Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 60 (1990)

Artikel: Division of slabs and development of flexible connectors
Autor: Abe, Hidehiko / Nakajima, Akinori
DOI: https://doi.org/10.5169/seals-46447

Division of Slabs and Development of Flexible Connectors

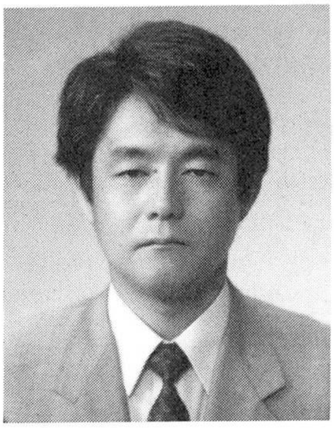
Division de dalles en béton et conception de connecteurs flexibles

Unterteilung von Brückenplatten und Entwicklung flexibler Verbindungen

Hidehiko ABE
Prof. of Civil Eng.
Univ. of Utsunomiya
Utsunomiya, Japan

Hidehiko Abe, born 1931, graduated and obtained his doctoral degree from the Univ. of Tokyo. For 30 years he worked for the Japanese National Railways, mainly engaged in the design of steel bridges. Since 1984 he has been teaching structural engineering at Univ. of Utsunomiya.

Akinori NAKAJIMA
Assoc. Prof. of Civil Eng.
Univ. of Utsunomiya
Utsunomiya, Japan



Akinori Nakajima, born 1954, graduated and obtained his doctoral degree from the Tohoku University, Japan. He is currently engaged in research on the behavior of steel-concrete composite structures and on dynamic strength of structures.

SUMMARY
For a long span railway girder bridge with concrete deck, either a non-composite structure or a composite structure with a divided concrete slab is often found to be more economical than an ordinary composite one. The paper deals with the effect of division of the concrete deck and flexibility of shear connectors on stress and slip composite structure, and with an experimental investigation for the development of fatigue-resistant flexible connectors.

RÉSUMÉ
On a trouvé qu'on pont-rail de grande portée avec poutres à tablier supérieur en béton, qu'il soit de structure non mixte ou mixte et avec dalle en béton à joints articulés, est souvent plus économique que celui à structure mixte ordinaire. Cet exposé examine l'influence qu'exerce la division du tablier supérieur en béton et la flexibilité des connecteurs à cisaillement sur les contraintes et le glissement d'une structure mixte; il traite en outre de la recherche expérimentale pour la mise au point d'un connecteur flexible résistant à la fatigue.

ZUSAMMENFASSUNG
Für eine Eisenbahnbrücke mit grosser Spannweite hat sich ein Träger mit Betondecke ohne Verbund oder mit Verbund und Fugen als Kostengünstiger erwiesen als eine normale Verbundskonstruktion. Der Beitrag behandelt den Einfluss der Unterteilung der Platte und der Flexibilität der Schubverbindungen auf Spannungen und Schlupf in einem Verbundtragwerk. Zur Entwicklung von ermüdungsfesten flexiblen Verbindungselementen wurde eine experimentelle Untersuchung durchgeführt.

1. INTRODUCTION

Long steel-concrete composite girder bridges of over 100 meters in span are used for railway bridges in Japan, mainly for abatement of the noise caused by train operation as well as for economy.

The elastic analysis is applied in general to design of railway bridges, because the fatigue effect must be taken into account. Accordingly, when steel of higher strength is used for the steel girders of composite structure of a longer span, a concrete slab of proportionally high strength is theoretically preferable from a view-point of balance. It is, however, practically difficult to cast reliable concrete of such a high strength at the construction site. If a thick concrete slab of ordinary strength is used, the dead load increases instead. Consequently it is considered to be reasonable and economical in such a case to control the amount of compressive force acting in the concrete slab by use of flexible shear connectors instead of rigid ones or by dividing the slab into short sections.

The paper deals with analytical results concerning the effect of division of the slab and flexibility of shear connectors on the stresses of various parts of a typical composite girder, and also presents the test results of flexible shear connectors which were newly developed by the authors.

2. EQUATIONS FOR COMPOSITE GIRDER WITH FLEXIBLE SHEAR CONNECTORS AND A DIVIDED SLAB

Assuming the discrete shear connectors as an equivalent uniformly distributed spring of factor C(N/m/m),

$$\delta = T/C \quad \text{and} \quad \frac{d\delta}{dx} = \frac{dT}{dx}\frac{1}{C} \qquad (1)$$

where δ is deformation of the spring and T is horizontal shear force per unit length along the beam axis to be transferred by shear connectors.

Fig.1 shows the deformation and equilibrium among the external forces acting on a beam section of length dx. Then,

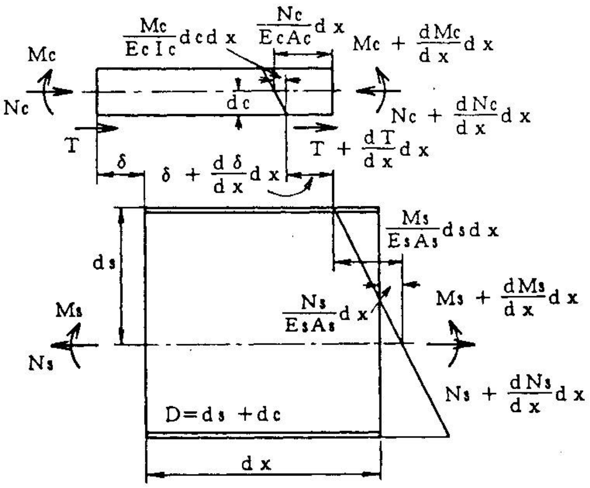


Fig.1 Equilibrium of Forces acting on Elements of Composite Beam

$$\frac{d^2N}{dx^2} - \omega^2 = -\gamma M_0 \qquad (2)$$

where N is axial force, M is bending moment,

$$\omega^2 = \left(\frac{1}{E_cA_c} + \frac{1}{E_sA_s} + \frac{D^2}{E_cI_c + E_sI_s}\right) C \quad \text{and} \quad \gamma = \left(\frac{D}{E_cI_c + E_sI_s}\right) C \qquad (3)$$

D in the above equation is the distance between the centroid of the concrete slab section and that of the steel beam section. Then, T = dN/dx is used for derivation of Eq.(2). Solving Eq.(2) under the boundary condition that at the both ends of each element of the divided concrete slab, the axial force N_c is zero, the stresses can be obtained.

3. EXAMPLES OF NUMERICAL ANALYSIS

3.1 Modelling

A simply supported composite girder of 20 meters in span length with a cross-sectional shape shown in Fig.2 is used as an example for numerical analysis. It is assumed that the beam is subjected to a uniformly distributed load of 49kN/m and that the elastic modulus of the steel material

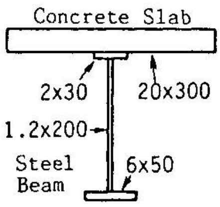


Fig.2 Dimensions in cm of Cross Section used for Analysis

and that of the slab concrete are 206GPa and 29.4GPa, respectively. The slab is divided into two to ten blocks of equal length.

3.2 Variation of Axial Force in Slab with Spring Factor of Shear Connectors

Fig.3 shows a few examples of distribution of the axial force in the divided concrete slab, compared with the case of infinitely rigid shear connectors. It is seen that the maximum axial force in the slab is small in either case where flexible shear connectors are used or where the slab is divided.

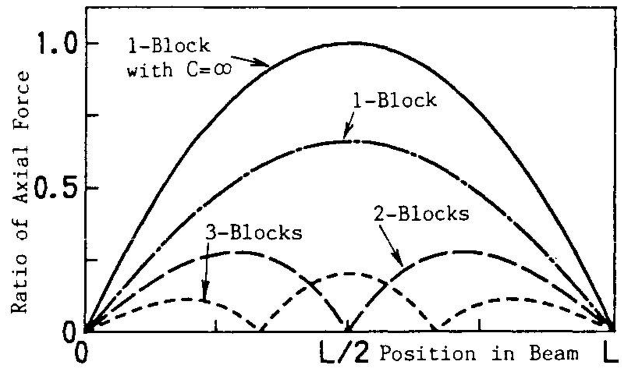


Fig.3 Axial Force in Slab (C=100MN/m/m)

Fig.4 shows how it decreases as the spring factor of shear connector C decreases. It is seen that irrespective of the number of division, it changes from zero to unity in a certain range of variation of spring factor, and the curve in the figure shifts to the right as the number of the division increases. It is estimated that the spring factor of actual composite bridges is as large as 10GN/m/m.

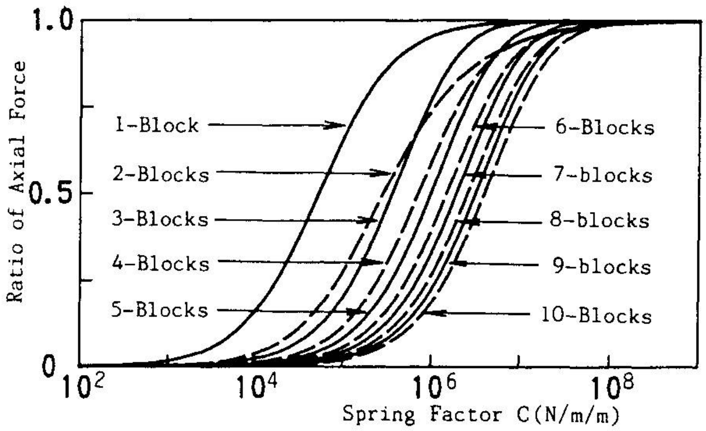


Fig.4 Relation between Spring Factor, Axial Stress in Slab and Number of Blocks

3.3 Relation between Stresses in Beam and Spring Factor of Shear Connector

Figs. 5(a) and (b) show the axial stresses in the concrete slab and the steel beam, respectively, in the cases of different number of division. The values here are normalized in

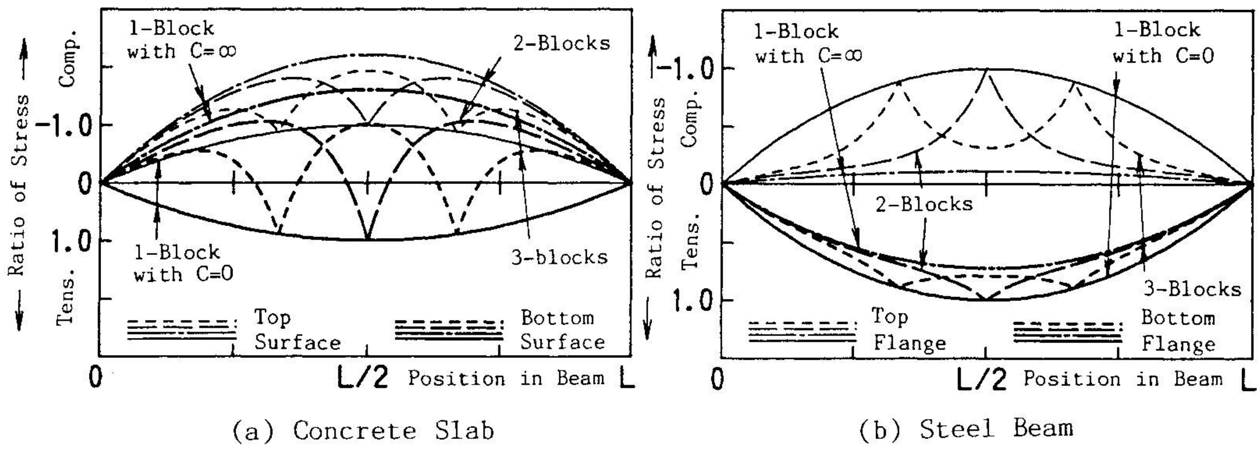


Fig.5 Axial Stresses (C=1.0GN/m/m)

reference to the case of non-divided slab with C=0. It is seen that the values vary between the values in the cases of non-divided slab with C=0 and ∞ and that while the maximum values are smaller than that in C=∞, they are equal to the values in C=0 at the division points.

3.4 Slip between Concrete Slab and Upper Flange of Steel Beam

Although the axial force in the concrete slab decreases, as the spring factor of shear connector C decreases, the amount of slip between the lower surface of the concrete slab and the upper flange of steel beam in contact increases. It may, however, be necessary to restrict the slip within a certain amount in railway composite girder bridges, which are subjected to cyclic loading. If a large slip is repeated, it will cause wearing of the concrete in contact with the steel flange.

Fig.6 shows examples of the variation of the slip along the longitudinal axis of the beam, compared with the value at the end of non-divided slab with C=0 (3.4mm). It is natural that in each block of the divided slab a maximum slip should take place at its both ends.

Fig.7 represents the relation between the spring factor of shear connector and the maximum slip for slabs divided into different numbers, compared with the case of the non-divided slab with C=0. It is revealed that the slip amount can be restricted to a given value by dividing the slab, though it tends to increase, as the spring factor decreases.

It should be noted that there must be a certain amount of gap between the blocks of a divided slab in order to allow the end movement, and gap must be filled with adequate elastic material to prevent water from penetration into the steel beam.

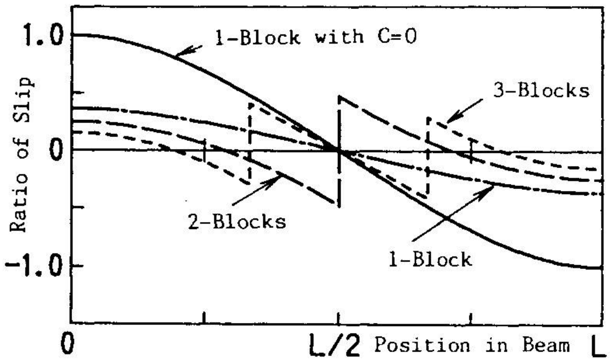


Fig.6 Axial Slip of Slab (C=100MN/m/m)

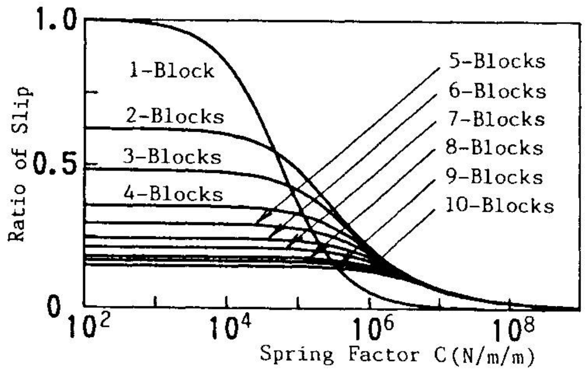


Fig.7 Relation between Spring Factor, Slip of Slab and Number of Blocks

4. EXPERIMENT OF FLEXIBLE SHEAR CONNECTORS

4.1 General

Flexible shear connectors must have ability to allow required amount of deformation without injuring their durability, that is, fatigue strength in case the structure is subjected to cyclic loading like in a railway bridge. They must work also as anchor against the vertical separation of the concrete slab. The authors have developed new economical and fatigue-resistant flexible shear connectors through experiment for this purpose.

4.2 Test Specimen

Fig.8 shows the configuration of the test specimen. The connectors were simply obtained by cutting an H-shaped rolled steel beam of 100x150x9x6(mm) into pieces 100mm long. The specified strength of concrete was 29.4MPa. There were two kinds of connectors tested, Type H and Type T. In the former, the both edges of its lower flange were fillet-welded to the main steel column and in the latter its lower flange was cut off and the bottom end of web was fillet-welded to the column. Four specimens of Type H and two specimens of Type T were tested.

The ultimate strength of the steel was 445MPa and the yield point was 335MPa. The web of the connector and the fillet-welds were wrapped with soft foaming polystyrol sheet 10mm thick, so that the connector could move several millimeters in the axial direction of the beam as freely as possible. Because only the bending of the web plate of 6mm in thickness of the connector serves as resistance to the relative movement between the concrete block and steel beam, its spring factor as shear connector is extremely low.

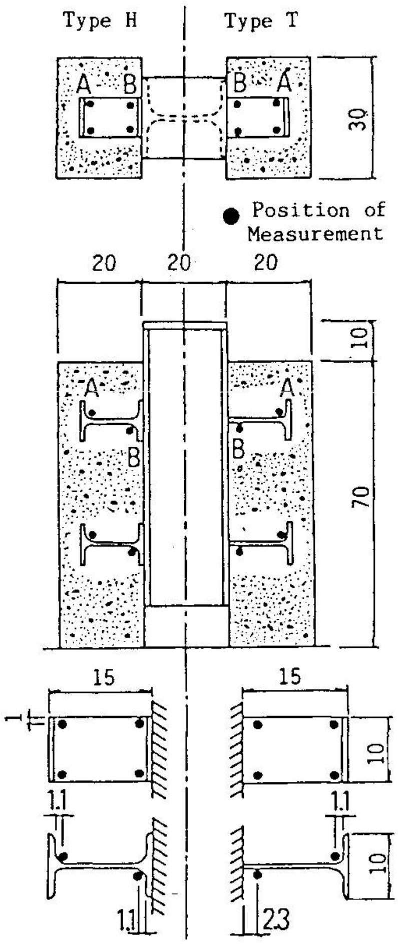


Fig.8 Dimensions of Test Specimen and Positions of Strain Measurement

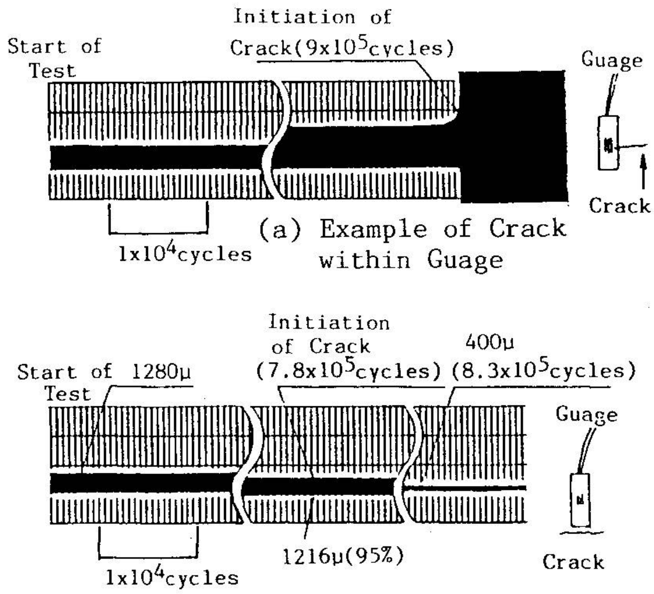
4.3 Test Procedure

The specimens were tested by an oil pressure-servo fatigue test machine under the control of stroke length (not loading). The minimum value in oscillation was set at zero. It was necessary to detect the initiation of cracks occurring in the connectors encased in concrete. Because it was anticipated that cracks would start at the web corners of the fillets between the web and the upper or lower flange, wire strain gauges were attached to all these points as shown in Fig.9 and their measurement was continuously recorded during test. It was estimated as the instant of initiation of crack, when their amplitudes remarkably changed. In practice, it increased suddenly in case a crack started within the guage or by its side as shown in Fig.9(a) and it decreased in case a crack started at a location adjacent to the guage in the longitudinal direction as shown in Fig.9(b). When four or five guages indicated such change in each specimen, the testing machine was stopped.

4.4 Results and Discussion

It was found that these kinds of shear connectors had spring factor of about 200MN/m and if they were attached to a steel girder at a distance of 20cm, the spring factor per unit length in the axial direction was as low as 100MN/m/m approximately, which would produce practically no shear resistance in a composite construction.

Fig.10 shows the relation between the amount of relative slip and the number of cycles to initiate a



(a) Example of Crack within Guage

(b) Example of Crack adjacent to Guage

Fig.9 Estimation of Initiation of Crack

crack at each strain-measurement point in the specimens. It reveals that the slip corresponding to two million cycles is as large as 1.3mm in Type H Specimen and that of Type T Specimen seems a little smaller.

In a few specimens, the concrete was removed to examine the cracks in the connectors after test. Fig.11 presents an illustration of location of the cracks. While cracks took place either at the upper fillet or the lower fillet in Type H Specimens, cracks occured always at the toe of the fillet-weld at the bottom in Type T Specimens.

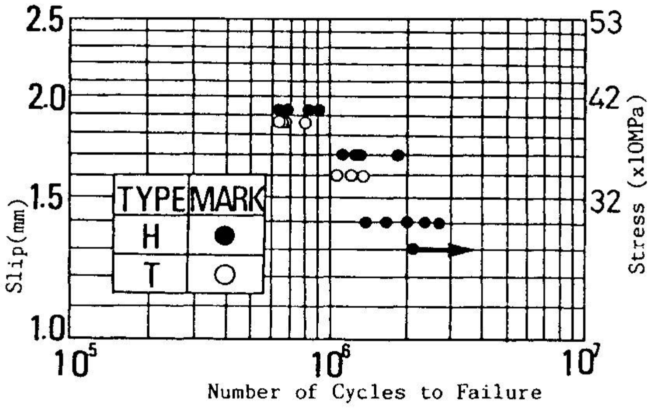


Fig.10 Result of Fatigue Test

The quality of fillet weld at the bottom of connector of Type T may change according to welder's skill and may accordingly influence largely the fatigue strength. In contrast, the fillet of connector of Type H is roll-formed and provide constantly smooth round surface with larger radius. Consequently the fatigue strength will be also high and stable. The fillet welds on the both edges of lower flange of H-shaped connector, which fix the connector to the upper flange of the main steel girder are subjected to such a low stress that their quality has practically nothing to do with the fatigue strength of connector itself. In result, the connector of H-type may generally be superior to the connector of T-type.

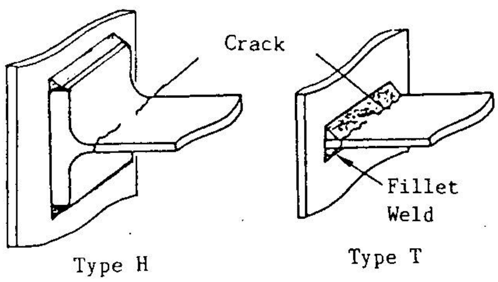


Fig.11 Location of Crack

5.CONCLUSIONS

1) Even if the slab is divided into a considerable number, the stress at the mid point of each block does not sufficiently decrease, as far as the shear connectors of currently used type are arranged. It will be required to install sufficiently flexible connectors in order to achieve this aim.

2) By combination of division of the slab in a proper number and use of shear connectors of adequate flexibility, both the stress in the concrete slab and the amount of slip can be reasonably controlled.

3) Through experiment including fatigue test conducted by the authors, a new shear connector has been developed, which allows a far larger slip than the currently used ones without fatigue failure.

REFERENCES

1. NEWMARK N.M., SIESS C.P. and VIEST I.M., Test and Analysis of Composite Beams with Incomplete Interaction. Proc. of the Society for Experimental Stress Analysis, Vol.9,No.1/1951/75-92.

2. ABE H., Experimental Investigation of Shear Connectors for Railway Composite Bridges, Railway Technical Research Report, No.961/March 1975 (in Japanese).