New method for connecting concrete slabs to steel bridge girders

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New Method for Connecting Concrete Slabs to Steel Bridge Girders

Nouvelle méthode de liaison de dalles avec des poutres métalliques de pont

Neues Verbindungsverfahren bei Verwendung von Betonplatten in Stahlbrücken

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SUMMARY

A new process developed for connecting concrete slabs and steel girders is useful in replacing traffic-damaged concrete slabs with precast concrete ones. According to this process, the joint called the box dowel permits level adjustment by screws, and ensures connection with the steel girders by welding. This paper deals with experimental results of the performance and rigidity effects of the box dowel, and introduces an application of the process to an actual bridge.

RÉSUMÉ

Un nouveau procédé de liaison de dalles et de poutres en acier s'avère utile pour remplacer les dalles détériorées par des dalles en béton préfabriqué. Ce procédé de liaison par goujons, permet de régler le niveau au moyen de vis et d'assurer la connexion avec les poutres en acier par soudage. Cette étude décrit les résultats expérimentaux en matière de performance et de rigidité des goujons . Une expérience pratique est mentionnée pour un pont existant.

ZUSAMMENFASSUNG

Ein neues Verfahren, das für die Verbindung von Platten mit Stahlträgern entwickelt wurde, ist geeignet, um Betonplatten, die durch starke Verkehrsbelastung beschädigt sind, mit vorgefertigten Betonplatten zu ersetzen. Dieses Verfahren, ermöglicht die als Boxdübel bezeichnete Verbindung Höhenlageneinstellungen mit Schrauben vorzunehmen und gewährleistet durch Schweissen die Verbindung mit den Stahlträgern. Die vorliegende Abhandlung beschreibt Versuchsergebnisse über die Leistung und Steife des Boxdübels und führt ein Anwendungsbeispiel bei einer tatsächlichen Brücke auf.

1. INTRODUCTION

Recently increases in traffic volume, in the sizes of vehicles and in the loads carried by them have been bearing harder and harder on the existing road steel girder bridges, and the number of reported cases of damage on their concrete slabs are increasing. Whole replacement of concrete slab must be carried out quickly and safely in a manner to minimize the period closed to traffic flow, and one of solutions to this has been the use of precast concrete slabs. The authors have developed a new jointing process, the connection of slabs and steel girders. This process called box dowel which permits level adjustment by screws and ensures connection with the steel girders by welding. This paper deals with experimental results of the performance and rigidity effect of the box dowel according to this newly developed jointing process, and also introduces an application of the process to an actual bridge.

2. BOX DOWEL

Figure 1 illustrates a newly developed box dowel and its connection to the steel girder. As shown, the box dowel consists of an outer cylinder embedded into a precast concrete slab and an inner cylinder that is threaded into the outer cylinder at site. After level adjustment of the precast concrete salb, the bottom end of the inner cylinder is integrated with the steel girder by welding. In practice, the clearance between the concrete slab and steel girder is filled up with non-shrink mortar. From the design point of view, however, the bond stress of mortar is disregarded, and all the shear force acting between the concrete slab and steel girder is assumed to be taken up by the box dowel. The mechanism of transmision of shear force from concrete slab to steel girder by the box dowel is illustrated in Figure 2.

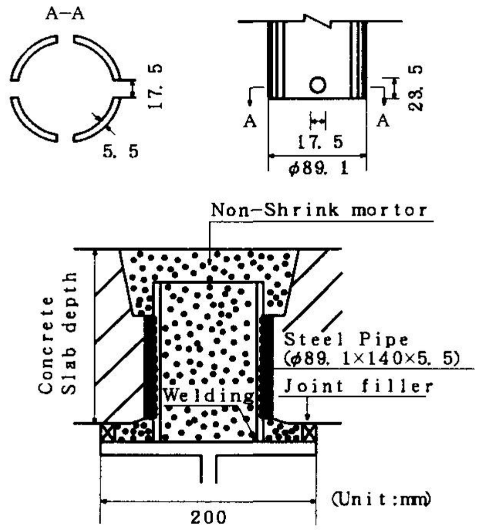

FIG. 1. SHAPE OF BOX DOWEL AND JOINTING METHOD

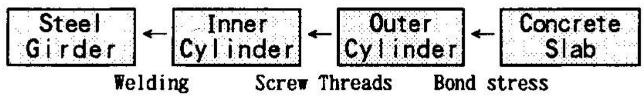

FIG. 2. MECHANISM OF TRANSMISION OF SHEAR FORCE BY BOX DOWEL

3. SPECIMENS AND TEST METHODS

According to a road bridge engineering manual available in Japan, the shearing strength per dowel is determined by the shearing capacity of a dowel itself whitch is a function of the type and dimensions of the dowel, or by cleaving strength or bearing strength of concrete. For the purpose of direct measurement of the shearing capacity per box dowel, the authors conducted a punching shearing test according to the loading arrangements illustrated in Figure 3. Specimens consisting of H-beam and concrete with foam styrol included in between were prepared so that all the shearing force acting on the specimen would be borne by the box dowel, and static loading test and fatigue test were carried out on five specimens, respectively. High-strength concrete with a standard design strength of 500 kgf/cm² was used for specimens. In the loading tests, the box dowel was given a shearing force by applying a uniform axial load on the center of the H-beam as illustrated in figure 3.In the static loading test, the loading hysteresis cycle was 0→20 tf→0→40 tf→0→60 tf→0→Max. load. Static rupture load, Pu(tf), and the load vs.Penetration curve were determined, and the dowel slip displacement caluculated.In the fatigue test,load was changed sinusoidally at a cycle of 150 times per minute from minimum value (10% of static rupture load) to maximum value (36, 42, 45, 48% of static rupture load)to determine the fatigue life (i.e., the number of cycles till the dowel fails). The changes in slip displacement of dowel were also measured using a dial gauge under minimum and maximum load conditions.

4. TEST RESULTS

4-1. Static loading test

In the static loading test, all failures of specimens took place in the form of shear fracture with slip at the welds of the box dowel, and were accompanied by the deformation of inner cylinder. The load vs. displacement curves measured in the static loading test showed almost the same tendency. An example of measurements taken with specimen S-4 is given in Figure 4.

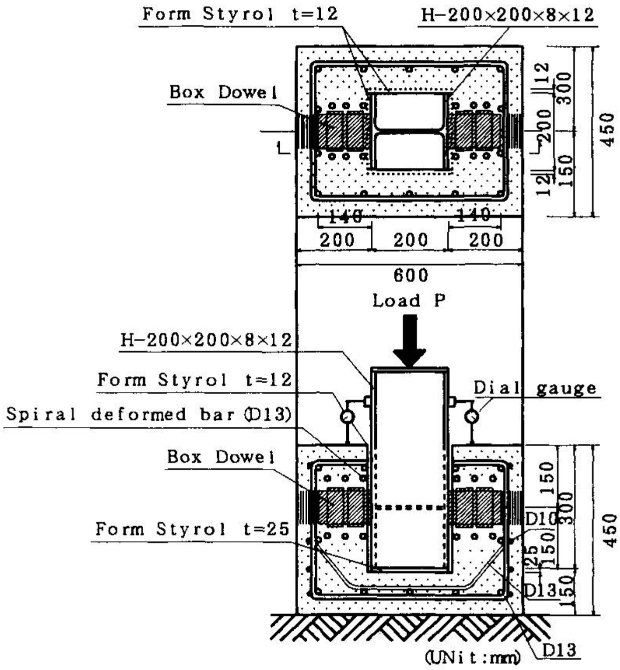

FIG. 3. SHAPE AND SIZE OF SPECIMEN AND LOADING METHOD

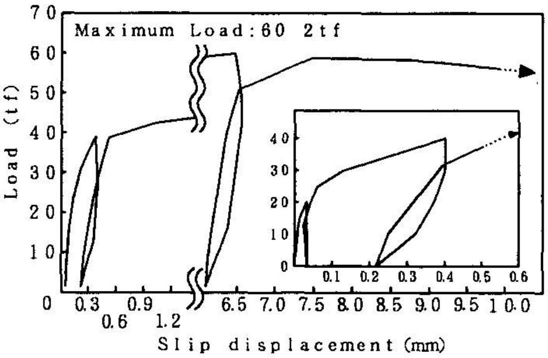

FIG. 4. LOAD VS. SLIP DISPLACEMENT CURVES (S-4 SPECIMEN)

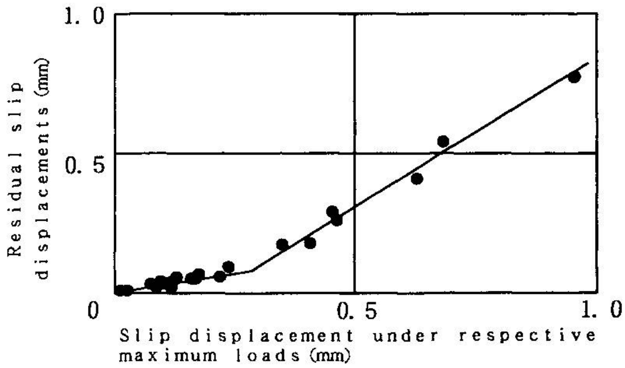

FIG. 5. RELATIONSHIP BETWEEN SLIP DISPLACEMENT UNDER LOAD VS. RESIDUAL SLIP DISPLACEMENT

It is evident from the measurements shown that the slip displacement of box dowel follows elastic behavior up to nearly P = 20 tf (τs = 700 kgf/cm²) where the slip displacement is about 0.05 mm. The rates of increase in slip displacement increase with load if P is in excess of 20 tf, and the maximum load (static fracture load) is observed at slip displacements ranging from 5 to 10 mm. Figure 5 shows the relationship between slip displacements under loads (P = 20 tf, 40 tf, 60 tf) and the residual slip displacements after removal of loads. The relationship between slip displacement under load and residual slip displacement after removal of load shows that the residual slip displacement increases sharply when the loading slip displacement exceeds 0.3 mm, suggesting that the load that causes a slip displacement of 0.3 mm will be a limit load for the functional performance of a composite system under static load conditions. Namely, the loads that develop a slip displacement of 0.05mm and 0.3 mm, respectively, are considered the limit loads within whitch the box dowel is structurally allowed to change its rigidity behavior. These limit loads were determined from the load vs. slip displacement curves of test specimens, and are given in Table 1 together with the shearing fracture strengths.

Specimen No.	Shearing strength per box dowel (tf)		
	Slip displacement 0.05mm	Slip displacement 0.3mm	Rupture load
S - 1	12.9	20.3	30.9
S - 2	9.4	17.8	33.6
S - 3	8.3	21.0	27.5
S - 4	11.0	18.3	30.1
S - 5	13.0	20.2	32.9
Average	10.9(750)	19.5(1350)	31.0(2150)

The values in parentheses refer to average shear stress intensity (kgf/cm²).

TABLE 1. SUMMARY OF STATIC LOADING TEST RESULTS

Specimen No.	Max. load ratio(%)	Number of cycles(x10^4)		
		$N_{0.3}$	$N_{1.0}$	Nu
D - 1	36	91.8	125.9	140.0
D - 2	42	13.3	21.6	25.45
D - 3	45	0.62	3.95	10.54
D - 4	48	5.08	10.24	10.45
D - 5	48	2.82	5.65	7.21

TABLE 2. SUMMARY OF FATIGUE TEST RESULTS

4-2. Fatigue test

The sizes of repetitive load applied to test specimens D-1 through D-5 are shown in Table 2. As an example, the number of loading cycles vs. slip displacement curves are shown in Figure 6. As the changes in slip displacement due to repetitive loading are ascribable to changes in residual slip displacement, the relationship between the number of loading cycles and the average loading slip displacement (i.e., the average value of the slip displacements under minimum and maximum loads) is shown in Figure 7.

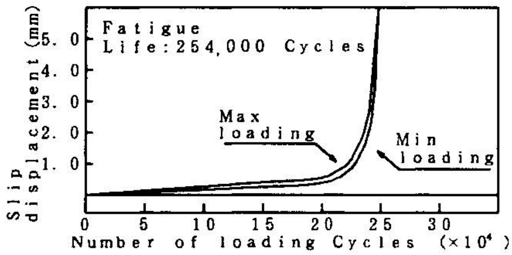

FIG. 6. NUMBER OF LOADING CYCLES VS. SLIP DISPLACEMENT (DURING MIN. AND MAX. LOADING)

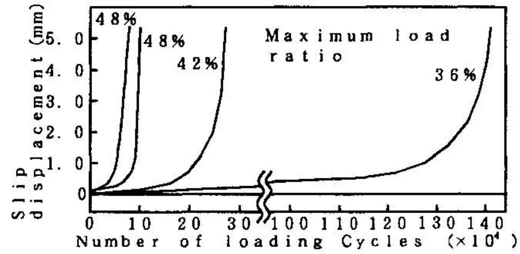

FIG. 7. NUMBER OF LOADING CYCLES VS. SLIP DISPLACEMENT CURVES (AVERAGE LOADS)

As will be clear from Figure 7, almost every test specimen shows slip displacements proportional to the number of loading cycles if the loading cycle ratio is within about 70% where the slip displacement is about 1.0 mm. The fact that the rate of change in slip displacement increases when a structure using box dowels is subjected to repetitive loads suggests that the rigidity effect changes irrespective of whether the box dowel fails or not. It is therefore considered that the number of cycles ($N_{1.0}$) for a slip displacement of 1.0 mm may be taken as the composite functional life under repetitive loading conditions. Accordingly, $N_{1.0}$ was determined from the number of loading cycles vs. slip displacement curves, and $N_{0.3}$ number of loading cycles run to reach a slip displacement of 0.3 mm taken as a slip displacement limit life under static loading conditions was also determined. They are shown in Table 2. Given in Figure 8 are S-N curves showing slip displacement life ($N_{0.3}$), functional life($N_{1.0}$), and fatigue life (Nu) in relation to maximum loading ratio.

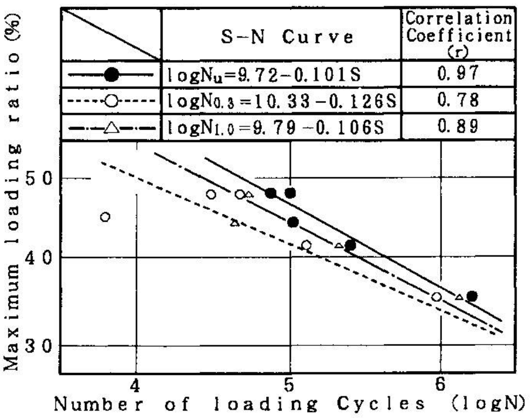

FIG. 8. S-N CURVES

5. AN APPLICATION EXAMPLE OF THE NEW JOINTING METHOD TO AN ACTUAL BRIDGE

It was determined to apply the newly developed jointing method to Kamishima-bashi Bridge, a simple composite steel plate girder bridge, situated in Sasebo City, Nagasaki Prefecture. It had reinforced concrete slabs with a thickness of 18 cm. Constructed in 1968 with a design load of TL-20, length (L) of 22.0 m and width (B) of 18.45 m, it was classified as a first-class bridge. It concrete slabs were damaged serious by heavy traffic, and had to be replaced with new precast concrete slabs according to the box dowel process. Stress frequency and deformation of main girders under actual service conditions before and after slab improvment were measured in the safety assessment of the bridge. Stress frequency of main girders was measured using a histogram -recorder for 24 hours under actual service conditions, for the purpose of evaluating the safety of the bridge. The technique used for safety assessment of the newly developed dowel joint was called the peak-valley method in whitch the frequencies of extremes (peaks and valleys) of stress (strain) waveforms developed by passing vehicles within a 24-hour period were counted for each specific stress level. Before and after slab improvement, the stress frequency was measured at the same midspan position on the underside of the lower flange of each of the main girders G1 through G7. The maximum values of the stress intensity and deflection developed in each of the main girders under actual live traffic loads before and after slab improvement are shown in Figure 9,10. Table 3 shows the live load-to-stress intensity ratios measured for respective main girders under actual live traffic load conditions after slab improvement. Figures 11 and 12 show an example of changes in frequency of stress and deflection of main girders before and after slab improvement.

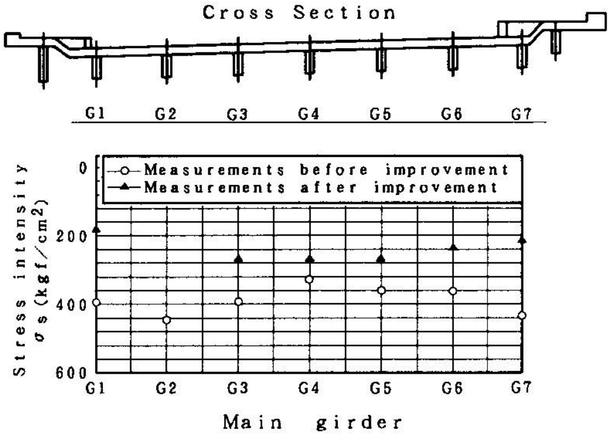

FIG. 9. MAXIMUM STRESS INTENSITY
(UNDER ACTUAL LIVE TRAFFIC LOAD CONDITION)

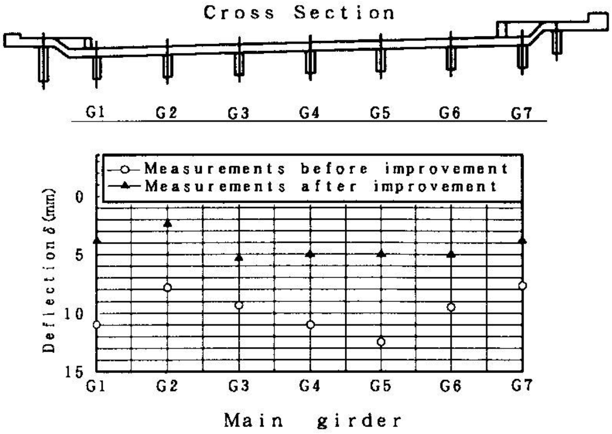

FIG. 10. MAXIMUM DEFLECTION
(UNDER ACTUAL LIVE TRAFFIC LOAD CONDITION)

Main girder No.	Stress intensity ratio under live load condition($\sigma max/\sigma 1$)		Deflection ratio under live load condition($\delta max/\delta 1$)	
	Before improvement	After improvement	Before improvement	After improvement
G1 girder	0.71	0.32	0.91	0.37
G2 girder	0.51	0.07	0.45	0.17
G3 girder	0.44	0.33	0.54	0.41
G4 girder	0.38	0.33	0.63	0.38
G5 girder	0.41	0.33	0.72	0.38
G6 girder	0.41	0.29	0.54	0.38
G7 girder	0.78	0.46	0.65	0.41

σ max:maximum stress intensity (measured value),
σ 1:calculated stress intensity
δ max:maximum deflection (measured value),
δ 1:calculated deflection

TABLE 3. STRESS INTENSITY RATIO AND DEFLECTION RATIO UNDER LIVE LOAD CONDITION (TL-20)

The measurements above indicate the following:

(1)It is apparent from Figures 9 and 10 that the maximum values of stress intensity and deflection measured for 24 hours after improvement under actual live traffic load conditions were improved by stress intensity and deflection as compared with pre-improvement values.

(2)Table 3 indicates that the measurements of stress intensity and deflection of main girders after slab improvement under actual live traffic load conditions were below half the calculated values (46 to 47% and 41 to 47%, respectively), or well below allowable values.

(3)The changes in frequency of stresses and deflections in main girders in Figures 11 and 12 show a substantial reduction in amplitudes of post-improvement stresses and deflections, suggesting that the rigidity has been improved markedly, and that the bridge is safer after than before improvement.

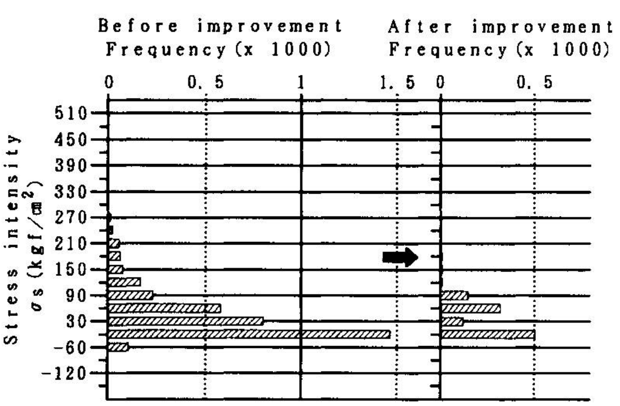

FIG. 11. STRESS FREQUENCY OF G1 GIRDER BEFORE AND AFTER IMPROVEMENT

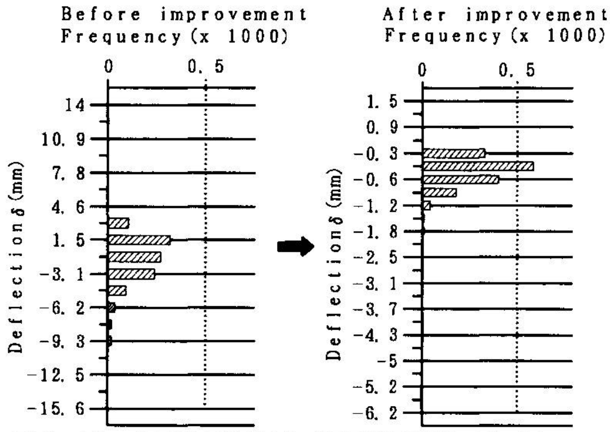

FIG. 12. DEFLECTION FREQUENCY OF G1 GIRDER BEFORE AND AFTER IMPROVEMENT

6. CONCLUSIONS

The experimental study of the newly developed box dowel in terms of performance and rigitity improvement effect, and the measurements of stress intensity and deflection in the main girders of a bridge to whitch the new jointing process was applied, have led to the following conclusions:

(1)The box dowel exhibits a sufficiently high capacity to check the dislocation of concrete slabs from the steel girders and to withstand shearing deformation, and is expected to perform its duty satisfactorily.

(2)The box dowel is practically warrantable for application to actual bridges if the shearing strength of the welds between the box dowel and steel girder is properly designed to effectively withstand the critical fatigue rupture strength due to repetitive loads.

(3)The measurements of stress intensity and deflection in the main girders of a bridge after slab improvement were smaller than those taken before improvement, bearing out the improvement in rigidity and safety of the bridge. All these recommend the newly developed jointing process as a practical solution to the simplification of site work, improvement of slab structural characteristics, and reduction of construction period for steel road bridges by taking advantage of the excellent features of precast concrete slabs unavailable from the conventional in-situ reinforced concrete slab process.

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