Spatial behaviour of plate girder bridges under redecking

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Spatial Behaviour of Plate Girder Bridges under Redecking

Comportement spatial des ponts à poutres à âme pleine lors de la rénovation de la chaussée

Räumliche Wirkung von Plattenbalken-Brücken bei Fahrbahnerneuerung

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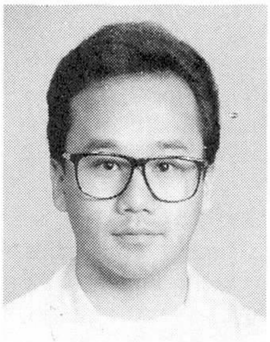
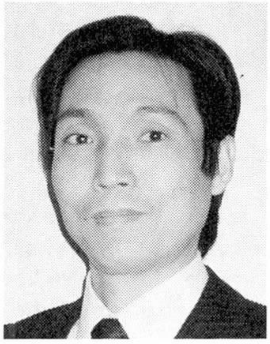




SUMMARY

Spatial behaviour of plate girder bridges under redecking is studied experimentally and theoretically. A series of statical loading tests were conducted under several loading and structural conditions which may occur when the bridge is partially open to traffic during redecking. A finite element method was developed in order to analyze the spatial behaviour of plate girder bridges and the results of analysis are compared with the test results. Both the displacements and the stresses obtained from these analyses show good agreement with those of tests. Validity and efficiency of the theoretical method are shown.

RÉSUMÉ

L'article présente l'étude du comportement théorique et expérimantal des ponts à poutres à âme pleine, lorsque l'on maintient la circulation sur une partie de la chaussée au cours de sa rénovation. A cet effet, ont été élaborés aussi bien une série d'essais statiques pour différents états de chargte et conditions structurales, qu'une analyse méthodique spatiale au moyen de la méthode des éléments finis. La comparaison des résultats de calculs avec ceux des mesures fait apparaître une très bonne concordance tant des déplacements que des contraintes. Enfin, l'auteur montre la validité et l'efficience de cette méthode de calcul.

ZUSAMMENFASSUNG

Theoretisch und experimentell wurde die räumliche Wahrung von Plattenbalken-Brücken studiert, wenn infolge Fahrbahnerneuerung nur Teile für den Verkehr geöffnet sind. Zu diesem Zweck wurde eine Serie statischer Belastungstests für mehrere Last- und Tragwerkszustände sowie eine Methodik zur räumlichen Analyse mittels Finite-Elementen entwickelt. Beim Vergleich der Rechen- mit den Messergebnissen zeigt sich eine gute Übereinstimmung in den Verschiebungen und Spannungen. Validität und Effizienz des Berechnungsverfahrens werden aufgezeigt.

1. INTRODUCTION

In recent years, many reinforced concrete (RC) floor slabs of highway bridges have been deteriorated or damaged and require rehabilitation, repair and replacement. This is caused by the increase in traffic volume and the illegal passing of over-loaded heavy vehicles. Although many studies have been reported in reference to the repairing or strengthening method of damaged RC floor slabs, the redecking method by orthotropic steel deck has become of major interest in the view of the reduction of the dead load and the expected remaining life of bridge lately[1,2]. The authors have been studied the useful method of replacing damaged floor slabs with the prefabricated steel deck of Battledeck Floor Type[3] which is easily manufactured[4,5]. The bridge has to be partially open to traffic because a long traffic close of bridges with heavy traffic is usually not allowed in the work of replacing. Therefore, it is important to clarify the spatial behavior as a whole system and local stresses of plate girder bridges during the redecking.

This paper presents the results of statical loading tests for a large scale model and the finite element analysis for plate girder bridges. In the analysis, the RC floor slab is modelled by thin plate elements having six degrees of freedom for one node and the main girder by equivalent substituted truss system. The supporting cross beam and the cross frame are modelled by beam-column elements. Since the shear connector transfers the load primarily by shear, it is assumed that their flexural and torsional stiffness can be neglected. Validity and efficiency of the theoretical method are examined by comparing with the experimental results. Many useful information for redecking design are obtained from the results of tests and analyses.

2. SUMMARY OF LOADING TEST

2.1 Test model

Although the test model is designed to simulate the replacement of a damaged RC floor slab with the steel deck, a bridge model with the steel deck in place of the RC floor slab is used here. This is due to the practical reason that the thin concrete slab in the model may cause the structural unbalance between the floor slab and steel girders and it may be difficult to conduct the casting and removing operations of the RC floor slab in the testing frame.

The bridge model is composed of three main girders, the prefabricated steel deck, supporting cross beams and cross frames. The steel deck used is the Battledeck Floor Type with welded longitudinal ribs as shown Fig.1 and is connected by high strength bolts to the main girders. In order to simulate the behavior of the actual bridge under redecking, the steel deck is divided into two panels along the length. The supporting cross beam is corresponding to the transverse rib of the orthotropic steel deck and is fastened by high strength bolts to main girders.

2.2 Test procedure

The objectives of the experimental programme are to investigate the spatial structural behavior of the girder bridges as a whole system and the local stress during the redecking. The statical load is applied at the centre of the span through 300mm x 120mm hard rubber plates which are placed on the steel deck. The loading conditions and the applied load are summarized in Table 1. The test procedure corresponding to the actual replacement of the RC floor slab with the steel deck is selected and consists of a total of seven steps as shown in Table 2. The models of STEP 1 & 2 are composed of three main girders and

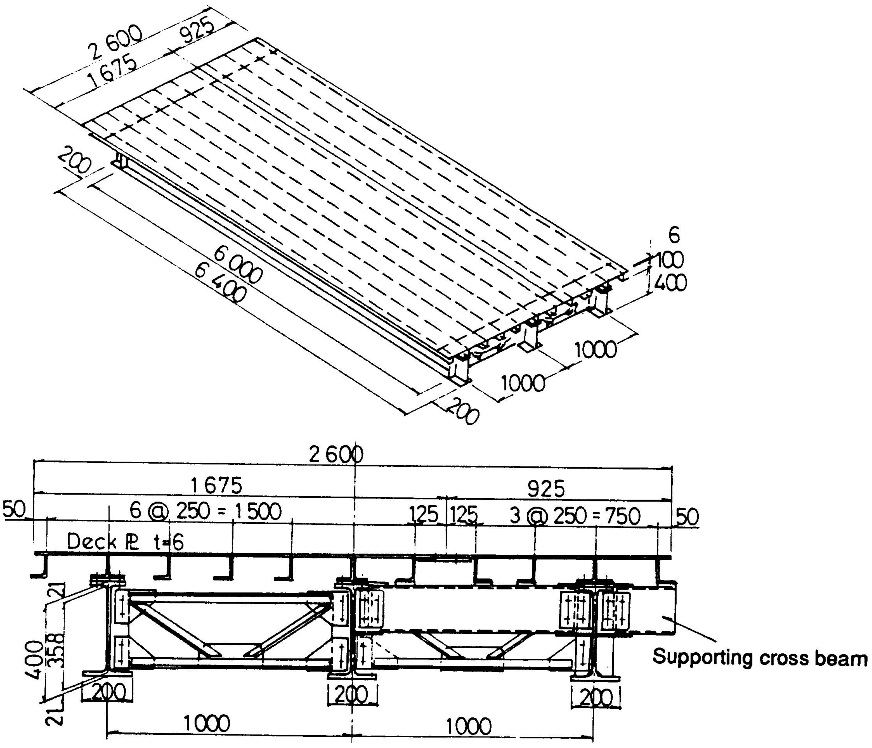


Fig. 1 General layout of the bridge model

Table 1 Loading cases

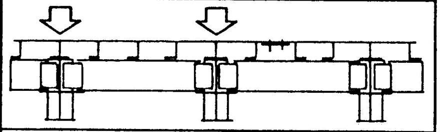
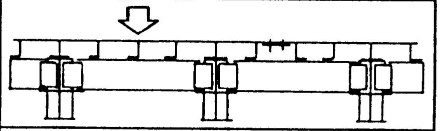
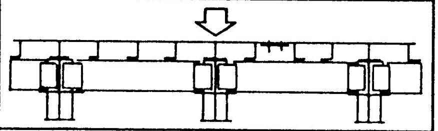
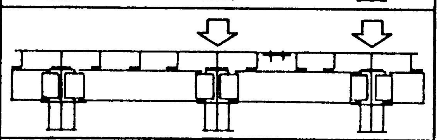
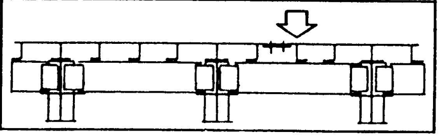
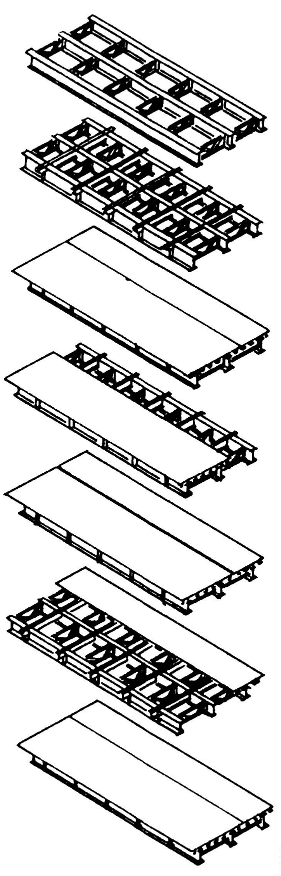
	Max. Load (kN)	Loading Conditions
CASE I	150	
CASE II	70	
CASE III	100	
CASE IV	150	
CASE V	70	

Table 2 Test procedure

		Loading Conditions
	STEP 1	CASE I ≀ CASE III
	STEP 2	CASE I ≀ CASE III
	STEP 3	CASE I ≀ CASE V
	STEP 4	CASE I ≀ CASE V
	STEP 5	CASE I ≀ CASE V
	STEP 6	CASE I ≀ CASE V
	STEP 7	CASE I ≀ CASE V

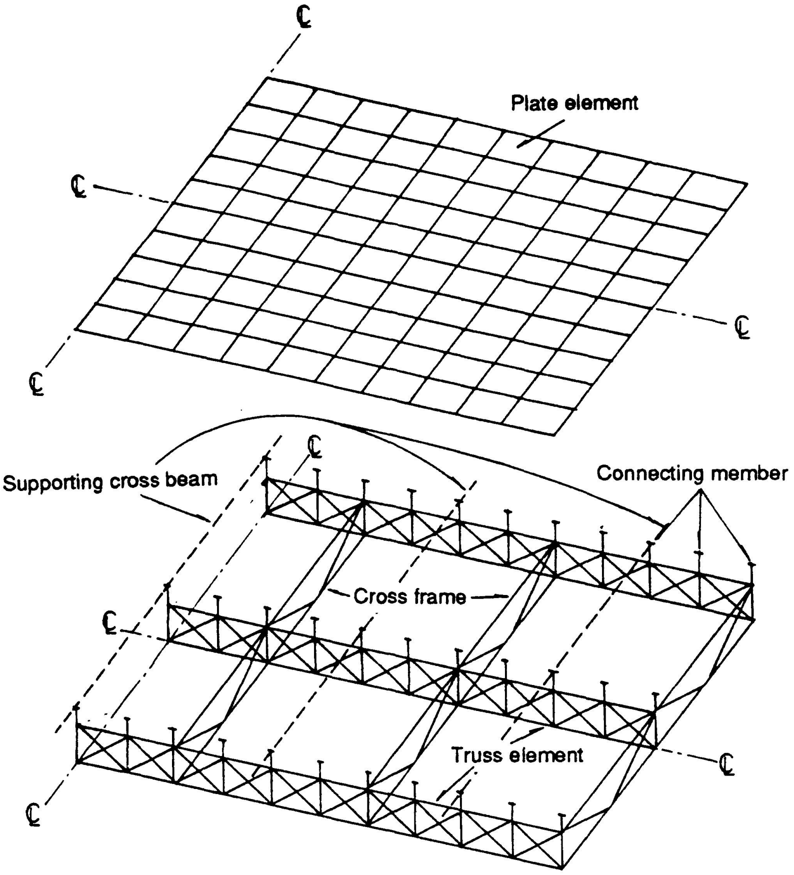


Fig. 2 Theoretical model

cross frames without the steel deck, and for the model of STEP 2 supporting cross beams are installed in addition to cross frames. Measurements of strains in the main girders, steel deck and supporting cross beams were made by using strain gages. The deflection of the steel girders and the shear slip between the deck plate and the main girder were measured using electrical and cantilever type displacement meters, respectively.

3. SUMMARY OF ANALYSIS

3.1 Theoretical model

The theoretical model used for the analysis of the plate girder bridge which composed of steel deck, main girders, supporting cross beams and cross frames is shown in Fig. 2. The steel deck is modelled by triangular thin plate elements having six degrees of freedom for one node. The stiffness matrix of the plate element is derived with the consideration for in-plane flexural stiffness[6]. The supporting cross beam is modelled by thin-walled beam-column elements[7] and the cross frame by truss elements. The main girder is modelled by an equivalent truss system which can store the same amount of strain energy with that stored in the plate girder. With reference to Fig. 3, the cross sectional areas of the substituted truss members are given by the following equations[8]:

Upper chord member: $A_{cc} = \dfrac{I}{(h_c+h_t)h_c}$

Lower chord member: $A_{ct} = \dfrac{I}{(h_c+h_t)h_t}$

Vertical member: $$A_v = \frac{6A_wG}{\mu E \tan\theta}$$

Diagonal member: $$A_d = \frac{3A_wG}{2\mu E \sin\theta \cos^2\theta}$$

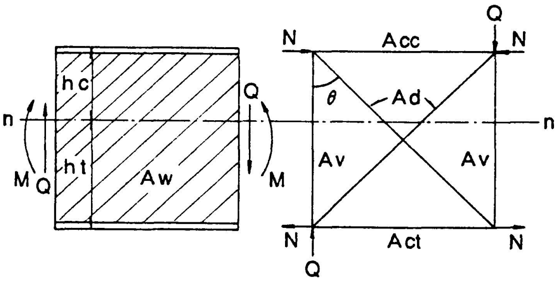


Fig.3 Substituted truss

where I is the moment inertia of the girder cross section about the neutral axis, ht and hc are the distances from the neutral axis to each outermost fiber, respectively, E and G are the Young's modulus and the shear modulus, μ is the shape factor and Aw is the cross sectional area of the web plate. Though the steel deck is connected by high strength bolts to main girders, the shear connector is modelled by cantilever elements which permits only the horizontal shear at the free end of element.

3.2 Computation method

The computation was carried out for the half of the girder bridge considering the symmetrical condition at the midspan. The deck plate is divided into 10 elements both along the length and the width of the deck. In the modeling, the cross sectional shape of the theoretical model is used the rectangular determined according to the condition that the flexural stiffness of the deck plate section equals those of experimental model. The bridge , part of which steel deck is removed, is modelled in the same way, but the thickness of deck plates supposed to be removed is assumed to be negligibly small (0.001cm) in the analysis.

4. RESULTS AND DISCUSSIONS

4.1 Load distribution effect of cross frames and supporting cross beams

The load distribution effects of cross frames and supporting cross beams are examined at the test steps 1 & 2 (without the steel deck) for the loading CASE I ~III.

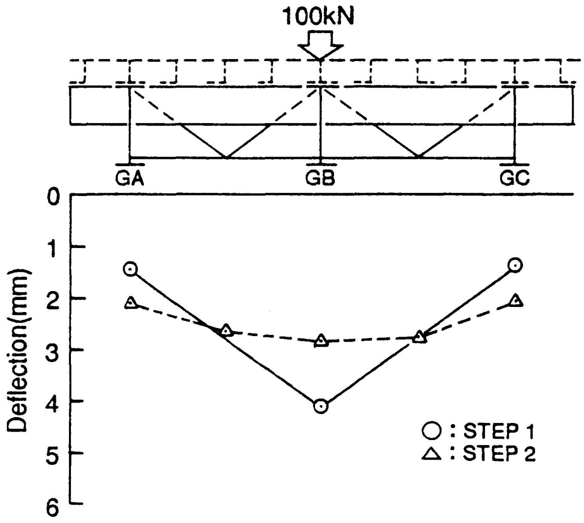


Fig. 4 Deflection of main girders at midspan

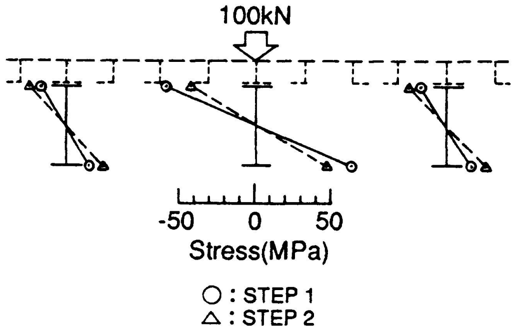
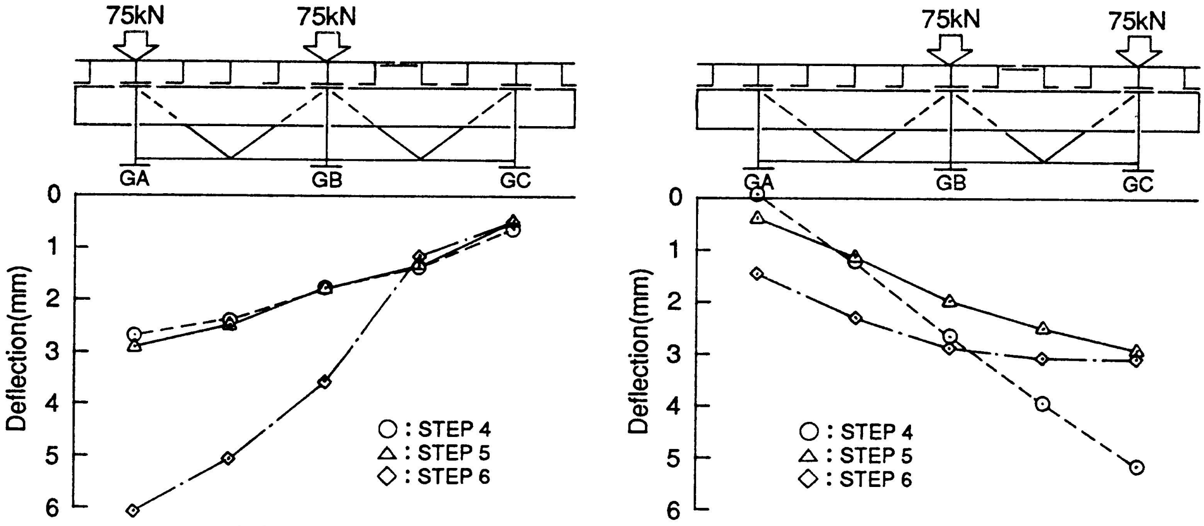
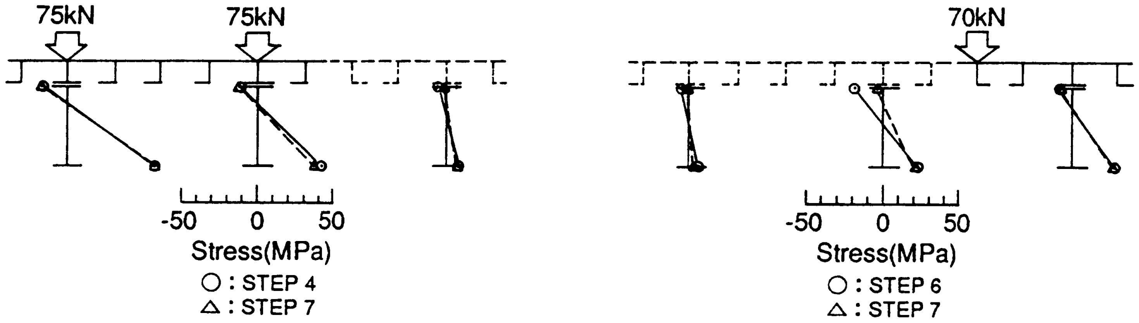


Fig. 5 Stress distribution of main girders at midspan



(a) CASE I (b) CASE IV

Fig. 6 Deflection at midspan for each STEP



(a) CASE I (b) CASE V

Fig. 7 Distribution of normal stresses at midspan

Figs. 4 and 5 show the deflection at midspan and the distribution of normal stresses on the girder under concentrated load at the midspan, respectively. It can be seen that 40% of the applied load is distributed to the exterior girders by using cross frames(STEP 1) and for the model of STEP 2 by using supporting cross beams in conjunction with cross frames 50 ~ 60% of the applied load is distributed to the exterior girders. From these test results, we can recognize that the use of supporting cross beams in the prefabricated steel deck system can give large effects of the load distribution.

4.2 Behavior during redecking

The deflection at midspan subjected to a lateral load at the midspan for STEP 4~6 are shown in Fig. 6. It may be found that the deflection for STEP 4 in CASE IV and STEP 6 in CASE I are larger than those of the other loading cases. This is due to the reason that the loads are directly applied to the main girders where part of the deck plate is removed. Fig. 7 shows the distribution of normal stresses on main girders at midspan for STEP 4,7 in CASE I and STEP 6, 7 in CASE V. By comparing the stress in the low flange of main girders with (STEP 7) and without (STEP 6) the deck plate, we notice that the stress of main girder without a part of deck plate is relatively small and is nearly equal to those of a complete system (STEP 7). The reason of this is that the moment inertia of the composite section is 2 ~ 3 times larger than that of a main girder and this section is mainly in charge of the applied load. From test results, it can be noticed that the supporting cross beams play satisfactory

Table 3 Comparison of test and analysis for each slip modulus k

(a) Deflection Unit:mm

		GA		GB		GC
Experiment		0.90	1.32	1.42	1.31	0.94
Analysis	k=9.8	0.86	1.16	1.31	1.16	0.86
	98	1.16	1.31	1.48	1.31	1.16

(b) Stress Unit:MPa

		GA		GB		GC	
		Comp	Tens	Comp	Tens	Comp	Tens
Experiment		5.2	16.5	12.2	34.4	4.8	15.8
Analysis	k=9.8	3.8	16.0	9.2	34.1	3.8	16.0
	98	6.0	17.0	16.6	34.8	6.0	17.0

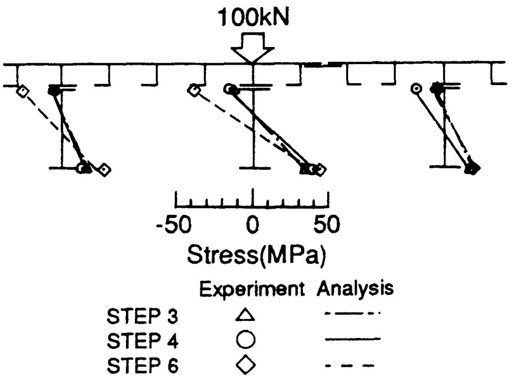
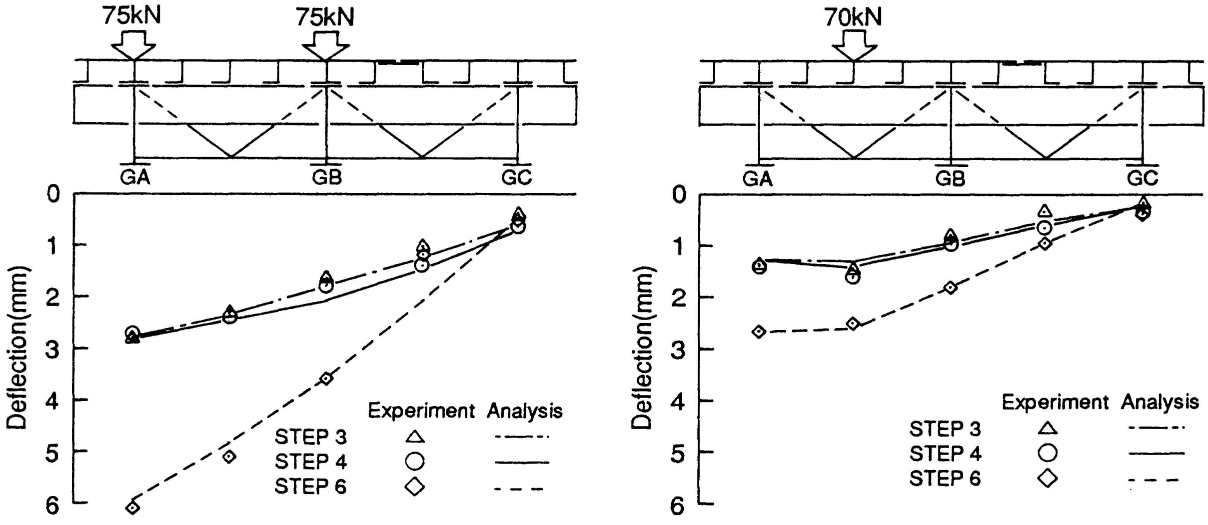


Fig. 9 Stress distribution at midspan



(a) CASE I (b) CASE II

Fig. 8 Comparison of deflection at midspan between theory and experiment

role for the load distribution in transverse direction together with for the outer girder without the deck.

4.3 Comparison of tests and theory

To determine the slip modulus k of the shear connector prior to model analysis, the complete models (STEP 3) subjected to a lateral load at midspan were analyzed for two k values, k= 9.8 and 98 (N/m/m), based on the previous studies [4,5]. The comparisons of tests and the theory for deflection and stress of main girders are given in Table 3. The slip modulus k= 9.8 (N/m/m) was adopted in this analysis because it tends to give overestimated conservative results in comparison with test results. The deflection at the midspan for STEP 3~6 in CASE I and II are shown in Fig. 8. Though the small differences between the theoretical and experimental results for STEP 6 in CASE I is observed, it can be noticed that the good agreement exists between the two sets of results. Fig. 9 shows the normal stress distributions on three main girders at the midspan for CASE III. The theoretical results correspond to the experimental results quite well. In spite of small differences for some loading cases, it can be seen that the results of the present analysis have fairly good correspondence with the test results as a whole. The validity of the present method can be recognized. This numerical method will be utilized to investigate the spatial behavior of existing plate girder bridges under redecking.

5. CONCLUSIONS

Spatial behavior of plate girder bridges under redecking is studied experimentally and theoretically. From this study the following conclusions can be drawn.

1) The redecking procedure of actual bridges with deteriorated RC slabs is simulated well by the experiment.
2) It is recognized that the use of supporting cross beams in the prefabricated steel deck system can give large effects of the load distribution.
3) In spite of small differences for some loading cases, it can be seen that the results of the present analysis show good agreement with the test results as a whole. The validity of the present method can be recognized.
4) The present method will be utilized to investigate the spatial behavior of existing plate girder bridges under redecking.

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