Experimental Studies on Retrofit by Partially Encased Concrete to the Steel I-Girder subjected to Buckling Deformation

Kenji HAYASHI[1], Shoji ONO[2] and Shun-ichi NAKAMURA[3]

Abstract: The authors have proposed a new type of steel-concrete composite bridge using the partially encased composite girder, reinforcing bars are welded to the flanges and concrete is filled into the areas surrounded by the flanges and web, and already proved through experiments and analyses that the encased composite girder had extremely high ultimate bending and shear strength as compared with the conventional steel I-girder. In this paper, the retrofit or rehabilitation method of partially encasing with concrete is suggested, to the steel I-girder deformed by buckling or subjected to damage. In order to confirm the effects of retrofit by the method and having the ultimate strength enough of the partially encased composite girder, bending tests and combined tests subjected to bending and shear simultaneously of the steel I-girder and the encased composite girder retrofitted by the above method are carried out. Consequently, the validity of this retrofit method is verified.

Key words: partially encased concrete, composite structure, steel I-girder, retrofit, maintenance, bending strength, buckling deformation, confined effect

1. Introduction

The continuous steel I-girder is one of the most common forms of bridge structures. At the intermediate supports, large bending moments and shear forces exist and the web is stiffened by vertical and horizontal stiffeners. Furthermore, the concrete slab is in tension due to hogging bending moments and does not contribute to bending strength. The lower flanges and lower parts of webs are in compression and are vulnerable to flexural-torsional and shear buckling. The flange size at intermediate supports is usually the maximum in the whole span. On the other hand, at the span center, bending moments are large but shear forces are small. The concrete slab is in compression due to sagging bending moments and contributes to bending strength. The upper flange is in compression but the lateral displacement is restrained after the concrete slab is erected. Therefore, the girder area around the intermediate supports is the critical part of the continuous girder.

A new structural form has been proposed to increase bending and shear strength of steel I-girders around the intermediate supports of continuous girders [1-3]; concrete is filled into areas surrounded by the upper flange, lower flange and web, as shown in Fig.1. The encased concrete is expected to prevent buckling of web and flange plates in compression and the concrete itself also contributes to the bending and shear strength. The use of encased girders can eliminate most of the stiffeners as the

[1]Manager, Engineering Department of Steel Structure Division, TOPY Industries Ltd.
[2]Chief, Engineering Department of Steel Structure Division, TOPY Industries Ltd.
[3]Professor, Department of Civil Engineering, Tokai University

web is stiffened by the encased concrete. It also prevents flexural-torsional and shear buckling of the plate girder and consequently the number of cross beams is reduced. In this bridge system with the encased composite girder, concrete is filled only around the intermediate supports and the weight of the encased concrete does not increase the design bending moment of girders very much.

However, measures must be taken so that the encased concrete would not fall off, if it should be crushed or damaged. There are certain ways to prevent this: studs are welded on the web, or reinforcing bars are welded to the web [4-7]. In this study, reinforcing bars are placed vertically and welded to the upper and lower flanges. This type of encased composite members has been proposed for the beams and columns of buildings [4-6], but they have used the rolled steel H-section with a width-to-height ratio (the flange width divided by the web height) of about 1.0. But, the bridge girders have a larger web height with a width-to-height ratio of under 0.3 and the research for the building members cannot be fully applied to the bridge girders.

From the above point of view, bending and shear tests have been already performed to study the bending and shear strength of the encased composite girders[3]. It has been proved that the encased composite girder had extremely high ultimate bending and shear strength as compared with the conventional steel I-girder. Next, the analytical methods have been also suggested and it has been verified that these methods were valid as the estimation method compared with the test results[3]. In this paper, it is the main purpose of establishing the new retrofit method to the steel I-girder bridge subjected to damage(buckling deformation, corrosion and fatigue crack, for example). Thereupon, as the application of the above-mentioned new type of steel-concrete composite bridge using the partially encased composite girder, the new retrofit or rehabilitation method of partially encasing with concrete is proposed to strengthen the steel I-girder deformed by buckling or subjected to damage. Previously, the bending test and combined (subjected to bending and shear simultaneously) test of the steel I-girder are performed to bring ultimate strength to occur local buckling. Next, for the partially encased composite I-girder strengthened by the new retrofit method, the bending and combined test are also carried out, and it is confirmed the encased girders have much strength capacity and the retrofit method is valid. This paper summarizes above results.

2. Partially encased composite I-girder

2.1 Outline of the encased I-girder

As above mentioned, although the continuous steel I-girder bridge is one of the most common bridge, large bending moment and shear force occur around the intermediate support and the lower flange is on compression side by negative bending moment. For that reason, an improvement is needed to prevent local buckling. Generally, the way that the thickness of upper/lower flange and web are large or many stiffeners are allocated around the intermediate support is adopted. But, the complicated work is needed at that way.

As a solution of this problem, the authors have proposed the new type of steel-concrete composite bridge using partially encased I-girder which reinforcing bars are welded to the flanges and concrete is filled into the areas surrounded by the flanges and web, and by the flanges and vertical stiffeners (Fig.1). By encased concrete, not only concrete contributes itself to increase the cross-sectional stiffness, but also the deformation of flanges and web is constrained by the encased concrete so that it is expected to increase the strength against the flexural-torsional buckling of compression flange and the shear buckling of the web.

2.2 Structural characteristics of the encased I-girder

First of all, the bending tests were carried out to grasp the structural characteristics of the partially encased composite I-girder and the conventional steel I-girder[3]. In the encased I-girder, the concrete restrained the local buckling of flange and web at the same time the concrete showed confined effect. As a result, the ultimate bending strength of the encased I-girder was 2.08 times than that of the steel I-girder.

Secondly, the shear tests of the encased I-girder and conventional steel I-girder were carried out. It was also cleared that the ultimate shear strength of the encased I-girder was 2.89 times than that of the steel I-girder. It was presumed that this improvement upon the ultimate shear strength of the encased I-girder would be due to the effect based on the truss theory, which consist of compression strut by concrete and tension strut by steel web.

3.Proposal of the retrofit by partially encased concrete

3.1 Damage of the steel I-girder and the retrofit

The corrosion (rust) of the steel plate, the fatigue crack from the weld part (as shown in Fig.2), the flexural-torsional buckling of the compression flange and the shear buckling of the web have been regarded as the damage of the steel I-girder. Usually, strengthening with cover plate and bolt (as shown in Fig.2) is carried out about corrosion or fatigue crack, however, it is often dealt with as a temporary strengthening method and has not been established as a permanent strengthening method.

Heating reform is taken as a retrofit method for the shear buckling of the web when deformation is small, but it is disadvantageous from a viewpoint that it must be done carefully in the site. In case of large deformation, a troublesome treatment, which is the method of exchanging and renewing object members, is needed. In addition, there are few examples for the flexural-torsional buckling of the compression flange.

3.2 Retrofit by partially encased concrete

In case that web or flange of the steel I-girder is taken large buckling deformation by the excessive load or crash of heavy equipments, there are hardly any proper strengthening method and the standardized method hasn’t been proposed so far. On these backgrounds, as a new attempt, the authors have proposed that these damaged steel I-girders should be strengthened by partially encasing with concrete into the damaged panel as shown in Fig.3.

4.Verification of the Retrofit Effect

4.1 Outline of the tests

Two specimens of the steel I-girder with shape and dimension shown as Fig.4 and Fig.5 were fabricated and the bending test and combined test about these specimens were carried out. Flange and web were excessively deformed by torsion and shear force respectively. Their specimens were encased with the concrete after the test, and above loading tests were carried out again.

For convenience, the bending test is simply expressed as M, and combined test as H, and the steel I-girder as S, the encased I-girder as C. For example, the steel I-girder in bending test is expressed as MS.

Rolled steel for welded structure(symbol SM490Y) was used for steel plate, and steel bar for concrete reinforcement(symbol SD345) and nominal diameter D10 was used for the steel bar. The high-early-strength portland cement was used for the concrete, and the nominal maximum size of coarse aggregate was set to 15mm[8]. Mechanical properties of the steel plates used are shown in Table 1. And requirements for mixture and compressive strength(28-day strength) of the concrete used are shown in Table 2.

The panel between two loading points was noticed about MC. Four vertical steel bars were welded between upper and lower flange at one side, and three horizontal steel bars were set (not welded) between two vertical stiffeners. The panels adjacent to the center loading point were noticed about HC.

The loading was held by load control using the oil pressure jack. The measurement subjects were load and displacement of the lower flange in the center of the span and the others, the detail of the measurement was omitted since they were the same as that of reference 3.

4.2 Experimental results and consideration

The tests of MS and HS were held previously. The final form of MS and HS after buckling deformation is shown as Fig.6 and Fig.7. In MS, after flexural-torsional deformation and buckling in the upper flange, the upper side of the web was deformed to the out-of-plane direction. In HS, flexural-torsional deformation and buckling was found in the upper flange of the left-side panel, simultaneously, diagonal tension struts were appeared in the panel. The edge of the upper flange was deformed 30mm to the vertical direction, and the web was deformed 15mm to the out-of-plane direction. HS was also deformed like that. MC and HC consist of these deformed steel I-girders and the encased concrete with the steel bars.

Fig.8 shows the relation between load and displacement of MS and MC in bending test. Fig.9 shows the relation between load and displacement of HS and HC in combined test. As a result, it became clear that the ultimate strength increased remarkably by encasing with the concrete and were 1.47 times and 1.59 times than that of the steel I-girder, respectively, and that they had enough deformation capacity.

5.Conclusions

In this paper, the application of the new type of steel-concrete composite bridge using the partially encased composite girder, the new retrofit method of partially encasing with concrete was proposed to strengthen the steel I-girder deformed by buckling or subjected to damage. And it was proved that the new structure, mentioned so far, was so valuable to retrofit the steel I-girder even if it was deformed excessively. Hereafter, it is important to investigate the effectiveness and availability for retrofitting fatigue crack and corrosion, and in the future, to establish the method of the retrofit using this new structure. In addition, the part of this research was done in Japanese Society of Steel Construction (Committee for High Performance Steel Bridge using Composite Structure, chairman: Professor Nakamura, Tokai Univ.)

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Table 1 Mechanical property

Test Specimen		Material	Yield point	Tensile Strength	Total elongation
			MPa	MPa	%
MS,MC	Flange (t=12mm)	SM490YA	372	511	30
	Web (t=6mm)		349	513	30
HS,HC	Flange (t=12mm)	SM490YA	400	513	33
	Web (t=6mm)		385	531	33

Table 2 Requirements of mixture

Test specimen	Slump	Entrained Air	Nominal Strength	Compressive Strength
	cm	%	N/mm^2	N/mm^2
MC	8.5	4.2	40	46.8
HC	11.5	4.4	40	58.3

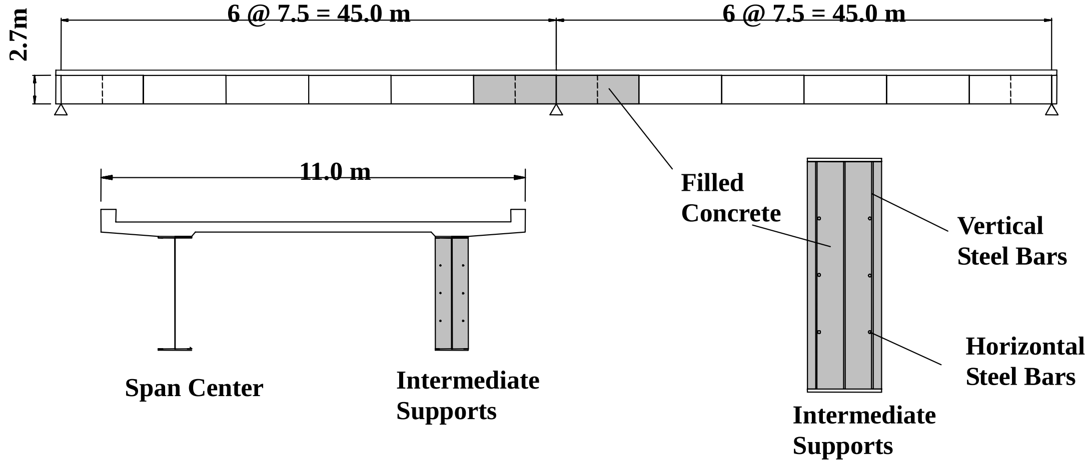

Fig.1 Partially concrete-filled steel I-girder Bridge.

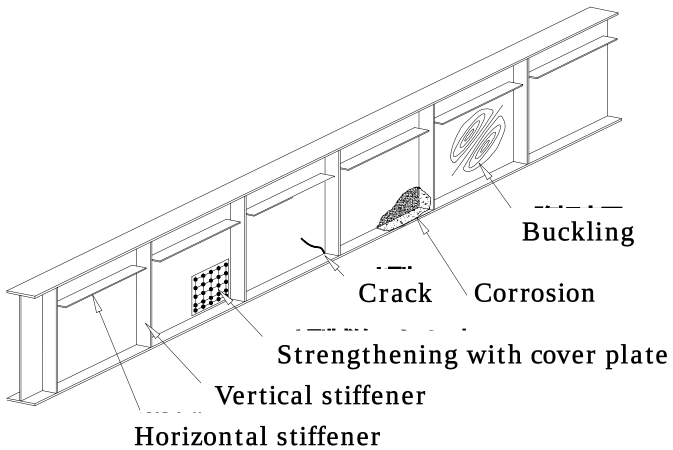

Fig.2 Damage of the steel I-girder bridge and the Strengthening(Repair).

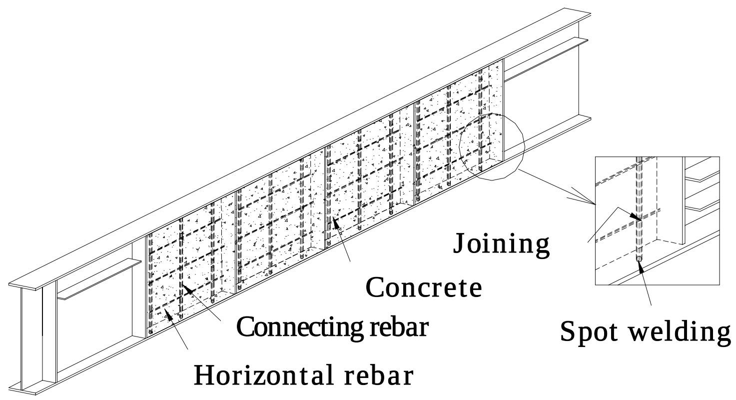

Fig.3 A new retrofit method.

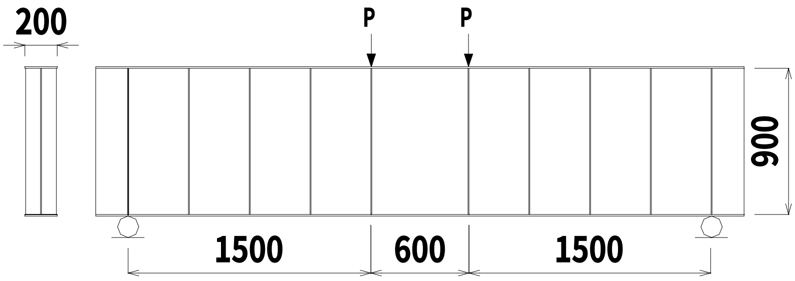

Fig.4　Bending Test.

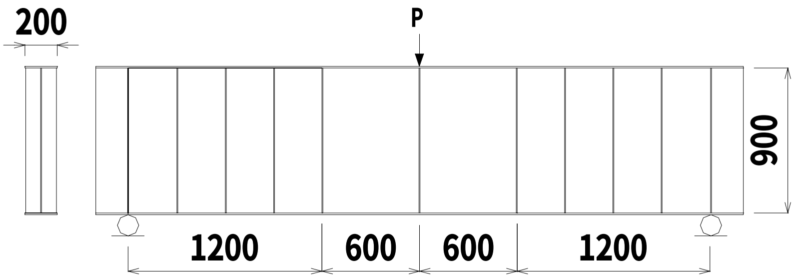

Fig.5　Bending and shear test.

(a) MS

(b) MC

Fig.6　Final deformation in bending test.

(a) HS

(b) HC

Fig.7　Final deformation in bending and shear test.

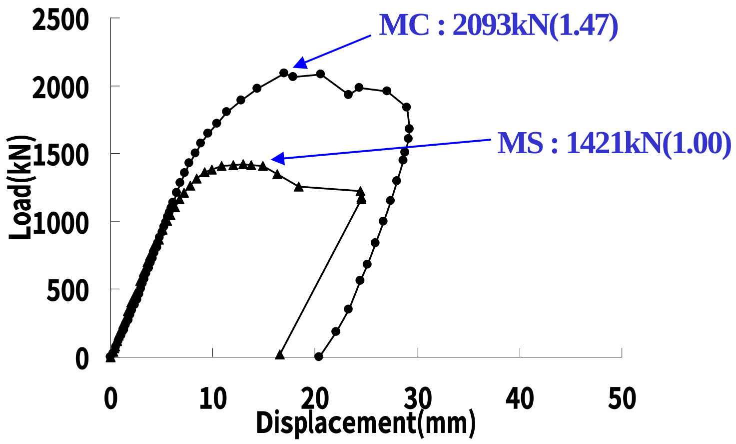

Fig.8 Load and Displacement in bending test.

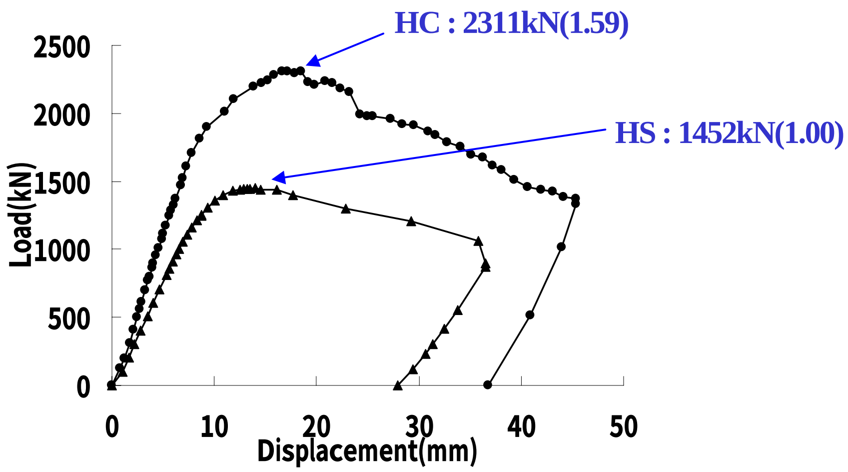

Fig.9 Load and Displacement in bending and shear test.