## JOINTLESS PRESTRESSED CONCRETE VIADUCT USING ENGINEERED CEMENTITIOUS COMPOSITE (ECC)

Tsunehisa YAMAGUCHI<sup>1</sup>, Masaru FUJISHIRO<sup>1</sup>, Kumiko SUDA<sup>2</sup>, and Y. NAGATA<sup>3</sup>

### <u>Abstract</u>

On concrete superstructure consisting with continuous multiple simple girders, the surface level difference at expansion joint has been disturbing drivers' comfort. And it has been causing vibration and making noise in surrounding areas. To solve the problems, the authors developed a jointless method that provides for quick construction by connecting separate girders of the joint clearance between separate girders using plates made of ECC (Engineered Cementitious Composite). This paper describes the material properties of ECC, an outline of the developed method, results of verification tests, report of field practice and development in the future.

## Introduction

Driving comfort on prestressed concrete viaduct is greatly affected by pavement and expansion joints installed at expansion spacing. Level differences are produced at expansion joints by passage of heavy vehicles, causing issues of vibration and noise, especially at bridges in urban areas and high-standard highway bridges, where traffic volume is large. Level differences at expansion joints also cause early deterioration in the joints, further disturbing driving comfort. Increases in vehicle weight and traffic volume are aggravating the problems.

As a tentative countermeasure, road administrators execute repair works, such as leveling the differences and joints installation (Figure 1). Frequency of repair works is high in particularly heavy-traffic sections, resulting in large expenses for maintaining highways. Thus, drastic measures need to be developed.

The deformation of expansion joints is induced by seasonal temperature changes and deflection of the girders by live loads. To solve the problems, various methods have been implemented to eliminate joints from bridges and thus realize continuous pavement surfaces. The authors have developed gapless connectors (ECC joints) using expansive and highly ductile cementitious composite called "engineered cementitious composite (ECC)". ECC joints can connect the gaps between slabs fast in construction, resulting in continuous united pavement surface. This paper describes the material properties of ECC, an outline of the developed method, results of verification tests, report of field practice and development in the future.

1. Senior Engineer, Civil Engineering Design Division, Kajima Corporation, Tokyo

2. Vice Project Manager, Uratakao Bridge Project, Tokyo Civil Branch, Kajima Corporation, Tokyo

3. Metropolitan Expressway Corporation, Tokyo



Figure 1. Example of repairing the difference formed at an expansion joint.

# **Material Properties of ECC**

Engineered cementitious composite (ECC) is highly ductile fiber-reinforced cement composite that has very high crack dispersibility and tensile expansiveness under uniaxial tensile stress. As tensile stress increases, ECC undergoes large tensile deformation producing narrow cracks one after another. Cracks are narrower than 0.2 mm. Even after cracks are produced, reinforcing fivers transmit tensile forces by their bridging effects and restrict the crack widths. In a uniaxial tension test, ECC maintained its tensile force even when strain of several percent was produced. A view of a uniaxial tension test of ECC is shown in Figure 2.



Figure 2. Uniaxial tension test of ECC

#### **Overview of ECC Joint Method**

Several methods have been used to eliminate expansion spacing from existing prestressed concrete bridges: the slab connection method and the embedded joints method. The slab connection method is removing existing joints and connecting the upper and lower reinforcing bars along the bridge axis. The slab connection method takes long time to execute and requires traffic to be restricted for twenty-four hours. Moreover, connecting slabs cause the change of the structural system and stress on piers, and thus are difficult to be used except for small-scale repairing. The embedded joints method uses elastic materials instead of expansion apparatus. Conventional embedded joints use special elastic materials that absorb the expansion and contraction transformation. However, the joints have a disadvantage of insufficient durability since the materials suffer plastic deformation by repetitive application of wheel loads, resulting in cracks, potholes, and flow of pavement.

ECC joint is a new embedded space-less joint. ECC joint is connected with the slab by the anchor. When displacement occurs in the gap between slabs connected by ECC joint, narrow and dispersed cracks are produced on the joints. And, the pavement is followed to the surface of ECC. Since a large area of the pavement deforms, the surface of the pavement maintains continuousness. ECC joint is durable and strong against wheel loads. ECC joint don't change the structural system of bridge. ECC joint can be constructed in short period of time. A structural overview of the joint is shown in Figure 3.



Figure 3. Overview of ECC joint installation.

### **Structural Performance Verification Test**

The performances of ECC joints were experimentally examined by preparing a full-scale model specimen and applying gap displacement similar to those in actual bridges. A view of the experiment is shown in Figure 4.

Loads were applied by controlling displacement so as to reproduce displacement between slabs. Loading steps were: Steps 1 and 2: design tensile strain of ECC (0.5%), Step 3: design compressive strain (strain at 1/3 compressive stress, 0.065%), and Step 4: 1/3 of the maximum compressive strain of 0.4% (0.13%). Gap displacements were determined as shown in Table 1 by considering the free length (1,050 mm) of ECC joints.

The test result showed that no failure occurred at ECC joint plates or anchors throughout Steps 1 to 4. The joints were shown to have sufficient expansive performance against repetitive tensile load equivalent to the design tensile strain of ECC (0.5%). Against compressive loads, the joints showed no deformation even by repetitive (at least five times) application of maximum compressive strain of ECC (0.13%). Ultimately, the upper surface of ECC buckled and broke at horizontal load of 667 kN and gap displacement of -2.95 mm (compressive strain of 0.28%). Cracks were produced near the anchors but not at the anchors. The compressive stress that acted on the ECC joint plate was 25 N/mm<sup>2</sup> and was smaller than the material test value of 36 N/mm<sup>2</sup>. Thus, the failure was not uniaxial compressive failure but was likely to have been caused by buckling.



Figure 4. Structure verification test.

STEP	Controlling displacement
1	From residual displacement to gap displacement + 5.3 mm $\times$ 10 times <sup>1)</sup>
2	From gap displacement 0.0mm to gap displacement + 5.3 mm $\times$ 10 times <sup>1)</sup>
3	From gap displacement -0.7mm to gap displacement + 5.3 mm $\times$ 5 times <sup>2)</sup>
4	From gap displacement -1.4mm to gap displacement + 5.3 mm $\times$ 5 times <sup>3)</sup>

Table 1. Loading method

1) Design tensile strain of ECC: 5.3 mm was calculated from tensile strain 0.5%.

2) Design compressive strain of ECC (strain at 1/3 compressive stress): 0.7 mm was calculated from 0.065%.

3) One-third of the strain at the maximum compressive stress of ECC: 1.4 mm was calculated from 0.13%.

#### **Field Practice**

The practicability of a slab connection using ECC joint has been verified by carrying out trial construction. The ECC joint that were constructed on field practice are currently functioning satisfactorily after more than two years since construction.

In the field practice, ECC joints were actually installed as joints of an elevated section of an urban expressway, consisted of prestressed concrete simple girders. An overview of bridges to which ECC joints were installed is shown in Figure 5. A detail of ECC joint panel used is shown in Figure 6. The dimensions of ECC joint were determined from the free length needed to absorb the gap displacement of the prestressed concrete girders, lane width, and conditions of fixed ends on both sides for transmitting tensile stress to the slabs. An ECC joint panel was 1,400 mm wide along the bridge axis, 1,694 mm across the bridge and 30 mm thick. Two ECC joint panels were installed per lane. Separators consisting of celluloid plates were installed between ECC joint panels and existing floor slabs to allow expansion deformation.

A construction flow chart with the construction time of each phase is shown in Figure 7. A completed ECC joint is shown in Figure 8. The application suggested that ECC joints can be installed in eight hours (overnight). Execution period can be further reduced by finding better filling materials, and simplifying anchorage mechanism.



Figure 5. Overview of bridges with ECC joints.



Figure 6. Detail of ECC joint panel



Total construction time; 8.0 hours

Figure 7. Construction flow chart of ECC joint



Figure 8. Completed ECC joint installation.

#### Applicable Girder Length of the ECC joint

In order to examine the range of applications of the ECC joint, the displacement of expansion joints due to temperature changes and live loading were measured. The displacement and temperature of expansion joints were measured continuously for two days on a bridge along the route where the ECC joint method was installed on a trial basis. The displacement of expansion joints due to live-load-induced deflection was also measured dynamically.

As a result, the displacement between bridges was 0.75 times of the expansion calculated from temperature change. The maximum rotation angle of the girder end caused by live loads was about 1/1200 rad. Applicable girder length of the ECC joints that had considered creep and shrinkage was calculated from these measurement results. An applicable girder length of the ECC joints is shown in Table 2.

At present, ECC joint method can be applied to a limited span length because of the critical compressive strain in ECC joint panels. ECC joint panels, however, have adequate tensile strain properties. Studies are now being made to find a structure that can reduce compressive strain. In the future, the ECC joint method will be applied to longer spans.

	Annual temperature fluctuation at the site		
	< 10 degrees	< 15 degrees	
Existing girder	Not exceeding 30 m	Not exceeding 20 m	
New girder	Not exceeding 20 m	Not exceeding 15 m	

 Table 2. Applicable Girder Length

#### **Future Prospects**

Although, ECC joints have been developed to improve the performance of joints at the end of existing girders, the possibility of the application to newly constructed bridges is examined aim at further improve driving comfort and reduce the frequency of repairs.

As the construction of new bridges in urban areas and expressway bridges, multi span continuous bridges are frequently adopted aiming for driving comfort and good roadside environment. However, multi span continuous bridge is structurally complex and expensive in construction cost compared with a simply supported bridge. Simply supported bridge using ECC joint is more advantageous than multi span continuous bridge in terms of bridge function and cost effectiveness.

Using ECC joint on marine bridges like the one shown in Figure 9 eliminates deterioration of expansion devices under severe salty environmental conditions, and is expected to reduce maintenance cost.



Figure 9. Schematic picture of ECC joint application.

# **Conclusions**

ECC joints for gapless slab connection have been verified by structural performance, and field practice. The following conclusions could be made:

- 1. ECC joints are a new embedded space-less joint and can be constructed in short period of time.
- 2. ECC joints don't change the structural system of bridge. ECC joints are durable and strong against wheel loads.
- 3. ECC joint that were constructed on field practice are currently functioning satisfactorily more than two years since construction.
- 4. ECC joint can be installed to the newly constructed bridges.

## **References**

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