EXPERIMENT ON THE JOINT AT THE LOWER END OF THE STRUT IN PC BOX GIRDER BRIDGE WITH STRUTS

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ABSTRACT

In Japan, there are not so many examples of widening of slabs of PC box girder bridge. In the second Murara Viaduct we had to construct a 3-lane complete section from a 2-lane provisional section.

The widening method is as follows: overhanging slabs are widened first; then the structure to support slabs by struts was employed. "Method to place precast cradles between the lower end of the struts and existing concrete structure" was determined to employed in this bridge.

It was the first time that it was adopted this method in a section where the axial line of struts does not perpendicularly connect with the joint surface of the existing concrete structure. Therefore, we carried out an experiment for establishment of the safety checking method at the joint.

Based on the results of the experiments, we have proved that shear transmission capacity of the PCa cradles can be obtained by the sum of shear key capacity and friction force, and reached the calculation formula of shear transmission capacity.

Keywords: corrugated steel web PC box girder bridge with struts, widening method, precast cradles, ultra high strength fiber reinforced concrete

INTRODUCTION

The second Murara Viaduct is a 2-span continuous rigid frame corrugated steel web PC box girder bridge with struts constructed adjacent to Fujieda-Okabe IC (tentative name) of the New Tomei Expressway in Shizuoka Prefecture. The construction of this bridge started with a 2-lane core section (upper slab width of 11.760 m) having a structure to be capable of future widening to a 3-lane complete section (upper slab width of 17.060 m). However, the plan was changed to construct a complete section before placing in service by considering the level of difficulty of the widening construction after placing in service in the future.

The widening method is as follows: overhanging slabs are widened first; then the structure to support slabs by struts was employed. The struts are precast members made of reinforced concrete.

However, the joint at the lower end of the strut was constructed without any preparations expecting a new joining method will be developed in the future (see Photo- 1). Therefore, "method to place precast cradles (hereinafter, called PCa cradles) between struts and the existing concrete structure" which was employed in Nakanogo Viaduct with similar background[1)] was determined to be employed in this bridge. The building method of the joint after construction in the uniform section (section where the axial line of struts perpendicularly connects with the joint surface of the existing concrete structure) has already been developed in Nakanogo Viaduct. However, no applied example exists for the non-uniform section (section where the axial line of struts does not perpendicularly connects with the joint surface of the existing concrete structure) such as in this bridge. Therefore, it was necessary to establish a safety checking method at the joint as the component of force will be generated by axial force.

This paper describes experimental studies to confirm the load-carrying capacity of the joint at the lower end of the strut using PCa cradles at the non-uniform section.

Photo.1 The joint at the lower end of the strut

OUTLINE OF THE BRIDGE

Outline of this bridge and specification data are shown below. Figure-1 and Figure-2 show the general view of the bridge and the cross sectional view of the main girder, respectively.

Name of work : Construction work of the second Murara Viaduct (superstructure of PC) in the Second Tomei Expressway
Type of structure: 2-span continuous rigid frame corrugated steel web PC box girder bridge with struts
Erection method : Core section : Cantilever method
: Widening slab : Traveling falsework using a widening traveler
Bridge length : Inbound lane, 132.200 m
: Outbound lane, 153.344 m
Span length : Inbound lane, 64.809 + 64.791 m
: Outbound lane, 75.360 + 75.384 m
Effective width : 16.500 m
Girder height : 3.5 m to 6.5 m

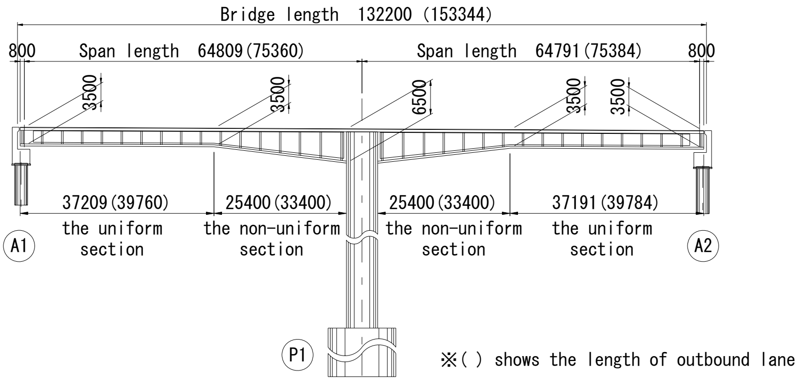


Fig.1 General view (side view)

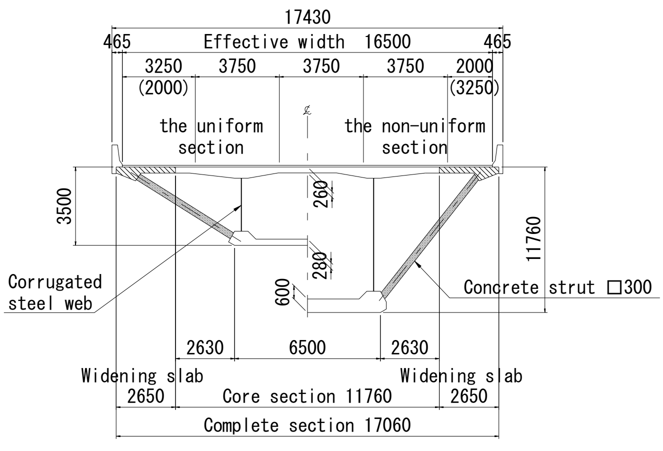


Fig.2 Cross section of main girder

STRUCTURE OF THE JOINT AND OBJECTIVE OF THE EXPERIMENT

For the joint at the lower end of the strut, the structure to transmit the load via the shear key of the PCa cradle which had been employed in Nakanogo Viaduct was employed (see Fig. 3). The PCa cradle was installed as follows: first a shear groove (concave) is formed in the existing concrete structure by a concrete cutter; next, epoxy resin is applied on the joint surface and the shear groove of the PCa cradle as an agent to adjust its unevenness; and last, the PCa is installed by joining the shear key (convex) with the shear groove (concave).

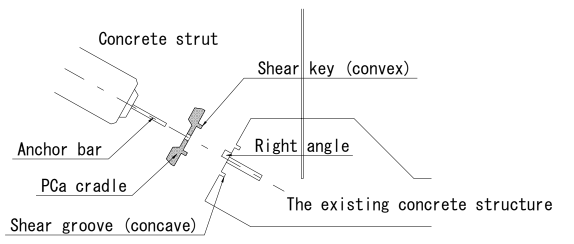
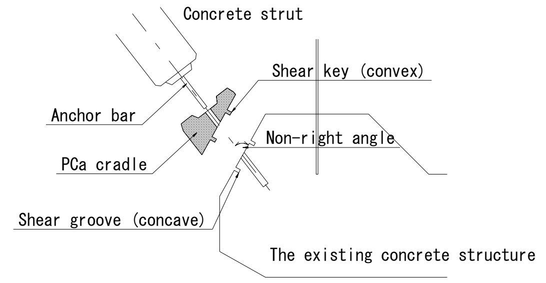
The uniform section (the type of Nakanogo Viaduct)	The non-uniform section (the type of the second Murara Viaduct)
	

Fig.3 Structure of the joint at the lower end of the strut

Axial line of the strut does not perpendicularly connect with the joint sureface of the existing concrete structure in the non-uniform section zone of this bridge, and the component of force of axial force acts as shear force on the joint surface. Therefore, in order to use this cradle, it was necessary to understand the shear transmission mechanism and the load-carrying capacity at the joint between the PCa cradle and the existing concrete structure by investigating the following factors in the experiment.

(a) Friction coefficient between the PCa cradle and the joint surface of the existing concrete structure (Case 1 of the experiment)
(b) Shear capacity of the shear key alone (Case 2 of the experiment)
(c) Share ratio of shear capacity of the shear key and friction resistance (Case 3 of the experiment)
(d) Effect of the change of installation angles (Case 4 of the experiment)

SPECIMENS AND OUTLINE OF THE EXPERIMENT

Two kinds of specimens were prepared: specimens for element experiments with the aim of estimating friction coefficient, shear transmission capacity of the shear key and share ratio in Case 1, 2 and 3 of the experiment; and specimens for the confirmation experiment with the aim of confirming the effect of angles between the axial line of the strut and the existing concrete structure in Case 4 of the experiment. Figures 4 and 5 show the schematic illustration of apparatus for the element experiments and the confirmation experiments, respectively.

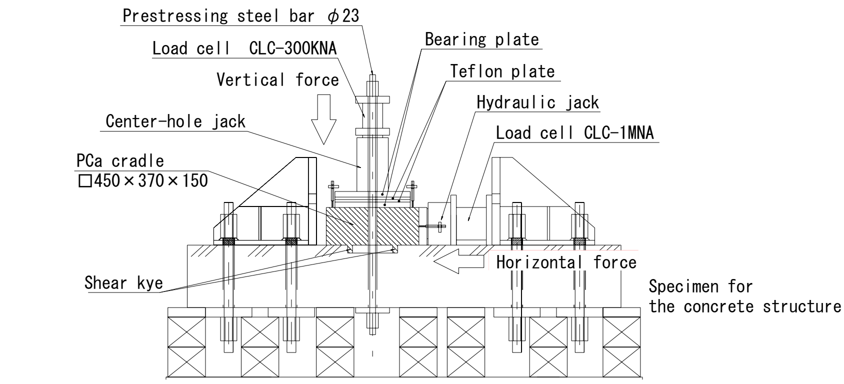


Fig.4 The setup for the element experiment

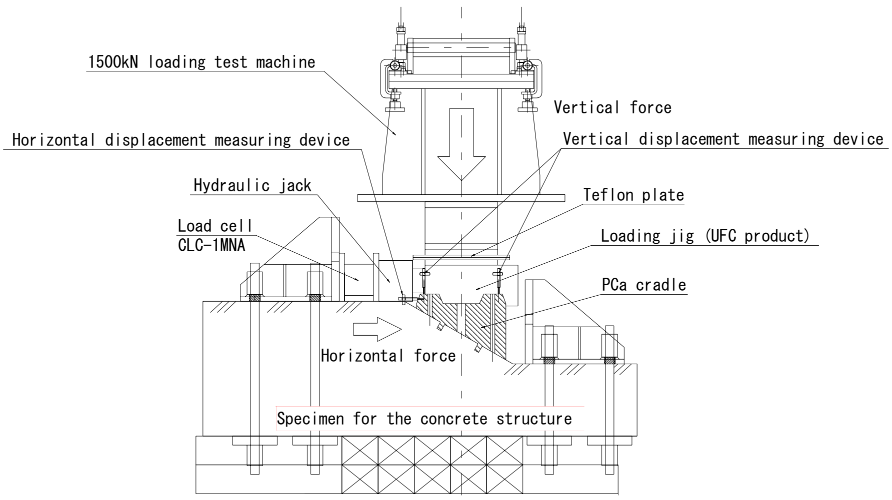


Fig.5 The setup for the confirmation experiment

Ultra high strength fiber reinforced concrete was used for the PCa cradle expecting its high toughness. Figure-6 shows the shape of the cradle. The specimen for the concrete structure was made by using high-early-strength Portland cement to simulate the structure under construction, and surface treatment of the joint level was performed by sandpaper. Epoxy resin which is used as an agent to adjust unevenness was not applied in order to investigate pure friction coefficient between the existing specimen and the PCa cradle, and shear capacity of the shear key in the experiment.

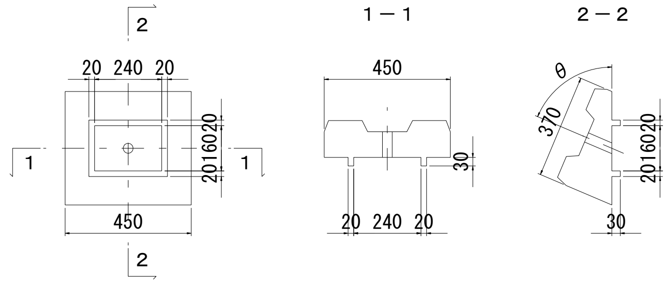


Fig.6 The PCa cradle

Table-1 shows each case of the experiment.

Table.1 Case of the experiment

Case		Element experiment				Confirmation experiment
		1	2		3	4
Installation angle		90	90		90	74,67,60
Shear key	One side	—	○	—	○	—
	Both	—	—	○	—	○
Surface treatment		○	—		○	○

In Case 1, the experiment was performed by changing vertical load using the PCa cradle without the shear key in order to investigate friction coefficient after the surface treatment of the joint level.

In Case 2, grease was applied on the PCa cradle without surface treatment in order to eliminate the effect of friction. And the experiment was performed by constraining displacement caused by uplift without loading vertical force in order to eliminate the effect of friction.

In Case 3, the experiment was performed by using the cradle with the shear key and changing vertical forces in order to investigate the share ratio of the shear key and friction resistance.

In Case 4, the experiment was performed by reproducing three kinds of full-size cradles with different angles between the axial line of the strut and the existing concrete structure. They are : 67 degrees to simulate the maximum angle of this bridge; 74 degrees which is in between the angle of the uniform section and the maximum angle; and 60 degrees which is beyond the maximum angle by considering further application to other constructions.

In all experiments, a load cell and a displacement measuring device were used, and load vs. displacement data were recorded.

EXPERIMENTAL RESULTS AND PROPOSALS FOR THE SAFETY CHECKING METHOD AT THE JOINT

The following is the summary of the experiments.

Figure-7 shows the relationship between the vertical load and the maximum horizontal load in Case 1. As can be seen in the figure, friction coefficient of the joint was indicated to be approximately $\mu = 0.5$.

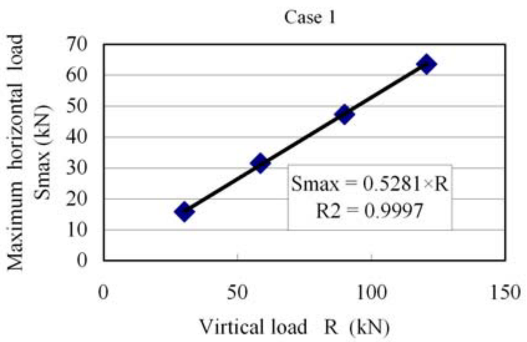


Fig.7 The relationship between the vertical load and the maximum horizontal load in Case 1

Failure modes of the shear key in Case 2 of the experiment were shear failure in the PCa cradle, and diagonal compressive failure in the specimen for the concrete structure, as shown in Photos -2 and -3, respectively.

The experimental results in Case 3 also showed the similar failure modes as that in Case 2.

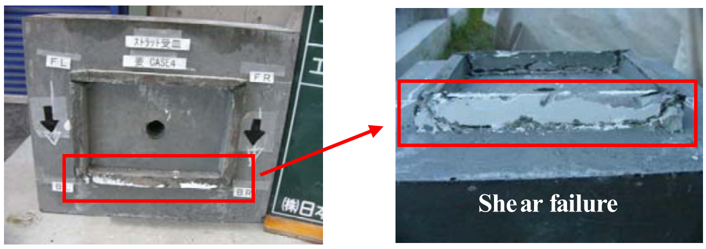


Photo.2 Failure modes of the PCa cradle

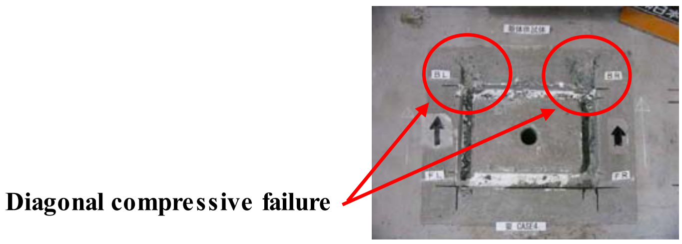


Photo.3 Failure modes of the specimen for the concrete structure

Based on the failure modes obtained in Cases 2 and 3, resistance areas were considered to be divided into shear failure type and diagonal compressive failure type, and they were considered to be the area shown in Figures 8 and 9, respectively.

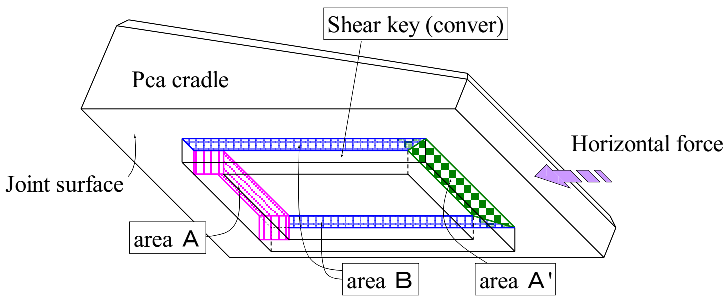


Fig.8 Resistance areas of the PCa cradle

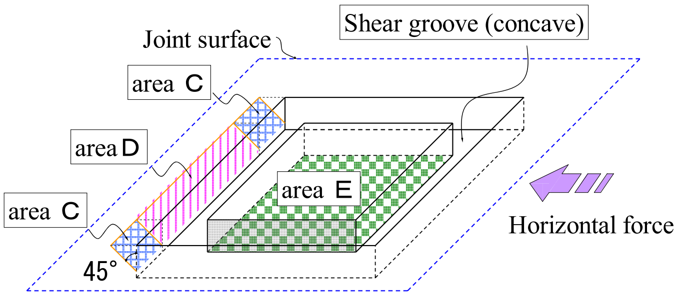


Fig.9 Resistance areas of the specimen for the concrete structure

In addition, shear transmission capacity, H_{uk}, was calculated by using equations in the standard specification for concrete structures of the Japan Society of Civil Engineers [2)] for each failure mode as described in Equations (1) and (2).

Shear failure mode:

$$H_{uk} = 0.1 \cdot f'_{cd} \cdot A_k \quad \cdots \text{Eq. (1) for the PCa cradle}$$

Diagonal compressive failure mode:

$$H_{uk} = f_{wcd} \cdot A_k = 1.25 \cdot \sqrt{f'_{cd}} \cdot A_k \quad \cdots \text{Eq. (2) for specimens of the concrete structure}$$

where the f'_{cd} is design strength, and the A_k is shear resistance area.

Shear transmission capacity was calculated to be the sum of lower capacity value at area resisting each other (e.g., area A of the PCa cradle and area D of the specimen of the concrete structure). When both elements of friction and one side shear key were exerted, simply added values of the design capacity of each element nearly agreed with the value obtained in the experiments. However, when the two shear keys are assumed to be effective, experimental values were approximately 0.83 to 0.98 of the value obtained by simply added design capacities (see Table-2).

Table.2 Comparison between experimental capacity values and design capacity values Unit : kN

Case	Experimental capacity values	Shear key		Friction resistance	Design capacity values	Ratio
		One side	Both			
Case2	180.8	158.9	—	—	158.9	1.14
Case3	223.6	158.9	—	45.5	204.4	1.09
Case2	260.8	—	272.3	—	272.3	0.96

It is estimated that two shear keys do not become effective simultaneously due to manufacturing accuracy of the shear key of the PCa cradle (convex) or the shear groove of the specimen of the concrete structure (concave), etc., but after starting the failure of one shear key, then the next shear key starts to become effective, since the peak appeared twice in the case of using the shear keys effective in both directions as shown in Figure-10.

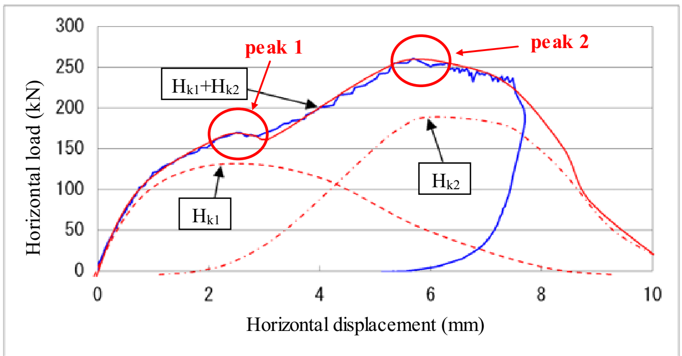


Fig.10 The relationship between the horizontal load and the horizontal displacement in the case of using the shear keys effective in both directions

Also in the confirmation experiment in Case 4 (see Photo-4), simply added values of friction resistance and shear key capacity nearly agreed with the value obtained in the experiments even in the case where installation angles were changed. Therefore, shear capacity can be calculated as in the calculation method of the installation at right angles.

Photo.4 Apparatus for confirmation experiment

Based on the results of the experiments, the calculation formula of shear transmission capacity, S_u, considering installation angles can be expressed in the following Eq. (3) (see Figure-11 for symbols).

Shear transmission capacity:

$$S_u = \frac{R\cdot(\mu/\gamma_{b1}\cdot\sin\theta-\cos\theta)+H_{uk}/\gamma_{b2}}{\sin\theta+\mu/\gamma_{b1}\cdot\cos\theta} \quad \cdots\text{Eq. (3)}$$

Shear key capacity for the joint surface:

$$H_{uk}=\min\{H_{uk}(A),H_{uk}(D)\}+\min\{H_{uk}(B),H_{uk}(C)\}+\min\{H_{uk}(A'),H_{uk}(E)\} \quad \cdots\text{Eq. (4)}$$

γ_{b1} : member factor for the variation due to the construction of the shear groove of the existing concrete structure (concave)

γ_{b2} : member factor for product accuracy of the shear key of the PCa cradle (convex)

Based on each experimental result, the value of 1.1 to 1.3 is desirable to.

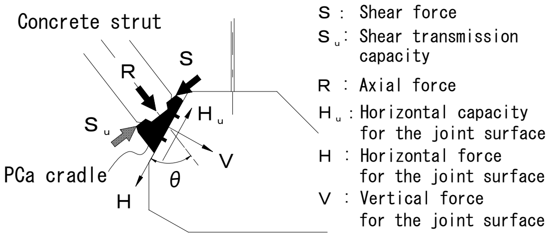


Fig.11 Forces for the joint surface

When this structure is employed, design shear transmission capacity of the joint level must exceed applied shear force in the ultimate limit state, in other words, it must satisfy the condition described in Eq. (5).

$$S_u \geq S \qquad \cdots\text{Eq. (5)}$$

CONCLUSIONS

The following findings were obtained by conducting the experiment.

(1) Shear transmission capacity of the PCa cradles can be obtained by the addition of shear key capacity and friction force.
(2) Shear transmission capacity of the shear key is equal to the combined value of lower capacity values at each portion resisting each other.

FINAL REMARKS

The second Murara Viaduct was completed using the joint structure confirmed in this experiment in October 2009 (see Photo-5).
We hope the results obtained in this experiment may contribute to the construction of other bridges facing similar challenges.

Photo.5 Full view of the second Murara Viaduct

REFERENCES

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