A Draft Design Code for Steel-Concrete Composite Slabs in Japan

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Summary

Design codes of the composite decks based on a limit state design method which are proposed by the Committee on Composite Structures in JSCE are introduced . There are many types of composite decks. But, the essential types are two such as concrete encased type and steel plate concrete composite deck. This paper reports concretely the design codes about the latter steel plate concrete composite decks.

1. Introduction

Reinforced concrete slabs (hereafter RC slabs) have been used for the decks of highway bridges with their lower cost and easier construction than other types of decks. But, since about 1966, heavy deterioration problems have occurred due to repetitions of heavy traffic loads and penetration of rain water. Therefore, development of durable decks has been required and some prestressed slabs, concrete filled steel grillage decks and steel plate concrete composite decks were developed. These tendencies are accelerated by recent decreasing of field workers and new demands to built bridges more economically. Composite decks seem to be favorable decks because they can be fabricated by semi-prefabrication. Also they will become more lighter than RC slabs and more durable. Various types of composite decks have been developed or proposed. But until now, a rational design method was not prepared for those composite decks except the one for grating slabs.
The task committee for composite structures(chairman is Prof. H.Nakai) of the sub-committee for ultimate strength, the committee of steel structures, JSCE has been discussing for these 3 years to propose the design codes for composite structures. Last year, the draft of the codes were completed and now the draft is under checking. This paper is introducing a part of the draft of composite decks, thus, about steel plate concrete composite deck and the detailed basic data are described.

2. Outline of the Draft Codes for Composite Decks

Table 1 shows the contents of the design codes for composite decks. In Chapter 1~6, common requirements for all kinds of composite decks are codified. The decks have to be checked with three limit states such as the ultimate limit state, the serviceability limit state and the fatigue limit state. When a deck is used for highway bridges, the ultimate strength of the deck will be very large comparing to the design wheel load and therefore the check

Table.1 Contents of the draft code for composite decks

Chapter 1. General
Chapter 2. Materials
Chapter 3. Analysis
Chapter 4. Strength and Quality of Materials
Chapter 5. Verification for Limit States
Chapter 6. Details of Composite Decks
Chapter 7. Design Robinson Type Composite Deck for Highway Bridge
Chapter 8. Design Grating Deck Slab for Highway Bridge

for the ultimate limit state can be neglected.
Fatigue limit state, however, should be checked, because the deck on highway bridge is subjected to high cycles of loading of wheel loads. Under running wheel loads, the fatigue failure modes can be presumed to be different from the ones obtained by the ordinary pulsating loading method. Until now, the fatigue characteristics under running wheel loads of only the two types of the composite decks were obtained and proved. Therefore, considering the different fatigue failure modes, special design codes for the steel plate concrete composite decks (Robinson type deck) and the concrete encased steel grille slabs (grating slabs) for the design of highway bridges are prepared in Chapters 7 and 8.

3. Design Codes for Steel Plate-Concrete Composite Decks

3.1 Features of Steel Plate-Concrete Composite Decks

Fig.1 shows an essential type of steel plate-concrete composite decks named as Robinson deck. Studs are used for the shear connectors between the steel plate and concrete slabs. Steel plate acts as scaffolding of concrete when casting concrete. After hardening of concrete, the steel plate will develop a great bending rigidity due to composite action combined with concrete as the reinforcements in RC slabs. They acts as tensile members. Also, there are some cases that the steel plates are stiffened by ribs at bottom surface or top surface. When the ribs are arranged, as they act as shear connectors, the number of studs can be reduced.

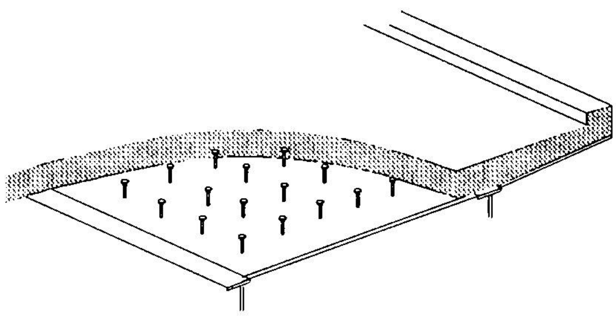

Fig.1 General view of steel plate concrete composite deck

When the deck is applied on the multi-girder bridges, the deck becomes a continuous deck and on the supporting girders negative moments will develop. To resist for the negative moment, near the top surface appropriate numbers of reinforcements should be arranged. As shown in Table 2, there are several actual bridges having the composite slab constructed and the almost slabs are designed with the design codes for RC-slab. In those cases, the steel plates act as top flanges of the supporting girders simultaneously.

Table.2 Actual bridges with composite decks

Bridge Name	The examples of the composite slab with stud	Slab span length
Nishinagahori Ramp Bridge	Hanshin express way public corporation	1.775m
Katamachi Bridge	Osaka city office	2.625m
New Osaka Castele Bridge	Osaka city office	1.700m
Tanaka Bridge	Asago village office	3.000m
Kanari Bridge	Asago village office	3.000m

3.2 Bending Moments to Design the Cross Section of the Deck

Bending moment distributions of decks under considerable severe loading of wheel loads are analyzed by FEM Analysis. Then, the maximum bending moments acting orthogonal directions in a deck were plotted and investigated with the span length as shown in Fig.2. The analytical results can be said to have a linear relation to the span length. In the large span region over 5m, the effect of the front axle weights becomes large and has to be considered on the maximum bending moments for design.

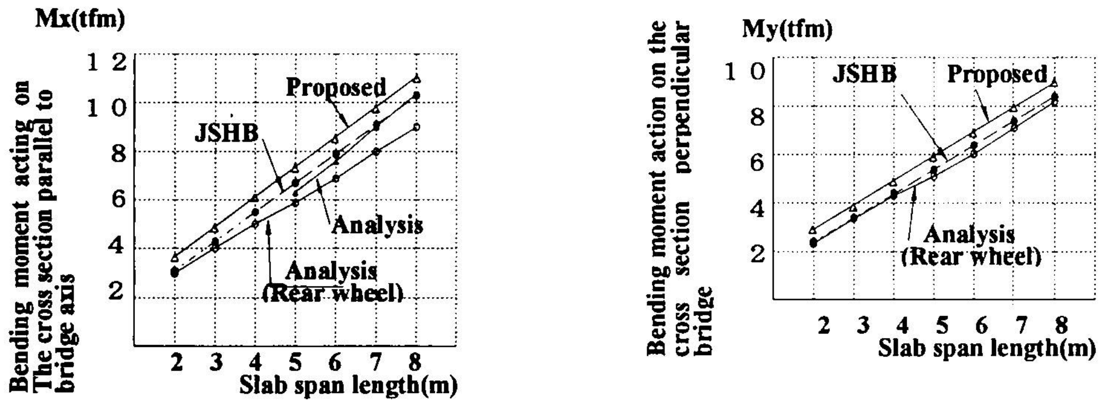

Fig 2. Design bending moments for steel plate concrete composite decks

By covering the maximum bending moments and giving some safety margin to the analytical results, bending moment formulae can be proposed. The upper straight lines are the formulae. Those are given with some safety margin from 20%(for slab span 2m) to 8% (for slab span 8m). The decrease of the safety margin as the span length becomes large is due to the decrease of probability of simultaneous loading of heavy wheels as the design

Table.3 Bending moments formula for continuous steel plate concrete composite decks.

Deck System	Aimed Section	Span Length(m)	Bending Moment: On cross section parallel to bridge axis	Bending Moment: On cross section perpendicular to bridge axis
Simple span	Span center	2≦L≦8	+(0.114+0.144)×P	+(0.095L+0.098)×P
Continuous deck	Span center	2≦L≦8	+80% of simple span	+80% of simple span
	On support		-80% of simple span	
Cantilever	On support	0<L≦1.5	-PL/(1.3L+0.25)	
	Free side			+(0.15L+0.13)×P

L ; Slab span
P ; Wheel load(=10t)

load.
The proposed bending moment formulae are the essential bending moments for a one-way slab of single span deck. Generally, the decks, however, will be continuous plates over multiple number of girders. Therefore, the formulae should be modified available to continuous decks. Table 3 is the final proposal about the bending moments for steel plate concrete composite decks.

3.3 Verification for Limit States

Essentially, for the decks of highway bridges the verification for the ultimate strength may be neglected because the ultimate strength becomes very large such as 8 to 10 times of the design wheel load. Never the less, deterioration will occur due to fatigue by running wheels and environmental effects. Therefore, for the design of decks a working stress method or an allowable stress method seems to be appropriate. But, this design method had to be expressed by an ultimate strength format. Here, the allowable stresses were set as 1/3 of compressive strength for concrete and 1/1.7 of yielding stress for steel plate. Then, by multiply the factors 3 or 1.7 to the bending moments, the intended cross section can be verified by the compressive strength for concrete surface and the yielding for the tension side steel plate.
Verification for fatigue on the main materials of concrete and steel plate can be neglected when the above mentioned design procedures is applied.

3.4 Minimum Requirements for Cross Sections

3.4.1 Steel plate thickness
For the decks of under 3m span length, the thickness of steel plate seems to be enough by 6mm. In the existing decks 4.5mm plate were frequently used. The thickness can be decided by the stress state. However, some problems are there such as fatigue failure of the steel plate at the welding parts of jointing or the places of stud welding and deformation by welding. Also, in Japan to obtain those thin steel plate is little bit difficult than normal thickness ones. Furthermore, treatment at the factory is more easy for the normal thickness plate than the thin ones. Considering the above mentioned problems and the margin for corrosion, the minimum thickness is decided as 8mm for the composite decks. For the wider

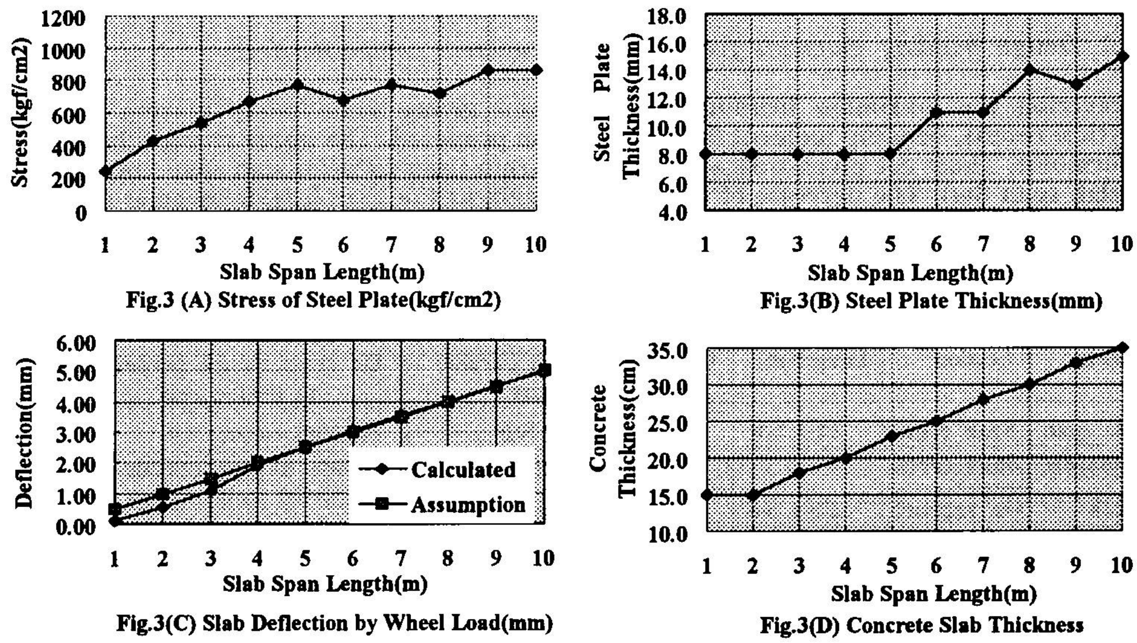

Fig.3 (A) Stress of Steel Plate(kgf/cm2)

Fig.3(B) Steel Plate Thickness(mm)

Fig.3(C) Slab Deflection by Wheel Load(mm)

Fig.3(D) Concrete Slab Thickness

Fig.3 Calculation results of steel plate concrete composite decks.

deck than 6m span length, the steel plate thickness becomes more thick than 8mm. Fig.3(A) and Fig.3(B) are shown the relations of the steel plate stress and required steel plate thickness to the span length respectively.

3.4.2 Concrete slab thickness

The concrete slab thickness on the steel plate can be reduced than the ones of ordinary RC slabs due to composite action with steel plate. This idea is supported with many experimental tests. However, in the case that a remarkable thin slab is used, deflection becomes large inducing some local deterioration of concrete and some harmful cracks occur on the top surface due to repetition of torsional bending moment. The cracks becomes penetration crack through full depth by joining the both cracks from the bottom and top surface which decreases the bending rigidity of the deck. Also, when the water penetration occurs into the cracks from top surface, the concrete will show early deterioration by fatigue.

Therefore, a limited thickness of concrete layer on the steel plate is required. From experimental knowladges, concrete thickness seems to be appropriate when the deflection under design loads is kept less that L/2000, where L is slab span length. When the concrete thickness is given likes the Fig.3(D), the deflection becomes under the assumption. In the draft, the thickness is decided as the following equation;

$$hc\ (cm) = 2.5 \times L\ (m) + 10$$

The minimum thickness was set to 15cm by the construction performance.

Fig.3(C) and Fig.3(D) are shown the relations of slab deflection and the concrete slab thickness to slab span length, respectively.

3.5 Design of Studs

3.5.1 Fatigue tests with wheel Running Machine

The authors have carried out many fatigue tests on the steel plate-concrete composite decks with the Wheel Running Machine. The machine is to give a running wheel load on the specimen as shown in Fig. 4 . It was developed to simulate the running wheel loading which was found out the most important factor of the fatigue of decks on highway bridges.

From the fatigue tests of the composite deck, the predominant fatigue failure mode was detected as shear-off failure of stud as shown in photo.1. When the deck is loaded by pulsating load on a fixed point, the failure mode will be a break of steel plate initiated at the welding points of studs. The difference of fatigue modes is caused by the difference of moving or not moving of wheel loads.

Under the running wheel load, the studs are subjected to rotating shearing forces and then the shear-off failure occurs. The authors are thinking the fatigue test method by the wheel running machine is favorable one by simulating the running of vehicles. Therefore, in the draft, the authors have recommended to do fatigue design for the studs considering shear-off failure of studs. The codes gives how to calculate the shearing force on studs and the limitation shear stress to avoid the fatigue failure.

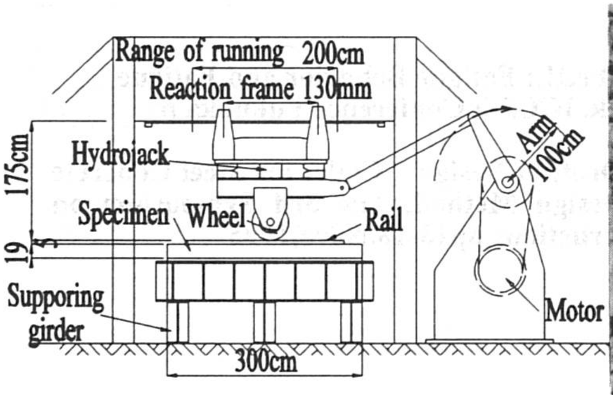

Fig.4 Wheel running machine

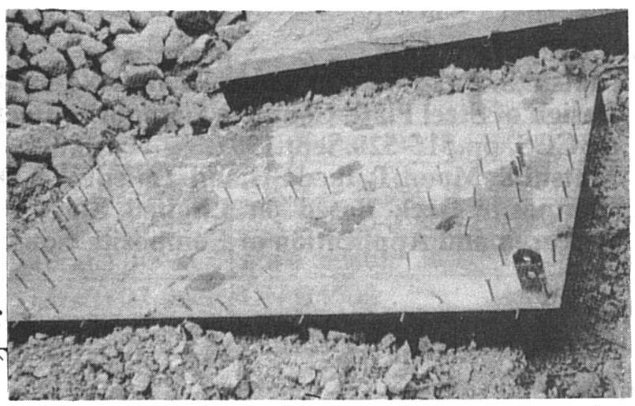

Photo.1 Typical shearing failure of studs

3.5.2. Allowable shearing stress of studs

As mentioned in the above, the studs fail by shear-off under running wheel load. The fatigue strength is evaluated by the shearing stress as shown in Fig.5. In the figure, the S-N data of push-out test method are presented simultaneously. Comparing the present data with the S-N data, the present fatigue strength seems to decrease to only 30-40% of the one of the push-out test. The reduction is very remarkable. It seems due to rotating shear force on studs by running of wheel.

To investigate more quantitatively the fatigue strength, the authors have developed a quite original fatigue device to give rotating shear force on a stud and have carried out many fatigue tests. The test results are also plotted by the black circles. The data situate little bit lower side than the data obtained from deck specimens(white circles). So, it can be understood that when the data obtained from single stud test are applied for the design, the result becomes conservative. On the other hand, the data obtained from the single stud have somewhat large scatterness and the slope of the mean S-N curve is very flat. So, through much discussion the constant shear stress of 5kg/mm2 is recommended as the allowable stress to prevent fatigue failure of studs.

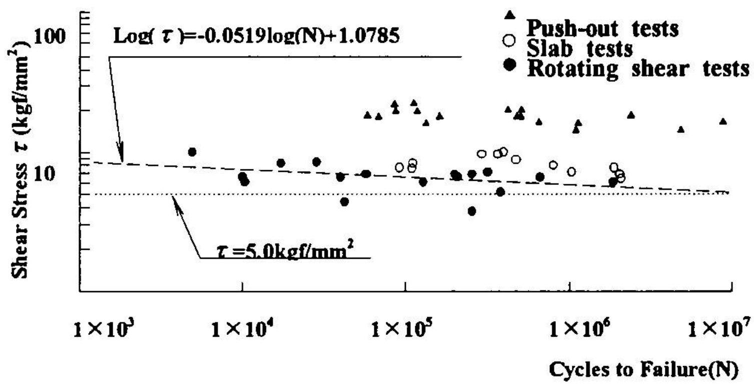

Fig.5 S-N results of studs (φ16)

4. Concluding remarks

In Japan, another types of shear connectors are developed. For those shear connectors or decks, the fatigue design method has to be investigated by another research works. At the time, the fatigue test method described here seems to be available. When this composite slabs is fabricated by precast type, the jointing between precast slabs becomes as a big problem. Various type of joints can be imagined but their durability should be checked by the fatigue tests.

REFERENCE

1) Matsui,S. Fukumoto,Y. Moon,T. and Watanabe,H,: Fatigue Behavior and Fatigue Design of Steel Plate-Concrete Composite Deck, ICCS-3 Conference Fukuoka by ASCCS, pp.515-520.Sept.1991.
2) Matsui,S. Moon,T. Ikeda,H.and Takeda,Y,: Draft of Design Codes for Steel Concrete Composite Deck Based on Limited State Design Method, The 3rd Symposium on Research and Application of Composite Constructions,pp13-18,Nove,1995