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# Fatigue Strength of Steel Plate-Concrete Composite Deck

Résistance à la fatigue de dalles mixtes acier-béton

Ermüdungsfestigkeit von Verbunddecks

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## SUMMARY

Fatigue failure characteristics of a steel plate-concrete composite deck for highway bridge under a wheel trucking machine are summarized. The typical failure is shearing-off of studs, which is quite different from the test results by ordinary fixed pulsating loading. To verify the fatigue strength, a new fatigue testing machine which gives rotating shear force to a stud was developed. The test results by the machine were also shown in comparison with the deck specimen tests.

## RÉSUMÉ

Cet article récapitule les caractéristiques de rupture due à la fatigue d'une dalle mixte acier-béton prévue pour un pont autoroutier, sous l'effet du passage d'un camion lourd. La rupture typique intervient par cisaillement des goujons, laquelle est sensiblement différente du résultat des essais sous charge pulsatoire comme cela est fixé d'ordinaire. Une nouvelle machine d'essai de fatigue, développant une force rotative de cisaillement dans le goujon, a été mise au point afin de vérifier la résistance à la fatigue. Les résultats des essais avec cette machine sont donnés et comparés à ceux des essais spécifiques sur un échantillon de dalle mixte.

## ZUSAMMENFASSUNG

Die Kriterien für die Ermüdungsfestigkeit von Verbunddecks für Strassenbrücken unter Radlasten werden zusammengefasst. Das typische Versagen ist der Dübelbruch, ganz im Gegensatz zum Verhalten unter pulsierenden festen Einzellasten. Zur Erprobung der Ermüdungsfestigkeit wurde ein Testgerät entwickelt, welches eine rotierende Scherkraft auf die Dübel ausübt. Die Versuchsergebnisse von Testgerät und Brückendeck werden verglichen.



1. INTRODUCTION

In Japan, development of durable decks is expected from the experience of deterioration of reinforced concrete slabs of highway bridges[1]. The authors have been developing a composite deck which consists of steel plate and concrete slab as shown in Fig.1 and studying the behaviors to establish a reasonable design method especially for fatigue[2]. The paper describes the fatigue test results using the wheel trucking machine which is newly developed to simulate running of wheels on actual deck[3]. The fatigue failure phenomena are quite different from the existing test results obtained by the ordinary fatigue tests in which a pulsating load is given on a fixed point of the model deck by hydraulic jack. The typical failure mode by the new testing method is shearing-off of studs from steel plate, as against that the cracking of steel plate at the root of welded studs were observed in the ordinary fatigue tests.

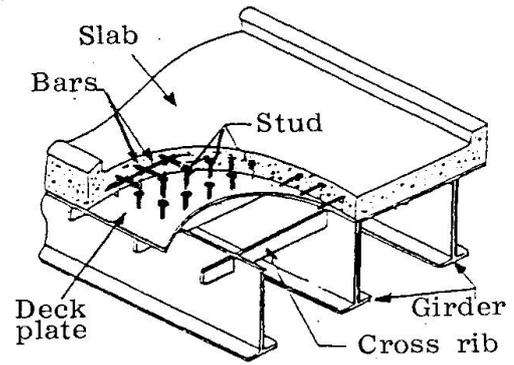


Fig.1 General view.

2. FATIGUE TESTS OF DECK SPECIMENS BY WHEEL TRUCKING MACHINE

2.1 Test specimens

In order to increase fatigue lives of the composite decks, the shearing forces acting on a stud must be reduced, for example, by increasing the number of studs or flexural rigidity of the deck, or by using studs in combination with other mechanical connectors. Steel plate, slab thickness and stud spacing are selected as the factors of the experiments as shown in Table 1. Seven specimens were arranged. Fig.2 shows the typical dimensions of the test decks. The thickness of steel plate is 6mm and the height of headed studs is 11cm.

Specimen	Steel plate	Slab thickness (cm)	Pitch of studs (cm)	Concrete strength (N/mm <sup>2</sup> )
2A-1	Flat pl.	12	20	40.6
2A-2	Flat pl.	12	20	40.6
2A-3	Flat pl.	12	20	47.8
1A	Flat pl.	12	10	40.6
2C-1	Checker	12	20	47.8
2C-2	Checker	12	20	47.8
2T	Flat pl.	15	20	47.8

Table 1 Characteristics of specimens.

2.2 Fatigue testing apparatus

Fig.3 shows the outline of the wheel trucking machine

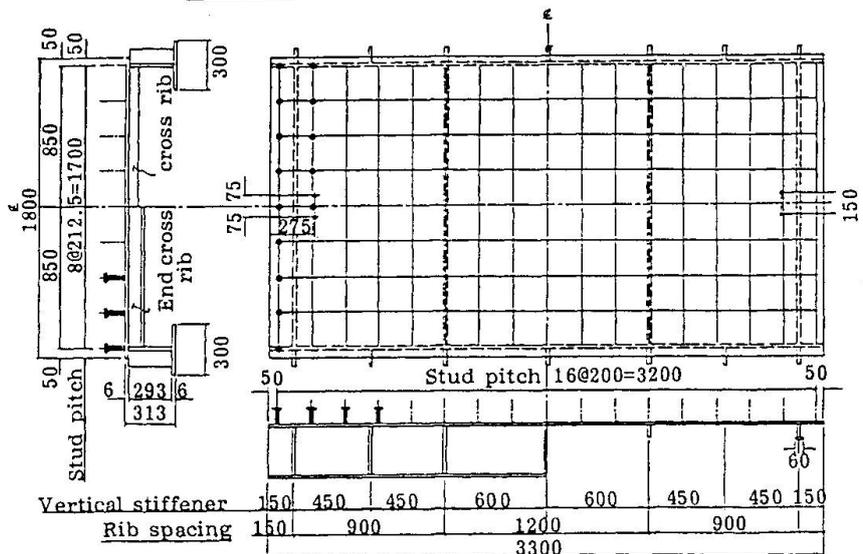


Fig.2 Typical Dimensions of specimen.

used for fatigue test of the deck specimens. The performance of the machine are as follows:

- Maximum loading capacity: 300N,
- Maximum stroke range : 2m,
- Stroke speed: 28 strokes/min.

### 2.3 Fatigue test results

The loads and number of cycles applied to each specimens are summarized in Table 2. Fig.4 shows a typical changing of strain difference between two points where locate on the plate surface front and back apart from a stud center by 20mm, as shown in Fig.4. The difference occurs due to a local bending of the plate at the base of stud. As the loading cycles progress, it can be seen that the difference in strain decreases from a constant level. From the fact, it can be presumed that a fatigue crack has initiated at the base of stud in coincidence with the changing point, and the stud has failed at the time of the difference becoming to zero.

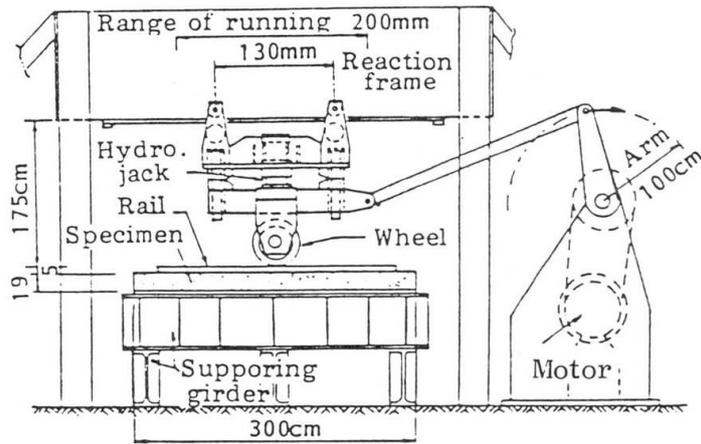


Fig.3 Wheel trucking machine.

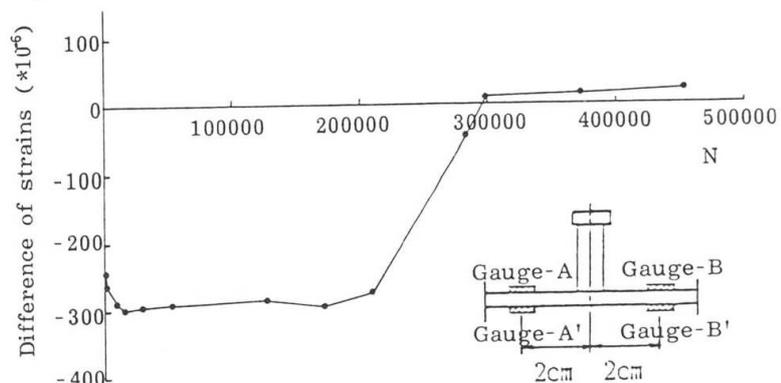


Fig.4 Change of strain difference.

Specimen	Cycles (load)
1A	$500 \times 10^3$ (100kN)
	$+155 \times 10^3$ (150kN)
2A-1	$227 \times 10^3$ (100kN)
2A-2	$267 \times 10^3$ (100kN)
2A-3	$50 \times 10^3$ (100kN)
	$+150 \times 10^3$ (150kN)
2C-1	$500 \times 10^3$ (100kN)
	$+300 \times 10^3$ (150kN)
2C-2	$185 \times 10^3$ (180kN)
2T	$100 \times 10^3$ (100kN)
	$+ 50 \times 10^3$ (120kN)
	$+ 50 \times 10^3$ (150kN)
	$+250 \times 10^3$ (180kN)
	$+100 \times 10^3$ (210kN)

Table 2 Loading cycles(load) of each specimen.



Fig.5 Typical shearing-off of studs(2A-2).

To confirm the fatigue failure mode, the concrete was removed after the testing. In the specimens of the type 2A, many studs had been sheared off as shown in Fig.5. In the figure, the bent studs were sound ones. They were



checked by bending whether any fatigue crack had occurred during the tests. In the ordinary fatigue tests for the decks, however, the typical fatigue failures were cracking of steel plates at the root of studs[4]. In highway bridges, since the live loads are running vehicles, the fatigue phenomena observed in this study seem to be more realistic and accordingly the actual decks must be designed for fatigue in accordance with the present test results.

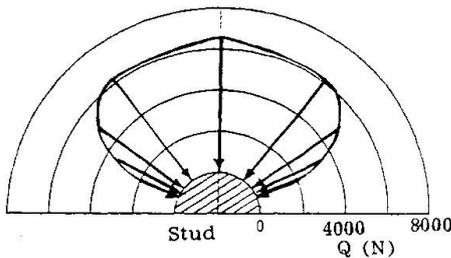


Fig. 7 Rotation of shearing force on a stud.

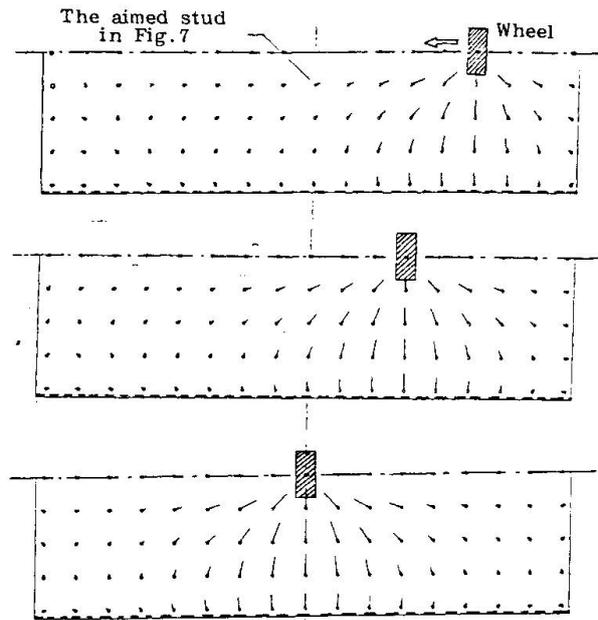


Fig. 6 Distribution of shearing forces to studs.

For the specimens of 1A, 2C-1, 2C-2 and 2T, the number of failed studs decreased remarkably although larger load than the ones of 2A-group were applied for long time. From those results, the effectiveness of the above mentioned three improvements were recognized.

To find out the reasons of the shearing-off of studs under a running wheel load, the authors analyzed the composite decks about shearing forces acting on studs by using a layered plate theory[5]. Fig. 6 shows the calculated distribution of the shearing force to studs. When paying attention to a stud, it can be seen that the shearing force changes its magnitude and acting direction rotates about  $160^\circ$  as the load moves from the right end to the left end, as shown in Fig. 7. The change of the direction of shearing force would be the main cause for shearing-off of the studs.

### 3. FATIGUE TESTS OF SINGLE STUD UNDER ROTATING SHEAR

#### 3.1 Testing machine and specimens

To make clear the fatigue strength of studs under rotating shearing forces, the authors have developed a new type fatigue testing machine which gives a rotating shearing force on single stud as shown in Fig. 8. The angle of rotation of specimen is  $165^\circ$  which is almost similar to the stud subjected to the maximum shearing force in the deck specimen. The shearing force is given by the springs and the magnitude can be adjusted by the eccentricity between the centroids of rotary bed and specimen. Fig. 9 shows a specimen before concrete casting. To prevent local crush and wear of concrete, a steel ring of 16mm thickness was used.

#### 3.2 Test results

Eleven specimens were tested. A typical failure mode of studs is shown in Fig. 10. All specimens have failed by shearing-off at the root of the stud. The failures can be classified into two types as shown in Fig. 11. When the

restraint for uplift of specimen is loose, the failure of the type I is apt to occur. Besides this failure mode, the main failure mode of the deck specimens was almost the type II because each stud was restricted to uplift by the surrounding studs and pressed down by the applied load.

**4. COMPARISONS OF FATIGUE STRENGTH**

In order to evaluate the fatigue strength of stud subjected to rotating shearing force, the test results obtained from two types of test were plotted in a S-N diagram having the ordinate axis of  $Q/Q_u$ , where  $Q$  is shearing force range and  $Q_u$  is the ultimate static strength in shear, as shown in Fig.12. The data obtained from the ordinary push-out test were also indicated in the figure. It is seen that the fatigue strength of studs subjected to

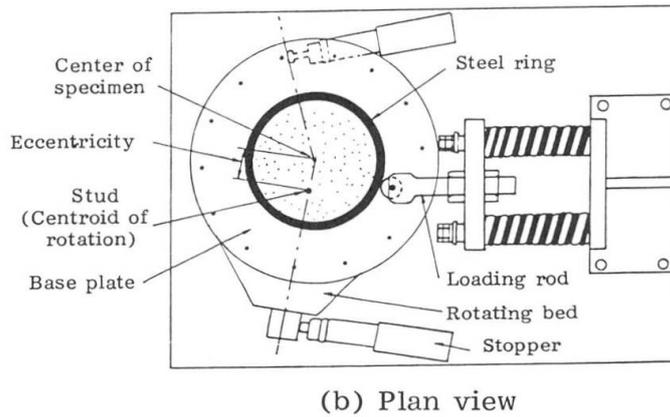
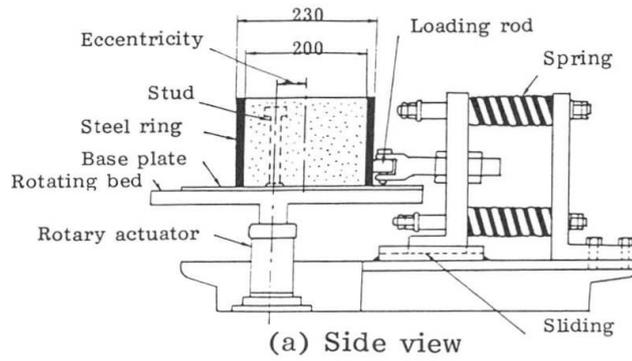


Fig.8 New fatigue testing machine for stud.

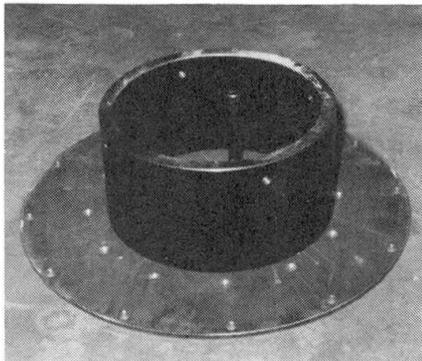
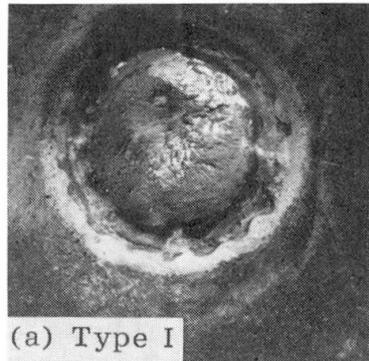
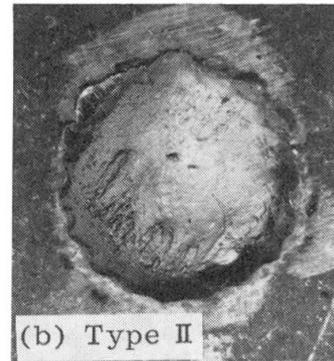


Fig.9 Specimen.



(a) Type I



(b) Type II

Fig.10 Typical failure results.

rotating shearing forces have remarkably decreased in comparison with those for the ordinary push-out tests. Alternation of the stress at any point of the welding part and a raise of the probability to initiate cracks at welding defects by the rotation of shearing force seem to be the main causes for the decrease of fatigue strengths of studs under rotating shearing forces. The fatigue lives of single stud under rotating shearing force seem to be slightly shorter than those of studs in the deck specimen. It may be caused by the

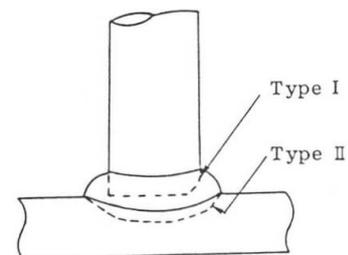


Fig.11 Failure type.



difference in speed of crack propagation. In the deck specimen, re-distribution of shearing forces to other studs will occur after initiation of a crack on a stud and it makes speed of crack propagation slow. On the other hand, in the test of single stud the speed of crack propagation raises up inversely due to decrease of cross area by the crack growing under a constant shearing force.

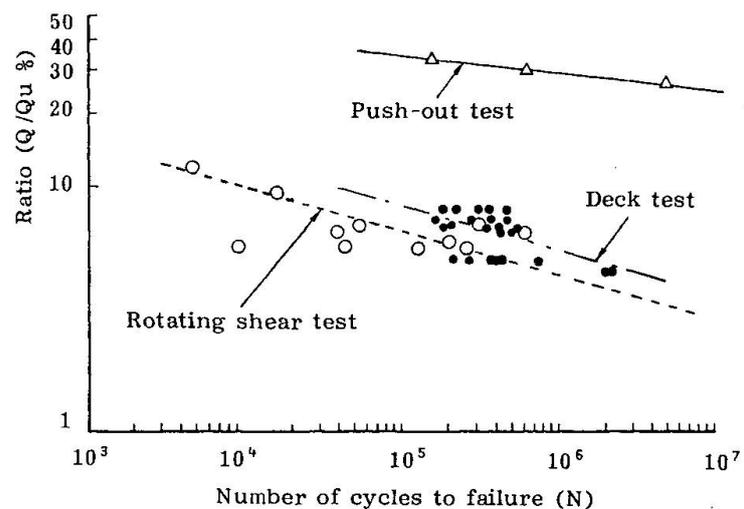


Fig.12  $Q/Q_u - N$  relations.

## 5. CONCLUSIONS

The fatigue characteristics of the steel plate-concrete composite decks using the studs under running wheel have been made clear. Furthermore, the fatigue strength of stud subjected to rotating shear force were made clear by the newly developed testing machine. The  $Q/Q_u - N$  relation obtained here presents the important effect to define the fatigue limit state of the composite decks using studs.

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