Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 8 (1968)

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DOI: https://doi.org/10.5169/seals-8860

Experiment on Lightweight-Concrete Composite Girder Bridges

Expériences sur des poutres métalliques composées avec du béton léger

Versuch über Leichtbeton-Verbundbrücken

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1. Introduction

Recently in Japan, due to the shortage of natural aggregate and to growing requirement of lightweight structure, inquiry and application of lightweight concrete have greatly been promoted. In case of a steel bridge with lightweight-concrete slab, a composite girder is found to be a reasonable and economical construction.

From such standpoint, after model tests were carried out, the first lightweight-concrete composite girder bridge in Japan was successfully constructed by the Hanshin Expressway Public Corporation.

Following experiments are conducted always in comparison with a lightweight concrete composite girder and a normal-weight-concrete composite girder.

2. Model test of shear connector and composite beam

2.1. Specimens

As shown in Figs.1 and 2, push-out test specimens, and composite beams with reinforced concrete slab and shear connectors were prepared.

Push-out test specimens contain various types with different pitches of shear connectors. Back surface of H-beam is oiled, and concrete placing

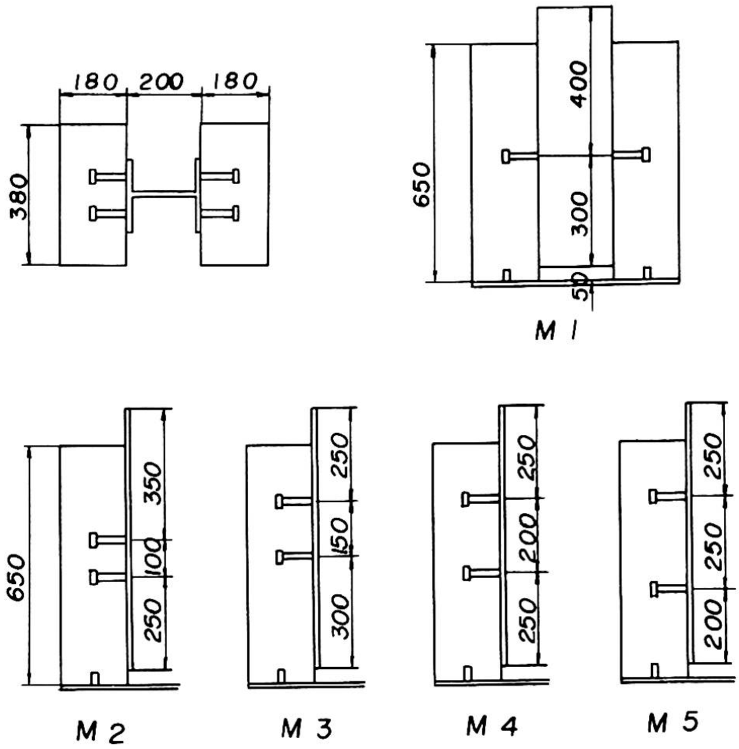


Fig. 1. Push-out specimens

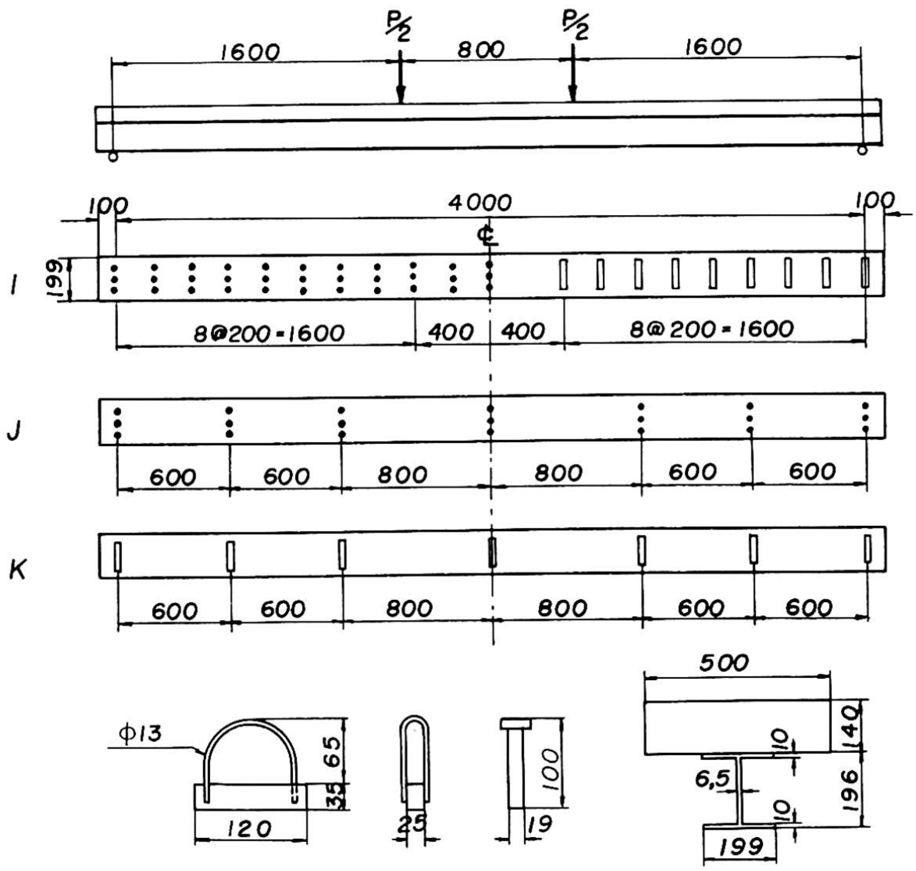


Fig. 2. Beam specimens

is executed from the lateral side, so that the bearing strength of shear connectors may not be influenced by bleeding of the concrete at the lower surface of the reinforcing bars.

Beam I has stud shear connectors and block shear connectors whose strength are quite equal as the preliminary test shows. Beams J and K are made to only few shear connectors, so that breaking strength of shear connectors as well as ultimate strength of beams may also be examined.

Table 1 shows the number of specimens, and Table 2 strength and Young's modulus of concrete on the 28th day in contrast with normal-weight concrete beam and lightweight-concrete beam. Mean value of yielding stress of steel is about 2700 kg/cm^2.

Table 1. Number of specimens

Specimen	Name	Number		Kind of shear connector
		NC	LC	
Push out	L	4	4	Block
	M	12	12	Stud
Composite beam	I	1	1	Block and stud
	J	1	1	Stud
	K	1	1	Block
Sum		19	19	

Table 2. Strength and Young's modulus of concrete (kg/cm^2)

Concrete	Compressive strength	Tensile strength	Bending strength	Young's modulus, $E_{0.3}$	n at $E_{0.3}$
NC	285	25.5	41.3	276,000	7.6
LC	313	24.1	30.6	194,000	10.8
NC/LC	0.91	1.05	1.35	1.42	

2.2. Push-out test

The load corresponding to useful capacity (residual slip = 0.08mm) [1] per one shear connector are shown in Table 3. Capacity of LC is larger than NC, even if in consideration of the difference of their compressive strength in Table 2.

Table 3. Useful capacity of shear connector

Concrete	M1	M2	M3	M4	M5
NC	4.1 ton	3.4	4.3	3.8	3.5
LC	5.5 ton	4.5	4.5	4.8	5.0
NC / LC	0.75	0.75	0.96	0.79	0.70

The pitch of stud shear connector has a slight influence upon its capacity, and ultimate strength of LC is a little lower than NC.

2.3. Beam test

Deflection and stress of LC beam are somewhat larger than those of NC beam. The deflection of beams are shown in Fig.3. where the calculated values are described as n = 7 for NC beam, and n = 10 for LC beam. As compared with these results, the theoretical values coincide well with the measured ones.

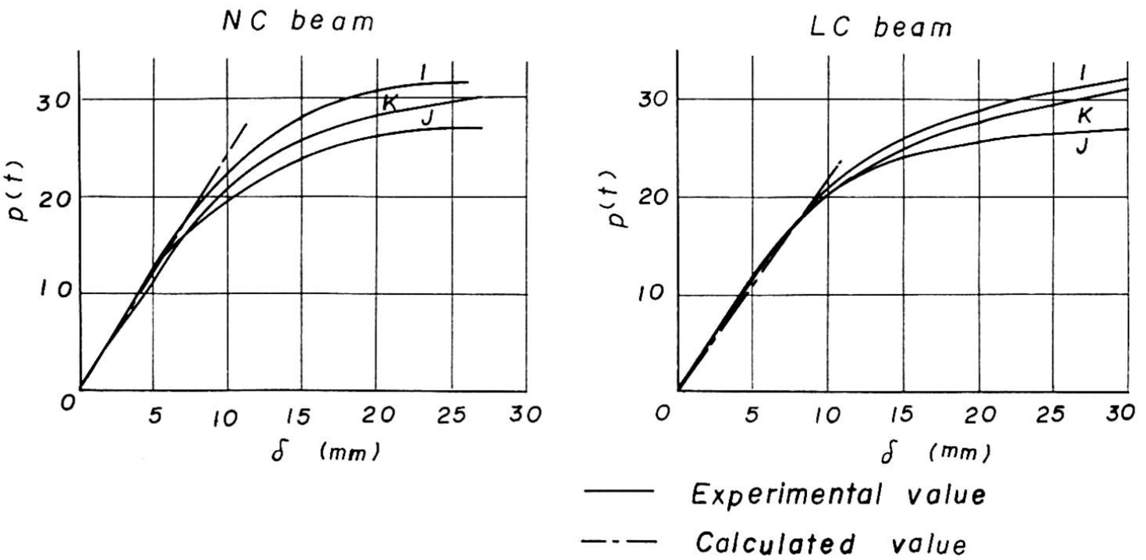


Fig.3. Deflection of beamsat center

Breaking state of NC beams as in LC beams are due to bending. The calculation method of breaking moment can be classified into 3 cases (Fig. 4), according to the strength of concrete and shear connector [2].

In both NC and LC beams, beam I corresponds to case II , beams J and K correspond to case III . By comparing the calculated breaking load with the experimental one in Table 4, we can see that they agree quite well.

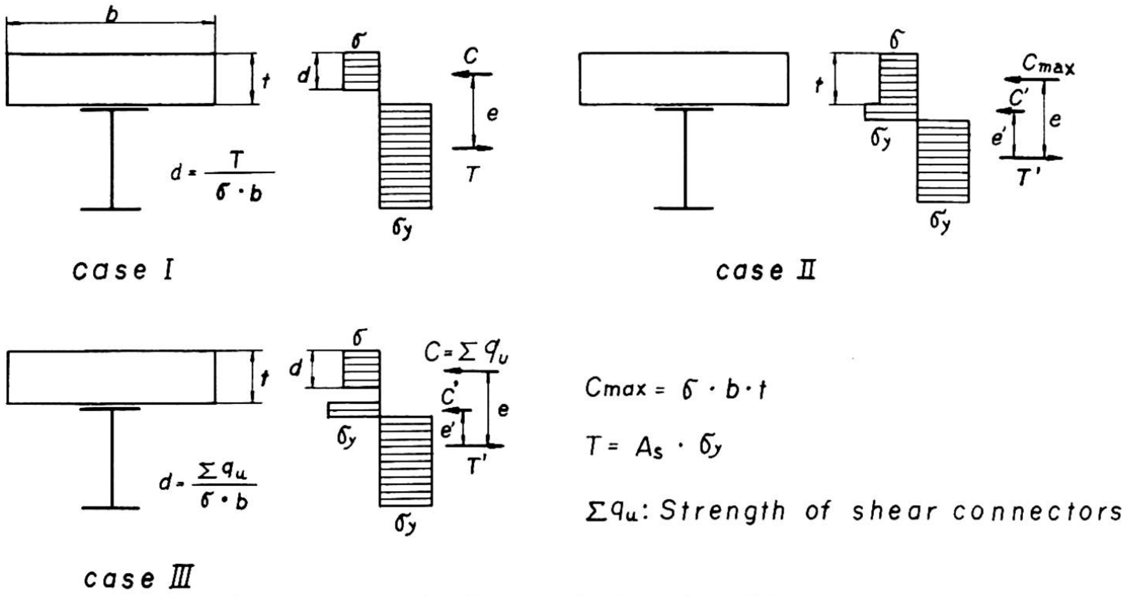


Fig. 4. Calculation method of breaking moment

Table 4. Breaking load of beams

Beam	NC			LC		
	I	J	K	I	J	K
Experimental value (ton)	33.8	29.4	31.0	35.2	30.2	33.0
Calculated value (ton)	33.3	29.3	31.0	34.2	29.1	30.6
Ex./ Cal.	1.02	1.00	1.00	1.03	1.04	1.08

3. Field experiment of two test bridges

3.1. Test bridges

Statical and dynamical tests were conducted in two multiple plate girder bridges in the Hanshin Expressway. One is a composite girder bridge built of the normal concrete (NC girder) and the other a bridge of the lightweight concrete (LC girder).

Table 5. Value of concrete

Concrete	Measured value		Value used in calculation	
	σ_c (kg/cm^2)	E_c (kg/cm^2)	E_c (kg/cm^2)	γ_c (kg/cm^3)
NC	302	2.47 x10^5(n=8.5)	3.00 x10^5(n=7)	2.5 x10^{-3}
LC	331	1.71 x10^5(n=12.3)	1.75 x10^5(n=12)	1.8 x10^{-3}

Table 5 shows 28th-day compressive strength σ_c, Young's modulus E_c and density γ_c for two concrete materials used in these bridges.

Besides, the shape and dimension of the two bridges are designed in the same way as shown in Fig. 5. Total steel weight of NC girder is 41.5 ton, that of LC girder being 39.6ton. In this case, weight of steel material is slightly saved. If the span length is longer, however, we shall be able to expect more economical design of a girder and substructure.

By the way, the pavement, hand-rail and curbs were not equipped during the tests to avoid the errors involved in the experimental results owing to their uncertain stiffness.

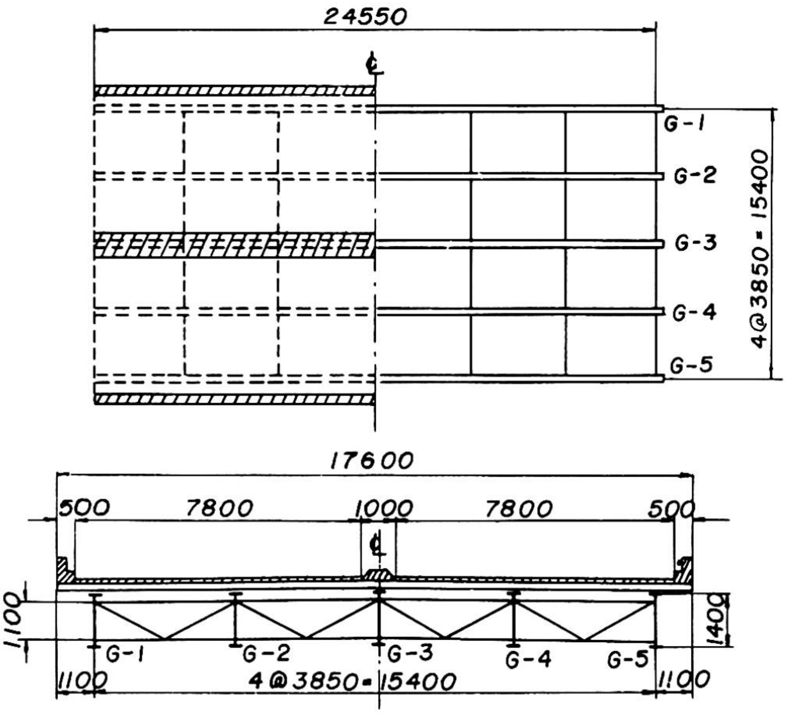


Fig. 5. General view of test bridges

3.2. Theoretical study

As the width of these bridges is greater compared with their span length, the vibration should be analyzed by regarding these bridges as two dimensional structures. Accordingly, the dynamical response of the multiple plate girder bridge has been developed in reference to the literatures [4] and [5].

The outline of analysis is as follows; First, the bridge is idealized in an orthotropic plate as is seen in the theory of Guyon and Massonnet[6]. Next, by assuming the mode of vibration in the transverse direction and by applying the Lagrange's equation, the fundamental differential equation of motion can be obtained. From this equation, simple and practical formula for determining the natural frequency, and a method of analyzing the response due to dynamical forces are derived. Finally, an approximate method to estimate deflection and stress-resultants under statical forces has also been proposed by the above theory.

3.3. Statical loading test

The statical loading tests were made by loading four 12tons vehicles with tire rollers. These vehicles were loaded upon the bridge, back to back, symmetrical with respect to the middle point of span under three loading conditions. Values of deflection for two typical loading conditions are plotted in Fig. 6.

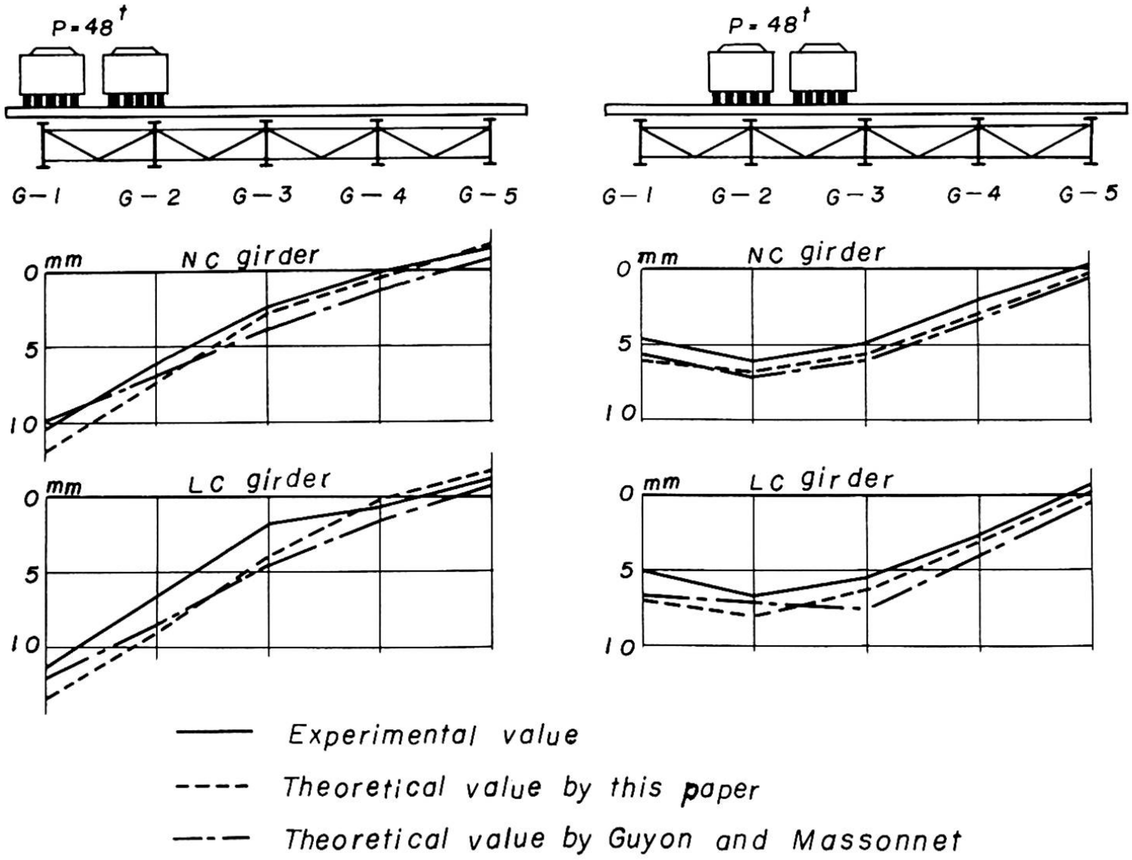


Fig.6. Deflection of girder

By comparing these results, the theoretical values are found to coincide well with the measured ones.

Thus we can see that the weakness of low Young's modulus of lightweight concrete can be made up for by making use of a composite girder.

3.4. Dynamical loading test

The dynamical tests were conducted by pulsating the bridges with an oscillator and by recording the dynamical deflection and stress with the oscillograph. From these data, resonance curves are drawn and three resonant frequencies are clearly obtained.

The vibration patterns are shown in Fig. 7 and experimental values together with the theoretical ones are summarized in Table 6, and we can see quite complete agreement between them.

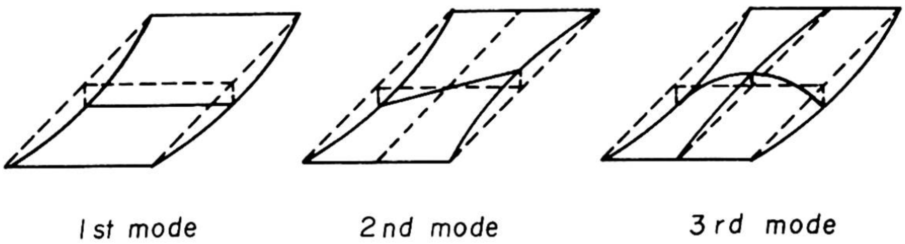
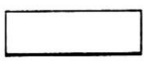
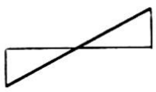


Fig. 7. Vibration pattern

Table 6. Natural frequencies (cycle/sec.)

Girder	Vibration mode	1st mode 	2nd mode 	3rd mode 
NC	Experimental value	4.55	5.03	8.77
	Theoretical value	4.59	5.35	8.66
	Th./Ex.	1.01	1.06	0.99
LC	Experimental value	4.71	5.66	9.77
	Theoretical value	4.82	5.67	9.49
	Th./Ex.	1.02	1.00	0.97

Then, by the drop test of wheel of tire roller, we obtained logarithmic damping coefficient, Δ=0.33 for LC girder, Δ=0.20 for NC girder.

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SUMMARY

In consequence of (1) the push-out test and the beam test, and of (2) the experiment of two test bridges equivalently designed, we can recognize that the lightweight-concrete composite girder brige is a quite useful type, as compared with a normal-weight-concrete composite girder bridge.

RÉSUMÉ

Suite au test des goujons (1) et au test de la poutre, ainsi qu'aux expériences (2) sur deux ponts dimensionnés identiquement, nous concluons que le pont en action combinée acier-béton léger constitue un type tout-à-fait acceptable, comparé au pont acier-béton normal.

ZUSAMMENFASSUNG

In Folgerung des Dübel- und Balkenversuchs (1) sowie der Untersuchung zweier gleichwertiger Brücken (2), können wir erkennen, dass die Leichtbetonverbundbrücke, verglichen mit der Normalbeton-Verbundbrücke, durchaus brauchbar ist.

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