

# **FLEXURAL CHARACTERISTICS OF FILAMENT WOUND GFRP COMPOSITE BRIDGE DECK**

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## **Abstract**

Recent days composite bridge deck is gaining attraction due to many advantages such as light weight, high strength, corrosion resistance, and high durability. In this study, glass reinforced composite deck models of hat, box, and triangular section type were designed and fabricated using vacuum process and flexural tests were carried out for these deck models. Based on test results of model decks, triangular shape was selected for the profile of full scale deck and filament winding process was adopted for fabrication of the deck. Flexural test and finite element analysis was carried out for this deck and flexural characteristics were analyzed. The paper presents the procedures involved in the laminate design, fabrication, experiments and analysis of composite deck.

## **1. Introduction**

Due to many advantages such as light weight, high strength, corrosion resistance, and high durability, increasing interests are aroused on the use of advanced composite materials in civil infrastructures.

Composite bridge deck is considered one of the promising applications among those and many studies are carried out[1,2]. When composite deck is used for the purpose of redecking and upgrading load carrying capacity of bridge, it has significant advantages compared with conventional concrete deck. Due to fast installation it reduces rehabilitation period dramatically so that significantly reduces traffic block time and saves direct and indirect costs. By saving dead load as much as 80 % compared with conventional concrete deck, load carrying capacity of the bridge is upgraded automatically without strengthening girder or substructures.

In addition, service life of the deck is much longer than concrete deck due to high durable material characteristics of composite. Thus maintenance costs will also be saved during the service life. It is also advantageous for the seismic behavior since it reduces weight considerably.

In Korea, almost one half of the 16,000 bridges in the entire nation are subject to upgrade due to highway code changes in 1978. Figure 1 shows recent redecking project for 1.2 km long Hannam Grand Bridge crossing the Han River in Seoul. It is considered that this light weight composite deck is one of

the efficient and economic alternatives for such bridge upgrade projects.

In this study, to select proper profile of deck, several models of composite deck were fabricated by VARTM(Vacuum Assisted Resin Transfer Molding) process[3] and flexural tests were conducted for these models. Based on the study for the model decks, full scale deck was fabricated by filament winding process. In the paper, the procedure and results involved in the development of composite bridge deck are presented. Also, at failure load, Tsai-Wu failure criteria were estimated and compared with actual failure condition. After study, real size composite deck was fabricated and installed first time in Korea and it demonstrated well the feasibility of such construction.

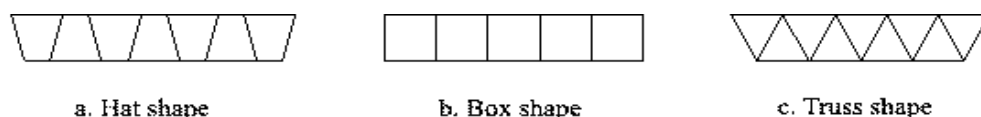


**Figure 1.** Redecking for Hannam Grand Bridge

## 2. Flexural characteristics of model composite decks

### 2.1 Model composite decks fabricated with VARTM

To decide proper section profile of composite bridge deck, 3 different shapes of model composite deck were studied. Figure 2 shows hat, box and truss shape profile considered. In this study, HS and HW designates model of strong and weak axis for the hat shape respectively, BS and BW for the box shape, and TS and TW for the truss shape. Stitched fabric of glass fiber, unsaturated polyester and polycyanurate core were used for fabrication by VARTM process. Table 1 shows fiber orientation and weight of stitched fabric used for fabrication. Figure 3 shows details of model deck sections. 300 mm wide and 1000 mm long panels in strong and weak axis were fabricated for each shape of model deck. Figure 4, 5 and 6 show procedure of fabrication of model deck by VARTM process.

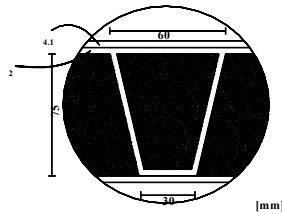


**Figure 2.** Profile of model composite deck

**Table 1.** Fiber orientation and weight of stitched fabric

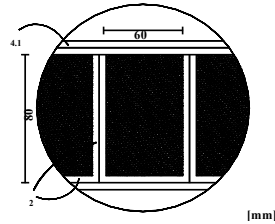
Fabric Type	Layers	Orientation [°]	Weight of layer[g/m <sup>2</sup> ]
DBLT 1150	4	0	295
		+45	276
		90	283
		-45	276
LT 1000	2	0	473
		90	495
L 900	2	0	864
		90	42

Core Tube: 4-DBLT1150  
Face sheet: 1-DBLT1150+3-LT1000+1-DBLT1150



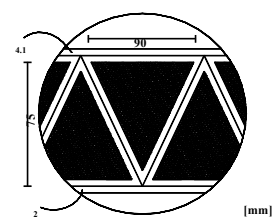
(a) Hat shape

Core Tube: 2-DBLT1150  
Face sheet: 1-DBLT1150+3-LT1000+1-DBLT1150



(b) Box shape

Core Tube: 2-DBLT1150  
Face sheet: 1-DBLT1150+3-LT1000+1-DBLT1150



(c) Truss shape

**Figure 3.** Details of model deck sections



(a) VARTM fabrication



(b) Completed model

**Figure 4.** Procedure of VARTM fabrication of model deck of hat shape



(a) VARTM fabrication



(b) Completed model

**Figure 5.** Procedure of VARTM fabrication of model deck of box shape



(a) VARTM fabrication

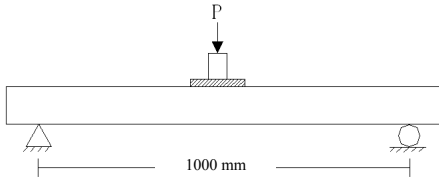


(b) Completed model

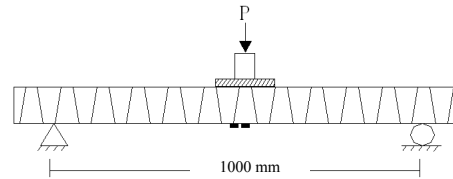
**Figure 6.** Procedure of VARTM fabrication of model deck of truss shape

## 2.2 3-point flexural test for model decks

For the fabricated model decks, 3-point flexural tests for the simply supported condition were carried out. Test for both strong and weak axis were conducted. Figure 7(a) shows test setup for strong axis and Figure 7(b) shows test setup for weak axis for the hat shape model deck.



(a) Strong axis setup



(b) Weak axis setup

**Figure 7.** Test setup for hat shape model deck

Line load was applied at the center of the panel. LVDTs and strain gauges were installed to the panel for the measurement. Figure 8 shows test figures and failure modes in the strong axis for each shape of model deck. Figure 9 shows those for weak axis. For comparison purpose, test results were normalized to have equivalent weight for each shape. Figure 10 shows load-deflection curve at center of the panel for strong axis. And Figure 11 shows load-deflection curve at center for weak axis. As shown in the Figure 10, the stiffness of strong axis for each shape does not show much differences. However, as shown in Figure 11, the stiffness of weak axis for each shape shows considerable differences. In Figure 11, truss shape i.e., triangular shape is much more efficient in the weak axis compared with other shape. From this results, triangular shape is considered as most efficient profile considering both axes. This study provides background materials for the decision of profile for full scale deck. Further results of the study can be found in the reference [4].

## 3. Full scale deck fabricated with filament winding

### 3.1 Laminate design



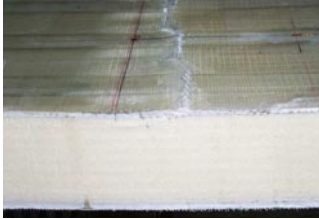
Test figure of HS model



Test figure of BS model



Test figure of TS model



Failure mode of HS model

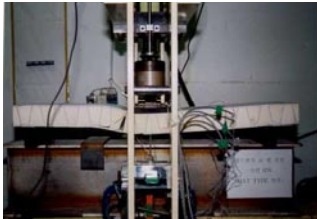


Failure mode of BS model

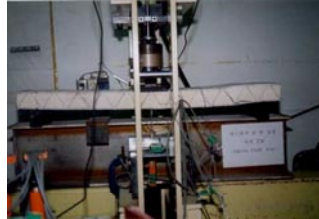


Failure mode of TS model

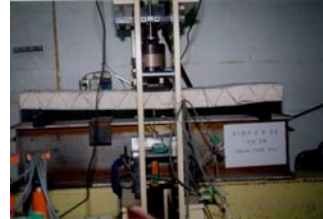
**Figure 8.** Test figures and failure modes in the strong axis for each shape of model deck



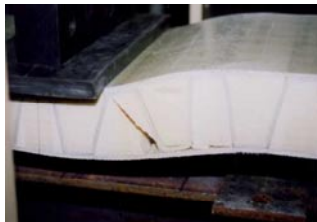
Test figure of HW model



Test figure of BW model



Test figure of TW model



Failure mode of HW model

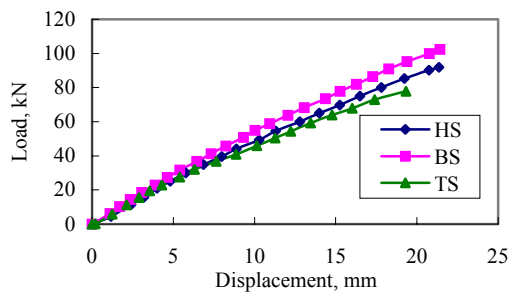


Failure mode of BW model

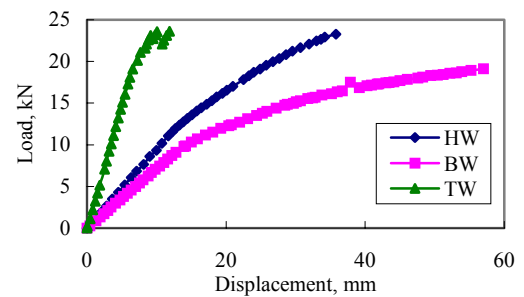


Failure mode of TW model

**Figure 9.** Test figures and failure modes in the weak axis for each shape of model deck

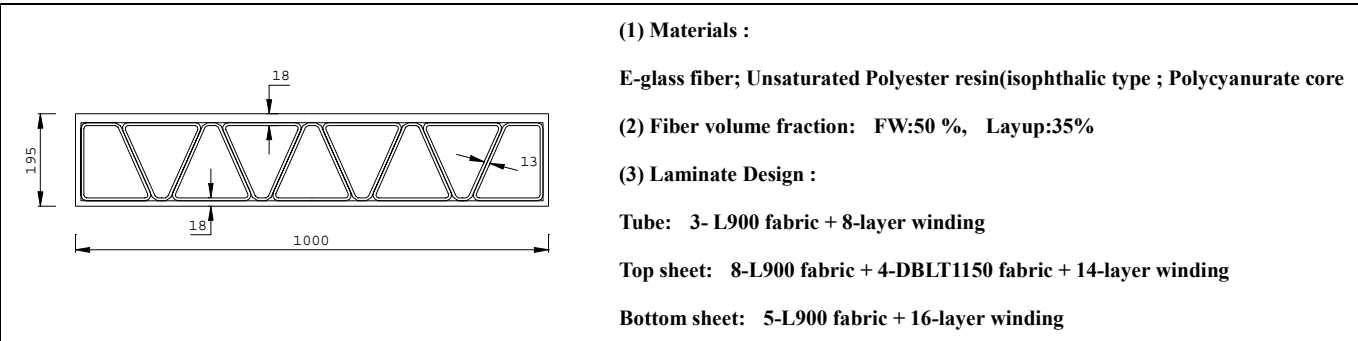


**Figure 10.** Load-deflection curve at center for strong axis

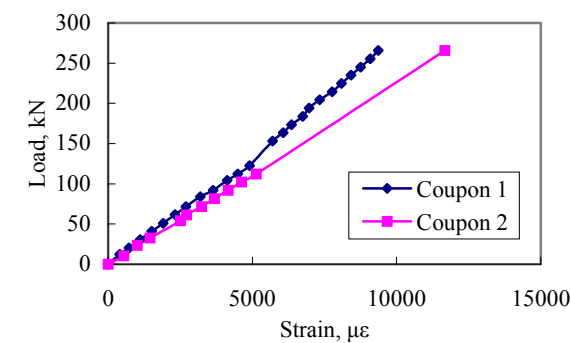


**Figure 11.** Load-deflection curve at center for weak axis

Based on the study of model composite decks, profile of triangular shape, which possessed good bending stiffness in longitudinal and transverse direction, was selected for full scale pilot deck. For fabrication of deck, filament winding process was adopted. By using filament winding process, both straight portion and curved portion of bridge deck can be easily fabricated. Also cost of fabrication can be saved by eliminating costly die. Figure 12 shows dimension and laminate design of deck. 195 mm profile section of 18 mm of top flange, 18 mm of bottom flange and 13 mm of web was designed as shown in Figure 12. Multiaxial stitched glass fabric of L900 and DBLT1150(Table 1) for layup and 4400 Tex glass roving for filament winding was used for fabrication. Figure 13 shows the test results of coupons in the longitudinal direction of top flange of fabricated deck. The mechanical properties of the deck are summarized in Table 2.



**Figure 12.** Dimension and laminate design of pilot deck



**Figure 13.** Coupon test results of upper flange

**Table 2.** Mechanical properties of deck

Description		Top flange	Bottom flange	Web
Modulus of elasticity	Ex (GPa)	12.1	13.3	10.7
	Ey (GPa)	25.5	24.6	32.9
Poisson’s ratio		0.20	0.24	0.26
Shear Modulus (GPa)		3.6	3.4	4.7
Tensile strength (MPa)		265	197	325

The deck consists of triangular tubes and face sheet around assembled tubes. For triangular tube, 4400 Tex E-glass roving was used in the 90°(transverse direction) by filament winding around foam core. For the other direction, multiaxial stitched fabric (0°/±45°) was used by layup. Figure 14 shows filament winding process for triangular tube and Figure 15 shows winding process for face sheet. Figure 16 shows completed deck after fabrication. Figure 17 shows another sample decks for straight and curved portion which demonstrate versatility of filament winding process.





**Figure 14.** Filament winding process for triangular tube



**Figure 15.** Filament winding process for face sheet



**Figure 16.** Completed deck after fabrication



**(a) Pilot decks for straight portion**

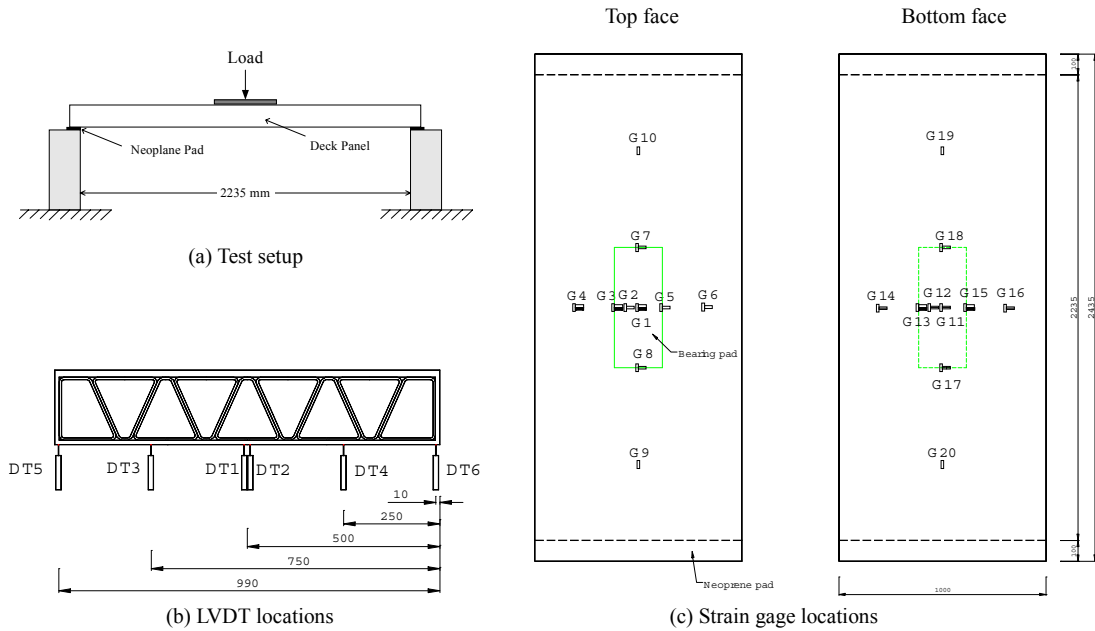


**(b) Pilot decks for curved portion**

**Figure 17.** Sample decks for straight and curved portion

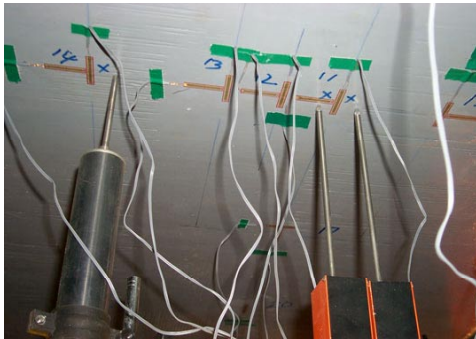
### ***3.2 Flexural test of pilot deck***

3-point bending test was carried out for the fabricated deck. The load were applied at center of the deck panel onto the tire contact area by 1000kN MTS actuator, located above the Neoplane rubber plate at loading point. Strain gauges and LVDTs were installed to measure strain and displacement. Figure 18 shows test setup and gauge locations for the test. Figure 19 shows sensors installed underneath of the deck and Figure 20 shows photo during test. The load was applied up to failure.



**Figure 18.** Test set up and gauge locations for flexural test

The deck carried 930 kN of failure load and maximum deflection for this load was 51.9 mm as shown in the Figure 21. Maximum bending moment capacity corresponding to this load is 518.4 kN-m and it is well beyond design moment of 51.7 kN-m for the concrete slab according to Korean highway code. Thus pilot composite deck is considered to possess very high safety factor for the strength. Estimated service load deflection for the live load plus impact for the DB24 Korean highway truck load is 1.3 mm and it is well lower than permissible limit of 5.88 mm according to ASSHTO criteria of  $L/425$ . Thus it has factor of safety of 4.4 for the deflection. Figure 21 shows load-deflection curve at center span of the deck. Figure 22 shows load –strain curves for the top face and Figure 23 for bottom face. Figure 24 shows failure mode of the deck. As shown in the Figure 24, the deck was failed only locally and considered to possess considerable remaining load carrying capacity. Further results of study can be found in the reference [5].

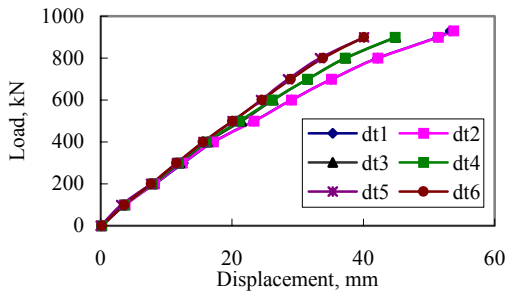


**Figure 19.** LVDTs installed underneath of the deck

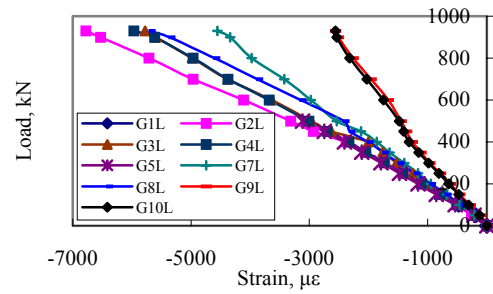


**Figure 20.** Deck under 3-point bending test

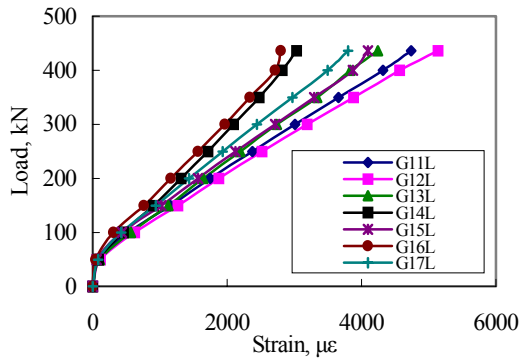




**Figure 21.** Load-deflection curve at center span of the deck



**Figure 22.** Load-strain curve for the top face



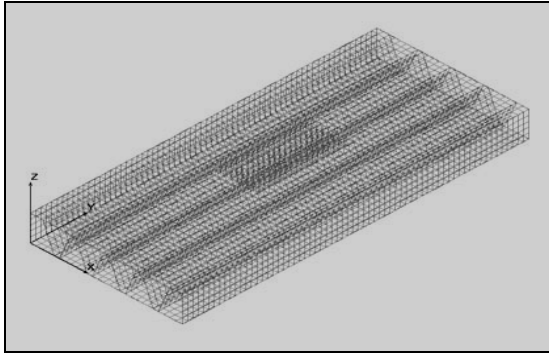
**Figure 23.** Load-strain curve for the bottom face



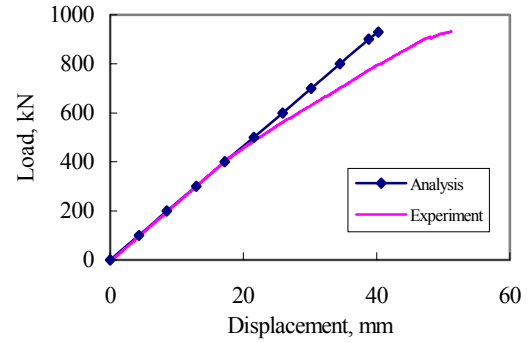
**Figure 24.** Failure mode of the deck.

### 3.3 Finite element analysis of deck

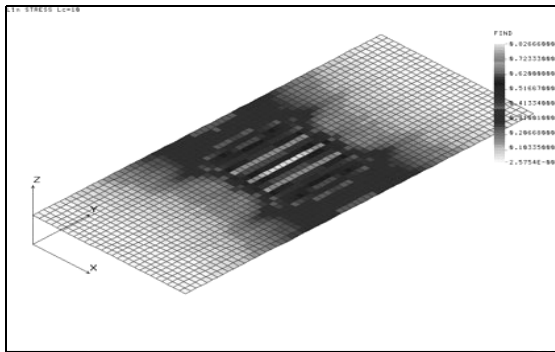
Along with flexural test of the deck, finite element analysis was also performed for the test model. FEM program COMOS/M was used for the analysis. The deck was modeled with SHELL4L element and analyzed with simply supported condition as for the test. Distributed load was applied in the tire contact area of 577x230 mm. Figure 25 shows finite element mesh and applied load for the modeling of test deck. Figure 26 shows comparison of test and analysis results for the central deflection. As shown in the Figure 26, they agree well each other up to approximately 1/2 of the failure load, however after that the result of analysis is a little stiffer than experiment. Figure 27 shows contour of Tsai-Wu failure criteria for the top face of the deck when failure load of 930 kN for the test is applied. Table 3 shows computed values of Tsai-Wu failure criteria at the gage locations of the test deck model. As shown in the Table, value of 0.826 at gage location 1, which is the position of local failure during test, is approaching 1.0 of failure criteria. Thus it is considered that analysis pretty well simulates experimental results of the test deck. After conducting experiments and analysis, real size deck for demonstration project was fabricated as shown in the Figure 28. This composite deck was installed onto the plate girder on April 2000, first time in Korea, as shown in the Figure 29 and it demonstrated well the feasibility of application of composites to the bridge construction.



**Figure 25.** Finite element model for the test deck



**Figure 26.** Load-deflection curve at center



**Figure 27.** Tsai-Wu failure criteria for top face

**Table 3.** Computed values of Tsai-Wu failure criteria

Gage Number	Failure Index	Gage Number	Failure Index
G1L	0.826	G6L	0.611
G2L	0.571	G7L	0.562
G3L	0.741	G8L	0.562
G4L	0.611	G9L	0.107
G5L	0.741	G10L	0.107



**Figure 28.** Completed deck for demonstration project



**Figure 29.** Installation of composite deck

#### 4. Concluding remarks

In this paper, flexural characteristics of glass fiber reinforced composite deck was studied. After studying the model composite decks of various shape, fabricated by VARTM process, full scale deck

was fabricated by filament winding. Conducting flexural tests and analysis for the fabricated deck, following conclusions are drawn ;

1. Experiments for model composite decks of triangular, trapezoidal and rectangular shape show that their stiffness in the longitudinal direction are similar but in the transverse direction, triangular shape possesses better stiffness. Thus it is considered that triangular shape is most efficient and selected for full scale deck fabrication.
2. Filament winding is considered advantageous deck manufacturing method due to easy fabrication for both straight and curved portion of bridge deck with inexpensive die.
3. Experiments show that pilot composite deck fabricated by filament winding is considered to possess safety factors for both strength and serviceability well beyond Korean highway code requirements.
4. Finite element analysis simulates experimental results of load-deflection and failure criteria pretty well for the test deck. Thus it is considered that real behavior of the deck can be predicted fairly well by analysis.
5. Composite deck bridge constructed first time in Korea well demonstrates that composite deck can be one of the alternative methods for the bridge upgrade and illustrates the feasibility of application of composites to civil infrastructures.

### **Acknowledgements**

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### **References**

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