THE STATE OF THE ART OF BRIDGE DECK DEVELOPMENT IN KOREA

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Abastract
Requirements for improved durability, reduced maintenance costs, and accelerated construction in urban areas are being stressed according to the rapid industrialization and urbanization. To meet social demand on reducing construction and maintenance cost, R&D on the innovative bridge decks have been actively conducted since late 1990s in Korea. This paper adresses the status of bridge deck technology in Korea, and ecsepcially focuses on technical trends of recently developed deck systems. In addition, moving wheel load equipment and research on long-span PSC slab for steel composite two-girder bridge are overviewed.

1. Introduction

Bridge deck, as a member receiving directly traffic loading, subjected to environmental attacks and crossing of heavy traffic loads is by means the element presenting the largest damage potentiality among the major structural members. Recently, the growth of economy scale in Korea according to the industrial development increased the volume of the bridge construction and the traffic exponentially together with the large augmentation of heavy vehicles. The bridge stock in Korea is constituted currently, as of December 31, 2005, by 22,871 bridges developing a total length of 1,987 km.[1] Following, requirements for improved durability, reduced maintenance costs, and accelerated construction in urban areas are being stressed according to the rapid industrialization and urbanization. To meet these social demands on reducing construction and maintenance cost, R&D on the innovative bridge decks have been actively conducted since late 1990s in Korea. This paper addresses the status of bridge deck technology in Korea, and especially focuses on technical trends of recently developed deck systems.

Researches on bridge decks started effectively in the late of 1990s, essentially under the initiative of the government. Researches on precast decks focused mainly on the connection and continuation method. In the case of steel-concrete composite bridge decks, diversified types have been considered of which the most recent one is steel-concrete composite deck with profiled sheeting. For decks adopting innovative material that is FRP, FRP deck and FRP-concrete composite deck have been developed. Particularly, the Delta Deck is the first FRP deck that has been successfully commercialized with a trial application in 2001 followed by 8 applications in new bridges or bridges to be built. On the other hand, researches on long-span decks rise as an absolute prerequisite for the development of rational as well as economically efficient few-girder bridges. In this optic, "Bridge 200" is a comprehensive research project of KICT extending for a period of 5 years (2002~2006), which constitutes a forefront R&D project for the development of bridge deck in Korea. The program intends to secure bridge technologies that extend the lifespan of bridge to 200 years if necessary. To that goal, 5 key technologies required for lifespan extension of bridge structures have been selected. Among 5 key technologies, "Development of Long-Life Deck Systems for Bridges" project intends to extend by more than 100% the actual lifespan of bridge decks by developing various new types of decks to replace former cast-in-place RC concrete decks. The decks to be developed are "precast deck", "steel-concrete composite deck", "FRP-concrete composite deck" and "FRP deck". By selecting the adequate deck according to the climate and traffic conditions on field, decks with extended lifespan considering economical efficiency can be realized and significant reduction of national budget can be achieved. In addition, moving wheel load equipment sponsored by the project has been also introduced. The equipment is a first one in Korea and it is expected to verify fatigue performance of bridge deck.

This paper addresses the status of bridge deck technology in Korea. First, the paper reviews technical trends of recently developed deck systems in Korea: precast deck, steel-composite deck, FRP deck, and FRP-concrete composite deck. In addition, moving wheel load equipment, which is installed in 2003, is briefly introduced. Research on long-span PSC slab for steel composite two-girder bridge is also reviewed.

2. Precast Deck

The research on the behavior of precast concrete bridge deck and connections led in 1996 by Daewoo Engineering & Construction Co. derived the structural characteristics of these components through a survey of construction achievements. This research was followed and completed by a research performed from 1997 to 1999 jointly by Seoul National University, Daewoo Engineering & Construction Co., and Korea Highway Corporation aiming the practicability of precast concrete decks. This project resulted in the construction of a composite bridge using precast deck with longitudinal prestress and without construction joints in the Jungbu Inland Expressway located in the test road of the Korea Highway Corporation. However, the applicability of the precast deck developed through this project remains limited for simple bridge. Thereafter, a joint research performed by Seoul National University, Daewoo Engineering & Construction Co., and Korea Highway Corporation from 2000 to 2001 achieved the continuation of precast deck, which enables the previously precast deck developed for simple bridge to be applied on continuous bridge. Moreover, a project on the continuation of precast deck conducted jointly by Posco Engineering & Construction Co., KICT and COWI Korea from 2003 to 2005 extended the applicability of precast deck to steel composite continuous bridge. The special features of this deck are the selection of loop joint method for the joint of basic connections and the installation of internal steel wires at the supports developing negative moments, which made it possible to realize continuation.

On the other hand, KICT is developing a precast deck improving the joint between decks through increase of the section and steel bar connection, as a topic involved in "Bridge 200" project. [2)] Static and fatigue tests of the girder joint model and, static, fatigue and wheel loading tests of a continuous bridge prototype were conducted from 2002 to 2006 (Photo 1), and verified that durability to fatigue and resistance to loading are secured.

Apart from these projects, Seoul National University of Technology performed recently researches on LB-DECK technology applying lattice bar and precast concrete deck using light weight concrete.

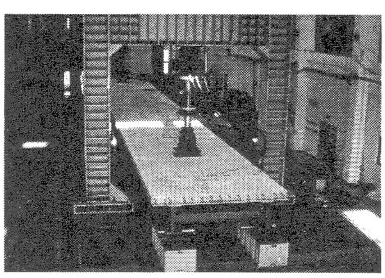


Photo 1: Full scaled test of precast deck (KICT, 2004)

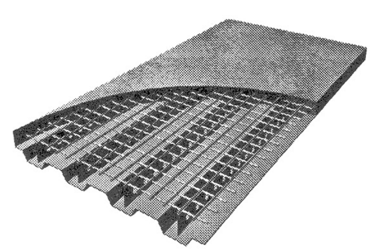


Figure 1: Steel-concrete composite deck with profiled steel sheeting

3. Steel-Concrete Composite Deck

Researches on steel-concrete composite deck started in the late of 1990s in Korea. Kyungnam University conducted a research in 1997 on Robinson-type composite decks composed of concrete and bottom steel plate. In 1999, Hyundai Engineering & Construction and Chung-Ang University performed a research on the effects of the shape of the hole perforated in I-girder for the composition with concrete and welding method on the behavior and performances of embedded I-girder decks. Chung-Ang University and KICT performed a similar research, in which the hollow embedded I-girder deck is introduced in order to reduce self weight. In 2000, the Korea Highway Corporation and the Korea Railroad Research Institute carried out a study on the optimal deck shape and applicability of I-girder lattice decks for the bridges of light rail transit.

Steel-concrete composite deck with profiled steel sheeting was developed through a project involved in "Bridge 200" of KICT(Figure 1). [2] The proposed deck system is composed of profiled sheeting that is perpendicular to the steel girder with perfobond rib shear connectors welded to the sheeting. The main objective of this study is to develop a long span composite deck for steel-girder bridges that weighs less than the typically designed CIP RC deck. To accomplish the objective of this study, a high strength composite deck profile was proposed and designed for a prototype two-cell steel-box girder bridge.

4. FRP Deck

Kookmin Composite Infrastructure (KCI) Ltd. and KICT developed jointly the Delta Deck from 2001 to 2004 (Figure 2). [3] The Delta Deck is the first FRP dck that has been successfully commercialized with a trial application in 2001 followed by 8 applications in new bridges or bridges to be built (Table 1, Photo2). Among them, the largest application in the world is previewed for Nulcha Bridge with a length of 300 m of which construction is expected to begin in 2006. Recently, KCI developed the snap-fit FRP deck enhancing the constructability of such deck. This deck is composed by prefabricated precast panels obtained by pultrusion, which are assembled on field through precast snap-fit-type mechanical. These panels can be disassembled and reused.

Table 1: FRP Decks in Korea

Bridge designation	Location	Completion year	Length (m)	Width (m)	Remarks
Beoncheon	Jungbu expressway	2001.4	8	4	Steel plate girder
Hyeongju	Gyeonbu expressway	2002.12	11	4.3	Steel plate girder
Biwoodang	Cheonggye stream, Seoul	2004.6	44.5	9	Steel plate girder
Gaejeong	Jangsu District, Province of Jeonbuk	2005.3	25	11	Steel plate girder
Access bridge of Gwangyang Harbor	Gwangyang Harbor	2004.11	150	10.9	Steel plate girder
Access bridge of Pyungtaek Harbor	Pyungtaek Harbor	2005.4	70.14	11.9	PSC girder
Malmoo	Busan	Late of 2006 *	120	30	Steel box girder
Nulcha	Busan	Early of 2006 *	300	35	RC girder

* Expected construction start

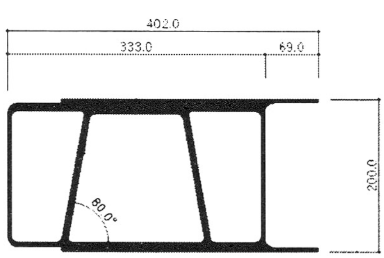


Figure 2: Delta Deck

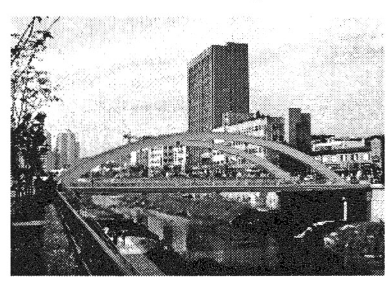


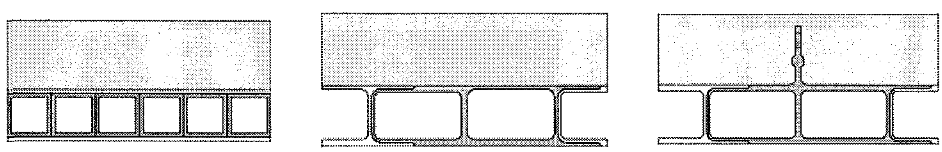
Photo 2: Biwoodang Bridge

On the other hand, a complete FRP composite bridge has been constructed in 2002 on the provincial road of Yeongweol in the Province of Gyunbuk using hand-layup method according to the research performed jointly by Daewon Science College, Sungwon Construction Co. Ltd. and WonChang Entec Co. Ltd. The bridge is actually under operation. In addition, the development of the Korean-type FRP deck is currently conducted as part of the "BRIDGE 200" project of KICT.

5. FRP-Concrete Composite Deck

The innovative FRP-concrete composite decks, so as to take selectively advantages of the merits of FRP and concrete, are developed under the "BRIDGE 200" project (2002~2006) of KICT, and conducted through a project of the HiperConmat Research Center (2005~2010). [2] FRP-concrete composite decks are manufactured by pouring concrete on GFRP panels fabricated through pultrusion and present a structure where FRP takes charge of the tension and concrete takes charge of the compression. Its section has been improved by means of diversified analyses and tests and, the development of relevant precast and concrete pouring methods is under plan.

Figure 1 depicts the evolution of the sectional shapes of the FRP module constituting the FRP-concrete composite deck developed by KICT by means of diversified analyses and tests. The original module of 2003 was made by attaching the FRP tubes and FRP plates available for sale. To ensure composite action, coar se sand coating is applied to the interface between concrete and FRP. The test results confirmed that the propos ed FRP-concrete composite deck is applicable to actual construction. However, undesirable failure mode occurred at the interface between FRP and FRP. The model 2004 was introduced the pultruded GFRP section similarly to pure FRP deck. Static test results revealed that the obtained section developed sufficient stiffness and strength. Ho wever, the model was seen to be vulnerable to fatigue. Finally, the model 2005 was conceived to overcome this shortcoming by fabricating the shear connecting plates and FRP module as a monolithic section. For the model 2005, failure did not occur after 2 million wheel loading cycles. Complementary fatigue tests and trial construct ions are under plan as well as the development of relevant precast and concrete pouring methods.



(a) Model 2003 (b) Model 2004 (c) Model 2005

Figure 3: Evolution of the FRP-concrete composite deck models developed by KICT

6. Long-span Bridge Deck for Steel Composite Two-girder Bridge

Recently, steel composite few-girder bridge using PSC slab is receiving attention regard to the rationalization of steel composite girder bridges. The current Korean Highway Bridge Design (KHBD) code (Ministry of Construction and Transportation, 2005) is only giving mention of such long-span bridge deck without proposing any new design method. Moreover, since the deck span corresponding to the design bending moment is limited to 7.3m, the current Code is inadequate for long-span decks. Following, researches on long-span decks rise as an absolute prerequisite for the development of rational as well as economically efficient few-girder bridges. In addition, examination and supplementation related to the design method of decks are also necessary for the practicability of long-span bridge decks.

KICT performed researches on the design moment and minimum thickness of long-span slab for steel composite two-girder bridge from 2003 to 2005. [4] These researches derived the minimum thickness of long-span deck considering the design moment formula, ultimate strength, fatigue strength and serviceability, and improved the punching and fatigue strength formula of PSC decks. These results are expected to be exploited for the revision or proposal of new specifications relative to long-span bridge decks in the KHBD code. In addition, this study performed fatigue test on 1/3 scaled PSC slab models under realistic moving wheel load (Photo 3). The result revealed that the PSC slab develops enough fatigue capacity compared to the requirement of the KHBD code. And, a fatigue strength formula for the PSC slab was proposed (Figure 4).

Photo 3: Bottom surface of PSC deck after moving wheel load test

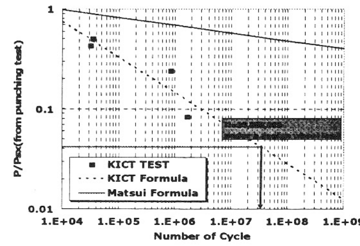


Figure 4: S-N curve for PSC deck

On the other hand, the design moment in the cantilever of long-span slab is also studied by Dankuk University through a project of the Korea Bridge Design & Engineering Research Center.

7. Moving Wheel Load Equipment

Moving wheel load laboratory and testing device sponsored by “Bridge 200” is constructed in 2003 in order to evaluate exactly the corresponding fatigue performance.[5)] The laboratory is located at KICT. The installed device is a crank-type equipment using fly wheel(Photo 4). The maximum dimensions of the deck or beam specimen are width 12.0m × length 6.0m × thickness 0.5m. The type of vehicle wheel load directly applied is a steel wheel mounted by default, but can be replaced by rubber tires or a specially manufactured loading device according to the specificity of the test. The transport of the specimens is done by a wagon (length 12 × width 6 × height 1.3m) installed on the test bed, which eases the setting and transport of the specimen from outside(Photo 5). Table 2 summarizes its characteristics. Up to date, FRP-concrete composite deck, FRP deck, precast deck and PSC deck studied in KICT have been tested in this test machine.

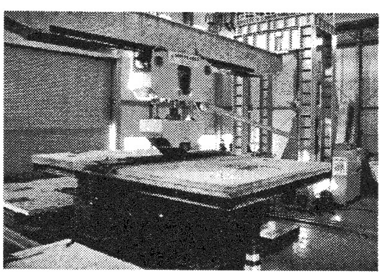


Photo 4: Moving wheel load equipment

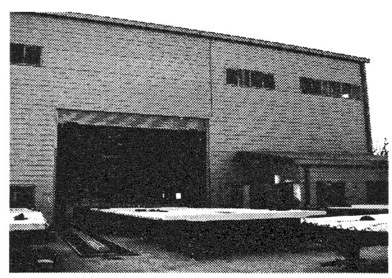


Photo 5: Wagon and rails extending outside the building

8. Concluding Remark

Recent development and research on brigde deck in Korea have been addressed. It has been seen that researches are conducted to develop decks exhibiting improved performances and, this trend is likely to continue actively in the future. Especially, it can be forecast that the development of more economic and efficient decks with life-cycle cost perspective will become the major domain of research rather than the initial construction cost. In such perspective, researches on the exploitation of innovative materials like high performance concrete or FRP will and should also be continuously implemented. It is expected that the wheel load testing equipment will play an important role for the verification of the long-term fatigue performance of the developed bridge decks.

Table 2: Characteristics of the wheel load testing equipment

<table>
<tr><th colspan="3">Item</th><th colspan="2">Characteristics</th></tr>
<tr><td colspan="2" rowspan="7">Shape and dimensions</td><td rowspan="2">Dimensions of equipment</td><td>Frame</td><td>Height 7m × Length 10m</td></tr>
<tr><td>Fly wheel</td><td>Diameter 5.5m</td></tr>
<tr><td rowspan="2">Dimensions of specimen</td><td colspan="2">Width 12.0m × Length 6.0m × Thickness 0.5m</td></tr>
<tr><td colspan="2">Deck comprising girder can also be tested</td></tr>
<tr><td rowspan="3">Wheel type</td><td>1 wheel</td><td>Width: 0.50m</td></tr>
<tr><td>1 couple of wheels</td><td>Width: 0.50m / Spacing: 1.8m</td></tr>
<tr><td>Elastomeric tire</td><td>Equivalent to 9.00-R20-14PR (airplane tire)</td></tr>
<tr><td rowspan="5">Perfor-mance</td><td rowspan="2">Driving</td><td>Moving range</td><td colspan="2">±0.5/±1.0/±1.25/±1.5/±1.75/±2.0/±2.25/±2.5m</td></tr>
<tr><td>Max. rotation speed</td><td colspan="2">59.8/42.3/37.8/ 34.7/ 31.0/ 28.0/ 25.0/ 22.0rpm</td></tr>
<tr><td rowspan="3">Loading</td><td rowspan="2">Maximum load</td><td>Motion state</td><td>50 tonf</td></tr>
<tr><td>Stationary state</td><td>100 tonf</td></tr>
<tr><td>stroke</td><td colspan="2">300 mm</td></tr>
</table>

Acknowledgement

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