OPENING THE GATE: CONSTRUCTION OF 300 M COMPOSITE-DECK BRIDGE IN KOREA

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ABSTRACT

Due to many advantages such as lightweight, high durability and speedy construction, the number of bridges of various girder types built with fiber-reinforced composite decks in Korea has been increased recently. This paper presents the procedures of our development of the pultruded composite deck, called ‘Delta Deck’, and its field applications including the world largest 300m-long composite-deck bridge, called ‘Noolcha Bridge’, at Busan Newport in Korea. This paper also introduces an innovative vertical snap-fit connection developed for the composite deck and its applications to pedestrian bridges.

KEYWORDS

Composite bridge deck, girder bridge, fiber, Delta Deck, snap-fit connection.

INTRODUCTION

Among many applications of composite materials to civil infrastructures, the composite decks for bridges seem to be the most noteworthy. Compared with conventional concrete decks, the composite deck is significantly lighter, much longer serviceable and more rapidly installable. Due to such distinguished advantages, various profiles of composite decks have been developed over the world and more actively used in recent days. It is reported that couple of hundreds bridges with composite decks have been in use in the United States (Keller 2006, ACMA 2006). In Korea, more than 10 composite-deck bridges have been built so far, and more will be constructed. By the year 2007, the total area of composite decks installed in Korea is expected to be 13,000m². Among them, 300m-long and 35m-wide ‘Noolcha Bridge’, the world largest composite-deck bridge is the most remarkable. We believe that this bridge will set a milestone for the earnest use of composite materials to civil infrastructures. The pultruded composite decks, called ‘Delta Deck’, with tongue-and-groove connections have been used for the bridges in Korea. Our construction experiences of these composite-deck bridges enable us to develop an innovative composite-deck profile with vertical snap-fit connections. In this paper, summary of our research and development for the ‘Delta Deck’ and the snap-fit connection is introduced, and their applications to vehicular and pedestrian bridges are presented.

PRE-STUDIES FOR DEVELOPMENT OF THE COMPOSITE DECK

As a preliminary study to select an optimal shape of the composite deck, 3 different profiles of the composite deck with 80mm height are studied. As shown in Fig.1, the composite decks of trapezoidal, box and triangular profiles are fabricated by VARTM (Vacuum Assisted Resin Transfer Molding) process. By flexural tests in strong and weak axes, the triangular and trapezoidal profiles are considered more efficient. Based on this result, a full scale composite deck of triangular profile (195mm height × 990mm width × 2335mm span) is fabricated with filament winding process (Fig. 2), and then 3-point bending tests are carried out under simply supported condition as shown in Fig. 3. The failure load of the deck is 930kN and the maximum deflection under this load is 51.9mm. The maximum bending moment capacity corresponding to this load is 518.4kN-m, and it is well beyond the required design moment (51.7kN-m) for the concrete slab according to the Korean Highway Bridge Code. Thus this composite deck is considered to possess very high factor of safety in strength. The estimated service load deflection under the live and impact loads of a Korean Highway DB24 truck (rear wheel load 94.1kN) is 1.3 mm for simply supported condition, and it is well lower than the permissible limit of 5.88mm (L/425). However, the local deflection of the upper flanges can be significantly large because of relatively wider...
distance between webs. In order to reduce the local deflection, the composite deck of quasi-triangular profile is selected and fabricated by pultrusion as shown in Fig. 4. The pultrusion process is much more efficient than the filament winding process especially in manufacturing massive products. Extensive analyses and structural tests on the pultruded decks are carried out. It is found that this pultruded deck needs further improvement to meet the criteria of local deflection and fatigue. Based on these pre-studies, the next deck profile is developed and summary of the development is described in the following section.

![Fabrication of model decks with VARTM process](image)

**Figure 1. Fabrication of model decks with VARTM process**

a) Trapezoidal shape  
b) Box shape  
c) Triangular shape

![Filament winding deck](image)  
![Test of FW deck panel](image)  
![Pultruded deck](image)

**Fig. 2 Filament winding deck  
Fig. 3 Test of FW deck panel  
Fig. 4. Pultruded deck**

COMPOSITE BRIDGE DECK OF TONGUE-AND-GROOVE CONNECTION – ‘DELTA DECK’

**Overview of Tongue-and-Groove Profile**

Through the extensive studies described above, a composite deck profile with tongue-and-groove connections called ‘Delta Deck’ is developed (Lee 2004). As shown in Fig. 5, it has 3 trapezoidal cells with 200mm height. The deck is designed for the Korean Highway DB24 truck load with typical girder spacing of 2.5~3.0m. As shown in Fig. 6, the pultruded deck tubes are assembled together by bonding each other to make a complete deck panel. In each laminate of the deck, 8800 Tex E-glass roving in the longitudinal direction and multi-axial stitched fabrics (90°/±45°) in the transverse direction are used. Unsaturated polyester is employed as resin base.

![Profile of 'Delta Deck'](image)  
![Assembly by tongue-and-groove](image)  
![Pultrusion of deck tube](image)

**Fig.5 Profile of ‘Delta Deck’  
Fig. 6 Assembly by tongue-and-groove  
Fig. 7 Pultrusion of deck tube**

**Research Summary for Tongue-and-Groove Composite Deck**

Finite element analysis is carried out to verify strength and serviceability of the designed composite deck. A plate girder bridge simply supported with 30m span having 5 girders with 2.5m spacing is considered. Analysis is performed for the DB24 truck load (Fig. 8). As analysis results, the designed deck is considered to possess 2.53 factor of safety for deflection (L/425 criteria), 10.4 for Tsai-Wu failure criteria and 10.7 for web buckling (Hyer 1988). The composite deck tube of 3-cell trapezoidal section with 200mm height, called ‘Delta-deck™’ are fabricated by pultrusion process (Fig. 7). Coupon tests, flexural tests (Fig. 9), shear tests (Fig. 10), compression fatigue tests (Fig. 11), flexural fatigue tests, barrier wall tests, pavement shear tests and various chemical tests are carried out for this deck. Fig. 12 shows results of compression fatigue test under 2-million cycles of wheel
load of DB 24 truck. As shown in Fig. 12, strains after 2-million cycles do not have significant change, thus it verifies good fatigue resistance of the deck. Since the composite deck has high durability and good fatigue resistance, its service life is expected to be longer than typical concrete decks that have relatively low durability and low fatigue resistance due to cracks. After extensive structural performance tests in the laboratory as described above, the developed pultruded deck is installed on a demonstration bridge of plate girder type in the lane enlargement project of Gyungbu Highway. Field load tests are carried out on this demonstration bridge as shown in Fig. 13. The maximum deflection of the deck is measured 1.92mm under a test truck load. Permissible deflection for the 2.0m girder spacing is estimated as 4.7mm when deflection serviceability criterion of L/425(2m/425) is applied. Thus the factor of safety 2.4 in deflection is obtained under the test truck load. When the test truck load is converted to a DB24 truck load, factor of safety is estimated to 2.9 in serviceability and 39 in strength. From the field load tests, it is demonstrated that developed pultruded deck possesses sufficient serviceability and strength. Results of dynamic field load tests on another bridge (Gwangyang Bridge in Fig. 21), not shown in this paper, verify that the developed deck profile well satisfies the strength and serviceability criteria under the Korean Highway truck load. Several field applications of the developed deck are described below.

![Fig. 8 FE analysis of deck](image8)
![Fig. 9 Flexural test of deck panel](image9)
![Fig. 10 Connection shear test](image10)

![Fig. 11 Compression fatigue test](image11)
![Fig. 12 Results of fatigue test](image12)
![Fig. 13 Field load test of deck](image13)

**COMPOSITE DECK OF VERTICAL SNAP-FIT CONNECTION**

**Overview of Snap-Fit Profile**

Until today tongue-and-groove connections, shown above, is prevailing practice in assembling composite decks. In conventional bridge construction, shear connectors are provided at plant on top of girders prior to placing decks. However, in installing composite decks with tongue-and-groove connection, shear connectors can not be provided until the composite decks are completely assembled. The deck should be assembled side by side horizontally on top of girders without having disturbance of vertical shear studs. Installation of shear connectors through pre-drilled small confined holes in the composite deck causes poor workability and welding quality so that it requires more costs and time. If the girders are made of concrete, installation process of shear connector is far more difficult. In addition, accumulated horizontal gap between bonded tubes becomes larger for the longer bridge so that it creates significant differences in length of the deck panel during construction. To resolve these problems, an innovative composite deck profile with vertical snap-fit connection is newly developed (Lee 2006). Fig. 14 shows the developed profile of snap-fit deck for vehicular bridge and Fig. 15 shows illustration of deck assembly by snap-fitting. The developed snap-fit deck, assembled each other in a vertical direction by snap-fit connection, significantly improves construction workability and quality, provides snap-fit mechanical connection with or without adhesive bonding, and saves installation time and costs. Another notable improvement of the snap-fit deck is easy applicability to curved bridges, while the deck of tongue-and-groove type practically cannot be implemented to. The vertical snap-fit connection provides easy assembly and disassembly by mechanical snap-fitting. Thus, applications of the snap-fit deck can further be extended not only to temporary bridges, but also to road-mats for oil and gas development, disaster relief, military operation, mining, logging and construction. It is hoped that the development of this vertical snap-fit connection will lead far wider applications of the composite decks.
Research Summary for Snap-Fit Composite Deck

For the vehicular deck with snap-fit connection shown in Fig. 14, finite element analysis is performed. It is found that firm connection is guaranteed and sufficient safety in strength is preserved at the connection when snap-fit is properly designed. To understand structural behavior during the snap-fit action, geometric nonlinear analyses are also performed. The results of analyses show that designed snap-fit deck well satisfies the Tsai-Wu failure criteria during snap-in assembly and snap-out disassembly, and the safety factor is greater than 2.8. The deck profile of 75mm height with snap-fit connection is fabricated by pultrusion. For this pultruded deck, tests on snap-fit action are conducted as shown in Fig. 16. Due to limited space of this paper, the results of the tests are not shown, but the stresses and deflections under tests are similar to those from the analyses.

APPLICATIONS OF COMPOSITE BRIDGE DECK TO VEHICULAR BRIDGES

Background

For the developed composite deck ‘Delta Deck’, extensive verifications at laboratory and field are carried out before its actual use. Based on the excellent field performance for the demonstration bridges at construction site in 2002 and at detour bridge of Kyungbu Highway in 2004, more composite-deck bridges of various girder types are being built and the number of the composite-deck bridges is continuously increasing in Korea.

The World Largest Composite-Deck Bridge of Reinforced Concrete (RC) Girder

The world largest composite-deck bridge, called ‘Noolcha Bridge’, is currently under construction in Busan new port, located in the southeastern coast of the Korean peninsula. This bridge is pier-type, 300m long and 35m wide, and will be completed by October 2007. The composite deck, ‘Delta Deck’, is installed on grids of reinforced concrete girder (Fig. 17), which is constructed above the steel marine pile foundation (Fig. 18). The composite deck is selected for this bridge to take benefits of cost savings in construction and maintenance. Due to the light weight property of the composite deck, it significantly reduces number of foundation marine piles so that the initial construction cost is reduced considerably. In addition, due to high durability of the composite deck against marine environment, the life-cycle cost is also reduced remarkably. Fast erection also gives savings in construction time and costs. Upon completion of the deck panel on the southbound (deck in left-hand side in Fig. 19), this portion is utilized as a work site for construction equipments such as pump-cars and remicon trucks to place concrete to build girders on the northbound (right-hand side in Fig. 17 and 19). By this way, it can speed up the construction dramatically. Fig. 17 shows lifting and erection of deck panel from storage yard onto the bridge girder on the northbound. The placed decks above the girders are assembled side by side with adhesive
bonding. After completion of deck placement, shear connectors are installed on the girder. Then, non-shrinkage concrete is placed around shear connectors to have composite action between the girders and the composite decks. Installation of the composite deck has been completed so far as shown in Fig. 19. Asphalt concrete pavement will be glued to the composite deck by using epoxy and quartz sands (Lee 2004).

**Composite-Deck Bridge of Steel Plate Girder – Non-Composite Action between Deck and Girder**

After 2 demonstration works including Kyunghu Highway detour described above, another large temporary bridge of plate girder, ‘Gwangyang Bridge’, located in the southwestern coast of the Korean peninsula have been constructed with Delta Decks in 2004 (Fig. 20, 21). It is 150m long and 10.4m wide. Though this bridge is temporary, it will be used more than 10 years during the long construction period of reclamation.

**Composite-Deck Bridge of Steel Plate Girder – Composite Action between Deck and Girder**

After successful implementation to the temporary bridges, Delta Decks have been installed on the permanent plate girder bridge, ‘Gaejung Bridge’, located at the southern inland of the Korean peninsula in 2004 (Fig. 22, 23). It is 25m long and 11m wide. No indication of defects is found since the bridge is opened to the traffic.

**Composite-Deck Bridge of Prestressed Concrete (PC) Girder**

With several construction experiences for the steel girder bridges, Delta Decks have been successfully installed for a bridge with prestressed concrete girders in 2005 (Fig. 24, 25). This bridge is called ‘Pyungtaek Bridge’ and located at the western coast of the Korean peninsula. It is 70m long and 11.9m wide and consists of 2 simply supported spans.

**APPLICATIONS OF COMPOSITE BRIDGE DECK TO PEDESTRIAN BRIDGES**

‘Delta Deck’ Applied to Pedestrian Part of Arch Bridge

To cope with requirement of minimal traffic blocking during the environmental recovery project of Seoul Metropolitan city in 2005, Delta Deck is applied to build pedestrian side ways for an arch bridge, shown in Fig. 26. The bridge is 44.5m long and 9m wide, and has pedestrian way on both sides. Delta Decks are bolt-connected to the cross beam with shear stud. Fig. 27 shows the completed bridge in use over the reopened environment-friendly ‘Cheonggae River’.

**Composite Snap-Fit Deck on Suspension Pedestrian Bridge**

The deck profile with the vertical snap-fit connection described above is considered very effective in constructing pedestrian bridges. In addition to light weight and high durability, it provides an extra benefit of
easy assembly and disassembly by mechanical snap-fit. As shown in Figs. 28 and 29, the developed snap-fit deck is successfully implemented to the suspension pedestrian bridge, ‘Wolchul-Mountain Bridge’, which is 53m long and 1m wide completed in 2006.

Composite Snap-Fit Deck on Arch Bridge with Steel Box Girder

The snap-fit composite deck is simply and elegantly placed above the steel box girder without brackets at both cantilevered sides in ‘Osanchun Bridge’, which is 140m long and 5m wide. Fig. 30 shows installation work and Fig. 31 shows the bridge in use after completion. As shown in Fig. 31, the beautiful scenery of the bridge makes environmental-friendly atmosphere to neighboring citizens.

CONCLUSION

The profiles of composite deck, ‘Delta Deck’, with the tongue-and-groove connection and the vertical snap-fit connection are introduced. The development procedures and several successful field applications of ‘Delta Deck’ to vehicular and pedestrian bridges of various girder types, including the word largest composite-deck bridge, ‘Noolcha Bridge’, are also presented. It is believed that ‘Noolcha Bridge’ will set a milestone for the earnest use of composite materials to civil infrastructures. Due to many advantages of the composite deck, increasing number of applications is anticipated in the near future.

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