International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 13, Issue 4 (April 2017), PP.58-66

Experimental Evaluation of Fatigue Performance of Steel Grid Composite Deck Joints

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ABSTRACT:- The steel grid composite deck is a composite structure made of a concrete slab disposed over a steel grid. The joints of the deck segments precast with regular width can be designed by means of lap-spliced rebar or mechanical connection composed of concrete shear key and bolts. This study intends to evaluate comparatively the fatigue performance with respect to the type of joint based upon the results of fatigue tests conducted on deck specimens equipped with such joints. The evaluation reveals that there is practically no change in the stiffness regardless of the type of joint even after 2 million loading cycles and that the safety and serviceability are secured under cyclic loading since the maximum crack widths remained below the allowable values.

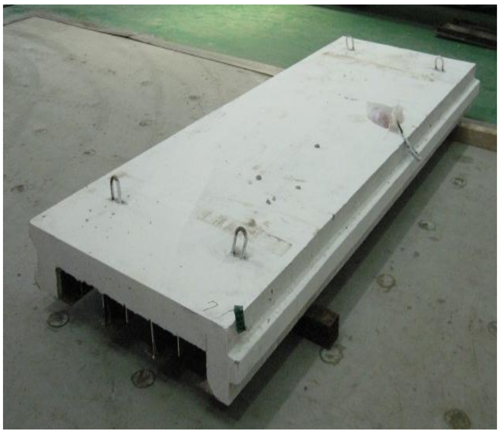
Keywords:- Composite deck, Joint, Mechanical connection, Lap-spliced rebar, Fatigue performance

I. INTRODUCTION

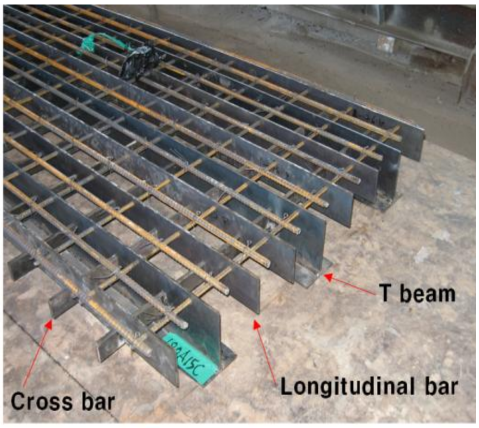
The steel grid composite deck is a deck in which a concrete slab is disposed over a steel grid (Fig.1). In this composite structure, the steel grid itself is composed of T-beams, which take charge of the flexural tension, and cross bars, which connect the beams perpendicularly. Following the adopted design method, the cross bars are sometimes connected perpendicularly by longitudinal bars to strengthen the grid. The composition between the steel grid and concrete slab is secured by shear connection installed on the top of the T-beams [1-8].

The joints of the steel grid composite deck can be realized by lap-spliced rebar as in the precast concrete deck (Fig. 2(a)). Recently, mechanical joints have been proposed by using concrete shear keys and bolts (Fig. 2(b)). Both types of joint can be applied for the connection of prefabricated composite deck segments and can bring substantial shortening of the construction period [6-9].

Even if the static flexural performance is of importance for the steel grid composite deck structure including the joints, it is also necessary to verify its behavior and fatigue performance when subjected to cyclic concentrated loading. Therefore, this paper intends to evaluate the safety and serviceability of the composite deck under cyclic loading considering whether the lap-spliced rebar or the mechanical joint is applied to connect the deck segments. To that goal, the experimental results acquired through fatigue test on decks applying both types of joint were analyzed [9]. In particular, the changes in the maximum deflection and in the maximum crack width were observed at each loading stage (1, 10, 100, 1,000, 10,000, 100,000, 500,000, 1 million, 1.5 million and 2 million loading cycles) and the data were compared to the allowable values. Moreover, the static flexural performance of deck specimens after the completion of the fatigue test and of undamaged deck specimens were compared to verify the occurrence of any loss of the flexural rigidity and flexural strength caused by the fatigue load.

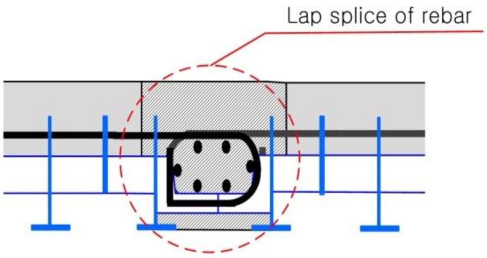


(a) Complete deck structure

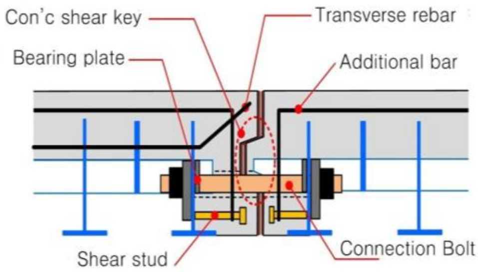


(b) Steel grid structure

Fig. 1: Steel grid composite deck [7, 8]



(a) Lap-spliced rebar



(b) Mechanical connection

Fig. 2: Details of steel grid composite deck joints [6-8]

II. TEST METHOD AND ANALYSIS OF TEST RESULTS

A. Test method

Table 1 arranges the designation and specifications of the steel grid composite deck specimens considered for the static bending and fatigue tests. For the fatigue test, the deck specimens JD9B-F and JDLS-F with mechanical and lap-spliced rebar joints, respectively, were loaded using an actuator with capacity of 500 kN. One specimen with width of 2.0 m and span length of 2.5 m was fabricated for each series. The load was applied through a 230×580 mm loading plate to simulate a truck wheel with reference to the Korean Standards for Road Bridge Design [10]. The behavior of the decks was measured by means of strain gauges and displacement sensors(LVDT), and the crack width by means of crack gauges installed at the bottom in the mid-span of the decks. The applied load was set to 125 kN considering an impact factor of 1.3 to the design wheel load of 96 kN, and was applied with a frequency range of 3 to 5 Hz. The measurement took place at 1, 10, 100, 1,000, 10,000, 100,000, 500,000, 1 million, 1.5 million and 2 million loading cycles. Static test was conducted after each of these loading cycles to measure the maximum deflection and crack width [9].

In addition, three-point bending test was performed to compare the static performance of the deck specimens that completed the fatigue test to those of undamaged specimens (JD9B-C and JDLS-C). For the static test, loading was applied through displacement control at speed of 0.01 mm/s [9].

Figs. 3 and 4 illustrate the setup of the specimens for fatigue test, and Fig. 5 shows the details of the specimens.

Table 1. Designation and specifications of deck specimens for static and fatigue tests [9]

Test method	Designation of specimen	Type of joint	Number of specimens	Remarks
Static bending test	JD9B-C	Mechanical connection (concrete shear key + bolt)	1	Reference specimens for comparison of the loss of flexural performance due to fatigue loading
	JDLS-C	Lap-spliced rebar	1	
Fatigue & static bending test	JD9B-F	Mechanical connection (concrete shear key + bolt)	1	Specimens for evaluation of fatigue performance with respect to type of joint (execution of static test after completion of fatigue test)
	JDLS-F	Lap-spliced rebar	1	

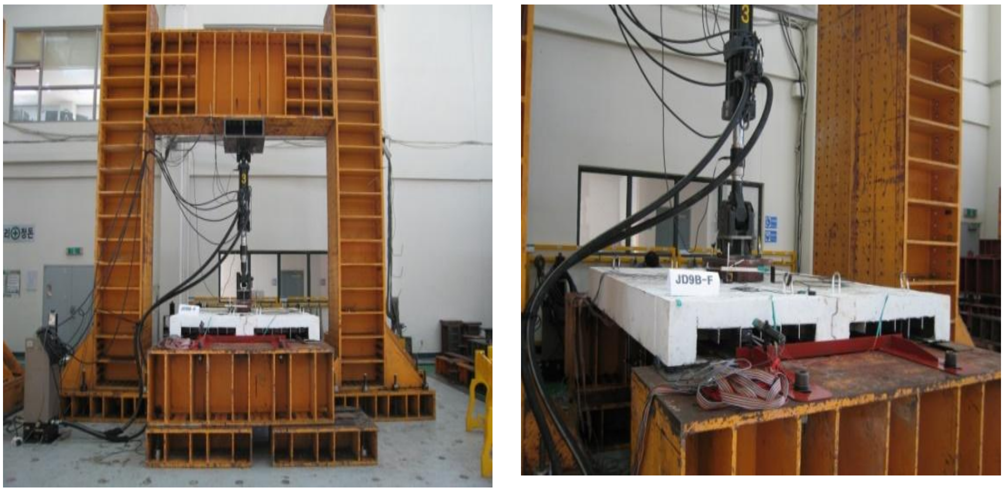


Fig. 3: Setup of deck specimens with mechanical joint (JD9B-F) [9]

Fig. 4: Setup of deck specimens with lap-spliced rebar joint (JDLS-F) [9]

(a) JD9B (b) JDLS

Fig. 5: Details of steel grid composite deck specimens [9]

B. Analysis of test results

A load of 125 kN was applied up to 2 million cycles to evaluate the fatigue performance of the deck specimens. Static test was conducted at definite loading cycles to compare the maximum deflection and maximum crack width plotted in Figs. 6, 8 and 9. Fig. 6 compares the change in the maximum deflection measured at mid-span according to the number of loading cycles. It appears that specimen JD9B-F equipped with joints made of concrete shear keys and bolts did not experience significant change from the reference deflection of 1.6 mm. Moreover, specimen JDLS-F with joints made of lap-spliced rebar did also show no particular variation from the reference deflection of 1.8 mm. The maximum deflections of specimens JD9B-F and JDLS-F correspond respectively to 52% and 58% of the allowable deflection of 3.1 mm recommended by the Korean Standards for Road Bridge Design [10] for a span length of 2.5 m. This indicates that the steel grid composite deck itself and its joints did practically experience no change of their stiffness even after 2 million loading cycles.

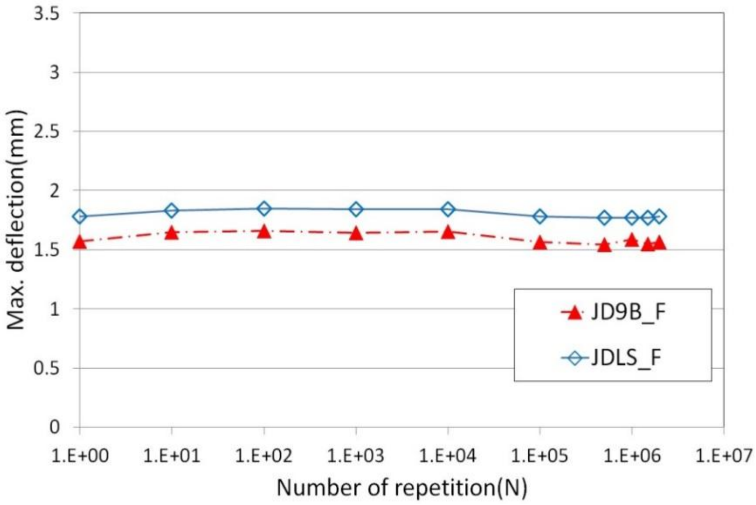


Fig. 6: Variation of maximum deflection at mid-span according to the number of loading cycles

Fig. 8 plots the variation of the maximum crack width developed in concrete at the bottom of the deck according to the number of loading cycles. Here, the maximum crack width corresponds to the one measured in the static test conducted after the fatigue test at each considered loading cycle and is the width of the crack developed under the application of the design load of 125 kN. Cracking of specimen JD9B-F initiated after 100,000 cycles and did not show significant change after 1 million cycles. Besides, specimen JDLS-F cracked since the start of the test and developed comparatively larger crack width than specimen JD9B-F. Fig. 9 plots the variation of the crack width according to the change in the load measured in the static test performed after 2 million cycles of loading. Moreover, Fig. 10 pictures the state of the joints in the deck specimens after 2 million loading cycles.

(a) Deck specimen with mechanical joint (JD9B-F)

(b) Deck specimen with lap-spliced rebar (JDLS-F)

Fig. 7: Measurement of crack width at bottom of joint [9]

Based upon the results shown in Fig. 8, the maximum crack widths of specimens JD9B-F and JDLS-F are respectively 0.035 mm and 0.077 mm, which correspond to 18% and 39% of the allowable crack width of 0.2 mm recommended by the Korean Standards for Road Bridge Design [10]. This indicates that the joints of the steel grid composite deck are satisfactory under cyclic loading in terms of safety and serviceability. The difference in the crack width exhibited by the specimens can be attributed to the arrangement of the reinforcement or the deformation characteristics of the whole structure according to the details of the joints. Numerical analysis shall be conducted in the future to have insight on the specific causes of such difference.

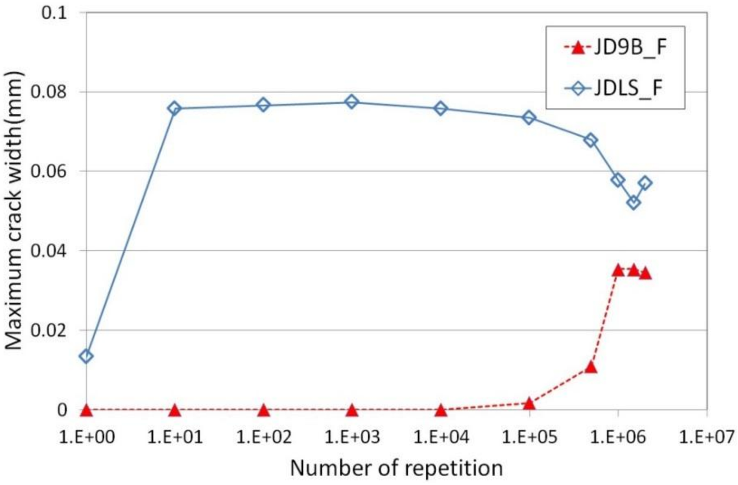


Fig. 8: Variation of maximum crack width according to the number of loading cycles

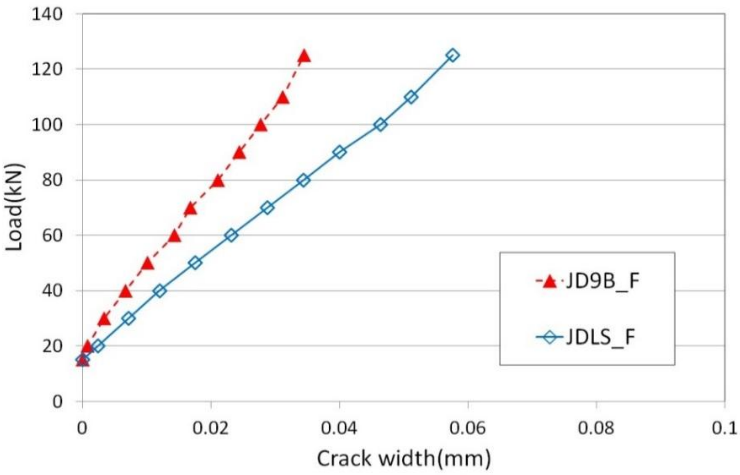
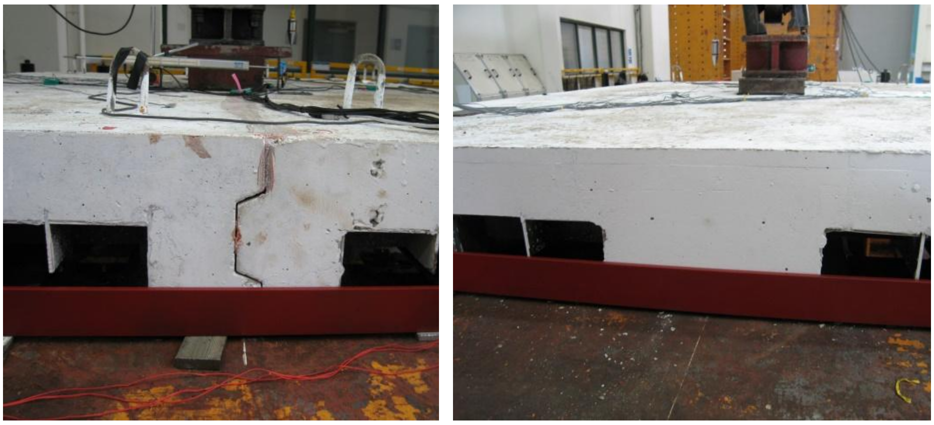


Fig. 9: Crack width measured by the static test after 2 million loading cycles



(a) Deck specimen with mechanical joint (JD9B-F) (b) Deck specimen with lap-spliced rebar (JDLS-F)

Fig. 10: State of the joints after 2 million loading cycles

The comparison of the static performance of the deck specimens that completed the fatigue test with that of undamaged specimens enables to verify the occurrence of any loss of the flexural rigidity and strength caused by the fatigue loading. Fig. 12 compares the load-deflection curves of specimens JD9B-F and JDLS-F to those of the undamaged specimens, and Table 2 summarizes the major experimental results. In view of Fig. 12, both specimens JD9B-F and JDLS-F did not experience loss of their performance until the maximum load but relatively steep loss of the load beyond the maximum load. This loss of the load was due to the occurrence of punching shear failure of the slab at the loading point. Note that the undamaged specimens JD9B-C and JDLS-C also experienced punching shear failure but with lesser loss of the load compared to specimens JD9B-F and JDLS-F. With regard to the maximum load, the values observed in the fatigue test specimens were relatively larger than those of the undamaged specimens. Moreover, the flexural rigidity appearing in the load-deflection curves also shows larger values for the fatigue test specimens.

In view of the comparison of the flexural performance, the fatigue load did not damage the joint even after 2 million cycles and appeared to have poor effect on the loss of the flexural rigidity and strength of the deck structure. Here, fabrication error may be pointed out as the cause of the relatively higher flexural rigidity and strength exhibited by the fatigue test specimens. The influence of the fatigue load on the slightly more brittle behavior exhibited by the fatigue test specimens at punching failure of the slab shall be examined experimentally and analytically in the future.

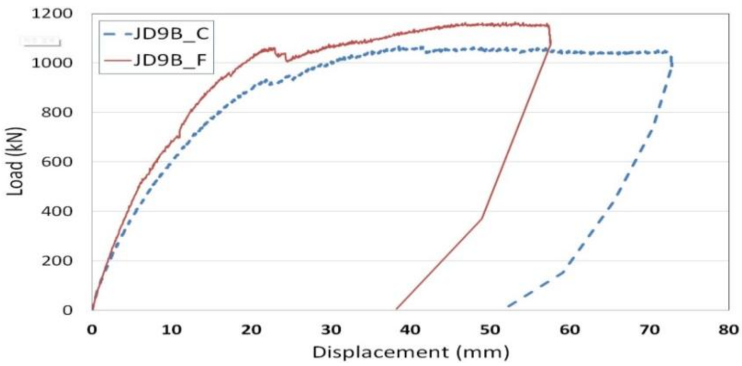
Besides, the failure load of the deck specimens measured in the static test and arranged by type of joint in Table 2 reveals that the mechanical connection realized by concrete shear key and bolt develops static structural performance equivalent to that of the monolithic joint formed by the lap-spliced rebar. The load at punching failure of specimen JD9B-C reached 936.6 kN and is similar to the punching failure load of 930.6 kN observed for specimen JDLS-C. Furthermore, the same similarity is observed in specimens JD9B-F and JDLS-F for which this load is respectively 1061.0 kN and 1075.6 kN. This indicates that both types of joint develop practically equivalent performance in terms of behavioral characteristics under fatigue loading and static structural performance.

Table 2. Static bending test results

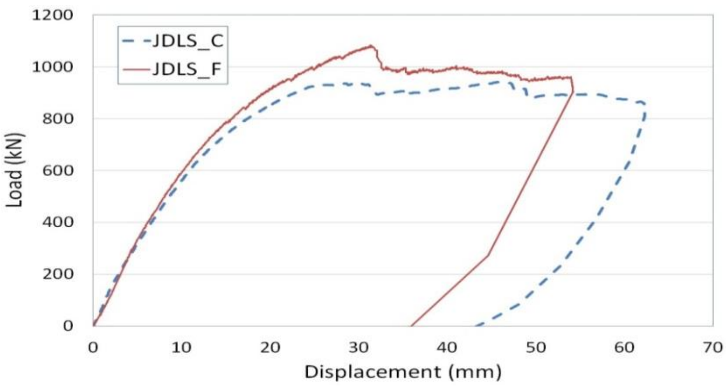
Specimen		**Yielding**		**Punching failure**		**Maximum loading**		**Final loading**	
		P_y (kN)	**$\square_y$ (mm)**	**$P_{f,test}$ (kN)**	**$\square_{f,test}$ (mm)**	**P_m (kN)**	**$\square_m$ (mm)**	**P_{final} (kN)**	**$\square_{final}$ (mm)**
Mechanical connection	JD9B-C	866.5	18.8	936.6	22.1	1065.3	41.5	1040.6	72.7
	JD9B-F	940.7	16.5	1061.0	22.9	1162.3	49.0	1152.7	57.4
Lap splice	JDLS-C	874.4	21.7	930.6	30.7	940.6	29.9	860.8	62.1
	JDLS-F	902.4	19.4	1075.6	31.6	1075.6	31.6	961.4	53.9

(a) Specimen JD9B-F (b) Specimen JDLS-F

Fig. 11: State of the joints and decks at maximum load



(a) Specimens JD9B_C and JD9B_F (mechanical connection)



(b) Specimens JDLS_C and JDLS_F (lap splice of rebar)

Fig. 12: Load-deflection curves measured in static bending test

III. CONCLUSIONS

The fatigue performance of the mechanical connection and lap-spliced rebar employed recently as joints in the steel grid composite deck were evaluated experimentally. The results showed that the maximum deflection of the deck with lap-spliced rebar and the deck with mechanical connection made of concrete shear key and bolt reached respectively 52% and 58% of the allowable value recommended by the Korean Standards for Road Bridge Design, and showed practically no change according to the number of loading cycles. This indicated that the decks did suffer nearly no change of their stiffness. Moreover, the width of the cracks developed at the bottom of the joints and mid-span of the decks was seen to be maximum 0.035 mm for the mechanical connection and 0.077

mm for the lap-spliced rebar joint, which correspond respectively to 18% and 39% of the allowable crack width of 0.2 mm specified by the Korean Standards for Road Bridge Design. These observations confirmed the safety and serviceability of the deck joints under fatigue loading. The comparison of the static flexural performance of the fatigue test deck specimens and those of undamaged specimens enabled to verify the occurrence of eventual loss of the flexural rigidity and strength caused by the fatigue loading. From the comparison, the fatigue load did not damage the joints even after 2 million cycles and appeared to have poor effect on the loss of the flexural rigidity and strength of the deck structure. The analysis of the behavioral characteristics under fatigue loading and of the static flexural performance showed that the mechanical connection realized by concrete shear key and bolt developed static structural performance equivalent to that of the monolithic joint formed by the lap-spliced rebar. There was also no particular difference in term of safety and serviceability. Accordingly, both types of joint are applicable and the type of joint to be applied shall be chosen appropriately with respect to the structural type and site conditions at hand.

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