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Experimental Study of Specific Cross Beam Types Appropriate for Modular Bridges

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Abstract**—** Recently in the field of bridges that are newly built or repaired, fast construction is required more than ever. For these reasons, precast prefabricated bridge that enables rapid construction is actively discussed and studied today. In South Korea, it is called modular bridge. Cross beam is an integral component of modular bridge. It functions for load distribution, reduction of bending moment, resistance of horizontal strength on lateral upper structure. In this study, the structural characteristics of domestic and foreign cross beam types were compared. Based on this, alternative cross beam connection types suitable for modular bridge were selected. And bulb-T girder specimens were fabricated with each type of connection. The behavior of each specimen was analyzed under static loading, and cross beam connection type which is expected to be best suited to modular bridge proposed.

Keywords**—**Bulb-T girder, Cross beam, Modular bridge.

I. Introduction

VARIOUS requirements have been ordered recently in the field of bridges that are newly built or repaired in order to minimize the adverse environmental effects and traffic congestion, shorten the construction period, and improve the quality and workability. In particular, work orders from various countries are requiring fast construction. As a result, active research of rapid construction method faster than conventional is underway.

To keep pace with the flow of these in bridge construction, precast method is widely used as shown in Fig. 1. Precast method is a type of construction work moving girders pre-fabricated in the factory to installation location. However it is faster compared to the other method, the plant is needed to produce girder and large machinery to move heavy segments.

In case of medium or small span bridges, precast method is difficult to apply on because of its construction costs and conditions. Thus, the necessity of standardized modular precast bridge that enables rapid construction of medium or small span bridge regardless of terrain or location is on the rise and actively being researched in the domestic [1].

Compared to steel bridges which is relatively light and weld able, concrete bridges are difficult to modularize, although cross section and connection of 30~40m span bridge's module has been standardized through various studies. The domestic modular research team adopted bulb T for the standard cross section. Splicing the precast decks on I-shaped cross-sectional was also considered to take full advantage of the benefits of precast method. It is advantageous to carry the girder, but additional construction process in the field is another burden. Usually, cross beam can be seen as an essential element of bridge configuration and greatly affect on straight, curved and skewed bridges, related research suitable for modular bridge is insufficient.

Fig. 1 Precast Modular Bridge System

Thus, considering workability, quality improvement, shortening the construction period and stability of high altitude operations, alternative for the development of appropriate cross beam suitable for prefabricated Pre-Stressed Concrete (PSC) T girder bridge was set in this study [2]. The structural performance of alternative was verified through experiments and cross beam suitable for prefabricated bridge proposed.

Covered in this study are as follows:

1) Structural features of concrete girder bridge cross beam have been investigated. And status of domestic and foreign application was analyzed.
2) Cross beam alternatives suitable for prefabricated concrete girder bridges were selected and made into specimens to investigate connection features.
3) The connection behavior of specimens was inspected through static load test. The experimental results were

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compared and analyzed.

4) Stability has been verified by comparing the results of structural performance through experiments. Consequently, cross beam system with workability suitable for prefabricated bridge proposed.

II. Overview and Status of the Cross Beam

The plates of typical PSC girder bridge super structure is supported by bridge direction beam or girder. At here, cross beam takes on a role for support in direction perpendicular to bridge, overturning prevention and transverse load distribution.

Cross beam that is typically installed on support is called diaphragm, within the span except support point at the top of pier is called intermediate diaphragm or cross beam.

According to research up to now, there is no disagreement about the necessity and function of diaphragm installed on the support, but medium cross beam is not [3].

Fig. 2 Placing Diaphragm in Field

Fig. 3 Steel Cross Beam

Those who think installation of intermediate cross beam is positive argue that intermediate cross beam has the effect of live load distribution and reducing the bending moment theoretically or empirically.

On the other hand, those who oppose to install insist that intermediate cross beam has almost no effect in terms of load distribution as proven in the actual bridge loading test. Also in the field of bridge construction, they argue that it has more negative effects such as construction delays or dead load increase, so except for curved and skewed bridge, there is no need to install it.

But intermediate cross beam appropriately planned and installed is very effective to resist horizontal forces of super structure. In the case of bridges crossing the road above, it is known that they can prevent the collapse of girder.

A. Current Status of Domestic Cross Beams

According to Korean Road Design Manual A1.9.11, the placement and location of cross beam are described as follows. The cross beams of PSC girder bridges have been installed at intervals of less than 6m at the ends and center for distribution of transverse loads and ensuring the safety of super structure [4].

However recently, installed cross beam quantity has been reduced in order to promote economic design because the plates already function for lateral load distribution. Therefore, the setting point of cross beam has been limited to three places, the both ends and center of beam, for design and construction.

Currently in the domestic, cross beam has been installed in a way that pouring the base plate and cross beam simultaneously after placing girder on the pier.

However in field conditions, it is hard to construct plate and cross beam simultaneously. Therefore the plates are placed after casting cross beams on site as shown in Fig. 2.

However at the site of intermediate cross beam, for the risk of safety hazards due to high altitude operations in dismantling and installing form work and shrinkage problems during the curing process of cast-in-place cross beam, as shown in Fig. 3, application of prefabricated steel cross beam has also been attempted.

Thus, according to Korean Highway Bridge Design Code and Korean Road Design Manual, the location and spacing of cross beam are defined to some extent, but not detailed. Accordingly, the research of cross beam system suitable for girder bridges is needed to ensure the prescribed strength and prevent girders overall [5].

B. Current Status of Foreign Cross Beam

According to AASHTO Standard Specifications for Highway Bridges (2002), diaphragm should be installed as a rule, but in case of span interval more than 12m, intermediate cross beam is recommended to be placed in one place where the maximum bending moment occurs [6].

Also, according to AASHTO LRFD Bridge Design Specification (2007) 5.13.2.2, cross beam should be placed obligatorily at supports [7].

But only in case of curved bridge, if high resistance of torsion is required or discontinuous plates have to be supported, intermediate cross beam should be placed.

Cross beam installation is advantageous to prevent overturning or twist and distribute the live load under construction.

However, it also has some problems, construction delays and increase in construction costs due to additional construction.

In the United States, intermediate cross beam type of concrete girder bridge can be classified into concrete and steel.

According to the survey report of Expressway and

Transportation Research Institute of Korea Expressway Corporation (2000) and Abendroth (1995), currently in the United States, intermediate cross beams are used in 42 states, absolutely not in 6 states, conditional in remaining 2 states [8]. It has also been constructed in 96% of the cast-in-place reinforced concrete cross beams at the bridge with vehicle being passed down [9].

Also in accordance with the provisions of current AASHTO, the location percentage of placing intermediate cross beam is 50% in the middle of span, 30% in the three equally divided, 10% in the four equally divided supports. As mentioned above, in the United States the research of cross beam location and effect of load balancing has been actively studied, but there is no progress in the features of each types.

According to the Japanese Highway Bridge Design Code, cross beam is regulated to be installed in at least one point regardless of span length. Spacing interval should be less than 15m, and absolutely the cross beam must be installed in the center of span where the maximum moment occurs. In addition, according to the related regulations of Japanese bridge design code, diaphragm must be located essentially. But in case of cross beams, they should be arranged in the central point of span where the maximum moment occurs with optimal intervals, only if it is deemed necessary in designing.

III. Experimental Plan

In this study, variety of alternatives that can improve the load-carrying capacity, ensure stability in high altitude operation, and shorten the construction period were selected for the suitable cross beam system of prefabricated PSC T girder bridges. And static loading experiments were performed to evaluate the structural behavior of each type.

A. Experimental Overview

Standard testing methods for PSC girder cross beam have not established. Therefore in this study, prefabricated PSC T girder with cross beam and without any cross beam were compared relatively. The two T girders were connected through cross beam and deck. Loading experiments were performed with the lower part of each flange supports.

The standardized experimental method does not exist, but general cross beam performance experiment is configured to evaluate the shear and torsion control performance with eccentric load.

However in the research of prefabricated bridge currently being studied, curved and skewed bridge are not included, and with existing method its structural performance cannot be examined. In addition, the cross section of prefabricated bridge has been optimized to be smaller in width and thickness for unit cost and transportation. Therefore it seems to be vulnerable compared to beam bridge, static load were applied to the center for verifying the effect of cross beam on girder. And static loading experiments were performed to evaluate the structural behavior of each type.

B. Materials for Experiments

Designed compressive strength of concrete used in the specimen is 30Mpa. Compressive strength was separately tested with Ø100×200 size of mold according to concrete compressive strength test method (KS F 2405), and strength development was confirmed through the 28 day average value [10].

SM400 type was used for reinforcement. For the tendon, one strand of SWPC 7B with diameter of 15.2mm was used in accordance with regulation KS D 7002. And in all members, high tension bolt F10T M20 was used. L-beam is SM400 type respectively in size of 150x150x12 and 100x100x8.

Each test materials are shown in Table I.

C. Experimental Method

1. Experimental Variables

In this study, to evaluate the structural performance of cross beam suitable for prefabricated PSC T girder bridges, ST specimen without cross beam was set as comparison group, and all other specimens were classified into 6 experimental groups based on the shape and installation method.

3 groups were set based on the similarity of each cross beam type. The characteristics of each specimen and group was observed and analyzed simultaneously. Summary of each specimen characteristics are shown in Table II below.

TABLE I
Material Properties

Concrete	Design strength(MPa)		Compressive strength(MPa)	
	30		33	
Steel(SM400)	Yield strength(MPa)		Tensile strength(MPa)	
	more than 245		more than 400	
Prestressing Strand	Type	Nominal cross-sectional area(mm^2)	Tensile load (kN)	Ductility(%)
	SWPC 7B	138.7	more than 261	more than 3.5
Bolt	External Diameter(mm)	Design Tension(kN)	Allowable Shearing Force(kN)	Tension(kN)
	20	161.7	46.2	95.4
L Plate(SM400)	Nominal Size(mm)	Unit Weight(kg/m)	Nominal Size(mm)	Unit Weight(kg/m)
	100x100x8	12.1	150x150x12	27.3

TABLE II
TEST PARAMETER

Type	Diaphragm Connecting System	Group
ST	None of Diaphragm	Control Group
CD	Placed Diaphragm in Field	A
PD	Connecting Diaphragm with Prestressing	
SD	Steel Diaphragm Connecting with Bolt	B
WD	Steel Diaphragm Connecting with Weld	
LD1	Steel L plate Diaphragm Fixate at Web with Steel Bar	C
LD2	Steel L plate Diaphragm Fixate at Web with Bolt	

Group A is concrete wall typed cross beam with field concrete or steel strand to connect. Group B is steel plate typed cross beam with different way in connecting. Group C is L-beam typed cross beam purely bonded only through the assembly with different method of fixing on web.

In summary, group A is concrete cross beam need a lot of field work, group B is steel plate filled cross beam, and group C is prefabricated L-beam typed steel cross beam.

Detailed specifications of each variable crossbeam section and shape of girder are shown in Fig. 4, manufacture process in Fig. 5.

Group A, B, C have much a difference in workability. CD type of Group A has problems in process of casting in the field. Construction period will be delayed due to curing for the minimum strength. PD type of group A also needs grouting work and longer period of construction and disadvantageous in managing post tensioning or other complicated task in the field. In case of group B and C, work in the field is very simple such as bolting or welding and there are no negative factors in delay of construction period. In terms of workability, group B and C is excellent than A.

Due to the features of prefabricated bridges, the field work should be minimized, and it affect significantly in selecting the cross beam type.

2. Gauge Location and Loading

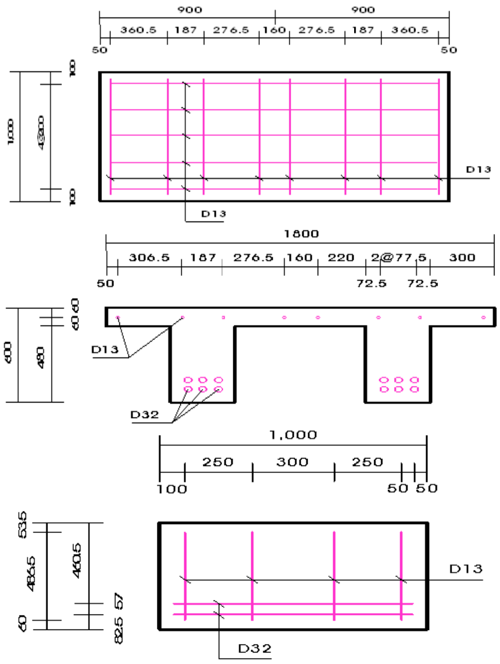
In accordance with the purpose of this study, Linear Variable Differential Transformer (LVDT) and strain gauge were placed as shown in Fig. 6 in order to identify the mechanical behavior of suitable cross beam system for prefabricated T girder bridge and the difference of behavior in each shape of specimen.

Steel gauge was installed to determine the behavior of rebar connection in flange and web. And concrete gauge was attached at three point, girder joint, flange-web connection and web to identify deformation at each point of specimen.

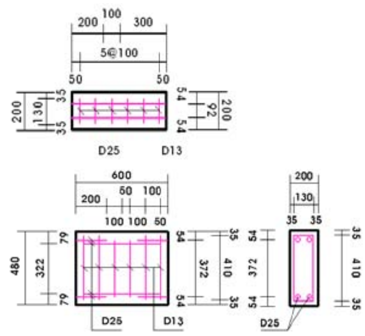
Furthermore, LVDT was attached at the center of girder joint to measure the deflection of T girder and crossbeam connected to girder.

After specimen produced and all measuring devices installed, loading test was performed [11].

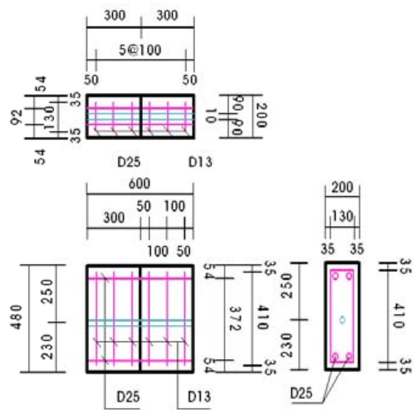
The load applied at 2 point in the central portion, and load data was monitored through the Load Cell.



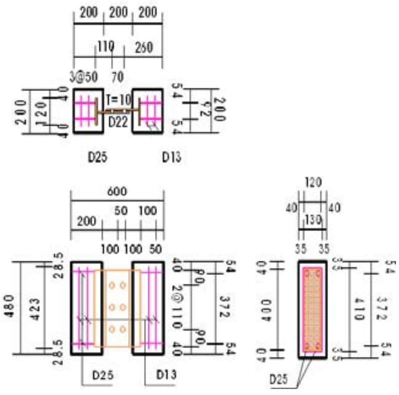
(a) ST type(Girder)



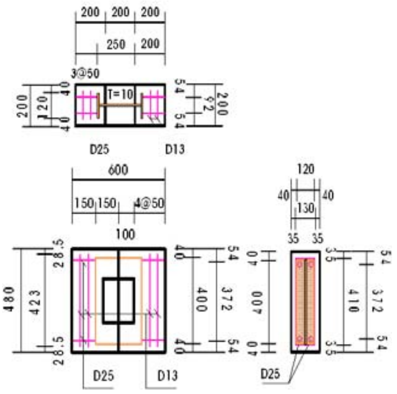
(b) CD type



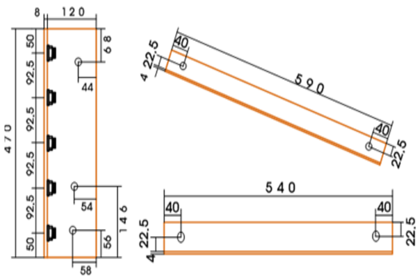
(c) PD type



(d) SD type



(e) WD type



(b) LD1, LD2 type

Fig. 4 Detail of Each Specimen

IV. Analysis of the Test Results

A. Load-Displacement of T Girder Connection (LVDT1)

Fig. 7 shows load-displacement curve measured in the center of each cross beam specimens through the static test.

The cracking load and maximum strength of each cross beam are summarized in Table III.

The cross beam and in-situ cross beam using strand in group A showed quadruple cracking load and three times maximum strength compared to the control group without cross beam. It is shown that the resistance to deflection increased due to the connection of upper flange and cross beam, and moved as a whole until destroyed.

(a) Installing Bar and Cast

(b) Placing Concrete

(c) Curing Concrete

(d) Connecting Segments

Fig. 5 Produce of Manufacturing Specimens

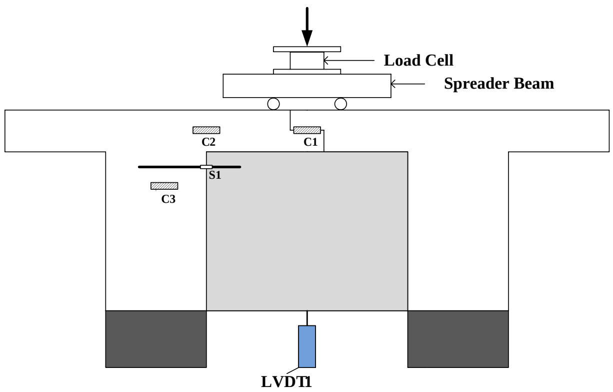


Fig. 6 Location of LVDT and Gauge, Loading

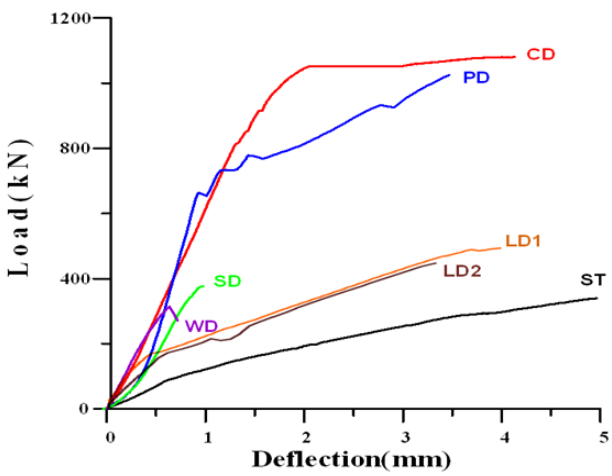


Fig. 7 Load-Deflection Curve at LVDT

And the two specimens of group C with L-beam showed greater cracking load and maximum strength of 30~50% compared to the specimens without cross beam, but about 50% compared to group A.

TABLE III
CRACKING LOAD AND MAXIMUM LOAD

Type	Cracking Load(kN)	Maximum Load(kN)
ST	150.9	339.6
CD	721.3	1080.4
PD	715.4	1025
SD	360.6	377.4
WD	284.2	314.3
LD1	470.8	540.7
LD2	220.4	457.6

Connected with the bolt and welded cross beam of group A showed a similar level of maximum strength but the cracking load doubled.

As shown in Fig. 8, the reasons for the similar maximum strength are considered to be the degree of unification between the cross beam and steel plate and crack occurred there.

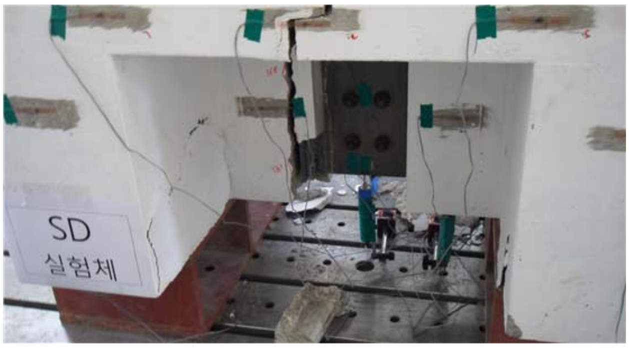


Fig. 8 Crack in SD Type

Since the maximum deflection was also measured when the specimen destroyed with a small deformation, the specimens should be retested after improving the method of bonding concrete and steel.

B. Concrete Strain

1. Concrete Strain in Front Flange Connections (C1)

Fig. 9 is the load-strain curve of point C1 located on the bottom of front center of upper flange as shown in Fig. 6.

It could be seen that only ST specimen with no cross beam of control group positioned in the compressive region, and all other groups in the tensile region.

The reason is considered that when the load is applied on the specimens with cross beam, the connection of upper flange was separated, and the upper flange played the role of cantilever and induced to tensile region [12].

Except in-situ cross beam (CD specimen), all cross beam types showed overall deformation.

Also in case of CD specimen, the load did not applied on the center and caused eccentric load with a tiny error in front. Understandably large deformation occurred relatively.

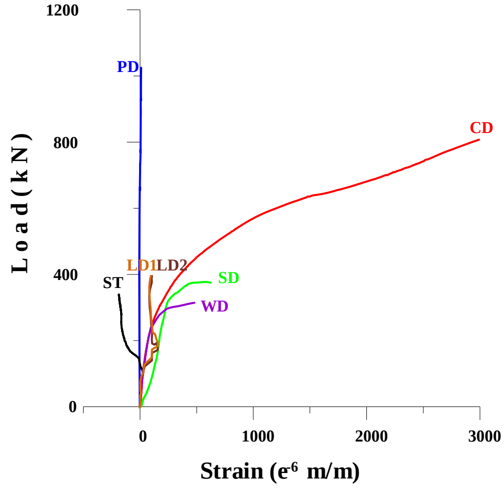


Fig. 9 Strain Curve at C1

2. Concrete Strain between Flange and Web (C2)

Fig. 10 is the load-strain curve at point C2, the intersection of the web and flange as shown in Fig. 6.

In case of control group which is with no cross beam, cracks occurred at the upper point of flange and girder joints, and large tension crack could be observed with the unaided eye and data as shown in Fig. 11.

On the other hand, in case of specimens with cross-beam, cracks occurred at cross beam as shown in Fig. 12, and it seems that the tensile force concentrated on the cross beam instead of girder.

Group A, B, C is good overall in strain. But there was a bolt pullout in LD2 specimen and the cross beam could not functioned properly that after 200kN, the behavior became similar to ST specimen.

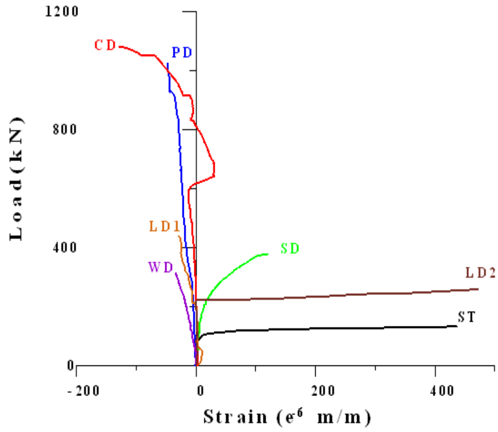


Fig. 10 Strain Curve at C2

Fig. 11 Crack in ST Type

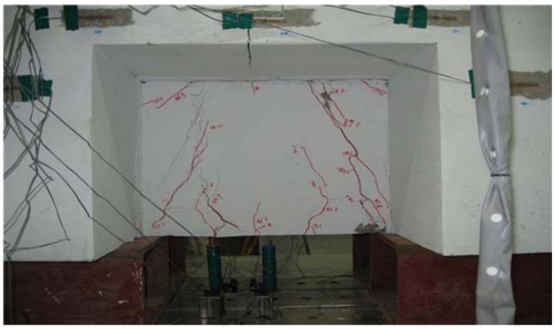


Fig. 12 Crack in SD Type

3. Concrete Strain on the Web

Fig. 13 is the load-strain curve at point C2 on the web.

All specimens positioned in the area of compression. But compared with ST specimen which is with no cross beam, all other specimens with cross beam showed relatively small compressive stress at web under same load condition.

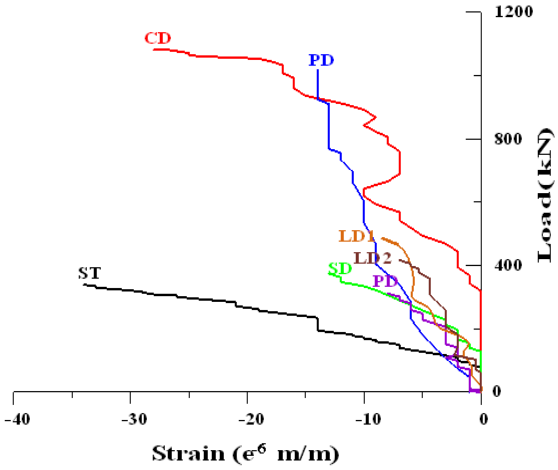


Fig. 13 Strain Curve at C3

Fig. 14 Crack in LD1 Type

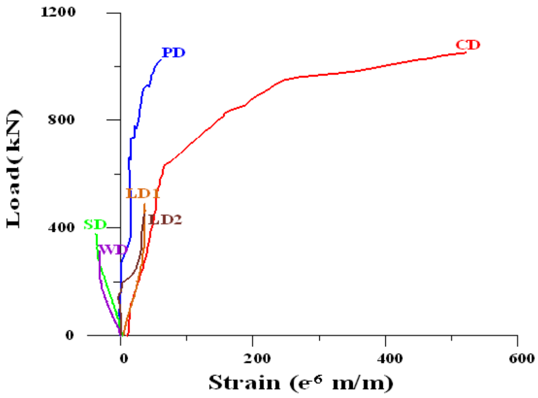


Fig. 15 Strain Curve at S1

As shown in Fig. 14, the crack did not occur in web mostly.

Through locating the cross beam to reduce compressive stress, it seems to be effective in a certain level of load distribution and enhancing stability.

C. Reinforced Strain

Fig. 15 is the reinforced load-strain curve at point S1, connecting area of cross beam and girder.

In group A and C, tensile stress occurred. And in group B, compressive stress occurred.

Overall, all types showed a low level of stress except CD specimen.

V. Conclusions

In this study, precast cross beam system appropriate to prefabricated modular T girder bridge has been proposed.

The experiments were conducted to clarify the role of cross beam and evaluate its structural performance.

Strand, bolting and welding was applied to connect cross beam on T girder.

Standard experimental method for cross beam applied to PSC girder have not been established, therefore structural experiments were conducted to compare in-situ specimen with cross beam and specimen without cross beam relatively.

The results obtained by limited experiments are as follows:

1) Specimens of group A (CD specimen), which is highly integrated when connecting T girders with each other in the field and prestressed specimen (PD specimen)

demonstrated the highest strength and approximately four times cracking load and three times maximum load compared with specimen without cross beam (ST specimen).

2) Specimens of group B, which are connected by bolting steel plates (SD specimen) and welded specimen (WD specimen) showed similar level in maximum load, but double cracking load compared with the specimen without cross beam (ST specimen) and small deflection. If the problem of connecting structural steel plate on concrete improved and verified, they will be applicable to cross beam system enough.
3) Compared to in-situ specimen (CD specimen), prestressed specimen (PD specimen) of group A showed similar level of cracking load and 95% in maximum load.
4) Specimens of group C, which are configured by connecting L-beam vertically and cross beam on web (LD1, LD2 specimen) showed similar behavior to specimens of Group A and B, and the value of cracking and maximum load were between them. Specimen with L-beam and steel bar (LD1 specimen) showed excellent adhesion ability than the specimen bolted (LD2 specimen).
5) Looking at the load-deformation curve at web, all specimens were positioned in compressive region. Under the same load condition, all specimens with cross beam showed lower level of compressive stress than the specimen without cross beam (ST specimen).

Therefore, the cross beam seems to resist to load subjected to girder partly.

As a result of this study, all specimens are considered to have effect of increase in strength from at least 1.5 times to four times in comparison with specimen without cross beam(ST specimen).Therefore cross beam which has less field works and enables fast installation should be selected under the condition of satisfying at least certain strength.

L-beam connected cross beam (LD1, LD2 specimen), which satisfy allowable strength and excellent in constructability are considered to be the optimal choices in modular bridge. But the steel plate bolted (LD2 specimen) and welded (WD specimen) also have a risk of bolt pullout. As a result, LD1 specimen seems to be the useful type.

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