

DURABILITY OF COMPOSITE GIRDERS WITH PRESTRESSED PRECAST CONCRETE SLABS UNDER MOVING VEHICLE

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A new composite girder with prestressed precast concrete slab has been developed by the authors et. al. In applying this new composite girder to the highway bridges, there are a few unclarified problems for evaluating the fatigue behavior of composite girders, especially the cracking of precast concrete slab under the heavy traffic vehicles. In order to investigate the effects of moving vehicles on the proposed composite girders, five model girders are tested systematically under the repeated loads making use of moving vehicle apparatus. This paper reports and discusses the durability of composite girder with prestressed precast concrete slab panels through the test results.

Keywords : composite girder, prestressed precast concrete slab, repeated load by moving vehicle

1. INTRODUCTION

During past decade, the damages of reinforced concrete slabs (thereafter referred to as RC-slabs) in the highway bridges have been a serious problem in accordance with the increases of volume and weight of traffic vehicles. Therefore, various methods to prevent crackings of RC-slabs and attempts for repairing or replacing the RC-slabs have been reported by many researchers^{1)~9)}.

Among them, a composite girder with prestressed precast concrete slabs is thought to be a useful method not only to apply the economical construction of a new type of bridge but also to repair or replace the concrete slabs of old bridges.

In applying this method to the highway bridges, however, the crackings of precast concrete slabs and the corresponding fatigue behavior of composite girders under the heavy traffic vehicles should be carefully inquired. Accordingly, the experimental study on five model girders are conducted systematically under the repeated loads by making use of a moving vehicle apparatus in order to investigate the fatigue effects of moving vehicle on the proposed type of composite girder bridges.

This paper reports the test results of strain distributions and changes of deflection in the model composite girders, slippings between steel girder and precast concrete slab as well as the propagations of cracks in the concrete slabs during the applications of repeated loads.

Then, both durability and serviceability for adopting the precast concrete slabs to the composite girders are discussed in comparisons with fatigue behavior of the ordinary RC-slab.

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2. TEST METHOD

(1) Loading apparatus

Fig. 1 shows the plane configuration of loading apparatus, where the test girders are located at two pits A (8.5×8.5 m) and B (4.5×8.5 m) in the circuit with clear width of roadway 6.0 m. A test vehicle, equipped the DC-electric motor, is driven with the running speed, $V=15\sim25$ km/h, around the center of this circuit through the tie bars having the radius of curvature, 12 m, for taking the centrifugal forces of vehicle.

In this manner, the fatigue test of model girders were conducted. Fig. 2 shows the principal dimensions and capacity of the test vehicle.

(2) Model girders

Five model girders, G-1 through G-5, were fabricated, in which model girder, G-1, was an almost full size model girder to investigate the fatigue behavior throughout the real composite girder bridge built by using the precast concrete slab.

On the other hand, the propagations of crack in concrete slabs were examined by much more small model girders, G-2 through G-5, where the model girder, G-2, was provided with the conventional RC-slab for the sake of comparisons of the cracking patterns with those of precast concrete slab.

For the materials of concrete slab, normal and expansive cement were used alternatively. The boundary conditions of concrete slab panel in the transverse direction of model girders are determined as continuously or simply supported at the interior steel girder in the model girder, G-1, whereas those in the remaining model girders, G-2 through G-5, being determined as simply supported.

These slabs were designed according to the design criteria of Japanese Specification for Highway Bridges (hereafter referred to as JSHB) by assuming wheel load intensity, $P=49.0$ kN, of the test vehicle in Fig. 2 (JSHB specifies $P=78.4$ kN) and the thickness of concrete slab of model girder, G-1, was determined as 160 mm (equivalent to the minimum required thickness of JSHB). While, those of model girders, G-2 through G-5, were taken as 100 mm. The stress level of main reinforcement bars with diameter, ϕ -16 mm, and pitch, 150 mm, in the transverse direction of model girder, G-1, is, of course, checked to fall within the actual stress ranges of composite girder bridges and the stress level is determined as $\sigma_s=90$ Mpa. The stress level of model girders, G-2 through G-5, with main reinforcement bars, ϕ -13 mm, spaced with 150 mm pitch, is nearly equal to twice value of G-1 so as to predominate the crackings of concrete slab.

The precast concrete slabs of model girders G-1 and G-3 through G-5, were prestressed in the longitudinal direction of the steel girders by posttensioning method.

In model girders, G-1 and G-5, the prestressed forces in the transverse direction of model girder were introduced through PC-bars with diameters, ϕ -9.2 mm and ϕ -7.4 mm, by the pretensioning method, respectively.

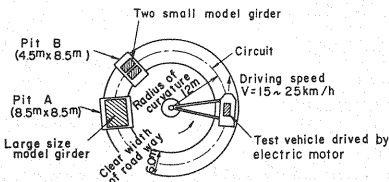


Fig. 1 Plane Configuration of Loading Apparatus.

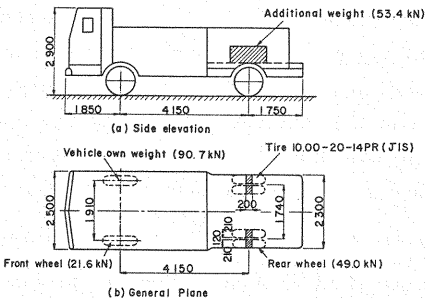


Fig. 2 Detail of Test Vehicle (Dimension in mm).

Table 1 Details of Concrete Slabs for Model Girders.

Model girder	Type of concrete slab	Boundary condition in trans. direction	Number of panels	Thickness of concrete slab(mm)	Width of concrete slab(cm)	Used concrete			Residual prestress in concrete slab(MPa)	
						Mix proportion	Quality	Strength (MPa)	Longitudinal	Transverse
G-1	Full size precast concrete slab	Continuous panel	4	160	500	A and B	NC* and EC**	42.2	3.0	0
			4		250			42.2		
			4			C	NC	52.0		4.2
G-2	Conventional RC-slab	-	-	100	180	D	NC	29.8	-	-
G-3	Completely released precast concrete slab	Simply supported panel	2	100	180	A and B	NC and EC	42.2	0	0
			2			C	NC	52.0		
G-4	Partially released precast concrete slab	Simply supported panel	2	100	180	A and B	NC and EC	42.2	3.0	0
			2			C	NC	52.0		
G-5	Two-directionally prestressed precast concrete slab	Simply supported panel	4	100	180	C	NC	52.0	3.0	5.3

Remarks: * NC : Normal Concrete, ** EC : Expansive Concrete

Table 2 Concrete Mix Proportion.

Cement	Type	Design strength (MPa)	Unit content (N/m ³)					W/C (%)	S/A (%)	Maximum aggregate size (mm)	Air entraining material (%)	Slump (cm)
			W	C	S	G	M					
Expansive	A	39.2	1441	2940	7350	11446	490*	42	40	20	2±1	6±1.5
	B	39.2	1441	3430	7350	11446	0	42	40	20	2±1	6±1.5
Normal	C	44.1	1490	3920	6684	11319	102**	38	38	20	2±1	6±1.5
	D	29.4	1421	3273	10800	7370	34***	43	40	20	4	8

*:Expansive admixture(Onoda Expan), ** and ***:Admixture (Pozzolith NL-4000 and No.10L)

The details of concrete slab are listed in Table 1.

Table 2 shows the mix proportions of concrete materials for the precast concrete slab panels and reinforced concrete slab. In type A and types B through D, expansive and normal concrete were used, respectively. Type D is designed for the reinforced concrete slab at the construction site, where the strength of concrete is designed as $\sigma_{CK}=29.4\text{Mpa}$ on the basis of real situation in highway bridges.

Then, their properties are detailed in Table 1.

Figs. 3 and 4 illustrate the details of precast concrete slab panels of the model girders, G-1 and G-5, respectively. The forms for precast concrete slab panels were fabricated by using the steel plates for the sake of keeping the dimensions of the concrete panels as much as accurate. Concrete was encased into the forms after the built-up of the reinforcements with diameter, 16 mm or 13 mm, and the spiral sheaths

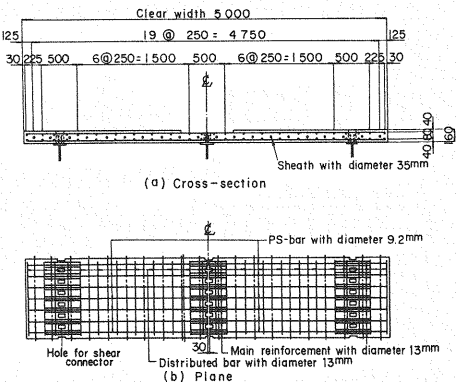


Fig. 3 Detail of Precast Concrete Slab Panel (G-1).

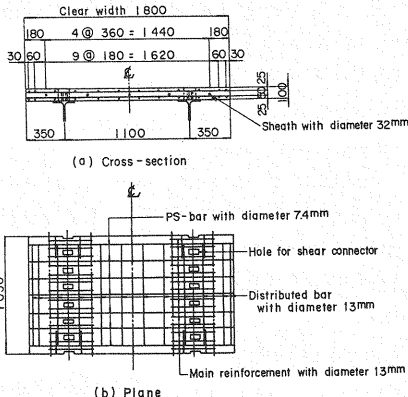


Fig. 4 Detail of Precast Concrete Slab Panel (G-5).

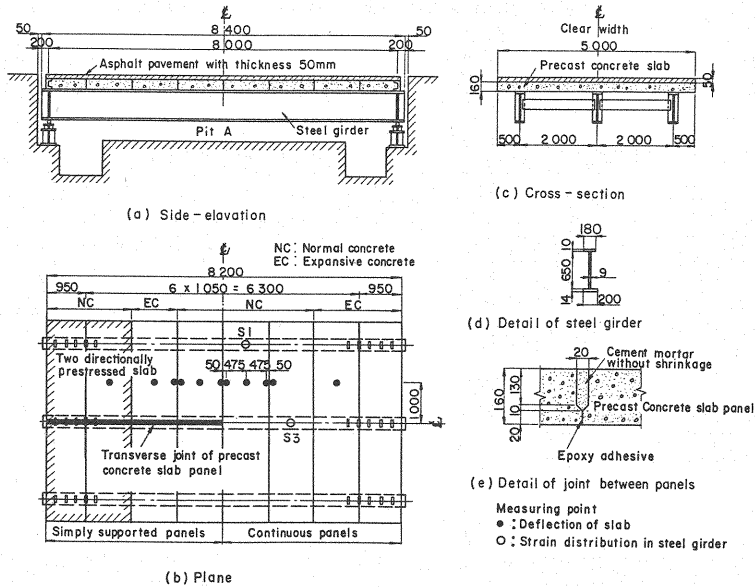


Fig. 5 Details of Model Girder G-1 (Dimension in mm).

having diameter, 35 mm or 32 mm, were distributed as shown in Figs. 3 and 4.

The transverse prestress forces in the precast concrete slab panels were introduced by the pretensioning method by using PS-bars, Class D and No. 1, which are specified in JIS G 3109-1977, with diameter, ϕ -9.2 mm or ϕ -7.4 mm. Table 3 shows the yield stress, design pretensioning stress and applied pretensioning forces of their PS-bars. The prestressings of precast concrete slab panels were carried out after the strength of concrete was resulted in more than 34.3 Mpa.

a) Detail of model girder G-1

Fig. 5 shows the details of model girder G-1 of which three steel girders are fabricated by the mild steel SS-41 (allowable unit stress, σ_{ta} = 137.2 Mpa) with thickness 9, 10 and 14 mm. The span length, l = 8.0 m, with both the ends simply supported and the girder depth, h = 65 cm, were determined so as to limit the maximum stress of steel girder is less than 0.25 σ_{ta} .

The precast concrete slabs, detailed in Table 1, were connected to steel girders through pairs of shear connectors having dimensions, ϕ -19 \times 110 mm, and pitch, 150 mm, after the introduction of prestress force (σ_c = 7.8 Mpa) to the longitudinal direction of precast concrete slab by twenty PC-wires with diameter, ϕ -19.3 mm, and hydraulic jack. Thereafter, these prestress forces were released down to σ_c = 3.0 Mpa, thus the model girder was completed. The test was con-

Table 3 Pretensioning Force of PS-bar.

Model girder	Diameter (mm)	Yield stress (MPa)	Design pretensioning stress (MPa)	Applied pretensioning force (kN)
G-1	9.2	1274	784	51.7
G-5	7.4	1274	980	40.4

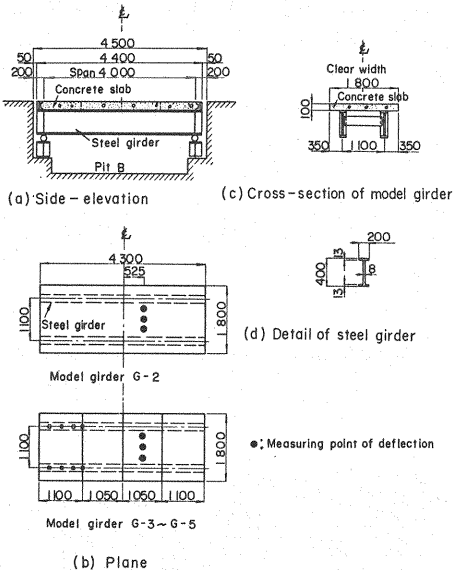


Fig. 6 Details of Model Girders G-2 through G-5 (Dimension in mm).

ducted by setting this girder into the pit A (see Fig.1).

b) Details of model girders G-2 through G-5

The model girders, G-2 through G-5, were fabricated in a manner similar to the above, except the steel girders were made of H-beam with the dimensions, $400 \times 200 \times 13 \times 8$ mm, and the shear connectors, $\phi - 16 \times 80$ mm, having pitch 150 mm. The concrete slabs were composed of ordinary RC-slab, precast concrete slab without or with residual prestress forces in the longitudinal and the transverse directions in model girders, G-2 through G-5, as detailed in Table 1 and Fig. 6. Two model girders were situated simultaneously in the test pit B (see Fig. 1).

(3) Measuring method

The model girders, G-1, G-2 and G-3 or G-4 through G-5, were located at the pits A and B, respectively, as shown in Fig. 1. A test vehicle was driven with the running speed, $V \approx 20$ km/h. Measuring was carried out by loading the rear wheel of test vehicle on the model girders statically after the appropriate running cycles.

Table 4 shows the running cycles and the corresponding rear wheel load at measuring of which points are shown in Figs. 5~6.

3. TEST RESULTS AND THEIR DISCUSSIONS

(1) Test results of model girder G-1

Strain distributions and deflections in the model girder G-1 during the erections were measured and quite well results are recognized as it is reported by reference 10). Therefore, the fundamentally important behavior due to the applications of moving vehicle are only explained and discussed herein as follows;

a) Variations of strain distributions

The strain distributions at the measuring section S 3 (see Fig. 5) are plotted as shown in Fig. 7. These measured values do not change, even in the case where the running cycle increase to $N = 500,000$. Accordingly, the strain distributions during the tests always coincide well with the elementary beam theory.

b) Variations of slip between concrete slab and steel girder

Table 4 Running Cycle and Corresponding Rear Wheel Load at Measuring.

G-1		G-2 and G-3		G-4 and G-5	
Running cycle	Rear wheel load (kN)	Running cycle	Rear wheel load (kN)	Running cycle	Rear wheel load (kN)
1	49	1	49	1	49
14000	49	10000	49	10000	49
88000	49	45000	49	77000	49
145000	49	99000	49	133100	49
190000	49	150000	49	185000	49
250000	49	250000	49	250000	49
295000	49	-----	---	250001	73.5
350000	49	-----	---	289000	73.5
500000	49	-----	---	375000	73.5
500001	73.5	-----	---	-----	---
539000	73.5	-----	---	-----	---
625000	73.5	-----	---	-----	---

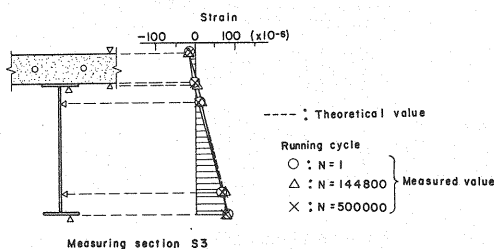


Fig. 7 Variations of Strain in Composite Girder.

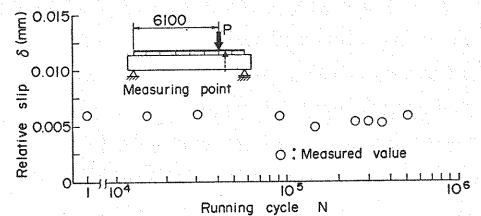


Fig. 8 Variations of Slip between Slab and Girder.

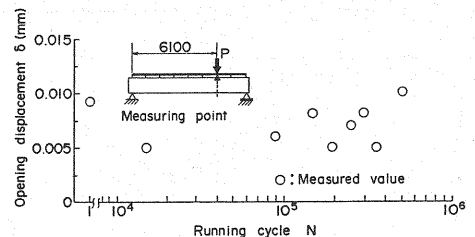


Fig. 9 Variations of Opening Displacement at Joint of Precast Concrete Slab (Large Scale Girder).

The relative slip between concrete slab and steel girder is within the range of 0.006 mm, being very small quantity after the last running test as illustrated in Fig. 8. Combining the above and this facts, it seems that the precast concrete slabs are completely connected to the steel girders.

c) Opening displacement between precast concrete slab panels

The precast concrete slab panels are combined together by the method as detailed in Fig. 5 e). For these joints, the opening displacement were measured at one of a lower surface of precast concrete slab. This results is plotted as shown in Fig. 9. It is observed from this figure that the test results fluctuate from 0.005 mm to 0.01 mm, but the maximum value is very small and do not influence upon the durability of composite girders built by precast concrete slab.

d) Deflection of concrete slab

The variations of deflection in a precast concrete slab at the mid-section along two steel girders are plotted as shown in Fig. 10. It can be seen from this figure that the deflection of slab remains within constant value with slight fluctuation at the joints adjacent to the precast concrete slab. In this figure, an analytical results by FEM analysis by using elastic elements connected to the border of the orthotropic plate elements, is also plotted by a dotted line. Through the comparisons of test results with the theoretical predictions, it is confirmed that the residual prestress forces in the precast concrete slabs can effectively be held up to the running cycle $N=500,000$.

e) Crack in precast concrete slab

In the model girder G-1, only one crack was observed in the continuous precast concrete slab panels near the interior steel girder at the running cycle $N=230,000$ as illustrated in Fig. 11. However, another cracks do not propagate up to the running cycle $N=500,000$.

Although various type of precast concrete slabs are utilized in this model girder, their qualities do not influence upon the propagations of crack, but their boundary conditions and methods to prestress the concrete slab will be an important factor.

(2) Test results of model girders G-2 through G-5

In the model girders, G2 through G-5, the propagation of cracking in the concrete slabs and the corresponding deflections are mainly investigated up to the running cycle $N=250,000$. These results can be predicated as follows;

a) Opening displacement between precast concrete slab panels

Fig. 12 shows the opening displacement at joints of precast concrete slab panels concerning the model girders, G-3 through G-5. The values of the opening displacements are almost constant and small in accordance with increase of the running cycle.

From this result, it seems that the joints between precast concrete slab panels are not damaged after repeated loading by the moving vehicle. And the maximum value of opening displacement is equal to the theoretical stretch of lower surface of slab as a body caused by the bending moment at loading position.

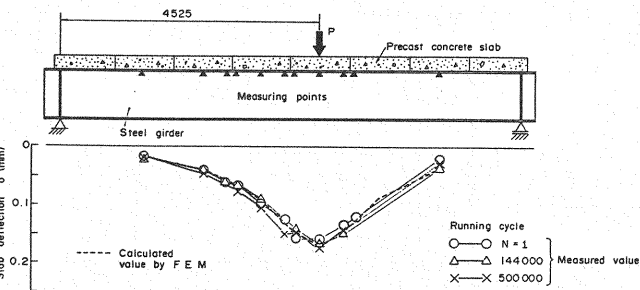


Fig. 10 Variations of Displacement of Precast Concrete Slab (Large Scale Model Girder).

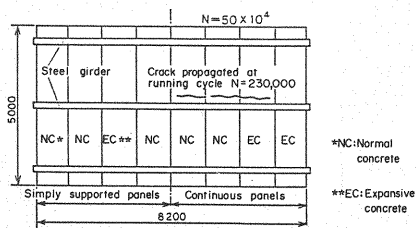


Fig. 11 Initiation of Crack in Model Girder G-1 (Dimension in mm).

b) Propagations of crack in concrete slab

Fig. 13 shows the patterns of cracking at each model girders on the reverse surface of concrete slab without model girder, G-5. Observing this figure, the transverse and longitudinal cracks of RC-slab in the model girder, G-2, are remarkable and the propagations of cracks have a similar tendency to coincide with the ordinary composite girder bridges having RC-slab. On the other hand, the transverse cracks in the model girders, G-3 and G-4, are not so significant and the longitudinal cracks in the latter is the less than the former. This might be caused by the residual prestress in the precast concrete slab. The cracks of model girder, G-5, with prestressed precast concrete slab in two directions were not observed. Then, their figure is omitted herein.

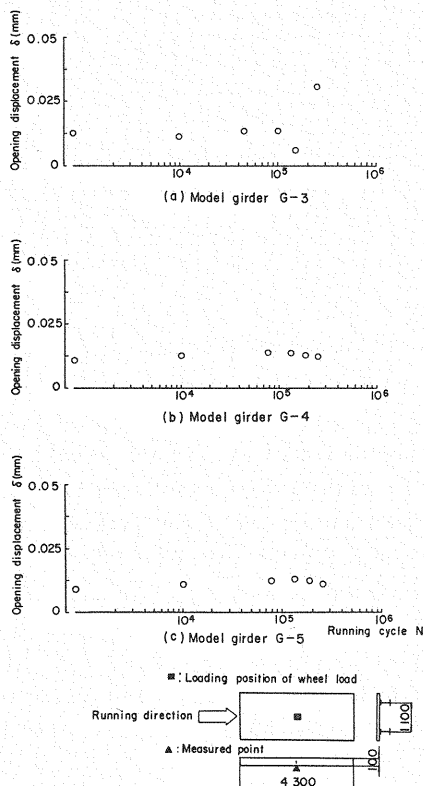


Fig. 12 Variations of Opening Displacement at joint of Precast Concrete Slab (Small Scale Model Girder).

It is worth to note from these test results that the transverse cracking of precast concrete slabs can be prevented by retaining the appropriate prestress forces in their longitudinal direction.

For the composite girder subjected to heavy traffic vehicles, it is a powerful method to design them as prestressed precast concrete slab in two directions.

c) Variations of deflection in concrete slab

Figs. 14 and 15 show the variations of deflection for the concrete slabs in the transverse and the

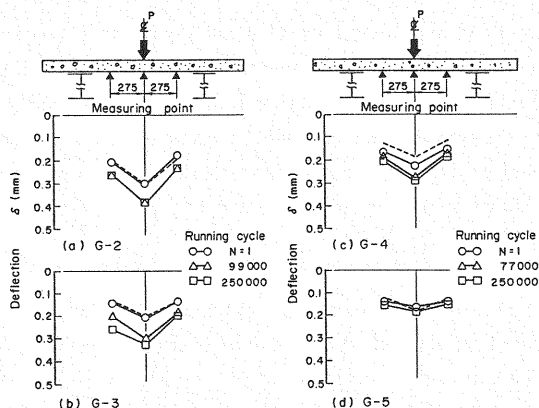


Fig. 14 Variations of Deflection for Concrete Slabs in Model Girders G-2~G-5.

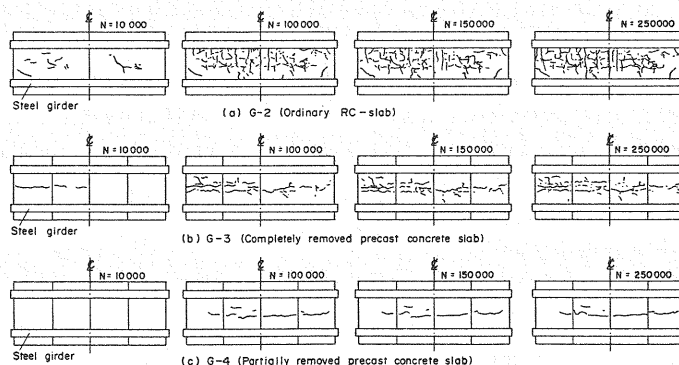


Fig. 13 Propagations of Crack for Model Girders G-2~G-4.

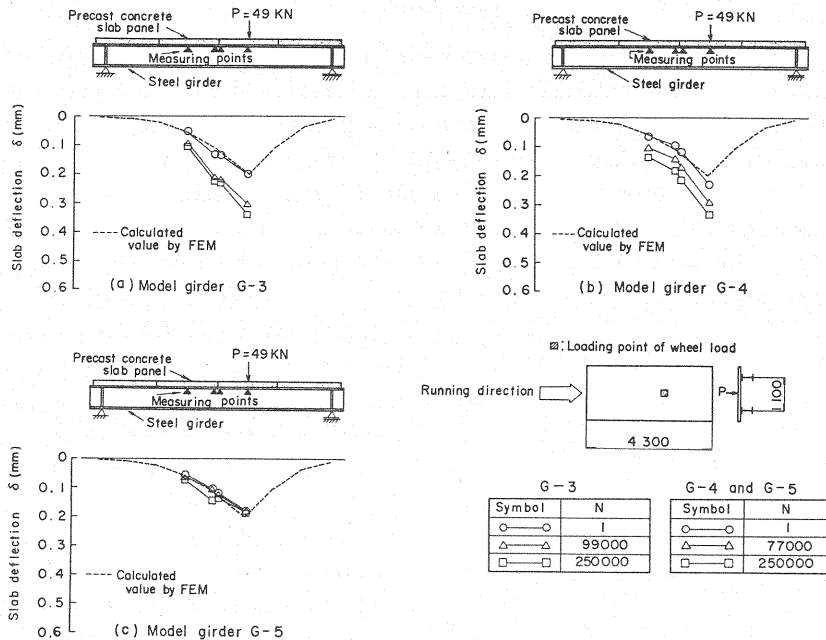


Fig. 15 Variations of Deflection for Precast Concrete Slab (Small Scale Model Girders).

longitudinal directions of steel girders.

The deflection of conventional RC-slab is gradually increased in accordance with the accumulations of running cycles. The similar tendency is observed in the case where the prestress forces are fully released in the precast concrete slab. Whereas, the variations of deflection are not noticeable in the case where a certain prestress forces are retained in the precast concrete slab. Furthermore, the deflections do not change in the case of prestressed precast concrete slab in two directions.

4. CONCLUSION

This paper presents the experimental study on the fatigue tests of composite girders by using precast concrete slabs through a moving vehicle apparatus. The main conclusions obtained from the test results are summarized as follows;

- (1) The composite girders built by using precast concrete slab behave as a complete composite beam with sufficient rigidity even in the case of moving vehicles.
- (2) The continuity conditions of axial displacement at the joints of precast concrete slab are held due to the prestress force, although the precast concrete slab is composed of a few discontinuous precast concrete slab panels.
- (3) The cracking of concrete slabs is significantly prevented through the introductions of appropriate prestress forces rather than the improvements of strength and quality of concrete materials.
- (4) The adjustments of longitudinal prestress forces in the precast concrete slab control not only transverse cracking, but also longitudinal cracking.
- (5) It is preferable to utilize two-directionally prestressed concrete slabs in the case where the concrete slab undergoes the extremely heavy traffic flows.

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