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Bending Behaviour of Sandwich Member Using Steel Shell with Joint

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Summary

The tunnel structure constructed by MMST method consists of steel and concrete sandwich members reinforced by double steel shells with joints, and RC members to connect the sandwich members. This paper proposes a friction type joint which uses addition connecting plates to connect the steel shells. Tension test of main girders connected by the proposed joints, and bending test of sandwich member with and without joint have been performed, and the applicability of ordinary RC theory is verified.

1. Introduction

Recently, as one of new shield tunnel construction methods to effectively use the limited underground space, the application of MMST method has been investigated. The MMST method is an effective shield tunnel construction method to construct shield of large section by combing many shields of small sections. The method is now being experimentally applied in the construction of ventilation tunnel of Kawasaki Crossing Highway by Capital Highway Public Corporation.

The tunnel structure constructed by MMST method consists of steel and concrete sandwich members (hereafter called sandwich member) reinforced by dOuble steel shells with joints, and RC members to connect the sandwich members.

The steel shell of sandwich member consists of a skin plate fully welded to main girders in longitudinal direction of member and to the vertical ribs in transverse direction of member, and the joints to connect steel shells (See Fig. 1). Therefore, it is necessary to study the performance of sandwich member reinforced by steel shells with joints.

In this paper, friction type connecting joint is proposed. The friction type joint is such a joint that addition connecting plates are arranged on the two sides of main girder (the addition connecting plate is attached to the main girder by high tension bolts), which transfer the tension forces of skin plate and main girder. The outline of the proposed joint is shown in Fig. 2.

In order to understand the performance of sandwich member reinforced by steel shells with friction type joints, and to study the applicability of RC theory in the case, the effects of the friction at joints and local stresses are first studied, and then the behavior of sandwich member in the cases with and without joints are compared.

In this study, tension test of main girders connected by addition connecting plates was first performed, and then bending tests of sandwich member reinforced by steel shells with and without joint were conducted. Based on the test results, bending behavior of sandwich type specimen reinforced by steel shells with friction type joint which uses addition connecting plates was investigated.

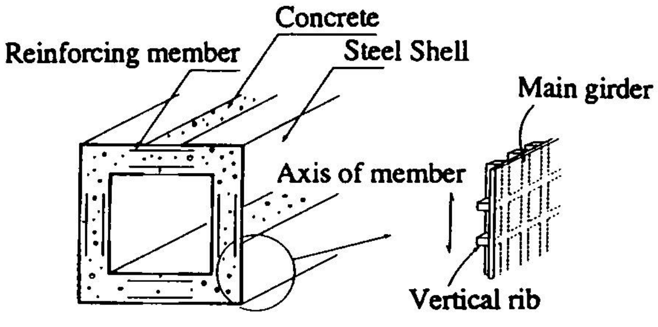


Fig. 1 Outline of steel shell for sandwich member

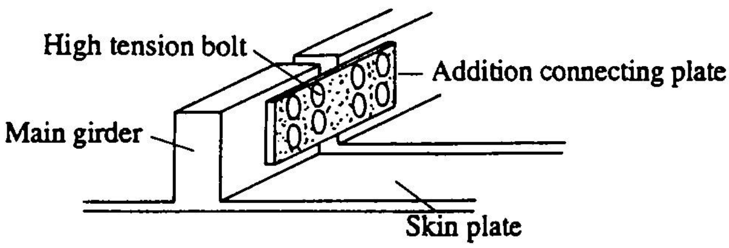


Fig. 2 Outline of friction type joint

2. Tension test of steel shell

2.1 Specimen and test method

The outline of specimen and arrangement of measurement points are shown in Fig. 3. The middle main girder of steel shell (175mm wide and 13mm thick) was put in between two addition connecting plates (113mm wide and 13mm thick), and 16 bolts (M16, F10T)) were used to fix the addition connecting plates to the main girder.

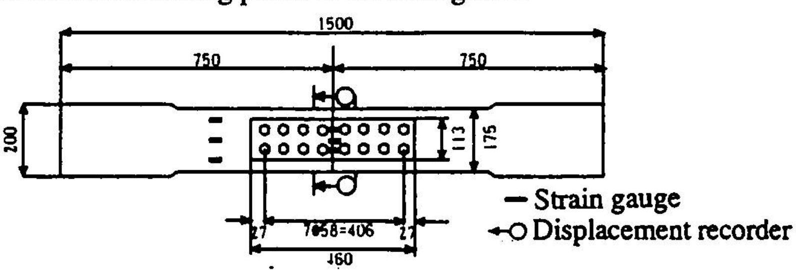


Fig. 3 Outline of specimen and arrangement of measurement points

The size of specimen was 1/2 of the size of real structure considering the minimum thickness of steel plate, and all plates used were plain plates corresponding to SS400. The material properties are indicated in table 1.

In the test, the joint part was set in the middle of tensioned region, and the two ends of main girder were fixed to the tension test machine.

Thickness (mm)	Yield strength (N/mm^2)	Tensile strength (N/mm^2)	Usage
3.2	285	439	Skin plate
4.5	310	434	Vertical rib
6.0	276	433	Main girder
13.0	266	428	Main girder & Addition plate

Table 1 Material properties of steel

2.2 Test results and discussions

Figure 4 represents the relationship between load and displacements of whole specimen and joint. From the figure, it can be seen that joint part yields when load reaches 600kN, while the maximum slide resistant force is 735kN when friction coefficient is set as 0.4. The yield loads for each part of specimen were as follows: 474kN for bolt hole part of main girder, 519kN for bolt hole part of addition connecting plate, and 605kN for main girder. Therefore, the yield load of joint part was almost the same as that of main girder. In addition, it was confirmed that the maximum load during the test was 828kN, which was larger than the tensile strength (753kN) of bolt hole part of main girder.

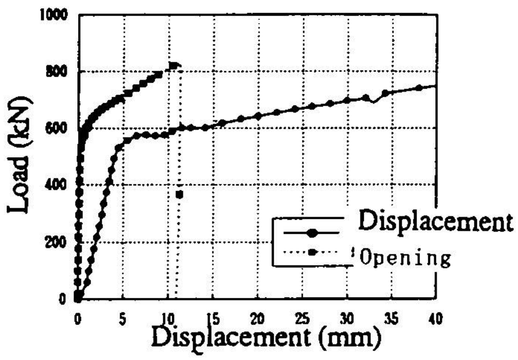


Fig. 4 Relationship between load and displacement

Figure 5 indicates the relationship between load and strain of addition connecting plate. It can be observed that the strain increases sharply after load exceeds 400kN. This may result from the uneven distribution of the force transfer ability on the addition connecting plate because of the existence of bolt holes. The maximum load was 828kN. Collapse mode was the failure of the main girder part at bolt hole. During the test, no clear slide was observed until the failure of main girder.

From the above results, it was confirmed that the local stress and friction affected the behavior of friction type joint under tension load.

3. Bending test of sandwich member

3.1 Specimen

Two specimens were prepared. One (HB1) was a model without joint, and the other (HB2) was a model with friction type joint. The size of the section of addition connecting plate was determined such that the yield load be the same as the sum of yield load of main girder and yield load of skin

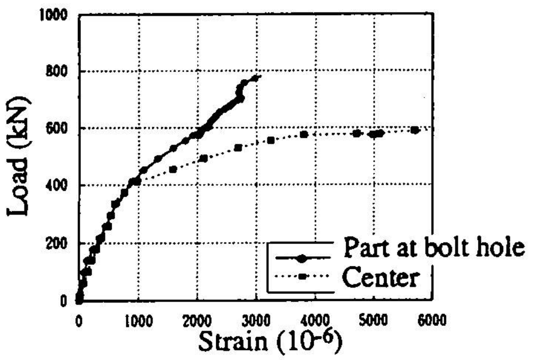


Fig. 5 Relationship between load and strain of addition connecting plate

plate (taking the effects of bolt hole into account). Shot blasting treatment was conducted at the interface between main girder and addition connecting plate, and axial force of 115kN was applied to each bolt under torque management. In total, 16 bolts (F10T, M16) were used.

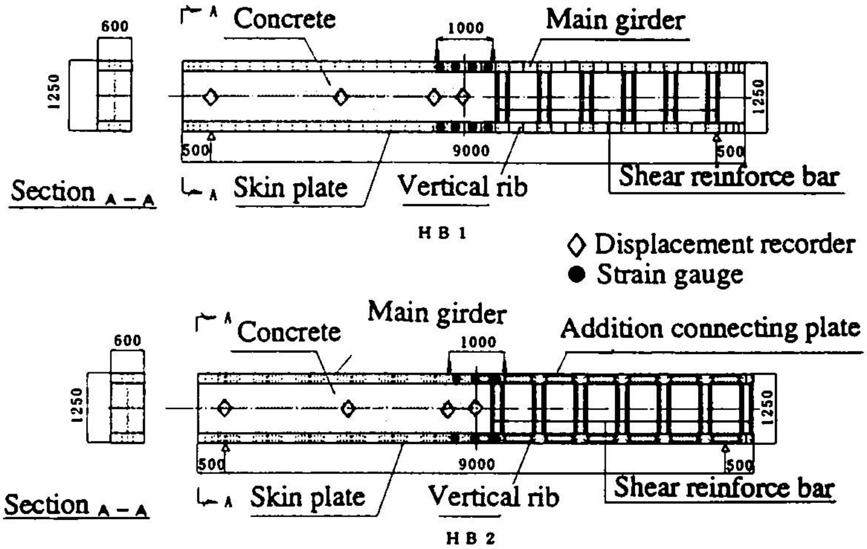


Fig. 6 Outline of specimen and arrangement of measurement points

The outline and arrangement of measurement points are shown in Fig. 6. The size of specimen and the material were the same as those used in tension test of steel shell (See Table 1).
The maximum size of coarse aggregate was set as 10mm taking the size scale of specimen (1/2 of real size) into account. In order to make casting effects the same in vertical direction, the specimen was set with side face down to the ground, and under this condition the concrete was casted. The compressive strength of the concrete during tests were 29N/mm^2 for HB1, and 25N/mm^2 for HB2.

3.2 Test method

Two point loading test method was adopted, and the length of same bending moment was set as 1000mm. Load was applied using jack with capacity of 5000kN. The load was first increased to the level that the stress reached the predicted allowable stress of steel (602kN), and next unload was conducted. And then the load was again applied until the specimen failed.

3.3 Test results and discussions

(1) The case using steel shells without joint

1) Test results

Figure 7 indicates the relationship between load and displacement of sandwich member reinforced by steel shells without joint. The distribution of cracks when specimen failed is shown in Fig. 8.

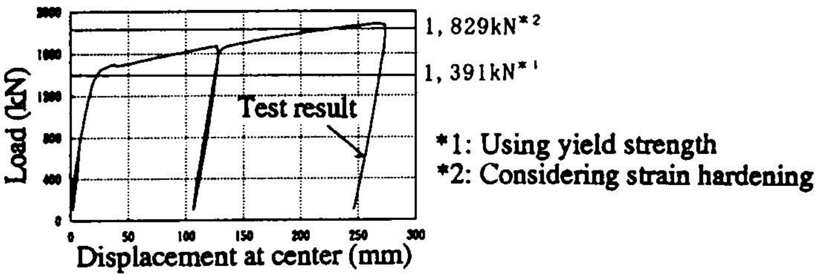


Fig. 7 Relationship between load and displacement (HB1)

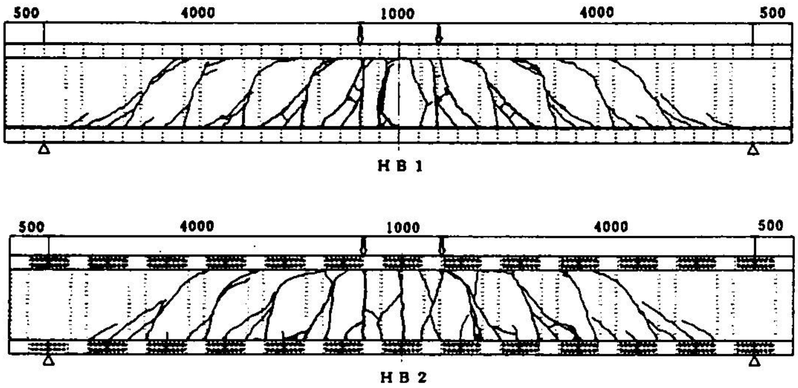


Fig. 8 Distribution of cracks (ultimate state)

The cracks were first observed at vertical rib in the middle of the region of equal bending moment when load reached 312kN, and then were gradually found at other ribs towards the loading points. The skin plate on the tensile side yielded when load touched 1020kN. When load reached 1420kN, the skin plate on the compressive side also yielded. After this stage, with 100kN increment at each step, the cracks in the shear span became wide. The maximum load of 1891kN was observed when displacement reached 268mm, and the skin plate on the compressive side buckled together with the sudden decrement of load. This is because the constrained force applied to the concrete by the steel shell on the compressive side was lower than the level that could cause buckling failure.

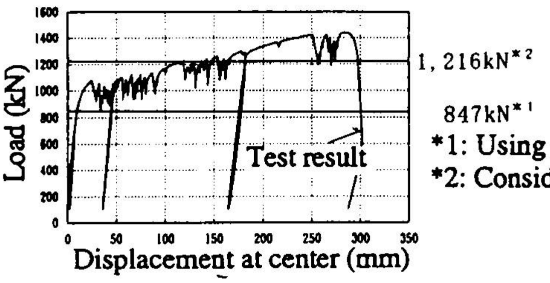
2) Comparison with predicted results

Figure 7 shows the computed result of 1391kN, which was calculated through resistant moment using the yield strength of steel by RC theory. As the strain of steel shell on the tensile side reached the strain hardening region at the final stage, the calculation considering the increment of resistance was also performed, and the result was 1829kN, which is also shown in Fig. 7. In the calculation, steel shell was treated as a single steel bar positioned at its geometry center. These two computed results were smaller than the test results, which are 1420kN and 1891kN, respectively. Therefore, the calculation using RC theory provided results on safe side.

(2) The case using steel shells with joint

1) Test results

Figure 9 represents the relationship between load and displacement of sandwich member reinforced by steel shells with joint. The distribution of cracks when specimen failed is shown in Fig. 8.



*1: Using yield strength
*2: Considering strain hardening

Fig. 9 Relationship between load and displacement (HB2)

The cracks first occurred at the vertical rib in the middle of the region of equal bending moment when load was increased to 292kN. And then, the cracks were gradually found not only at the ribs but also at the position of joint towards the loading points. When the load reached 990kN (the stage just before the skin plate and addition connecting plate on the tensile side yielded), the relative displacement of bolt or concrete were found, and temporary load decrement occurred. After this stage, similar trend was observed, but the load increased.

The maximum load of 1445kN was reached when displacement was 284mm, and failure was found at position of the closest bolt to the joint part together with sudden decrement of load. The failure pattern was different from that of the case with only steel shells. In the test of steel shell, the addition connecting plate first yielded, and then the relative displacement of bolt was observed, and finally the failure of main girder occurred. The reasons for the difference in failure pattern are as follows. In the case with sandwich member, after the crack occurred at the position of joint, only the addition connection plates bear the load, and local stress occurred due to both tensile force and bending moment applied to the addition connecting plate. In the case with only steel shells, eccentric load acted on the specimen because there was no skin plate. The skin plate on the compressive side deformed out of the original plane in several places, although no yield was observed.

2) Comparison with predicted results

Figure 9 shows the computed results of 847kN, which was calculated through resistant bending moment using the yield strength of addition connecting plate based on RC theory. The computation using the tensile strength of addition connecting plate was also performed. The computed result of 1216kN is also shown in Fig. 9. Computed yield load and maximum load were smaller than the test results, and the prediction provided results on safe side. In the case of steel shell without joint, the prediction through resistant bending moment using yield strength of steel by RC theory gives yield load on safe side. In the case of steel shell with joint, by taking the effects of bolt holes into account, the prediction through resistant bending moment using yield strength of steel based on RC theory can also provide results on safe side.

4. Conclusions

On the performance of sandwich member reinforced by double steel shell with joint, following conclusions are drawn.

(1) It is clarified that, in the case using friction type joint by addition connecting plate, the tensile behavior are affected by local stress and friction; and (2) it is found that, by taking the characteristics of joint into account, ordinary RC theory can predict the bending behavior of sandwich member with friction type joint.

Reference

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