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An Experimental Study on Development of the Connection System of Concrete Barriers Applicable to Modular Bridge

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***Abstract*—**Although many studies on the assembly technology of the bridge construction have dealt mostly with on the pier, girder or the deck of the bridge, studies on the prefabricated barrier have rarely been performed. For understanding structural characteristics and application of the concrete barrier in the modular bridge, which is an assembly of structure members, static loading test was performed. Structural performances as a road barrier of the three methods, conventional cast-in-place(ST), vertical bolt connection(BVC) and horizontal bolt connection(BHC) were evaluated and compared through the analyses of load-displacement curves, strain curves of the steel, concrete strain curves and the visual appearances of crack patterns. The vertical bolt connection(BVC) method demonstrated comparable performance as an alternative to conventional cast-in-place(ST) while providing all the advantages of prefabricated technology. Necessities for the future improvement in nuts enforcement as well as legal standard and regulation are also addressed.

***Keywords*—**Modular Bridge, Concrete Barrier, Bolt Connection

I. Introduction

PRECAST modular bridge has been studied actively recently for an alternative of environmental reasons like scattering dust, assurance of quality in winter, and economic cost caused by ineluctable traffic control during the construction or repairing deteriorated bridge. However prefabricated precast bridge has being built by segmental construction method in foreign countries along with research and construction in Korea, most studies are limited on piers, girders and decks not on facilities like median or roadside barriers of the bridge. In case of Korea, there was a research of precast concrete barrier with loop joint at Daewoo Institute of Construction Technology by Jeon Se Jin[1]-[2], but in terms of semi-permanent use, it's hard to replace when it needs to be repaired or reinforced and undergo for curing time of non-shrink mortar. So the bolted joint proposed in this study seems to be more efficient.

Although precast median barriers were applied by FHWA(Federal Highway Administration, United States) in foreign cases, the system with connection and assembling is not a case of feasible barriers on the bridge roadside.[3]

Domestic barriers are constructed by wall forms or slipform machine. But with wall forms, schedule delays due to its procedure installing and stripping. Using the slipform machine is inconvenient in controlling on the bridge deck.

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Also, these cast-in-place methods are not good in constructability when an unexpected crack occurs or concrete collapses.

Fig. 1 Slipform Machine

Fig. 2 Crack in Barrier

Fig. 3 Barrier Repair

In situations precast prefabricated bridges (Modular Bridge) are being actively investigated in the study of how to use recently, installing the barrier with wall forms or using Slipform machine has many demerits like maintenance costs when it needs some repair and construction delays associated with the problems as stated above. In addition to considering the connection with other members, it seems to be impossible to apply on the prefabricated bridges. Considering that one of the advantages of prefabricated bridges is its easy replacement, cast-in-place barriers are impossible to remove. Thus, the research on how to connect the girders to concrete barriers applicable to prefabricated bridges is needed. In this paper, a prefabricated concrete barrier was discussed and approached the connection systems by experimental methods. Recently in Korea, the volume of traffic increased from a surge in demand for automobiles and population growth. Vehicles are larger, heavier and faster than before, per accident casualties and property damage has increased despite the slowdown in the incidence of road traffic accidents.

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As a result, these socio-economic problems are emerging. Purposed to prevent car accidents on general bridge, offshore bridge, and long span bridge recently being built, the importance of the roadside barriers is on the rise. For example, there was a fall accident that bus crashed under 10 meters from Incheon Bridge in 2010. This shows road safety facilities are absolutely important in the lives of motorist and passengers. Also, incorrectly installed facilities cause economic loss in some cases. To reflect this trend, the section of safety barrier's has been expanded along with the strengthened design grade. Road safety facilities regulated by third amendment of 'the Road Rules' and thirty seventh of 'the Rules of Road Facilities and Standard' are features that are installed to ensure smooth traffic flow and supplement insufficient road infrastructure to enhance the service level. In particular, the roadside safety features like median barriers, bridge barriers, roadside barriers and shock absorbers etc. are the facilities in order to prevent fatal traffic accident by demonstrating a fully functional. As described above, the study of prefabricated bridges is limited to girder and deck. The research and development of barriers applicable to prefabricated bridges by structural verification of performance is deemed necessary. Therefore, a bolt-jointed system between concrete barriers and decks applicable to prefabricated bridges was developed in this paper, and tested specimens with similar one being used on to verify the structural performance of its connection system. Static load experiments were performed to analyze the behavior of the joint under concentrated loadings.

II. The Regulations of Installing Bridge Barriers

In general, safety barriers are installed for road safety facilities to prevent vehicles or pedestrians on the road get out of the course or opposing the lane. Especially on the bridge, the bridge safety barriers are set up to function equally to prevent vehicles driven out of its course, sidewalk and fall outside the bridge.

In Korea, New Jersey-typed rigid concrete barriers with height of 810mm from the top of the road used mainly. But recently, F-typed rigid concrete barriers adjusted to height of 1,000mm are being used to enhance the protection capability against heavy vehicles with elevated center of gravity.

Domestic installing regulations are shown in Table I only with the barrier's shape according to each grade[5]. In field, barriers are molded within the barrier-shaped rebar cage when girders are constructed.

III. Experimental Program

In this study, two types of alternative splicing with horizontal and vertical bolt were set up for experiments to compare with the existing integral barriers to develop the bonding methods suitable for concrete barriers on prefabricated bridges.

A. Test Materials

Specimens are of ready-mixed concrete with designed strength of 24Mpa and 30Mpa, reinforced steel bars with yield strength of 300Mpa. High-tensile bolts (F10 M25) were used to connect the barriers to the deck.

TABLE I
Level Of Barrier In Korea

Classification	Index of Impact Severity (kJ)	Type of Design Speed						
		Low Speed(Under Designed 60km/h)	Normal Speed(60km/h to 80km/h, Arterial Road)			High Speed(Over 100km/h, Highway)		
			Standard Section	Bridges, Sections with Median	Interchange, Heavy Vehicles	Standard Section	Bridges, Sections with Median	Interchange, Heavy Vehicles
SB1	60	◎						
SB2	90	○	◎					
SB3	130		○			◎		
SB4	160			◎		○		
SB5	230			○	◎		◎	
SB6	420				○		○	◎
SB7	600							○

◎ : Highly Recommended

○ : Recommended

1. Concrete

Compressive strength of ready-mixed concrete used in the experiment is 24Mpa in barriers and 30Mpa in decks. When casting, cylindrical specimens was made within size of Φ100×200mm separately, and tested 28 days compressive strength shown in Table. II.

TABLE II
RESULT OF COMPRESSIVE STRENGTH

Type	Compressive Strength of Concrete Cylinders(MPa)			Averages (MPa)
Deck (30MPa)	32.1	30.0	36.8	33.0
Barrier (24MPa)	20.9	20.4	20.1	20.5

TABLE III
PROPERTIES OF STEEL

Classification	Diameter (mm)	Cross-sectional Area(mm^2)	Tensile Strength(MPa)	Yield Strength(MPa)
SD30	12.7	126.7	More than 440	More than 300

TABLE IV
PROPERTIES OF BOLT

Classification	Cross-sectional Area(mm^2)	Tensile Strength(MPa)	Yield Strength(MPa)
F10T M25	352.5	1,000~1,200	Over 900

1. Reinforcement

SD30 deformed bars specified in KSD 3504D were used. Material properties are shown in Table. 3. D19 was used in decks for tensile and compressive reinforcement. D16 and D13 were used each for transverse reinforcement and concrete barrier.

2. High-tensile Bolts

In this experiment, high-tensile bolts(F10T M25) were used. Each characteristics and size are shown in Table. 4.

B. Variables in the Experiment and Specimen Shape

1. Variables

Variables of this static experiment are the connection type between deck and barrier shown in Table. 5. Three specimens were produced, integral specimen already used in service by cast-in-place(ST), vertically bolted specimen(BVC) and horizontally bolted specimen(BHC). The quantity of specimen produced and bolt are also shown in Table. 5.

TABLE V
PROPERTIES OF BOLT

Experiment Model	Parameter	Number of Specimen	Number of Bolt	Remarks
ST	-	1	0	Cast-in-Place
BVC	Vertical Bolt Connection	2	4	Precast
BHC	Horizontal Bolt Connection	2	4	

To determine the applicability of prefabricated bridges, nuts were placed inside instead of using anchors. Shape of the nut is shown in Fig. 4. And spiral reinforcement was used to prevent the local failure around bolts after loaded as shown in Fig. 5.

Fig. 4 Shape of the Nut

Fig. 5 Shape of the Spiral Bar

2. Specimen Shape and Fabrication

Specimens were made through a series of process shown in Fig. 6. Each connection types are shown in Fig. 7.

In case of ST specimen, after casting the deck, reinforcements of deck and barrier were assembled before placing the barriers. On the other hand, BVC and BHC specimen were made on the deck after assembling the reinforcements by match-casting method placing with forms.

1. Installing Bar

2. Installing Cast and Placing on Concrete Deck

3. Installing Cast and Placing Concrete in Barrier

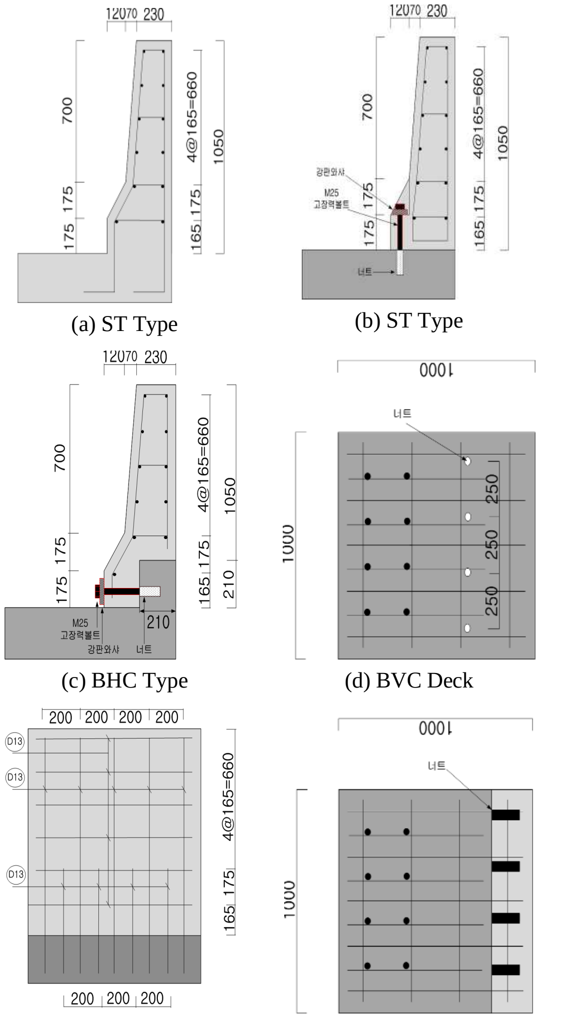
4. Connecting Barrier to the Deck

Fig. 6 Procedure of Building Specimen

C. Placing Load and Measurement

1. Placing Load

Collision patterns of barriers under static load in experiment are similar to vehicle crash. According to the Design Code of Highway Bridge in Korea (2005), uniformly distributed load of a certain height has suggested when calculating the horizontal collision force. But it is for use in designing the deck only. AASHTO LRFD Bridge Design Specification (2007) suggested load types and collision loads in detail, but this experiment is of the performance at each connection system not of the structure. The specimen is made in unit length, 1 meter. Concentrated load, not uniformly distributed, was loaded in accordance with AASHTO at the height of 810mm by actuator using displacement controlled system of 1mm per minute until destruction. To get accurate load data, Load Cells were installed. The loading system of specimen is shown in Fig. 8.



(a) ST Type (b) ST Type (c) BHC Type (d) BVC Deck (e) Steel detail of specimen (f) BHC Deck

Fig. 7 Detail of Each Specimen

Fig. 8 Shape of the Actuator

2. Measurement

With the purpose of this study to identify and analyze concrete barrier suitable for prefabricated bridges, several gauges and LVDTs were installed.

At each specimen, steel gauges are attached to identify the strain before concrete cast, and concrete gauges before the beginning of experiment. Location of each measuring instruments are shown in Fig. 9, and uses in Table. 6. Vertical and horizontal LVDTs were installed to measure lateral displacement of concrete barrier and girder deflection after integrated to decks, as shown in Fig. 10.

IV. Analysis of Experimental Results

As a result of comparing the capacity of two joint type by impact calculation formula of AASHTO, vertical joint satisfied with 161% while horizontal did not with 93%.

The following formulas are for impact calculation based on the AASHTO code.

$$R_w = \left(\frac{2}{2L_c - L_t}\right) \times \left(8M_b + 8M_w + \frac{M_c L_c}{H}\right)$$

R_w : Resist performance of concrete barrier

H : Height of concrete barrier

L_c : Destruction length of concrete barrier

L_t : Length of impact load

M_b : Resist moment on the upside of concrete barrier based on behavior of beam

M_w : Resist moment of unit height of rigid barrier

M_c : Resist moment of unit length based on behavior of cantilever between rigid barrier and deck

For more detailed analysis of experiment results, load-displacement, steel strain, concrete strain and crack patterns were examined in this chapter.

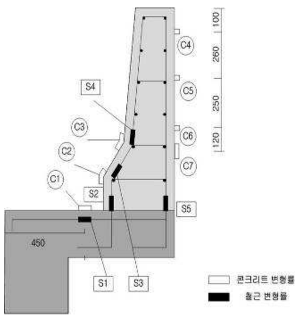


Fig. 9 Location of Strain Gauges

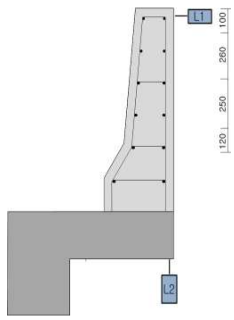


Fig. 10 Location of LVDTs

TABLE VI
MEASURING INSTRUMENTS

ID	Measuring Instrument	Purpose
L1	LVDT	Measuring Lateral Displacement of Load-Direction
L2	LVDT	Measuring Vertical Displacement of the Deck
S1	Steel Strain Gauge	Measuring Strain of the Main Reinforced Bar

S4	Steel Strain Gauge	Measuring Vertical Steel Strain at the Front of Barrier
C1	Steel Strain Gauge	Measuring Strain at the Top of Deck
C4	Concrete Strain Gauge	Measuring Vertical Strain at the Back of Barrier
C7	Concrete Strain Gauge	Measuring Horizontal Strain at the Back of Barrier

A. Load-Displacement Curve

1. Lateral Displacement of Barrier(L1, Fig. 10)

Loading has been taken under displacement control of 1mm per minute. As shown in Fig. 11, load-displacement curve is drawn from the value of measured displacement on the central upper part of the barrier. Experimentally measured cracking load and ultimate strength for each specimen are shown in Table. 7.

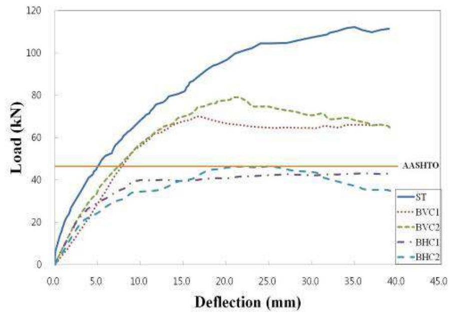


Fig. 11 Load-Deflection Curve at LVDT1

TABLE VII
CRACKING AND MAXIMUM LOAD

Type	Cracking Load(kN)	Maximum Load(kN)
ST	41.6	94.33
BVC-1	46.0	71.0
BVC-2	33.2	79.2
BHC-1	20.6	40.0
BHC-2	19.9	46.7

Demonstrated strength of BVC specimen #1, #2 was approximately 75~85%, BHC #1, #2 approximately 42~50%, compared with integral ST specimen. It seems to be attributed due to the different load resistance of each section at BHC and BVC specimen. In case of BHC specimens, the bolts were pulled out due to the horizontal direction of loading, and it led to separation from the deck since the loads were concentrated on the bolts. As shown in Fig. 11, large changes of displacement were observed in a relatively small load. On the other hand, BVC specimens resisted at right angles to the direction of the load. Compared to BHC specimens, BVC specimens had significantly superior capacity and small displacement by the resistance of concrete and bolts together. As a result of lateral displacement experiment which can represent the broken condition by the impact, horizontally jointed BHC specimen is unreasonable to apply to prefabricated bridges. But vertically jointed BVC specimen is considered to be applicable to prefabricated bridges. In addition, the strength calculated in accordance with AASHTO was 46.5kN. The average of the vertically jointed specimen was 75kN in excess of 61%, and horizontally jointed one 43.35kN under 7%.

2. Vertical Displacement of the Deck(L2, Fig. 10)

The maximum moment occurs on the interface of the deck and barrier after loading. These loads are delivered through the deck to cause vertical displacement. Fig. 12 shows the vertical displacement of the deck. It is similar to the result of lateral displacement measured from the barrier. Compared with BVC and ST specimen, load-displacement relation is nearly identical enough to judge the barrier of BVC specimen integrated with the deck.

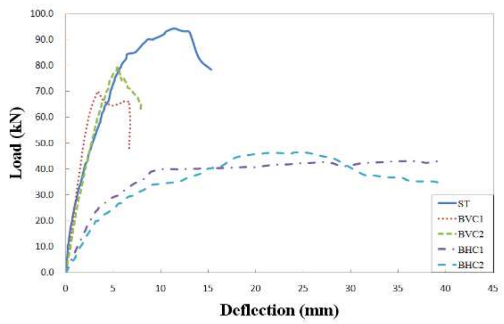


Fig. 12 Load-Deflection Curve at LVDT2

B. Strain Curve of Steel

1. Steel Strain between the Deck and Girder(S1, Fig. 9)

When designing the deck, the forces acting on barriers must be considered because of the deformation on the reinforced steel. Fig. 13 shows the strain of the reinforcement at S1 for each specimen. In case of BHC specimen, the load did not deliver to the deck since the distance of interface increased. Similar to the load-displacement results as mentioned earlier, the most loads were resisted by the bolts.

2. Reinforced Strain in Barrier(S4, Fig. 9)

Fig. 14 shows the reinforced strain at tapered, the place of the initial crack occurred. It shows that the strain is increasing rapidly after cracking. While ST specimen strain increased continuously, BVC and BHC specimen did not deformed consistently. Because some load has transferred to the bolts after the initial crack occurred.

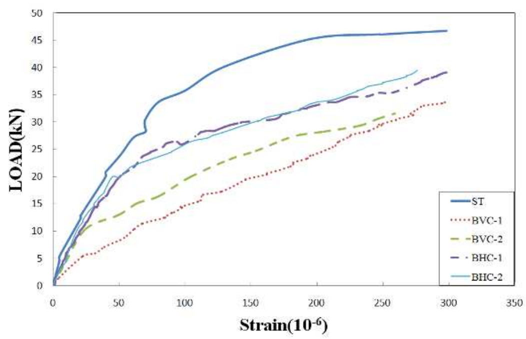


Fig. 13 Strain Curve S1

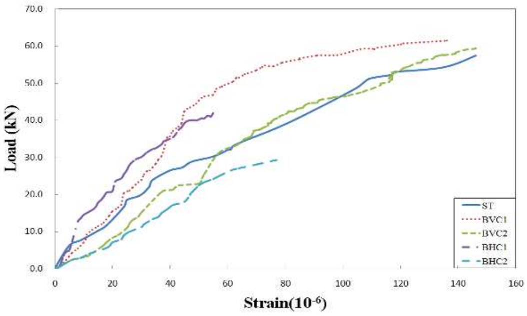


Fig. 14 Strain Curve S4

C. Concrete Strain Curve

1. Strain of Tapered in Barrier(C3, Fig. 9)

As shown in Fig. 15, the load-strain curve is extracted from the concrete gauge located at C3 on tapered of barrier. This is the position with the most significant cracks and tensile strain. Whereas concrete and reinforcement in integrally typed ST and vertically jointed BVC specimen showed integral behavior with a small strain, horizontally jointed BHC specimen showed a large strain as the load increase due to the separation on the interface.

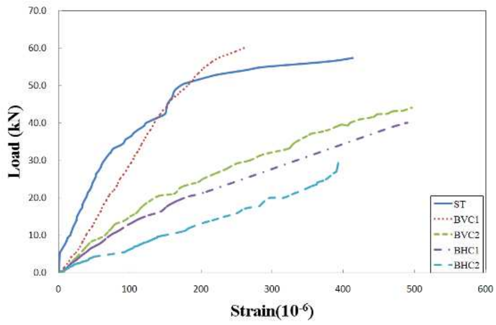


Fig. 15 Strain Curve C3

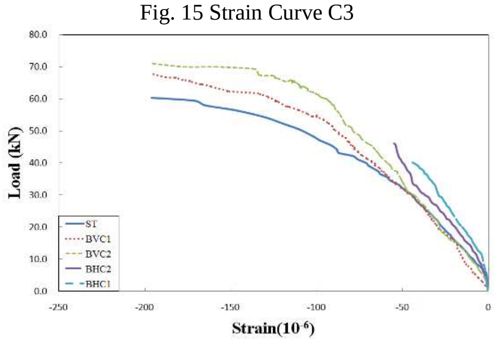


Fig. 16 Strain Curve C7

2. Concrete strain in rear side of barrier (C7, Fig. 9)

Fig. 16 shows load-strain curve at the compression point on the rear side of barrier, the point with the largest compressive strain. In comparison with ST specimen, BVC and BHC showed a very small strain due to pulled-out bolts on interface as the force increases. It caused the concrete barrier to be separated. The rear side concrete was not affected on compression dissimilar to the ST specimen.

D. Crack Patterns

The final crack pattern of static test on concrete barriers was shown in the figure below. As shown in Fig. 17, the ST and BVC specimen showed very similar crack patterns and process. The initial cracks occurred from the end of barriers to the decks vertically. As the load increases, bending and shear cracks began on tapered of the barrier. As the maximum load is reached, the displacement and crack width increased. And vertical cracks began to appear around the bolts that secured the deck. In the case of BHC specimen, the initial cracks were similar at the deck. As the load increase, the separation occurred on interface. And the distance continued to increase up to reach the maximum load. It was unable to detect the crack on barrier. As the distance increase, vertical cracks occurred at the barrier and end of the deck. Without any increase of load over time, the crack width increased continuously.

(a) ST Specimen

(b) BVC Specimen

(b) BHC Specimen

Fig. 17 Crack pattern of specimen

(a) BVC Specimen (b) BHC Specimen

Fig. 18 Crack pattern of Interface

BHC and BVC specimen were separated from each other to look at the crack of interface between the deck and barrier. As a result, the nuts placed before casting were pulled out and a large crack was found around. It can be found at Fig. 18.

V. CONCLUSION

In this study, connection system using bolts on concrete barrier applicable to prefabricated bridges was proposed. Static tests were performed for evaluating the structural performance of connection system. With variables of connection type, vertical and horizontal bolts, cast-in-place concrete barrier and prefabricated barrier were made to derive the relative comparison experiments.

The main conclusion drawn from the experiments are as follows.

1. The vertically bolted(BVC) demonstrated the strength of approximately 75~85% of the cast-in-place(ST), as of an impact calculation expressed as AASHTO code. It deems to be enough to compensate the gaps, as an alternative to cast-in-place(ST), considering all the benefits of prefabricated barriers, such as labor-saving, reducing construction period, etc.
2. The horizontally bolted(BHC) found to be not sufficient as a joint method of the prefabricated barriers for preventing road traffic accidents such as run-off-road collision, etc.
3. Visual evaluation of the concrete crack patterns showed some significant cracks around the nuts, although there was no pull-out of the nuts, which indicate the necessity of additional reinforcement around to lessen such a local destruction.
4. In terms of the performance of the prefabricated barriers, it is suggested to raise the legal standards and regulations. It is considered that there is some room for improvement in the performance of vertically bolted(BVC) through the further studies of the figuration and deformation of the nuts.

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