Experimental Study of Composite Girder with Corrugated Steel Web

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1. INTRODUCTION

Recently, many composite girder bridges with corrugated steel web have been constructed and designed in Japan. The authors are studying a structure of composite PC girder bridges with external tendons of large eccentricity. Now, the authors have experiments for getting the data that is needed to design it. Specimens used to experiment were hypothesized to be a part of the girder with corrugated steel web.

In Honda et al [1], an experiment of the structure with flanges not reinforced for shear was reported. In this paper, we report four experiments after that.

2. EXPERIMENT

The authors conducted four experiments.

What the authors had to confirm in experiment are:

Failure modes

Distribution of axial stress (Bernoulli-Euler theory)

Behavior under loads

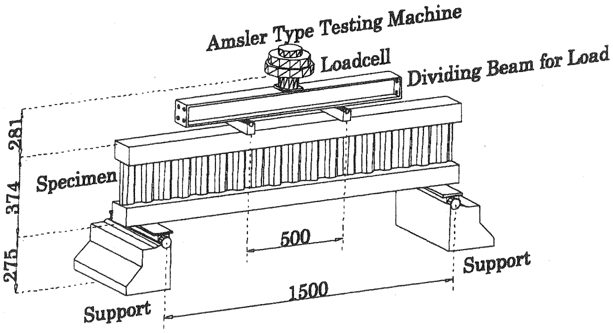


Fig.1 Device of Test 1

2-1 SPECIMEN

Specimens are shown in Figs.2~3, and material properties are shown in Table.1. Relations between specimens and tests are arranged in Table.2. Side view and section of specimen are shown in Fig.2. Type-A was a specimen with flanges not reinforced for shear. Type-B was a specimen with flanges reinforced for shear. All specimens incorporated the corrugated steel web as shown in Fig.3.

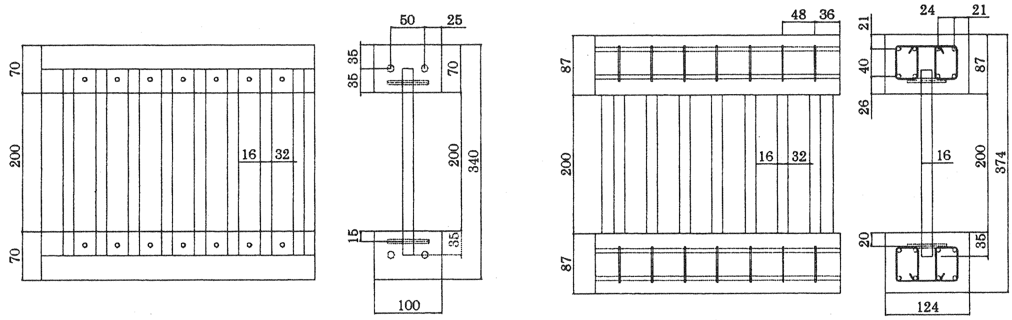


Fig.2 Specimen

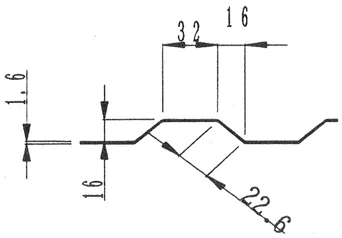


Fig.3 Shape of corrugated steel web

Table.1 Material Property

Flexural reinforcement	
type	D6,D10
yield strength fy	350N/mm²
elastic modulus Es	21kN/mm²
Concrete	
compressive strength f'c	30N/mm²
ultimate compressive strain εu	0.0035
Corrugated steel web	
type	SS400
thickness	1.6mm
Shear reinforcement	
type	φ1.9

Table.2 Specimens list

	Specimen	Length
Test-1	Type-B	1728mm
Test-2	Type-A	340mm
Test-3	Type-B	360mm
Test-4	Type-B	360mm

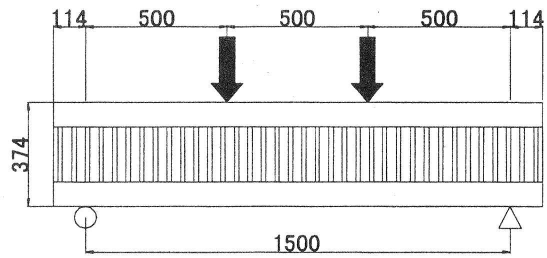


Fig.4 Two point load test

2-2 METHOD OF TESTS

An amsler type testing machine was used in four loading tests. Test-1 was conducted for a specimen under same loading method of Honda et al [1]. In tests-2～4, there were specimens which contained the parts same as those used in tests by Honda et al [1]. They were loaded individually in three directions identical to those tested by Honda, namely, axial, longitudinal and diagonal.

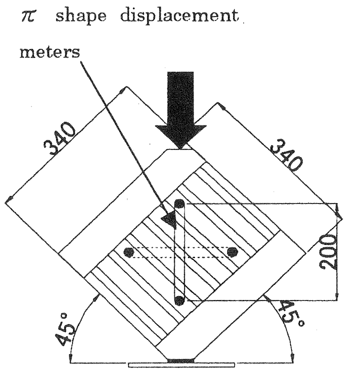


Fig.5 Diagonal load test

(a) Test-1 (two point loading test)

Loading method is shown in Fig.4. Static two point symmetrical loading with a distance between loading points of 0.5m was adopted for studying flexural and shear behavior. The specimen was Type-B with length of 1.728m.

(b) Test-2 (diagonal load test)

Loading method is shown in Fig.5. Behavior of corrugated steel web was confirmed under diagonal uni-axial loading in the direction that principal stress occurred. The specimen was Type-A with length of 0.34m.

(c) Test-3 (axial load test)

Loading method is shown in Fig.6. Behavior of the beam was confirmed under axial loading. The specimen was Type-B with length of 0.36m.

(d) Test-4 (vertical load test)

Loading method is shown in Fig.7. Behavior of the corrugated steel web was confirmed under vertical loading. The specimen was same as Test-3.

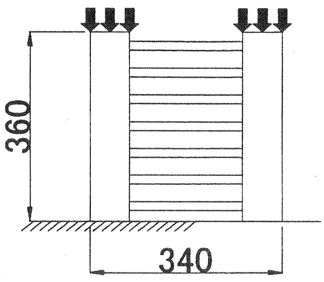


Fig.6 Axial load test

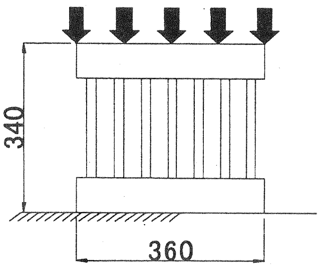


Fig.7 Vertical load test

3. RESURT AND DISCUSSIONS

(a) Test-1

Relationship between load and displacement (at center span) is shown in Fig.8. It is found that stiffness of the beam is lower than prediction in elastic domain. Main steel was yielded at displacement equal to 3.56mm, and load equal to 126kN, against predictions 1.67mm, 105kN respectively. After that, the specimen was in yield state. The increase in load was gradual, but displacement increased considerably.

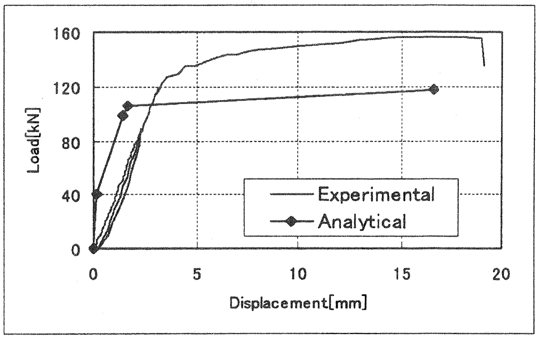


Fig.8 Load-Displacement of Test-1

Finally, a diagonal tension crack extended rapidly at 18.9mm, 155kN respectively, and load reduced. The failure is diagonal tension failure in the top flange as shown in Photo1.

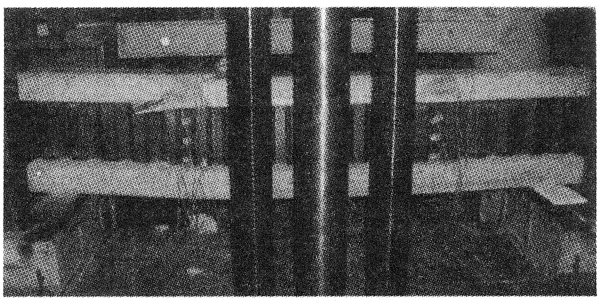
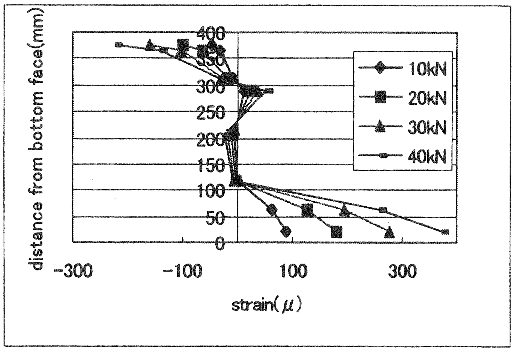


Photo1 Failure of Test-1

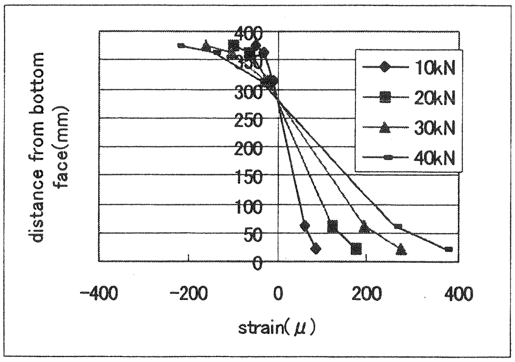
Distribution of strain in a section at L/4 (where, L is span length) from support is shown in Fig.9. Distribution of strain in elastic domain is shown in Fig.9 (a). Data of strain in corrugated steel web were approximately zero. Strains in individual panels of corrugated steel web did not change under flexural moment. It means that corrugated steel web does not react against flexural moment.

Distribution of strain was plotted after eliminating strains within the web in Fig.9 (b). It is found that closer to the upper and lower face, slope of stain changed. The distribution of strain is not linear. So, Bernoulli-Euler theory was not applicable to this structure. It is thought that effect of shear is large. However, it is found that neutral axis exists at the point, 283mm above the bottom face. It is approximately same point of 286mm in hight calculated by Bernoulli-Euler theory. The authors think it means that possibility to use the theory exists.

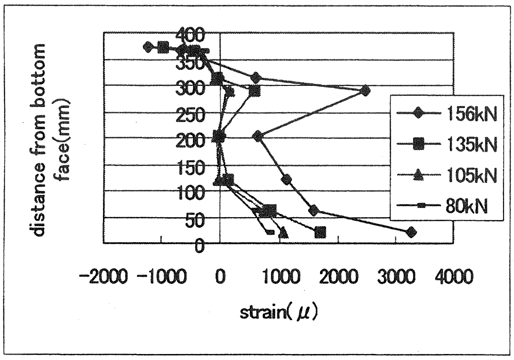
Distribution of strain after yield is shown in Fig.9 (c). It is found that strain of corrugated steel web is as large as not able to be ignored, and the distribution shows that the structure is like a three layered structure. It means that corrugated steel web affects flexural strength at an ultimate state.



(a) Elastic domain



(b) Elastic domain (plotted after eliminating strains within the web)



(c) After yield

Fig.9 Distribution of strain in a section at L/4 of Test-2

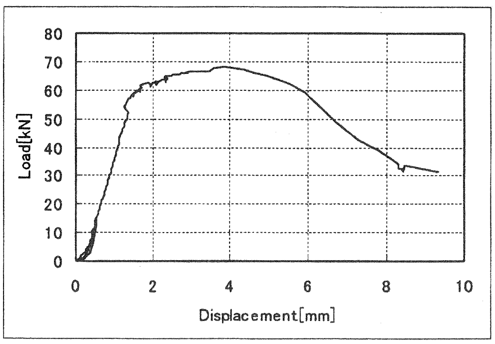


Fig.10 Load-Displacement of Test-2

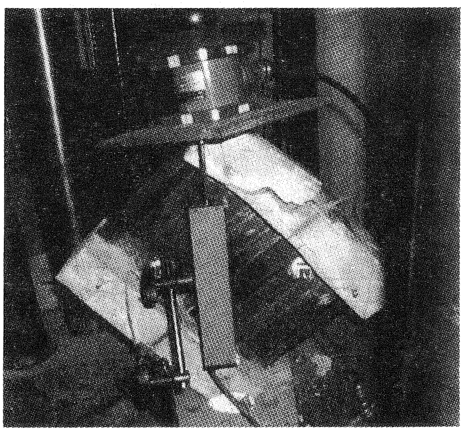


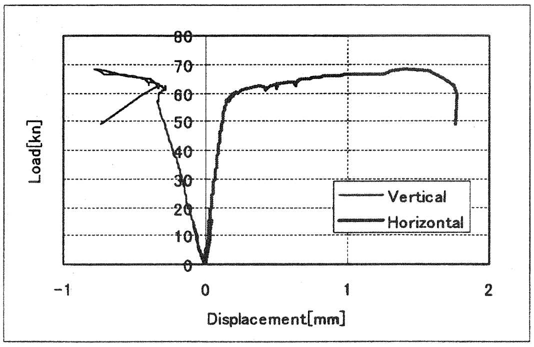
Photo2 Failure of Test-2

(b) Test-2

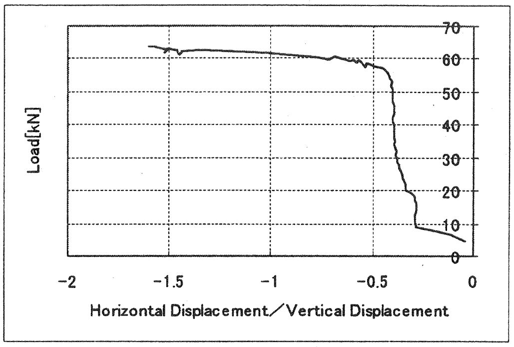
Relationship between load and displacement (between loading point and support face) is shown in Fig.10. The behavior is elastic until the load was 57kN. The crack that was formed in the center of upper flange at load 47kN opened wide and rapidly at load 62kN. At load 68kN, load was largest in this test, and then local buckling occurred in corrugated steel web. Finally, the failure is as shown in Photo2.

Relationship between load and displacement (displacement was measured by a π shape displacement meter) is shown in Fig.11 (a). Two π shape displacement meters were attached in parallel and transverse to the load direction as shown in Fig.6. It is found that the behavior is elastic until load 57kN. Relationship between load and Poisson's ratio (horizontal displacement / vertical displacement) is shown in Fig.11 (b). In this case, Poisson's ratio was about 0.4. This is larger than Poisson's ratio which is said to be 1/6～1/5 of concrete.

(c) Test-3



(a) Load-Displacement



(b) Poison's ratio

Fig.11 Relation of horizontal and vertical displacement

Distribution of strain in the section L/2 from support face is shown in Fig.12. Data of strain in corrugated steel web were approximately zero. It is found that corrugated steel web hardly react against axially acting force. Finally, the failure was crushing around support face as shown in Photo3

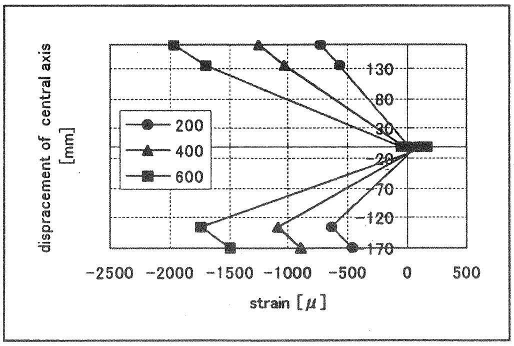


Fig.12 Distribution of strain of test-3

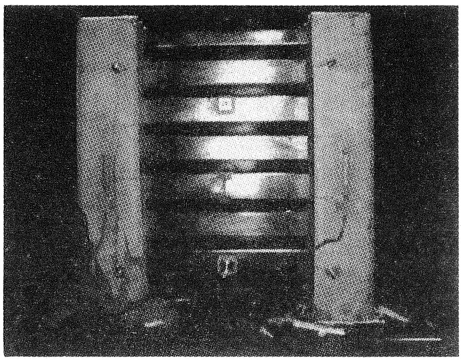


Photo3 Failure of Test3

(d) Test-4

Relationship between load and displacement (between loading point and support face) is shown in Fig.13. The behavior is elastic until load 120kN against yield load equal to 145kN which is calculated by a nominal yield stress, f_y=235N/mm^2, times cross sectional area, A=618mm^2. At load 124kN, load was largest in this test, and then overall buckling occurred in corrugated steel web, and then load reduced rapidly. The scheme of overall buckling is shown in Photo4.

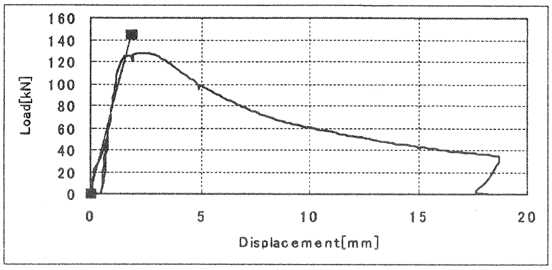


Fig.13 Load-Displacement of test-4

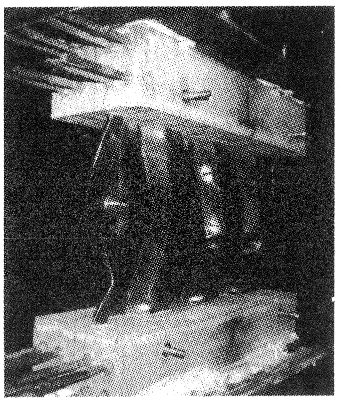


Photo4 Failure of Test-4

4.CONCLUSION

The authors reported four tests in this paper. Something confirmed in experiment are as follows.

- Distribution of strain that was plotted after eliminating strains within the web was not linear. Bernoulli-Euler theory is not applicable to this composite girder with corrugated steel web. However, neutral axis existed at approximately same point calculated by Bernoulli-Euler theory. Possibility to use the theory for design exists.
- In elastic domain, strains of the corrugated steel web did not occur under flexural moment and axial force. This shows that the corrugated steel web does not react against flexural moment and axial force.
- After yielding, strains in the corrugated steel web were as large as not able to be ignored under flexural moment. The distribution shows that the structure is like a three layered beam. Hence, this means that the corrugated steel web affects flexural strength at an ultimate state.
- In elastic domain, Poisson's ratio was about 0.4 under diagonal uni-axial loading. This is lager than Poisson's ratio of concrete which is in the range of 1/6～1/5.
- Manners of failure in individual tests were confirmed, Test-1 - diagonal tension failure in the top flange, Test-2 - local buckling in corrugated steel web, Test-3 - crushing around support face, Test-4 - overall buckling in the corrugated steel web.

We will try to study in the next step behavior under prestressing and problems of PC composite girder bridges with external tendons of large eccentricity.

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REFERENCES

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[2] : "Recommended Practice for Composite Bridges, Design and Construction (Draft)", PC Engineering Association Dec. 1999 (in Japanese)