Prefabricated steel deck plates sandwiching concrete

Prefabricated Steel Deck Plates Sandwiching Concrete

Chaussées de ponts préfabriquées à section mixte en sandwich, acier-béton-acier

Vorfabrizierte stählerne Fahrbahndecken in Verbundbauweise

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1. Introduction

With a recent remarkable increase of traffic, some of the slabs have often collapsed within a much shorter time than a serviceable life of main girders. Consequently, it has been demanded to develope a new type of bridge deck which would have more durability and rigidity than ordinary ones. When a long-span bridge like a suspension bridge is to be built more economically, easily and fast, its deck plates as an overall member must be preferably prefabricated, too.

Recently, a new deck plate named Steel Deck Plate Sandwiching Concrete in prefab-type has been proposed by the authors in Japan, in order to solve the above mentioned problems. The proposed deck consists of two steel plates and concrete sandwiched between them. Upper and lower steel plates are connected witl stud bolts made of high strength steel, and stud shear connectors are welded to the both steel plates to resist against shearing forces between steel plates and concrete, making a steel-concrete composite deck plate. Photo. 1 shows a shop assembly of this deck plate before filling up concrete.

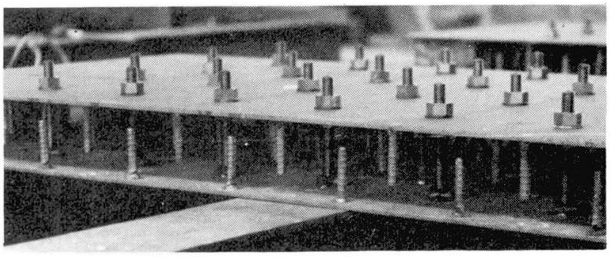

Photo. 1 Assembly of deck

Due to composite interactions, this deck plate has a larger flexural rigidity in comparison with its smaller thickness and light weight. The both surface steel plates would give an excellent durability and enable to use the deck plate as a continuous plate subjected to a negative moment.

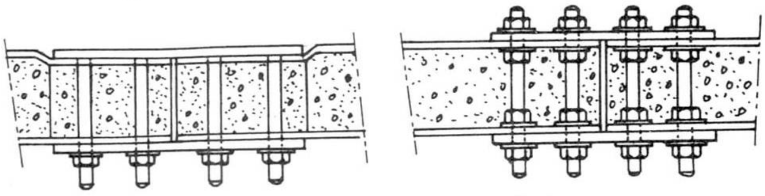

Fig. 1 Jointing of deck plates

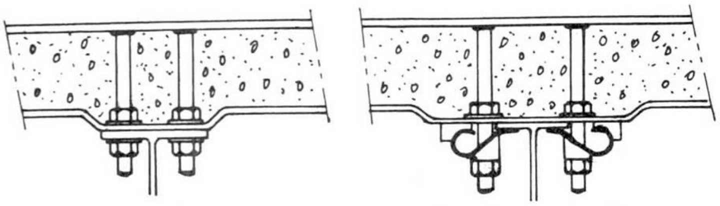

Fig. 2 Jointing of deck plate to beam

Jointing of one unit deck to other unit decks and of the deck to a steel beam, will be carried out simply and firmly at the construction site by using stud bolts in a friction type as shown in Figs. 1 and 2.

If stud bolts are substituted for shear connectors, named bolt shear connectors, between a deck plate and a supporting beam, this deck can be used for a slab of composite beam of highway bridges. Furthermore, this composite beam can be also used easily for a continuous composite beam subjected to negative moment near an intermediate support. The reduction of moment of inertia of an overall cross section neglecting of concrete in tention, is less than that of a conventional composite beam with a reinforced concrete slab. Therefore, an easy and simple prefabrication is possible for not only bridge decks, but also an overall bridge structure.

Tests on large-sized deck plates and composite beams of the proposed type have revealed that an application of the proposed deck to a bridge structure is possible in practice, and that their larger load-carrying capacity[1] and more improved structural behavior can be expected than ordinary slabs and composite beams.

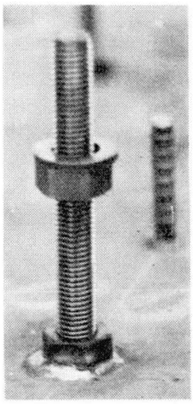

Photo. 2
Attaching of high-strength bolt

2. Fabrication of Deck Plate for Tests

A prototype deck plate is fabricated in the following sequence: (a) Welding of stud bolts to specified points on the upper surface plate and drilling of bolt holes in the lower surface plate. (b) Welding of stud shear connectors on the both upper and lower surface plates. (c) Attaching of inner bolt nuts and circular washers to stud bolts, to hold a specified distance between the both surface plates, and connecting the lower plate with the upper plate by applying a required torque through outer circular washers and bolt nuts. (d) Filling up concrete between the both surface plates, finally.

(e) In the case of fabricating composite beam, removing the outer nuts and washers, and then fixing deck plates to the beam like the connection of lower surface plates to upper surface plates in the deck plates.

In the fabrication of this deck, a method of welding of a nut made of mild steel to the surface plate and of screwing down a bolt in it, was used in place of stud welding of bolts, as shown in Photo. 2, because welding of high strength bolts as the studs seemed to initiate a crack at the welded part of bolts, due to a deterioration of bolt material.

3. Description of Specimens and Test Procedures

3.1 Description of test specimens

Plan views and profile sections of deck plate specimens are shown in Fig. 3. Deck plate specimens were classified into three series denoted by B-3, B-4 and B-6, according to spacing of studs and bolts.

Fig. 4 illustrates a cross section of composite beam specimens and spacing of stud bolts and stud shear connectors in the deck plate. Three test beams of the same type were prepared for the beam test, denoted by CB-1-1, CB-1-2 and CB-2.

3.2 Materials

Steel plate materials of all specimens were a structural carbon steel SS41 designated by JIS (Japanese Industrial Standards). As the result of static tension tests of those steel materials, stress at yielding point, tensile strength, and elongation were 3280kg/cm^2, 4960kg/cm^2 and 36% for the surface steel plates, and 2460kg/cm^2, 4370kg/cm^2 and 30% for the steel beams in composite beams, respectively.

Stud bolt materials were a high-strength low-alloy structural steel F11T for shear connectors and F9T for stud bolts of deck plate, designated by JIS.

An applied torque was 7500kg·cm for the bolt shear connectors and 3700kg·cm for the stud bolts of deck plate. Stud shear connectors on the deck plate were made of deformed bar designated SD30 by JIS.

High-early-strength concrete, of which mean compressive strength and modulas of elasticity at two weeks were $275 kg/cm^2$ and $2.14\times10^{-5} kg/cm^2$, respectively, was used for sandwiched concrete for all of the specimens.

3.3 Test procedures

For each specimen of the deck plate, a load was applied at the locations shown in Fig. 3 by a hydraulic jack of 200-ton testing machine. The test under this central-loading condition was conducted to determine such physical properties of the sandwiching structures as relation of load versus deflection, stress distribution, ultimate strength, reduction of stress concentration around the bolt holes of surface plate due to a use of high strength bolts, and whether the deck subjected to a negative moment had or not the same rigidity as the one subjected to a positive moment, in order to use it for a continuous deck plate.

In the composite beam tests, a load was applied at the location shown in Fig. 4. Specimens CB-1-1 and CB-1-2 were subjected to a positive moment and a specimen CB-2 was subjected to a negative moment. These tests were run to study basic behaviors of the composite beams, adaptability of stud bolts to shear connectors, ultimate strength, and whether it was proper or not to apply

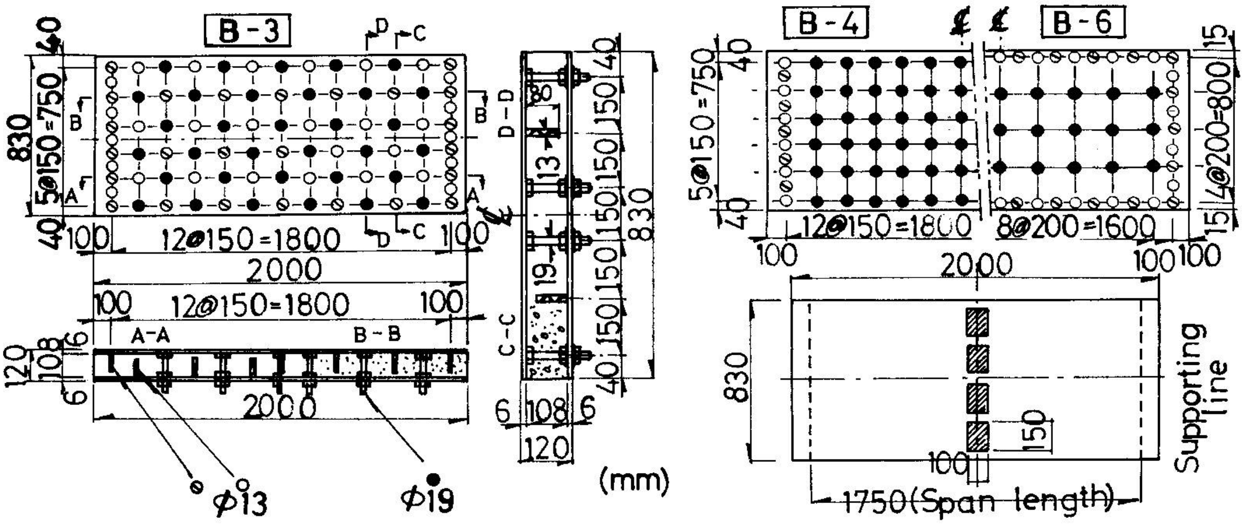

Fig. 3 Deck plate specimen and loading locations

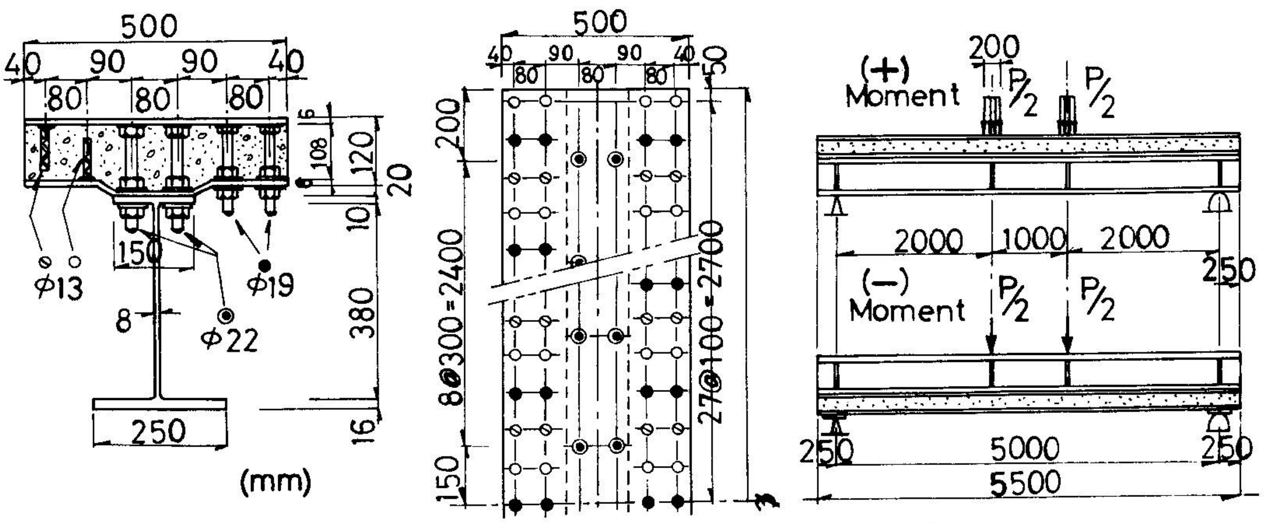

Fig. 4 Composite beam specimen and loding locations

these beams to a continuous composite beam. Photos. 3 and 4 show the both views of actual loading.

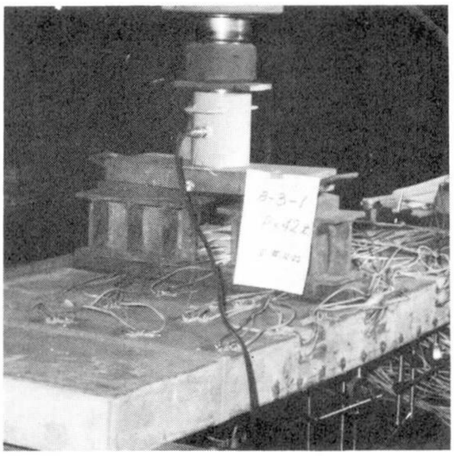

Photo. 3 Deck plate test

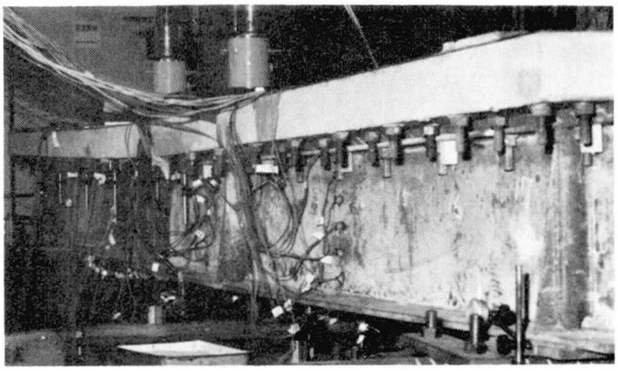

Photo. 4 Composite beam test

4. Test Result and Discussions

4.1 Deck plate test

4.1.1 Deflection and strain measurements

With regards to the test result, load versus maximum deflection and load versus maximum strain at mid-span are indicated in Figs. 5 and 6, respectively.

As is evident from the figures, the following characteristics could be recognized:

(a) The proposed deck plates are apt to deform due to shearing force. Their elastic behaviors, however, can be explained by the elementary steel-concrete composite theory, because general tendencies of the deflection curves under unloading and reloading processes are coincident well with the theoretical one. Also, scarece increments of resudial strains and a general agreement of strain measurements with their theoretical values will prove the above discussion to be reasonable.

(b) For the spacing of stud bolts and stud shear connectors in the proposed deck, the one seen in Specimen B-3 will be the most appropriate for a practical usage.

(c) Between the test results for a positive or negative moment, so large difference are not recognized. Therefore, the proposed deck may be considered to be applicable for a continuous deck plate of highway bridge.

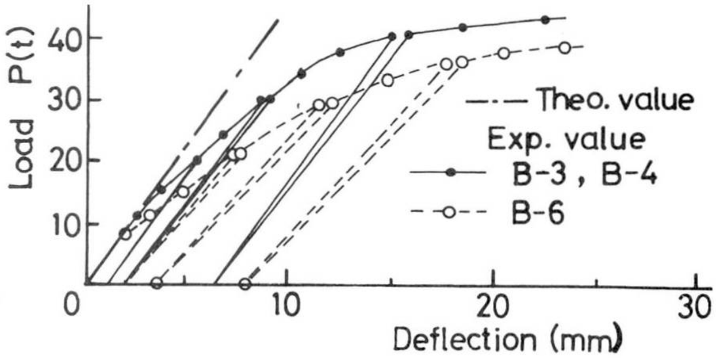

Fig. 5 Load versus deflection

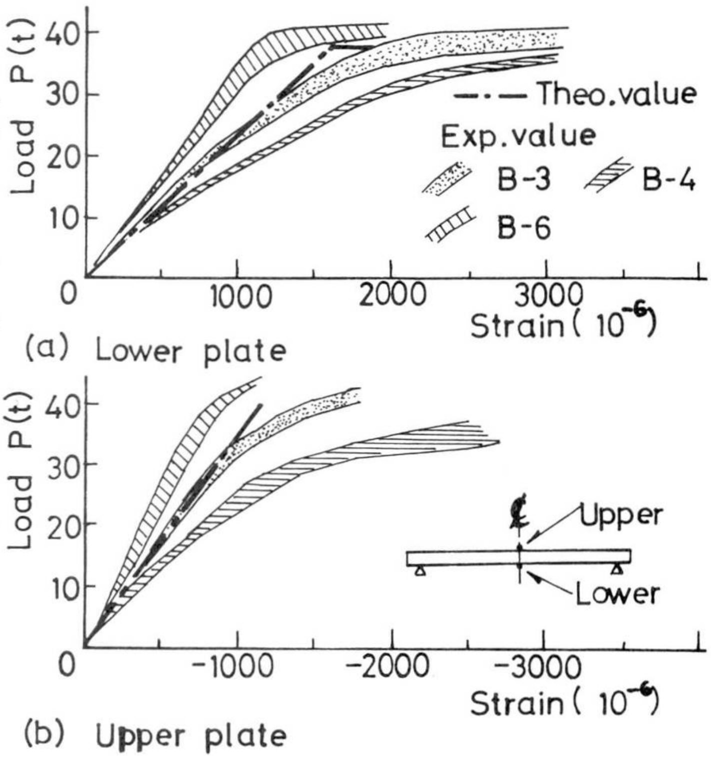

Fig. 6 Load versus strain

4.1.2 Ultimate load-carrying capacity

The ultimate loads of these specimens are tabulated in Table 1. The test values P_{ex} are larger by about 18% than theoretical values P_{th} , which were computed under the assumption of forming of a plastic hinge at the point of maximum moment.

Table 1 Ultimate load

Specimen	P_{ex} (t)	P_{th} (t)	P_{ex}/P_{th}
B-3-1	62.5	47.6	1.31
B-3-2	54.0	46.4	1.16
B-4-1	54.5	46.3	1.18
B-4-2	55.5	46.2	1.20
B-6-1	50.0	46.6	1.07
B-6-2	54.0	46.6	1.16

Photo. 5 illustrates that failures under these loads are due to a bending, and this fact confirms that the above assumption will be right.

As regards to specimens B-3-2 and B-6-2 subjected to a negative moment, a failure occurred at one of the supports due to a shearing force, as shown in Photo. 6, because diaphragms to avoid such a shear failure at the supports were not provided i these specimens. For a practical use of the propose deck plates, it seems to be favorable to take a necessary step for preventing shear failures of the deck at the location of supporting beams.

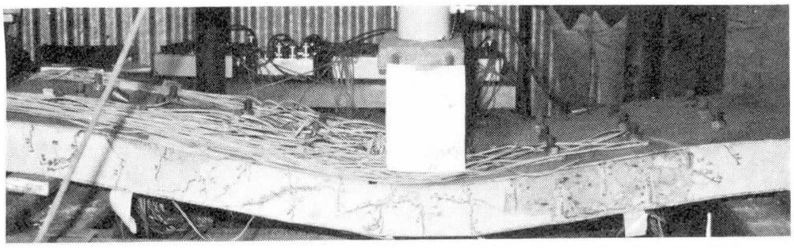

Photo. 5 Failure of deck plate

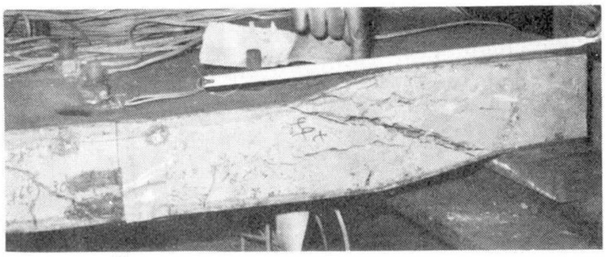

Photo. 6 Shear failure at a support

4.1.3 Comparison between test specimens and other ordinary deck plates and slabs

In this study, the comparison was made on only weights and load-carrying capacity. The following four types of deck plates and slabs will be an object of this comparison:

(a) Robinson deck plate in 12cm depth, with a mark of RD.
(b) Open-grating floor in 15cm depth, with a mark of OG.
(c) Solid-grating floor filled with concrete in 12.4cm depth, with a mark of SG.
(d) Reinforced concrete slab in 16$\sim$30cm depth, with a mark of RC.

(1) Comparison of weights

The weight of deck plates and slabs is in proportion to their depth except OG as tabulated in Table 2. Therefore, the proposed deck plate is very light in comparison with RC which is used mostly for bridge decks.

With regard to the weight of steel section, this deck is the heaviest due to a use of upper and lower steel plates. This defect, however, may be canceled with the feature that this deck would not require any special technique for an application to a continuous plate and that the deck can be prefabricated completely, to cut down an erection cost greatly.

(2) Comparison of ultimate strength

It may be assumed that the ultimate load of each deck plate and slab is such a load at which a plastic hinge is formed at a loading point. The ultimate load-carrying capacities of proposed deck plates are about 2 to 3 times those of RD and SG, and about 3 to 4 times that of RC in 16cm depth. Moreover, this deck has little probability to cause such a critical failure

Table 2 Comparison of ultimate load and weights

Deck or	Total weight (kg/m^2)	Steel weight (kg/m^2)	Ultimate load (t)
Proposed deck	365	110	46.3
RD	342	74	34.5
OG	107	107	25.0
SG	351	60	17.0
RC	416 $\sim$745	40	13.5 $\sim$41.0

due to a punching shear as seen often in RC.

4.1.4 Availability for mass productions

(1) The proposed deck plates are the most suitable for mass production due to its simple fabricating process as mentioned in Chapter 2.

(2) It is possible to vary arbitrarily the depth of the deck plate by adjusting the position at elevation of inner and outer nuts, so that a stock of standard panels through prefabrication can meet any demands.

(3) Connection of each panel can be carried out simply at the construction site, because the deck plates are provided with the jointing parts at their edges as shown in Fig. 1.

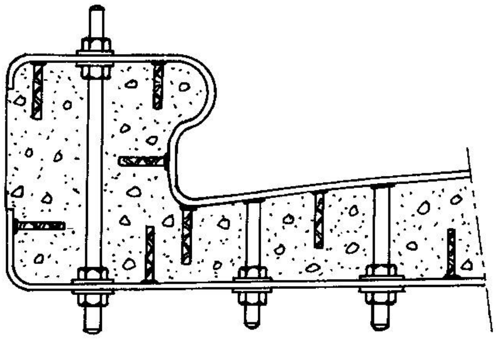

Fig. 7 Curb embodied in deck

(4) This deck plate would be useful for fabricating various shaped standard panels. A prefabricated safety curb which could be embodied in the deck plate, is a good example of them, as shown in Fig. 7, since the steel plates can be easily shaped at a shop and the bolts in the curb are available for fixing guard-rail posts.

4.2 Composite beam test

4.2.1 Deflection and strain measurements

Typical relation of load versus maximum deflection and of load versus maximum strain at the mid-span are indicated in Figs. 8 and 9.

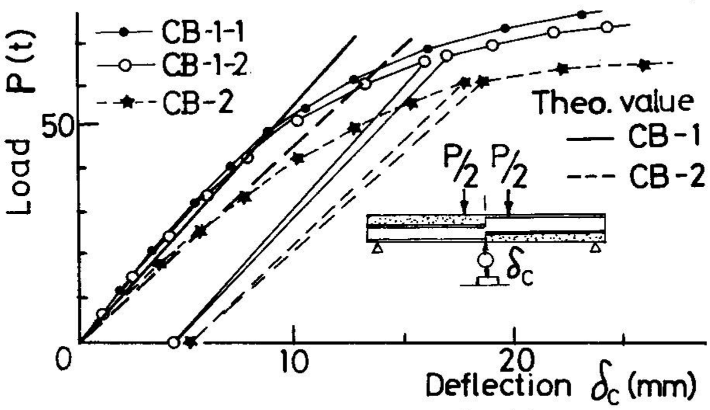

Fig. 8 Load versus deflection

Those results for the specimen subjected to positive moments agree well with the theoretical values up to the yield point of lower flange. When the applied load reached this yield load of about 60t, the beam made a shock noise due to slip of bolt shear connectors made of high strength steel.

The working shearing force per one bolt shear connector under this load are about 9.8t, which coincides with a slip load in a tension test of a joint consisting of high strength bolts. Since any behavior of specimens is explained by the composite beam theory, the stud bolts for connection of beam to slab would be expected to be a substitute for shear connectors.

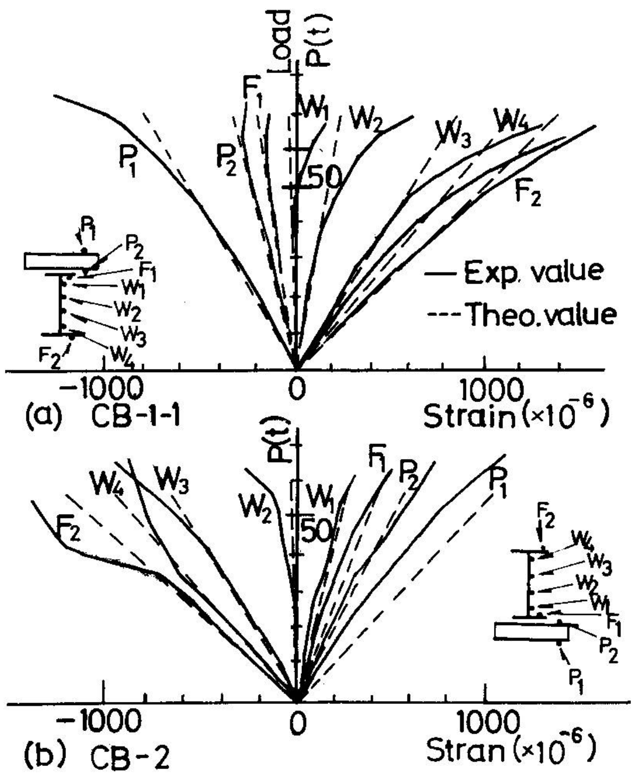

Fig. 9 Load versus Strain

In Specimen CB-2 subjected to a negative moment, the vergin deflection curve deviates slightly from the theoretical curve. The results under unloading and reloading processes, however, are explained by the ordinary composite beam theory, as well as at the discussion mentioned for the deck plates.

For a composite beam with the proposed deck plate, the reduction of moment of inertia of a cross section by neglecting concrete in a tension range is only 20% of the overall composite section. Such a small value would not be expected in ordinary composite beams with reinforced concrete slabs.

4.2.2 Ultimate load-carrying capacity

The test values of ultimate load P_{ex} and the theoretical values P_{th} are tabulated in Table 3. P_{ex} for Specimens CB-1 subjected to a positive moment are larger by about 10% than P_{th}. These large ultimate load-carrying capacities prove that the entire cross section of the composite beam is effective for a composite action up to its failure, in spite of slip of bolt shear connectors.

Table 3 Ultimate load and Slip load

Specimen	Ultimate load		Slip load	
	P_{ex} (t)	P_{th} (t)	Load (t)	Shearing force (t/one bolt)
CB-1-1	102.0	95.0	64.0	9.8
CB-1-2	107.0	95.8	64.0	9.8
CB-2	76.5	75.0		

As soon as the applied load reached its ultimate value, the upper surface plate of deck buckled upward due to snap-through caused by concrete crush in the vicinity of loading points, as shown in Photo. 7.

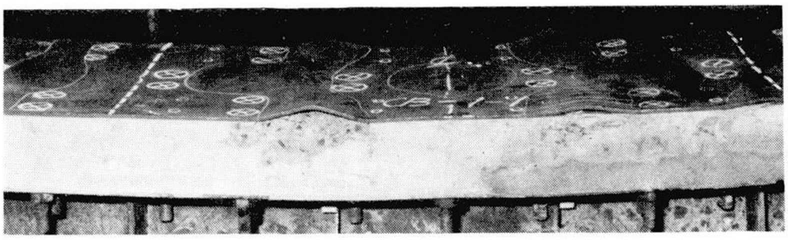

Photo. 7 Snap-through of surface plate in composite beam

The test value of CB-2 agrees with the theoretical value, but this agreement is accidental due to a local buckling of steel beam. If this buckling were prevented, the ultimate load would have become as large as for the specimens CB-1.

4.2.3 Comparison between deck plate composite beams and ordinary composite beams with reinforced concrete slabs

In this comparison, all dimensions on a cross section and a span length of the compared composite beams are similar to the test specimens except the slab thickness, which vary with a depth of 14, 16, 18 and 20cm. Yield point of steel σ_y, ratio of Young's moduli E_s/E_c, and compressive strength of concrete σ_c, are assumed to be 2800kg/cm^2, 10 and 280kg/cm^2, respectively. Comparison for moment of inertia of a cross section I_v, ultimate load P_{ult}, weight per unit length W_d, are tabulated in Table 4.

Superiority of the composite beams with a steel deck plate sandwiching concrete will be confirmed evidently from this table. In spite of a small thickness of deck plate, this composite beam has a larger moment of inertia and load-carrying capacity.

With regard to the weight per unit length, it may be recognized that this difference of dead weights will be more significant in an actual highway bridge with a long span and a large distance of installed beams.

Table 4 Comparison between test beam and composite beams with RC-slab

Specimen	Moment of inertia I_v (cm^4)	Ultimate load P_{ult} (t)	Weight per unit length W_d (kg/m)
CB-1	81800	95.4	249
RC-14 *	69990	78.8	242
RC-16 *	76910	84.0	267
RC-18 *	84060	89.2	292
RC-20 *	91480	94.0	317

* Designation; RC - Ordinary composite beam with RC-slab, Numeral - Depth of RC-slab.

Moreover, reduction of the number of shear connectors due to a use of high strength bolts, application of this structure to a continuous beam without any special technique and possibility of prefabrication, will give a great contribution to a mass production of steel structures.

5. Conclusions

On the both proposed deck plates and composite beams, the following are concluded from the present investigation:

(1) The elastic behavior of the both of deck plates and composite beams can be well explained by the elementary steel–concrete composite beam theory. Their load-carrying capacity are much larger than those of ordinary deck plate or slabs and composite beams with reinforced concrete slabs.

(2) The proposed deck would be available for a continuous deck plate. Furthermore, the composite beam with this deck plate would be applicable to a continuous composite beam of a highway bridge, too.

(3) The steel deck plates sandwiching conctere are the most suitable structures for mass production according to their complete prefabrications, and for collaboration with a steel girder.

The proposed decks are going to be used for decks of suspension bridges and H–steel beam bridges, and for slabs of composite beams for an elevated highway bridge in Japan.

SUMMARY

A new type deck plate named Steel Deck Plate Sandwiching Concrete is proposed, in order to contribute to prefabrication of highway bridges and to lightening its dead weight. In the paper, the test results on large-sized deck plate specimens and composite beam specimens with proposed deck plates, are discussed in detail, emphasizing their structural merits from the point of practice for the mass production of structure.

RESUME

Dans le but de contribuer à la préfabrication des ponts d'autoroutes et à la réduction de leur poids, on propose un nouveau type de dalle de chaussée (Steel Deck Plate Sandwiching Concrete) qui se compose de deux tôles d'acier situées de part et d'autre d'une dalle de béton, le tout agissant en section mixte. Dans cet article on expose les résultats d'essais exécutés sur des modèles de grandes dimensions de la plaque proposée et sur des poutres d'acier collaborant avec cette plaque; et l'on insiste sur les avantages constructifs au point de vue de la préfabrication.

ZUSAMMENFASSUNG

Es wird ein neuer Typ einer Fahrbahndecke, genannt Stählerne Fahrbahndecke in Verbundbauweise (Steel Deck Plate Sandwiching Concrete), vorgeschlagen, um zur Vorfabrikation von Strassenbrücken beizutragen und deren Eigengewicht zu erleichtern. Im Bericht werden die Versuchsergebnisse an Probeausführungen grosser Decken und an Verbundträgern mit den vorgeschlagenen Fahrbahndecken im einzelnen diskutiert, und dabei ihre baulichen Vorzüge vom Standpunkt der Praxis aus für die Seriefabrikation hervorgehoben.