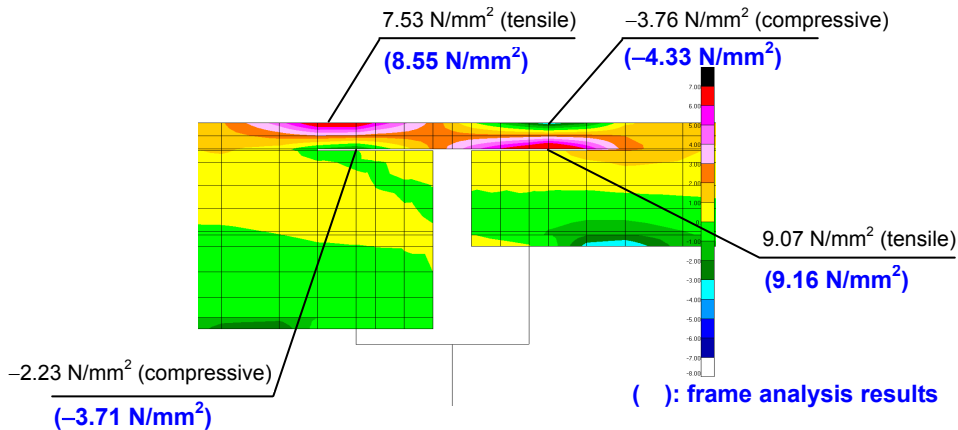


Figure 8. Verification of the Frame Analysis on the Support Region by FEM Analysis

3. STRUCTURAL PERFORMANCE TEST

The authors carried out loading tests, using partial test pieces cut out of full-scale models of Types 1 and 2, for the purpose of understanding structural behavior of the slab connection systems and verifying the validity of the structural design. This section describes the test on the Type 2 system.

Figure 9 shows the loading method and a deformation diagram. Load was applied only to

one end of a test piece in this experiment. This was an attempt to reproduce the critical condition for the slab members in the actual structure where bending moment due to asymmetrical load was expected to be prominent. Figure 10 shows the reinforcement arrangement.

Figure 11 shows the relationship between the applied load and strain in the reinforcing steels near the end of the slab span where stress was the largest in the slab. The diagram also shows for reference a curve from a nonlinear analysis using a fiber model. Although the test results well matched the analytical curve until the crack initiation, actual strain in the reinforcing steels after that point was found to be smaller than that by the analysis.

With the focus on the stress in the slab reinforcing steels, the authors determined the load levels equivalent to the dead load and the design load, respectively, in the calculation of cross-sectional stress of the reinforced concrete (hereinafter referred to as “RC”) member. Like in the experiment on the slab members, measured stress (and strain) in the reinforcing steels was smaller as compared to the estimated stress under specific assumptions used in the structural design.

The smaller measurements of the stress in the reinforcing steels were considered to be partly due to the assumption used in the cross-sectional stress calculation for the RC member that the elastic modular ratio of steel to concrete, n , was 15. The other likely reason is the tensile strength provided by the addition of vinylon short fibers (2.00vol%).

In either case the experimental results demonstrated that this design method would provide sufficient structural safety margin due to deviation from the assumptions used in the structural design calculations, tensile strength of the short fibers or other factors, suggesting no structural problem.

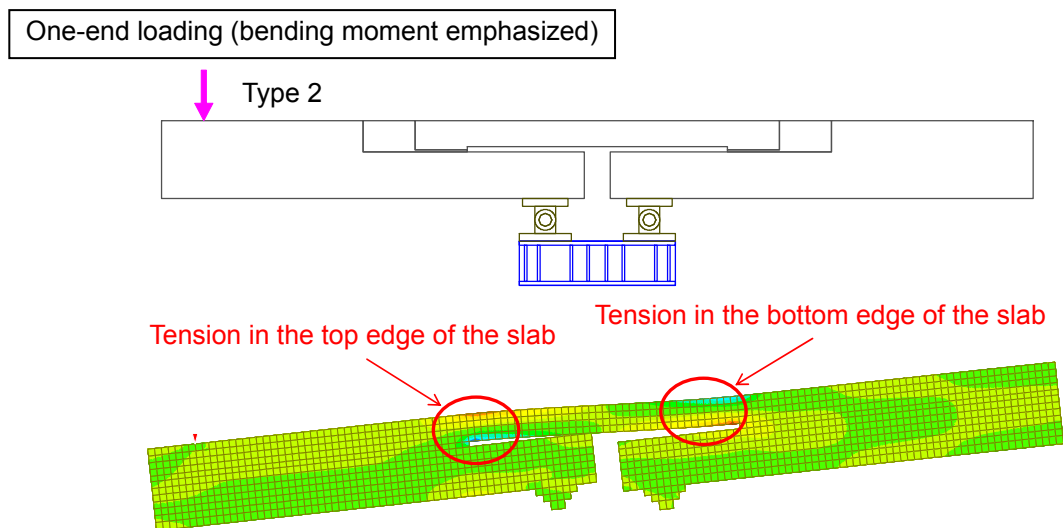


Figure 9. Loading Method and Deformation Diagram

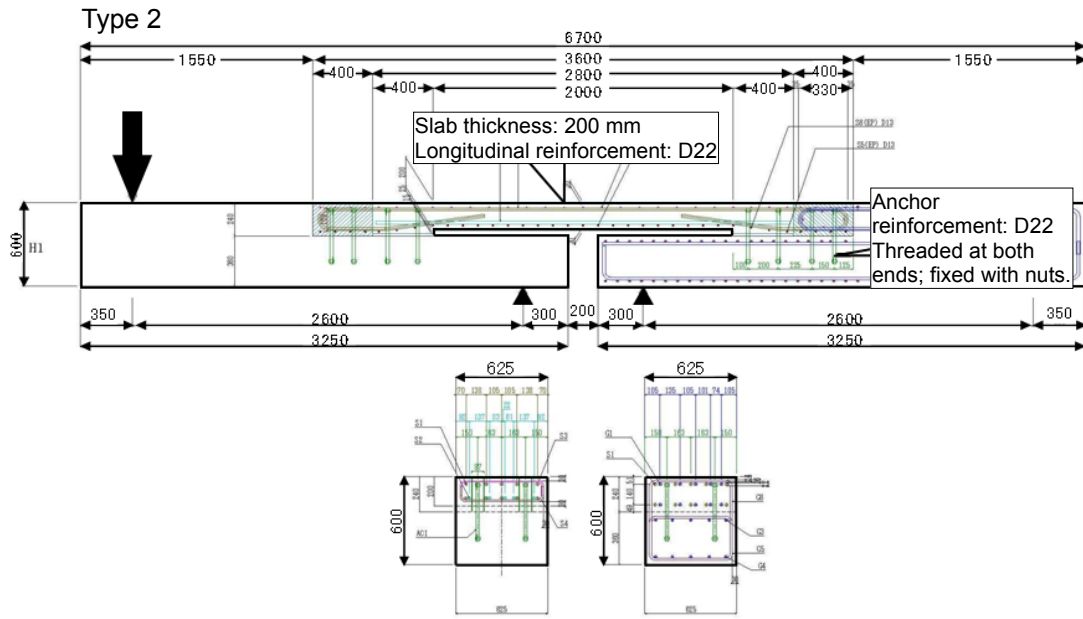


Figure 10. Test Piece Reinforcement Arrangement

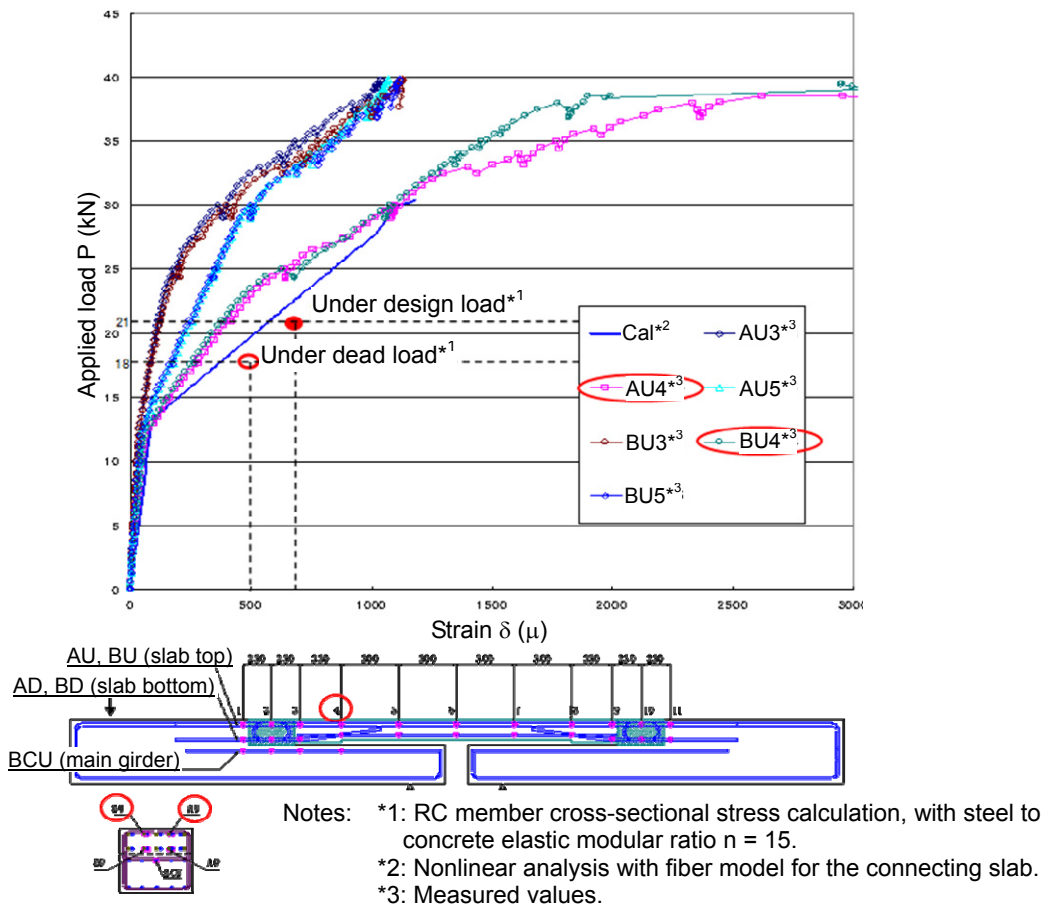


Figure 11. Load and Strain in Reinforcing Steels

4. CONCLUSION

This report described a combined technique of a new structure (slab connection system) and a new material (low-elasticity high-ductility fiber-reinforced cementitious composite) developed for the construction of the Tanabe Parking Area, including its design method and structural experiment results. Due to the adoption of the new structure and new material, a considerably large safety margin was taken in this project. In order to promote wide use of the proposed technique, it is necessary to establish proper structure and durability design which fully takes advantage of the high ductility and excellent crack distributing effect of the low-elasticity high-ductility fiber-reinforced cementitious composite. With rationalization of the structure and improvement of work efficiency during construction, practical applicability of the proposed technique will be increased, ranging from new construction to renewal work on existing bridges.

REFERENCES

- Ooyagi, R., Taniguchi, H., Sasaki, W., Higuchi, M., Shiina, N. and Oshiro, T. "Development of Low-Elasticity High-Ductility Fiber-Reinforced Cementitious Composite for Use in PC Girder Connecting Slabs." Submitted to the Proc. of SCMT3, August 2013, Kyoto, Japan.
- Taniguchi, H., Taira, Y., Muroda, K. and Oshiro, T. (2011). "Construction of the Link Slab for PC Girders using Fiber Reinforced Cementitious Composite." *Concrete Journal*, JCI, Vol. 49, No. 4, 22-29.