(I1) CONSTRUCTING MORE COMPOSITE-DECK BRIDGES AND DEVELOPING INNOVATIVE SNAP-FIT DECK

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

Key Words : *Composite bridge deck, girder bridge, fiber, Delta Deck, snap-fit connection*

1. INTRODUCTION

Among many applications of composites to civil infrastructures, the application to bridge decks seems to be the most notable. Compared with conventional concrete deck, the composite bridge deck is significantly lighter, much longer serviceable and more rapidly installable. Due to such notable advantages, various profiles of composite bridge deck have been developed over the world and more actively used in recent days[1)]. It is reported that couple of hundreds bridges with composite decks including pedestrian bridges are already in use in the United States[2)]. In Korea, more than 10 composite-deck bridges have been built and the number is continuously increasing. By the year 2007, the total area of composite decks to be installed in Korea is expected to be 13,000m^2. The most notable one among them is 300m long and 35m wide, the world largest ‘Noolcha Bridge’. It is believed that this bridge will set another milestone for the earnest use of composites to the civil infrastructure. The pultruded composite deck, called ‘Delta Deck’, of tongue-and-groove connection is used in this bridge. Based on such construction experiences of many composite-deck bridges, a truly innovative composite deck profile of vertical snap-fit connection is newly developed. In this paper, some results of research and development on the ‘Delta Deck’ and its applications to vehicular and pedestrian bridges are presented.

2. PRESTUDIES FOR DEVELOPMENT OF COMPOSITE DECK

As a preliminary study to select an optimized shape of composite deck, 3 different profiles of preliminary composite decks of 80mm height are studied. As shown in the Fig.1, trapezoidal, box and triangular shape profiles are fabricated by VARTM (Vacuum Assisted Resin Transfer Molding) process. From flexural tests in strong and weak axis, triangular and trapezoidal shape profiles are considered more efficient. Based on this study for the preliminary composite decks, full scale composite deck of triangular shape, with 195mm height, is fabricated with filament winding process (Fig. 2) and 3-point bending tests are carried out for the simply supported deck panel as shown in Fig. 3. Failure load of the panel is 930kN and maximum deflection for this load is 51.9mm. Maximum bending moment capacity corresponding to this load is 518.4kN-m and it is well beyond the required design moment of 51.7kN-m for the concrete slab according to Korean highway code. Thus this composite deck is considered to possess very high safety factor in strength. The estimated service-load deflection under the live and impact load for the DB24 Korean highway truck is 1.3mm in the simply supported condition, and it is well lower than permissible limit of 5.88mm according to the criteria of L/425.

After these studies, the composite deck of quasi-triangular shape is fabricated more effectively by developed pultrusion process as shown in Fig. 4. For this pultruded deck panel, extensive analyses and structural tests are carried out, and it is found that this pultruded deck need further enhancement to meet criteria for local deflection and fatigue. For this reason, the next deck profile is developed and some details are described in the following section.

a) Trapezoidal shape

b) Box shape

c) Triangular shape

Fig. 1 Fabrication of model decks with VARTM process

Fig. 2 Filament winding for the triangular profile deck

Fig. 3 Bending test of filament winded deck panel

Fig 4. 1st generation of pultruded deck

3. COMPOSITE DECK WITH TONGUE-AND-GROOVE CONNECTION: 'DELTA DECK'

(1) Overview of tongue-and-groove profile

Through the extensive studies described above, a composite deck profile with tongue-and-groove connection called 'Delta Deck' is developed[3)]. As shown in Fig. 5, it has 3 trapezoidal cells of 200mm height. It is fabricated by pultrusion as shown in Fig. 6. The deck is designed for typical girders with spacing of 2.5~3.0m under the Korean Highway truck load of DB24 (rear axle load of 94.1kN). As shown in Fig. 7, the pultruded deck tubes are assembled together by bonding each other to make a deck panel for use in the bridge. In laminates of the deck, 8800 tex E-glass roving is used in the longitudinal direction, and multi-axial stitched fabrics (90°/±45°) are used in the transverse direction. Unsaturated polyester is used as resin-base.

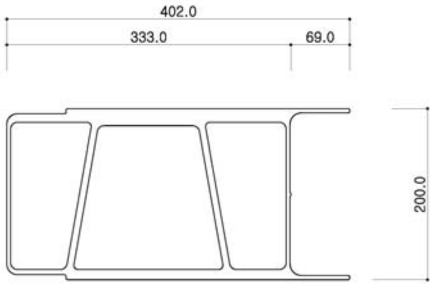

Fig.5 Profile of 'Delta Deck'


Fig. 6 Pultrusion of deck tube

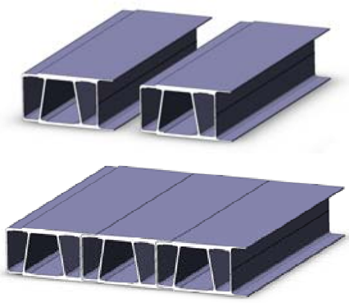
Fig. 7 Assembly by tongue-and-groove

(2) Research results on tongue-and-groove composite deck

Finite element analysis is carried out to verify strength and serviceability criteria for the designed 'Delta Deck'. A simply supported plate-girder bridge, which is consisted of 5 girders having 30m span with 2.5m spacing, is considered. Analysis is performed for the DB24 truck load (Fig. 8). The designed deck is considered to possess factor of safety of 2.53 for deflection (L/425 criteria), 10.4 for Tsai-Wu failure criteria and 10.7 for web buckling for the DB24 truck load in the analysis.

Coupon tests, flexural tests (Fig. 9), shear test (Fig. 10), compression fatigue tests (Fig. 11), flexural fatigue tests, barrier wall tests, asphalt pavement shear tests and various chemical tests are carried out for the deck. Fig. 12 shows results of compression fatigue test for 2 million cycles of wheel load of DB 24 truck. The strains after 2 million cycles do not have much change in the figure, thus it verifies good fatigue resistance characteristics of the deck panel.

The developed pultruded deck is installed for lane improvement project in Gyungbu Highway in a demonstration bridge of plate-girder type. For this demonstration bridge, field load tests are carried out as shown in Fig. 13. Maximum deck deflection is measured 1.92mm for the test truck. The permissble deflection for the 2.0m girder spacing is estimated as 4.7mm when the deflection serviceability criterion of L/425 was applied. Thus the deflection ratio of the permissible to the measured is 2.4 for this test truck. When test truck load is converted to DB24 truck load, the deflection ratio is estimated as 2.9. Under the equivalent DB24 truck load, the maximum stress obtained from measured strain at the bottom flange of the deck in the direction of bridge axis is 1/39 times smaller than the ultimate strength of the deck. It is demonstrated that the developed pultruded deck possesses sufficient serviceability and strength. Though not shown in this paper, results of dynamic load test on Gwangyang Bridge (Fig. 20 & 21) show that the developed deck well satisfies the strength and serviceability criteria for the Korean Highway truck load. Several field applications of the developed deck are described in Section 5.

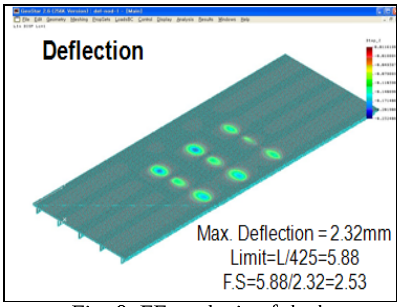

Fig. 8 FE analysis of deck

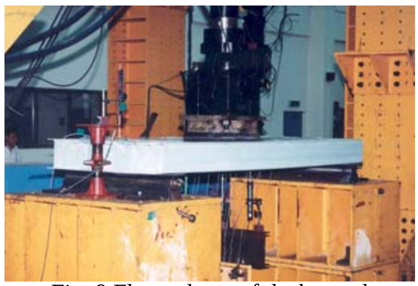
Fig. 9 Flexural test of deck panel


Fig. 10 Connection shear test

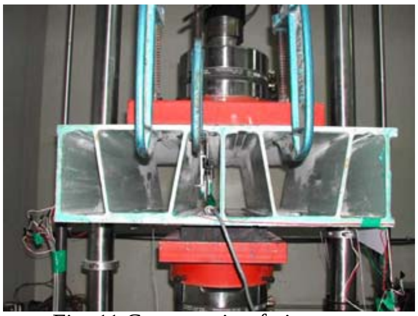

Fig. 11 Compression fatigue test

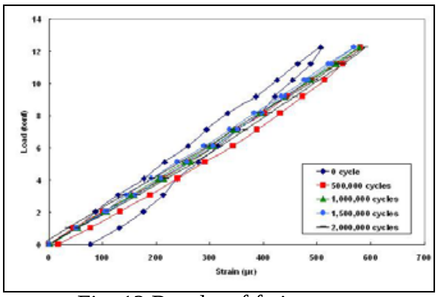

Fig. 12 Results of fatigue test

Fig. 13 Field load test of deck

4. COMPOSITE DECK OF VERTICAL SNAP-FIT CONNECTION

(1) Overview of snap-fit profile

Until today tongue-and-groove connection method mentioned above is prevailing practice in assemblying of the composite decks. In conventional way of bridge construction, the shear connectors are provided on top of the girder prior to placing decks. However, when composite decks are installed by tongue-and-groove connection, the shear connectors can not be provided until the decks are completely assembled. The deck should be assembled side by side horizontally on top of the girder without having any barrier such as vertical shear stud. Welding shear connectors to steel girders through pre-drilled small confined holes in the deck causes poor workability and welding quality, and it requires more costs and time. If girder is made of concrete, installation process of shear connector is far more difficult. In addition, accumulated horizontal gaps between bonded tubes becomes larger for the longer bridge so that it can create mismatch between locations of shear connectors and predrilled holes.

To avoid the mentioned problem, an innovative composite-deck profile of multi-cell polygonal shape with vertical snap-fit connection is innovatively developed[4)]. Fig. 14 shows the developed profile of snap-fit deck for vehicular bridge and Fig. 15 shows illustration of deck assembly by snap-fit. Developed snap-fit decks significantly improves construction workability and quality, provides snap-fit mechanical connection with or without adhesive bonding, and saves installation time and costs. Furthermore, the snap-fit deck is easily applicable to curved bridges, while the deck of tongue-and-groove type practically cannot be. Vertical snap-fit connection provides easy assembly and disassembly if decks are connected by mechanical snap-fit without adhesive bonding. This advantage enable us to apply snap-fit decks 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 pave ways far wider to various applications of composite decks.

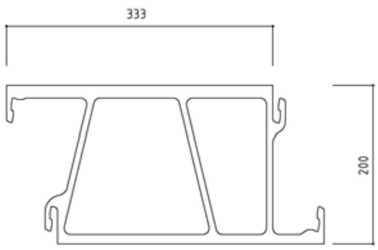

Fig. 14 Profile of snap-fit deck

Fig. 15 Deck assembly by snap-fit

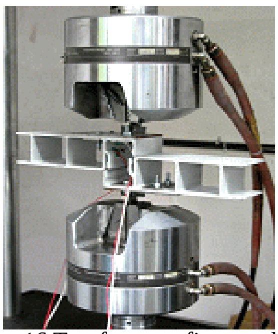

Fig. 16 Test for snap-fit assembly

(2) Research results on snap-fit composite deck

For the vehicular deck of snap-fit connection shown in Fig. 14, finite element analyses considering geometric nonlinearity are performed to investigate structural behavior during the snap-fit action. The results of analyses show that designed snap-fit shape well satisfies the Tsai-Wu failure criteria during snap-in assembly and snap-out disassembly, and the safety factor is greater than 2.8. It is found that firm connection is guaranteed and sufficient safety in strength is preserved for the properly designed snap-fit connection.

The deck tube having shallow height (75mm depth) with snap-fit connection is fabricated by pultrusion. This pultruded deck is tested during the snap-fit assembly as shown in Fig. 16. Due to limited space, results of the tests are not shown in this paper. However, the stresses and deflections from tests are similar to those from the analyses. In the following Section 6, several applications of this snap-fit deck to pedestrian bridges are described.

Fig. 17 Side view of installed deck

Fig. 18 Installation at Noolcha Bridge

Fig. 19 View after installation

5. APPLICATIONS OF COMPOSITE DECK TO VEHICULAR BRIDGES

(1) Background

For the developed tongue-and-groove composite deck, 'Delta Deck', extensive experimental verification at laboratory and field are carried out before its actual use. After the excellent field performance of the demonstration bridges at construction site in 2002 and at the detour bridge of Kyungbu Highway in 2004, more composite-deck bridges of various girder types are being built, and the number is continuously increasing in Korea.

(2) World largest composite-deck bridge of reinforced concrete (RC) girders

World largest composite-deck bridge is currently under construction in Busan new port, located in the southeast of Korean peninsula. This bridge of pier-type, called 'Noolcha Bridge', is 300m long and 35m wide and will be completed in 2007. Composite deck, 'Delta Deck', is installed onto the grid of reinforced concrete girder, which is established above the steel marine-pile foundation.

Composite deck is selected to use for this bridge to take benefits of cost savings in construction and maintenance. Due to light-weight property of composite deck, it significantly reduces number of marine piles in foundation so that initial construction cost is reduced considerably. In addition, due to high durability of the deck against marine environment, life-cycle cost is also reduced remarkably. Fast erection also gives savings in construction time and costs. Fig. 17 shows marine piles in foundation, and composite deck installed on the grid of concrete girders (also see Fig. 18). Upon completion of deck on the south bound (deck in left side in Fig. 19), this portion is utilized as a work site for construction equipment such as pump-cars and remicon trucks to place concrete for girders on the north bound (right side lanes in Fig. 18 and 19). The instinct utilization of the completed portion of the bridge can speed up total construction time dramatically.

Fig. 18 shows lifting and erection of deck panel from storage yard onto the girders on the north bound. The placed deck panels above the girder are assembled side by side with adhesive bonding. After completion of deck placement, shear connectors are installed through the decks onto the girder. Then, non-shrinkage concrete is placed in pre-drilled holes around shear connectors to have composite action between girders and decks. Fig. 19 shows the completely established decks on the girders after installing shear connectors. Asphalt pavement will be installed on top surface of the decks to protect them against traffic.

(3) Composite-deck bridge of steel plate girder: non-composite action between decks and girders

After 2 demonstration works including Kyungbu highway detour described above, another large temporary bridge of plate girder with ‘Delta Deck’, ‘Gwangyang Bridge’, located in the southwest coast of peninsula have been built 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.

(4) Composite-deck bridge of steel plate girder: composite action between decks and girders

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

(5) Composite-deck bridge of prestressed concrete (PC) girder

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

Fig. 20 Installation at Gwangyang Bridge

Fig. 21 Gwangyang Bridge at service

Fig. 22 Installation at Gaejung Bridge

Fig. 23 Gaejung Bridge at service

Fig. 24 Installation at Pyungtaek Bridge

Fig. 25 Pyungtaek Bridge at service

6. APPLICATIONS OF COMPOSITE DECK TO PEDESTRIAN BRIDEGES

(1) ‘Delta Deck’ applied to pedestrian part of an arch bridge

To satisfy the requirement of minimal traffic blocking during the environmental recovery project of Seoul Metropolitan city in 2005, ‘Delta Deck’ is applied to an arch bridge, shown in Fig. 26. The bridge is 44.5m long and 9m wide, and have pedestrian sideways on both sides. The deck is bolt-connected to the cross beam by shear stud. Fig. 27 shows the completed bridge in use over the reopened environment-friendly ‘Cheongge River’.

(2) Composite snap-fit deck on suspension pedestrian bridge

Deck profile of vertical snap-fit connection, described in Section 4, is considered very effective for building pedestrian bridges. In addition to light weight and high durability, it possesses property of easy assembly and disassembly. The developed deck is successfully implemented to the suspension pedestrian bridge, 'Wolchul-Mountain Bridge' which is 53m long and 1m wide, in 2006 as shown in Figs. 28 and 29.

(3) Composite snap-fit deck on arch bridge with steel box girder

Snap-fit composite decks at 'Osanchun Bridge', which is 140m long and 5m wide, is just simply and elegantly placed above the steel box girder without brackets supporting cantilevered decks. Fig. 30 shows installation work and Fig. 31 shows the bridge in use after completion. As shown in Fig. 31, the beautiful shape of the bridge matches very well with surrounding environment.

Fig. 26 Installation at Cheongge Bridge

Fig. 27 Cheongge Bridge at service

Fig. 28 Installation at Wolchul Bridge

Fig. 29 Wolchul Bridge at service

Fig. 30 Installation at Osan Bridge

Fig. 31 Osan Bridge at service

7. CONCLUSION

Profiles of composite deck of tongue-and-groove connection and vertical snap-fit connection are introduced. 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 presented. It is believed that 'Noolcha Bridge' will set another milestone for the earnest use of composites to the civil infrastructure. Due to many advantages of composite deck, increasing applications are anticipated in the near future.

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