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論 文

[2132] サンドウィッチタイプ合成構造部材のせん断抵抗機構

SHEAR RESISTING MECHANISM OF SANDWICH-COMPOSITE MEMBER WITH SINGLE OR MULTIPLE WEB REINFORCEMENTS

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1. INTRODUCTION

There are many studies attempting to find new types of structures which are suitable for conventional and new types of constructions. Among them the composite member with concrete sandwiched by steel plates is applied to slabs and offshore structures. There are advantages of this kind of composite member. It can endure large deformation and absorb a great deal of energy until the failure. For the same size of section, the composite member can obtain higher strength than conventional reinforced concrete. Buckling resistance of the steel component becomes greater than that in steel structure. Although there are many types of composite members, the rational design for shear and flexural resistances has not been established.

In this study, shear resisting mechanism of the sandwich- composite member was investigated and especially stresses in shear span including web stress were discussed.

2. EXPERIMENTAL PHASE

Five specimens were tested and all details are shown in Fig.1 and Table 1. All specimens had the width and the height of 10 cm and 20 cm respectively. Right angle steel was used for shear connector. At west side of Specimen no.1, two tie plates were allocated at both side of concrete surfaces on the same location along the member axis. At east side of Specimen no.2, the location of the tie plate was deviated from the center of shear span. At west side of Specimen no.3, the plate was separated into two identical tie plates whose location and cross-section area were the same as those of west side of Specimen no.2. And at east side of Specimen no.4, west and east of Specimen no.5, the diaphragms, tie plates, and stirrups were used for multiple web reinforcements respectively.

The specimens were tested under two concentrated loads. A hydraulic jack was used to load the specimens simply supported with a span of 1.80 m. Width of loading and supporting plates are 5 cm. The increment of loading is 0.5 ton for all beams. After either west or east sides of beam failed, the support was removed to the point under the failed side. Then

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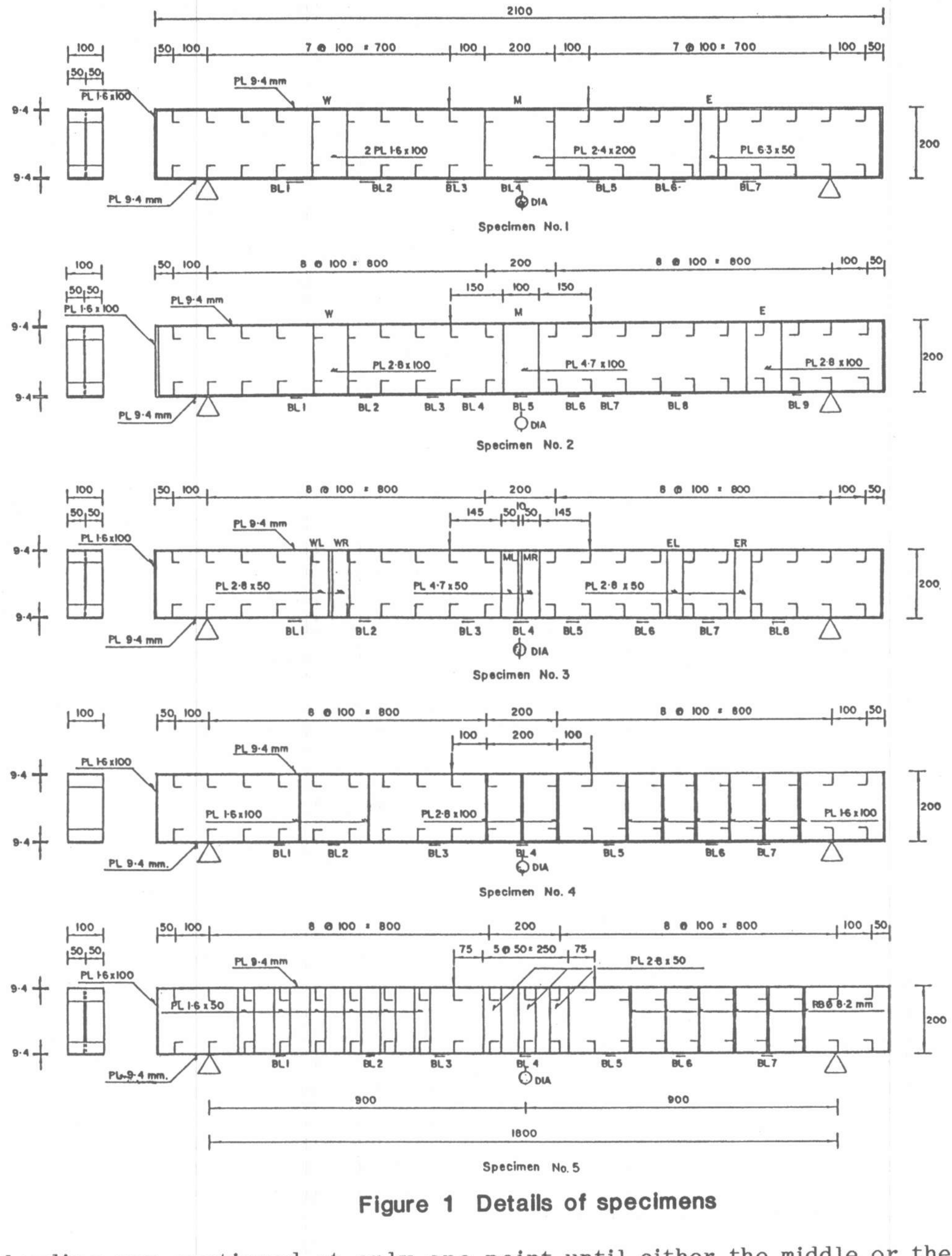


Figure 1 Details of specimens

loading was continued at only one point until either the middle or the remaining side of west or east would fail.

The electrical resistance strain gages, whose gage length was 5 mm, were mounted on both steel flanges and web reinforcement. And the electrical resistance strain gages with gage length of 40 mm were also mounted on the concrete surface to measure the principle strain and its angle. The deflection at midspan was observed by mechanical dial gage.

Specimen		Flange plate (mm)	Web reinforcement (mm)	ρ_ω (%)	flange fsu (Mpa)	flange fsy (Mpa)	web fsu (Mpa)	web fsy (Mpa)	fc' (Mpa)	d (mm)	a/d	Vutest (kN)	mode of failure
No.1	West	9.4x100	•T 2x1.6x100	4.81	470.1	318.5	429.4	343.0	31.8	195.3	3.58	68.6	1#
	East	9.4x100	T 6.3x50	4.81	470.1	318.5	492.5	367.5	31.8	195.3	3.58	68.6	1
	Middle	9.4x100	T 2.4x200	4.81	470.1	318.5	453.8	318.5	31.8	195.3	2.05	>115.7	
No.2	West	9.4x100	T 2.8x100	4.86	470.1	318.5	366.0	274.4	31.4	193.3	3.62	> 73.5	
	East	9.4x100	T 2.8x100	4.86	470.1	318.5	366.0	274.4	31.4	193.3	3.62	41.2	1
	Middle	9.4x100	T 4.7x100	4.86	470.1	318.5	312.5	194.0	31.4	193.3	2.07	129.4	2##
No.3	West	9.4x100	T 2x2.8x50	4.86	470.1	318.5	366.0	274.4	38.1	193.3	3.62	63.7	1
	East	9.4x100	T 2x2.8x50	4.86	470.1	318.5	366.0	274.4	38.1	193.3	3.62	> 75.5	
	Middle	9.4x100	T 2x4.7x50	4.86	470.1	318.5	312.5	194.0	38.1	193.3	2.07	133.4	2
No.4	West	9.4x100	••D 2x1.6x100	4.81	470.1	318.5	429.4	343.0	36.8	195.3	3.58	86.3	2
	East	9.4x100	D 6x1.6x100	4.81	470.1	318.5	429.4	343.0	36.8	195.3	3.58	> 86.3	
	Middle	9.4x100	D 3x2.8x100	4.81	470.1	318.5	366.0	274.4	36.8	195.3	2.05	-	
No.5	West	9.4x100	T 6x1.6x50	4.86	470.1	318.5	429.4	343.0	37.0	193.3	3.62	> 81.4	
	East	9.4x100	•••RB 608.2	4.86	470.1	318.5	305.8	274.4	37.0	193.3	3.62	81.4	2
	Middle	9.4x100	T 3x2.8x50	4.86	470.1	318.5	366.0	274.4	37.0	193.3	2.07	115.7	2

• T = Tied plate •• D = Diaphragm ••• RB = Round Bar
1 = Shear cracking failure mode of concrete
2 = Yielding of web reinforcement

Table 1 Sandwich-composite member's strength

3. TEST RESULTS AND DISCUSSION

3.1 STRESSES IN SHEAR SPAN

There were many phenomena which confirmed the formation of truss mechanism in the member. The proposed truss mechanism is shown in Fig.2 and the diagonal strut of the truss is the diagonal line between support and web reinforcement, between web reinforcement and loading point, or between adjacent web reinforcements. The upper steel plate and concrete under compression are idealized as the upper chord, the diagonal concrete compression is as the diagonal strut, the web reinforcement is as the vertical member, and the steel plate under tension is as the lower chord. The distribution of force between concrete and steel plate is calculated by the assumption that strain is proportional to the distance from neutral axis. For the compression and tension flange , the measured strains at different locations in shear span are the same (see BL2 and BL3 or BL5 and BL6 of Specimen no.1 in Fig.1). This phenomenon can not be explained by beam theory but truss theory. By truss theory, the strain of the compression or tension flange in shear span can be the same if the measured strains were located in the same compression or tension chord. The angles of the measured principle strain of concrete agreed to the angle of the proposed truss model. The depth of the upper chord was assumed to equal the depth of neutral axis and the width of diagonal concrete strut was also assumed to equal 90% of the depth of neutral axis calculated from the beam theory. This width of concrete strut was obtained from the measured principle strain by comparing to the diagonal force of the truss analogy. From Table 1, it can be seen that one of the failure modes is the yielding of web reinforcement, so

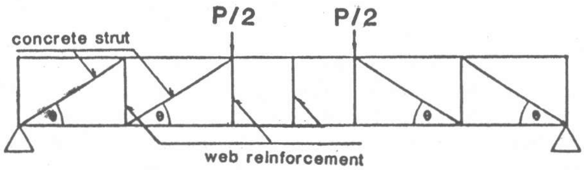


Figure 2 Truss analogy

that the web stress becomes necessary to be investigated. By measuring the strain of web reinforcement, it was observed that the external shear force was not only resisted by the truss but also resisted by other than the truss (or V_c). The shear resisted by other than the truss was not constant as the applied shear increases (see Fig.3). The V_T line shown in Fig.3 was obtained by assuming that the shear was resisted by only the truss. It can be seen that the V_T line is the asymptote of the observed curve.

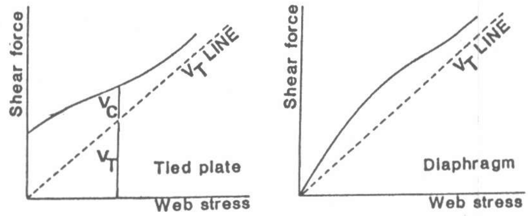
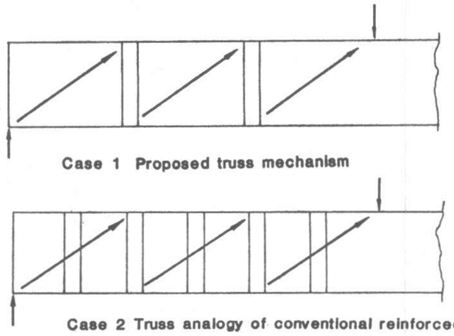


Figure 3 Shear force web-stress relation of web reinforcement

There are many factors which affect the strain of web reinforcement. First is the type of web reinforcement. In the case of the member with tie plate, the increment of web strain is very small until shear cracking occurs. But for the case of the member with diaphragm web reinforcement, the web strain starts to increase linearly from the beginning (see Fig.3). The increment of observed strain at early stage is somewhat smaller than the one by truss theory (V_T line). At later stage, the shear strain curve approaches to the V_T line. It can be stated that, for the member with tie plate, before shear cracking, the external shear force is resisted by concrete (in other words other than the truss), but for the member with diaphragm, even before shear cracking, the external shear force is mostly resisted by diaphragm (in other words the truss).


Case 1 Proposed truss mechanism

Case 2 Truss analogy of conventional reinforced concrete with web reinforcement

FIGURE 4 CHARACTERISTICS OF TRUSS MECHANISM

The web spacing to effective depth ratio (s/d) affects the characteristics of diagonal concrete strut, which will affect the strain of web reinforcement. If the s/d is large, the proposed truss model can be applied (case 1 in Fig.4). But if the s/d ratio is too small, diagonal strut is changed to behave like the conventional truss analogy of reinforced concrete with multiple web reinforcement (case 2 in Fig.4) whose the diagonal concrete struts cross the web reinforcement. This effect of s/d ratio occurs only in the member with tie plate. In the case of the member with diaphragm, diagonal concrete strut always forms between adjacent diaphragms even with a small s/d ratio.

Within the results of the authors' experiment, the wider tie plate obtained the higher V_c for the same area of tie plate. The possible reason is that the wider tie

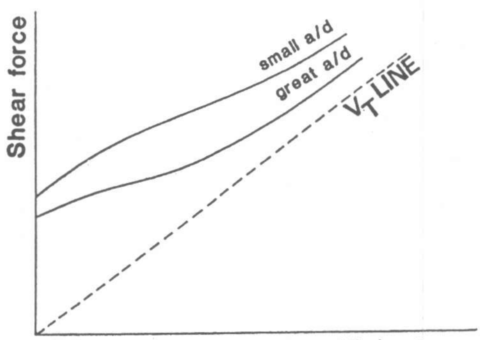


Figure 5 Effect of a/d on Vc

plate had better confinement of concrete due to the less clear distance between adjacent tie plates. However, there could be a limit for the effect of width of tie plate on V_c which would not change the proposed shear mechanism. The observed tensile strain in tie plate indicated that the tie plate strain at support side was always greater than that at loading point side.

The shear span to effective depth ratio (a/d) affects the V_c in such a way that the greater a/d ratio yields faster decrease in V_c after shear cracking (see Fig.5).

The conventional method for reinforced concrete to predict web reinforcement strain may not be applied in the case where diagonal struts form between adjacent web reinforcement as shown in Fig.4 (case 1). Furthermore, this conventional method cannot be utilized for all the cases with diaphragm. Only the case of small s/d ratio with tie plates or stirrups can allow us to use the conventional method.

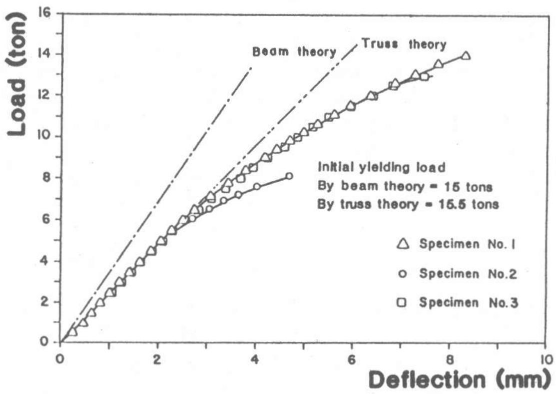


Figure 6 Load-deflection relation

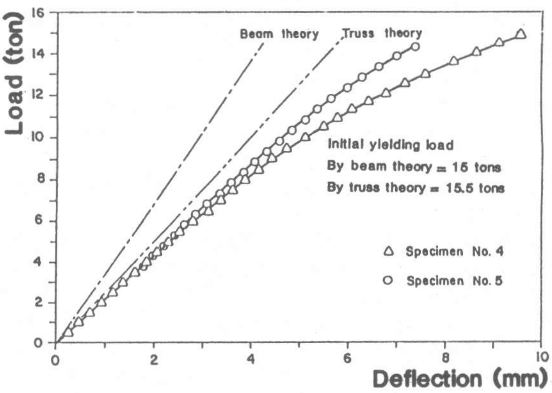


Figure 7 Load-deflection relation

3.2 LOAD-DEFLECTION RELATION

The measured deflections under the static load test are illustrated in Fig.5-6 and the deflection calculated according to beam and truss theory are also shown. By beam theory, the calculated deflection is the combination of the bending deflection and the shear deflection, assuming fully cracked section for bending and elastic shear modulus for shear. To obtain the deflection by truss theory at midspan of members, the method of virtual work was applied by assuming that the size of each truss member corresponds with the observation (see Sec.3.1). From the test results, it can be seen that the deflection curves are closer to the calculated one by truss than beam theory.

4.CONCLUSION

The truss mechanism was observed in the sandwich-composite member with web reinforcement. It can explain the stresses of steel and concrete in shear span in good agreement. The web spacing to effective depth ratio affects the truss mechanism for the member with tie plate but not for the member with diaphragm. The web stress is affected by the type of web reinforcement, width of type plate and shear span to effective depth ratio. Truss mechanism can also predict the deflection of member with good approximation.

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