Development of Composite Beam for Productivity

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SUMMARY:
Due to the depression of economy, the resent construction market is in need of new process of the construction technology, which is efficient and economically sustainable development. Especially, due to the increase in steel costs, the research and development for the composite beam of steel frame buildings is actively taking place. Most types of the existing field assembly composite beams are concrete encased composite beams and they can be divided in two types: one is to produce in factories and assembled on site, such as common steel frame structure, the other is to place concrete after making a form around H-Beam. In the former case, the poured concrete increases the weight of beam and it causes a lot of time in handling on site. In the latter case, producing the form in the field results in an increase of construction time. Hence, this study shall develop the GSF(Green & Smart Frame) composite beam, which is able to solve the problems mentioned above. Besides it shall be verified its performance by experiment.

Keywords: Concrete Encased Composite Beam, Green Smart Frame Composite Beam, H-Beam

1. INTRODUCTION

The current economic depression has a great effect on the construction industry. Construction sites decrease due to reduced demand for buildings, and construction companies are concentrating on overseas construction and technical development to stimulate the economy. The trend in the domestic and overseas construction market shows preference for buildings that are practical and symbolic at the same time. With skyscrapers, long spans, and super-size buildings thrust into the limelight, R&D for the production of new materials with high performance, high strength, and outstanding features, and for environment-friendliness is ongoing. In particular, the development and application of the steel beam composite method with improved workability and economic feasibility are in full swing. Nonetheless, there are difficulties in the arrangement of bars and placing of concrete with the existing steel composite beam because of the generally complex shape of its section. In addition, encased composite beams have restriction in transport and lifting at the site compared to the general steel frame due to the increase in the dead load of the member. Consequently, the GSF (Green & Smart Frame) composite beam, which may be constructed with the same method as general steel frame by simplifying the complex section with the minimized weight of the member and maximized strength, is developed. The GSF composite beam is a composite beam whose weight and strength are maximized by arranging bars and placing concrete to where increase in strength is necessary according to the distribution of the moment. In other words, bars are arranged and concrete is placed to an H-beam web to increase the strength for the part where it is required. Therefore, there is a need to review shear reinforcing bars to control the cracking of concrete on the side of a web, stud bolts to secure adhesive strength between steel web and concrete, anchorage length of the main bars to secure bending strength, and concrete placing length.

The object of this study is to optimize the section detail of such GSF composite beam through experiments. With variables for the section detail such as existence of stud bolt, anchorage length of main bars, and placing length of concrete, the performance is compared and reviewed among 1 H-beam specimen, 1 GSF specimen without slab, and 3 GSF specimens with slab.

2. GSF COMPOSITE BEAM

2.1. Structural Principle

The basic concept of a GSF composite beam involves placing from the center part where the maximum moment is applied to the zone where the load required is satisfied by the H-beam's own strength according to the distribution of moment. The review of accurate placing length and anchorage length of a main bar is described in section 2.2 of this chapter. The basic conceptual diagram of the GSF composite beam is shown in Figure 1.

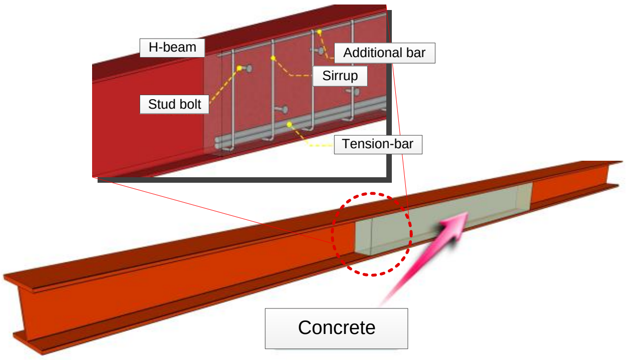


Figure 1. Concept of GSF composite beam

2.2. Concept of Placing Length

In the case of the GSF composite beam, the basic concept involves placing concrete to the zone where the bending strength (M_n^S) of the member with little bending strength satisfies the load required (βM_u), since there are two sections with different bending strengths in one member. Consequently, aL wherein H-beam's own bending strength (M_n^S) satisfies the load required (βM_u) is selected as the placing length. The aforesaid concept of placing length is presented in Figure 2.

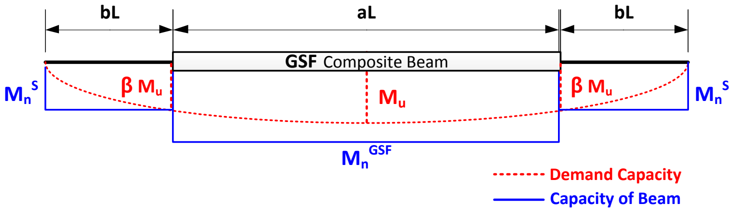


Figure 2. Concept of placing length

3. SPECIMEN PLAN

3.1. Section Shape of the GSF Composite Beam

The GSF composite beam is fabricated by arranging bars and placing concrete at the web tensile of an H-beam. Consequently, it consists of shear reinforcing bars to control the cracking of concrete on the outside of concrete, stud bolts to secure adhesive strength between steel plate web and concrete, and main bars and concrete to increase the bending strength of a member. The section shape and composition detail are shown in Figure 3. Moreover, the arrangement is made with 20 mm sheath thickness for shear reinforcing bars; 20 mm interval is used for the main bars on the lower flange.

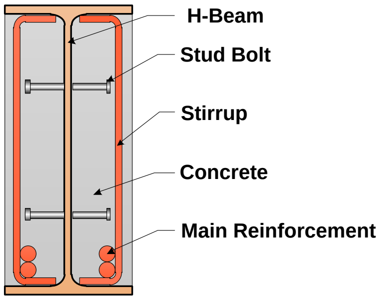


Figure 3. Section shape of GSF

3.2. Design of Placing Length and Anchorage Length

To set up the effective placing length of the GSF composite beam, the ratio of H-beam bending strength and the GSF composite beam area is required as described in section 2.2. In other words, the bending strength of the H-beam itself (M_n^S) shall be higher than the load applied in the bL location in Figure 2. Figure 4 presents the result of estimation of the bending strength of H-beam and the bending strength of the GSF composite beam by the bending theory equation.

Based on the estimation result in Figure 4, the difference between two sections is 1.64X and 1.47X for the center part when considering the strength reduction factor (Φ=0.9), since it is a GSF composite beam; the GSF composite beam: H-beam bearing strength ratio is 1:0.68 (refer to Figure 5). In other words, an area of 0.68 corresponds to the bearing strength of the H-beam if the maximum moment ratio in the center part is 1. As shown in Figure 5, the length of the center part up to the area where the moment ratio is 0.68 is 0.54 L. Since 0.54 L is the minimum placing length required based on the required strength, the final placing length is determined by considering the anchorage length of the main bar additionally. In KBC 2009 0508, the anchorage length of the bending bar for the area where bars are no longer required is defined as more than 300 mm or 12 d_b (12×25 mm=300 mm). Consequently, for the specimen with L=12 m and bending bar HD25, 300/12,000=0.025 L is the anchorage length used. In other words, the placing length is 0.59 L when applying the anchorage length of 0.025 L on both sides; therefore, the placing length is determined to be 0.6L (7.2 m).

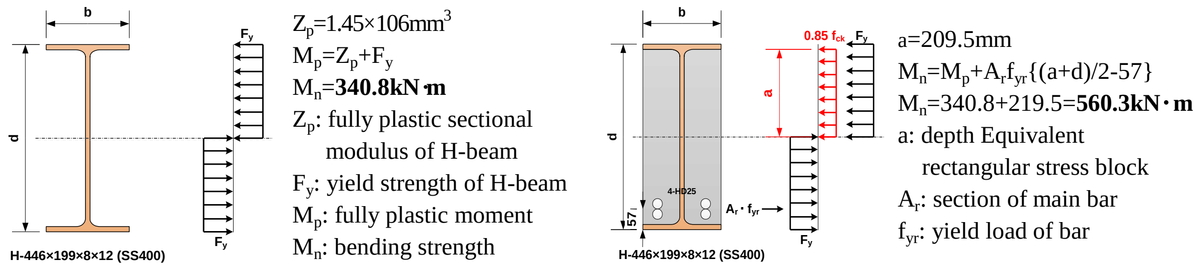


Figure 4. Calculation of the bending strength of H-beam and GSF Beam

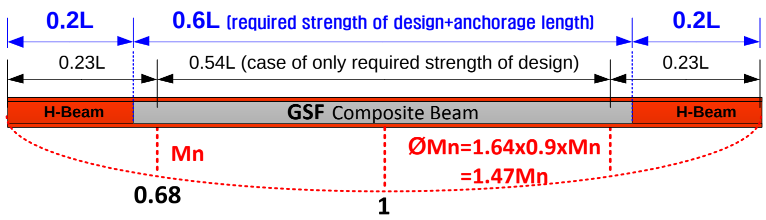


Figure 5. Estimation of placing length

3.3. Design of Shear Connecter

The design of shear connecting materials of the GSF composite beam consists of two parts: The adhesive joint between the slab concrete and H-beam upper flange and web placing concrete. The complete composite design of the slab is designed in accordance with KBC2009 (Korean Building Code 2009). The web part concrete that is not mentioned in the standard is designed as follows:

3.3.1. Design of shear connecter on web

The design of shear connecter for the web part of the GSF composite beam is not dealt with in KBC and ACI standard. In case the following matters are satisfied in Eurocode 4, however, the web part encased in concrete is assumed to be reinforced sufficiently:

- In case of welding a stirrup to the web, reinforcing by pushing the bar with diameter of 6 mm or more through the web or welding a stud bolt with diameter of 10 mm or more to the web
- In case the interval between studs or reinforcing bars is 400mm or less, and the interval between the inner side of the flange and the stud reinforced to the web is 200 mm or less

Accordingly, the shear connecting materials for the specimen in this study are designed as follows for the shear force generated by the difference of bending stress applied in the placing area (the difference between the moment of the center part and the end of placing is shown in Figure 6):

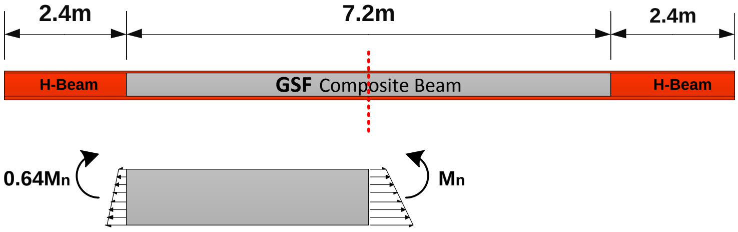


Figure 6. Difference between the moment of the center and the end of placing

The precise difference between the moment of the center part and the end of placing is 0.36X as in Figure 6 but is fixed at 0.5X considering the safety factor. The shear strength of one shear connector is calculated with Equation (1) and Equation (2), and the shear force and the space between shear connecting materials are calculated with Equation (3), (4), and (5).

$$0.5A_{sc}\sqrt{(f_{ck}E_c)} = 53.1\text{kN} \quad (1)$$
$$R_gR_pA_{sc}F_u = 52.8\text{kN} \quad (2)$$
$$\therefore\ Q_n = 80.4\text{kN}$$
$$V_s = 0.5F_yA_s = 0.5\times235\times8{,}430\times103 = 991\text{kN} \quad (3)$$
$$n = V_s/Q_n = 991/52.8 = 18.7,\ \therefore n = 19\ (2\ \text{side}),\ 9.5\ (1\ \text{side}) \quad (4)$$
$$s = (L/2)/n = 3{,}600/9.5 = 379\text{mm},\ \therefore s = 750\text{mm}\ (2\ \text{rows}) \quad (5)$$

Accordingly, shear connecting materials for the web of the GSF composite beam are designed with 2 rows and 750 mm spaces. Note, however, that the spacing of this design is deemed to secure sufficient safety factor considering adhesive power of 0.6 MPa between steel and concrete from Mullett, D.L, since the adhesion between steel and concrete has not been considered.

3.4 Specimen Detail

The specimen of the GSF composite beam is classified into two types: the specimen without slab to review the condition during construction, the behavior of pure GSF composite beam, and the effect of increase in strength, and; the specimen with slab to consider the completion of construction. Note, however, that the concrete is designed to be twice as hard, and the effective width is reduced to 1,500 mm for the transport of the specimen and the smooth progress of the test, although the effective width is 3,000 mm for the slab in the specimen with slab. Consequently, the compression strength of specimen is designed to be 48 MPa for slab and 24 MPa for web concrete.
The placing length and the existence of stub bolts are set up as the main variables for the section detail of the specimen, and the design is based on sections 3.2 and 3.3. The section detail of the specimen and the specification of the H-beam used in the specimen are presented in Figure 7 and Table 1, respectively.

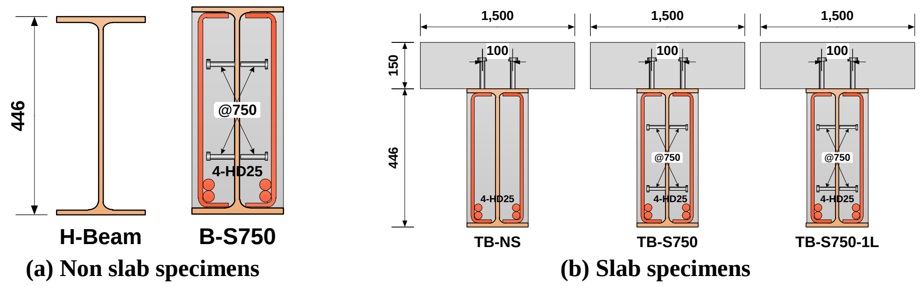


Figure 7. Cross section detail of the specimens

Table 1. Specimen List

Name of specimen		Type of stirrup	Stud bolt	Placing length
No.1	H-Beam	-	-	-
No.2	B-S750	“C” type	2@750	0.6L
No.3	TB-NS	“C” type	-	0.6L
No.4	TB-S750	“C” type	2@750	0.6L
No.5	TB-S750-1L	“C” type	2@750	1.0L

3.5 Loading and Measurement Plan

The two-point monotonic loading test is executed on 12m span for the loading of the specimen as shown in Figure 8. The placing area is divided into three to set up 2.4m two-point loading span so that the transverse tension crack is shown clearly in the placing area. The observation for the cracking condition is executed in the following three steps: when the yield strain is reached in the main bar, right after the maximum load, and when the test is completed. As shown in Figure 9, measurement is executed with a strain gauge. The measurement of the deflection displacement is done by measuring the center part and the loading point where the displacement is at its peak with the no. 2, 3, and 4 displacement gauges, the rotation angle of the member by no. 5 and 6, the slip amount of the web concrete by nos. 7 and 8, and the slip amount of the slab concrete by no. 9. The measurement of strain is executed with the strain of the upper and lower flanges of the main bar and H-beam. Nos. 10 – 16 show the strain of the main bar, nos. 20 – 22, the upper flange of H-beam, and nos. 30 – 36, the strain of compression and tension of the lower flange.

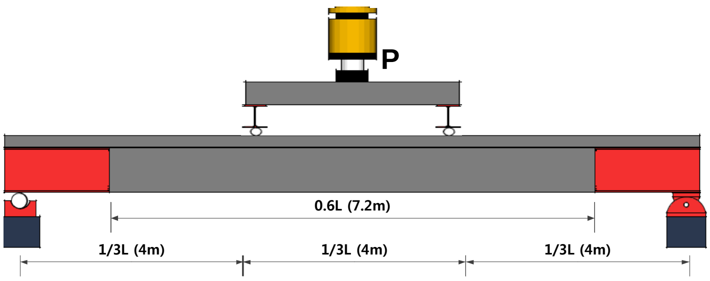
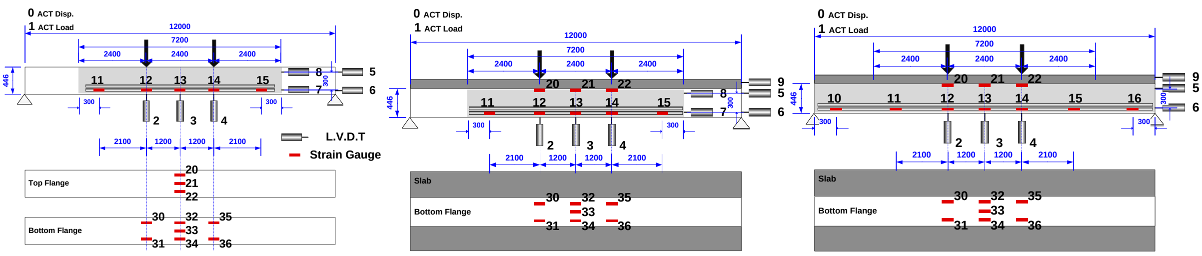


Figure 8. Test set-up



(a) H-Beam & B-S750 **(b) TB-NS & TB-S750** **(c) TB-S750-1L**

Figure 9. Measurement of deflections and strains

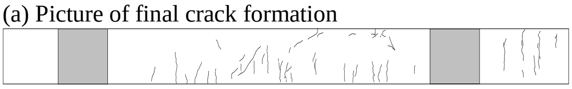
4. TEST RESULT

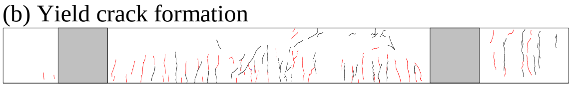
4.1. Crack Formation

The overall condition of cracking showed the typical aspect of cracking. Invasion depth was classified by the location of the neutral axis. In case of a specimen with no slab, the neutral axis was located at the center of the web, and the transverse tension crack progressed near the center of the web; the collapsing crack was shown at the center of the beam on the compression side. For the case of specimen with slab, the transverse tension crack was confirmed to have passed the web and progressed to the bottom of the slab because the entire web part was applied to the tensile side since the neutral axis was located at the slab. In contrast, TB-S750-1L displayed diagonal tension crack near the right side of the center after the yield load and maximum load. Such was attributed to the decrease in adhesive strength of the concrete and bars due to the excessive steel ratio (11%) at the joints by the connection of the main bars. Figures 10 – 13 show the cracking condition classified into photo of the final condition, yield, maximum load and the final condition.

Figure 14 presents the graph of strain of each part of the main bar for TB-S750 and TB-S750-1L specimens with the same space of shear connecting materials. According to Figure 14, the strain of the point in the center where the maximum moment is applied (nos. 12, 13, and 14) rapidly increased after yield and decreased or diffused for all three specimens; for the case of the main bar anchorage (no. 11 and 15), the strain continuously increased after yield and right before unloading only for the TB-S750 specimen where no diagonal tension crack occurred. In other words, the continuous increase in strain means constant resistance to the external force and suggests that there was no slip with the concrete. The TB-S750-1L specimen showed drastic decrease of the strain (no. 14) in the overlapped zone, however, and the strain in the anchorage zone (no. 11 and 15) did not increase further. It coincided with the time the diagonal tension crack occurred. Thus, the slip in the overlapped zone was believed to have been generated from that moment.

(a) Picture of final crack formation


(b) Yield crack formation


(c) Maximum load crack formation

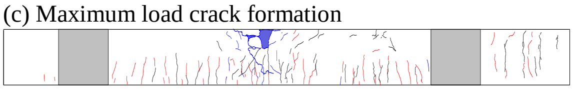
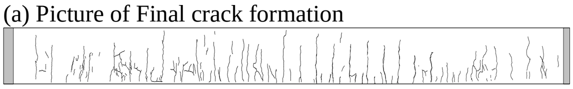
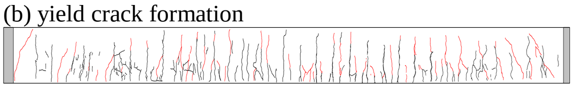

(d) Final crack formation

Figure 10. Crack pattern of B-S750

(a) Picture of Final crack formation


(b) yield crack formation


(c) Maximum load crack formation

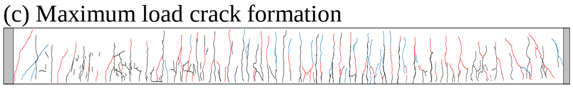
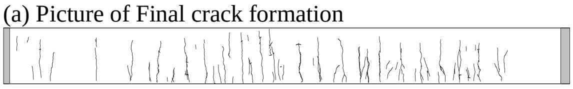

(d) Final crack formation

Figure 11. Crack pattern of TB-NS

(a) Picture of Final crack formation


(b) yield crack formation

(c) Blank

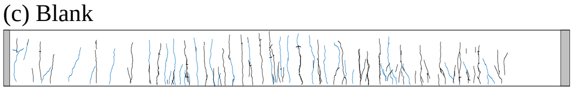
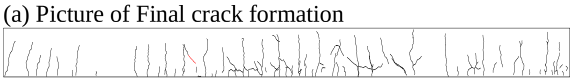
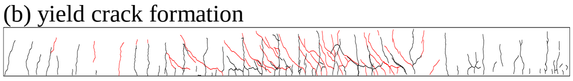

(d) Final crack formation

Figure 12. Crack pattern of B-S750


(a) Picture of Final crack formation


(b) yield crack formation


(c) Maximum load crack formation

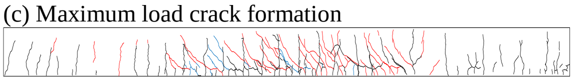
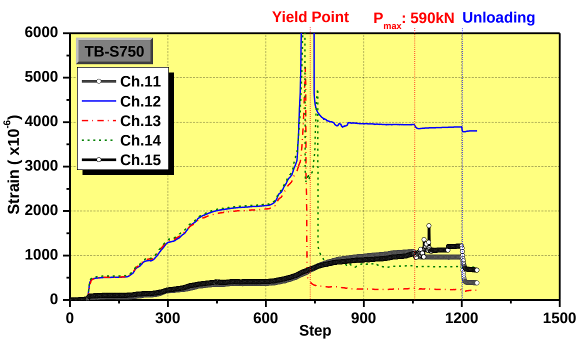
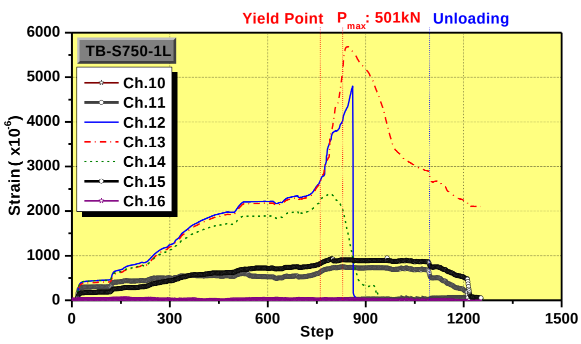

(d) Final crack formation

Figure 13. Crack pattern of TB-S750



(a) TB-S750

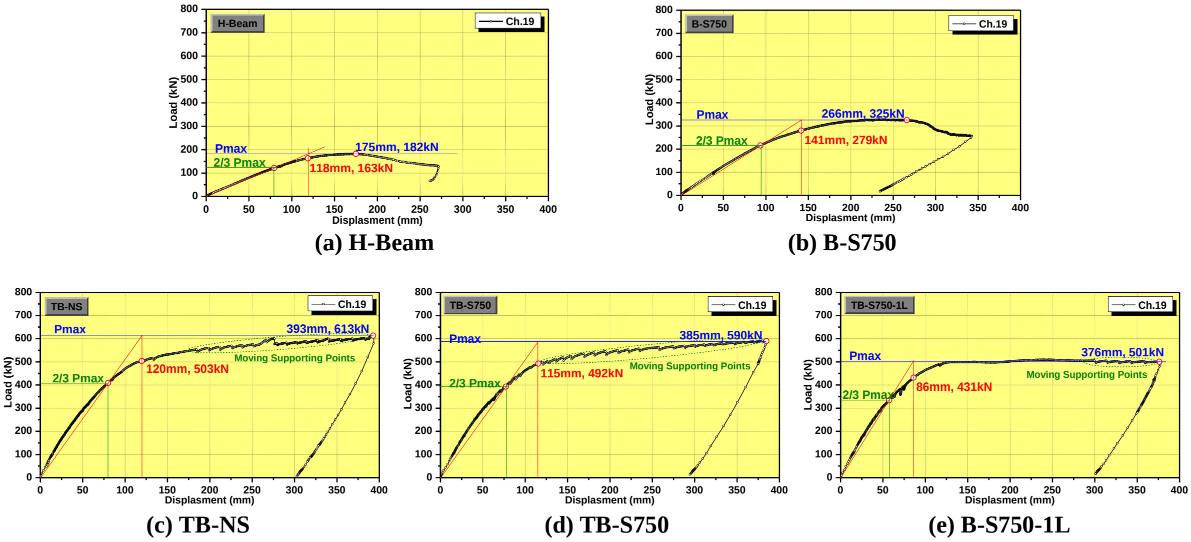


(b) TB-S750-1L

Figure 14. Strain of main bar

4.2. Load-Displacement Relationship

The test is conducted for a total of seven specimens roughly classified into three types: Pure steel H-Beam, GSF specimen with no slab (B-S750), and GSF specimen with slab (TB-NS, S750 and S750-1L). The yield point by the load - displacement relationship for each specimen and Moehle Method are presented in Figure 15. The maximum load and the calculated value are summarized in Table 2. As shown in Figure 15, the load- displacement relationship for all specimens showed typical bending behavior. The maximum load for each specimen is classified into three types: Pure steel H-Beam, GSF with no slab, and GSF with slab. Moreover, the difference between the calculated value by design strength and the test value was an average of 1.3X, excluding the TB-S750-1L specimen since it had lower value due to the slip of bars as described in section 4.1.



(a) H-Beam (b) B-S750

(c) TB-NS (d) TB-S750 (e) B-S750-1L

Figure 15. Load-displacement relationship

Table 2. Comparison of the Maximum Load and the Calculated Value

Specimen No.		Calculated value		Maximum load		Ratio
		kN·m	kN·m	kN·m	kN·m	cal./test
		(1)	(2)	(3)	(4)	(5)
NO.01	H-Beam	341	142	437	182	1.3
No.02	B-S750	560	233	780	325	1.4
NO.03	TB-NS	1,112	463	1471	613	1.3
No.04	TB-S750	1,112	463	1416	590	1.3
No.05	TB-S750-1L	1,112	463	1202	501	1.1

(1) Design bending strength, (2) Required strength of design about design bending strength, (d) Bending of test value, (4) Test load, (5) Test value ratio about calculated value

4.3. Evaluation of Ductility Capacity

The yield point for the ductility of the GSF composite beam was evaluated with two methods: Moehle Method (yield point 1), which is frequently used for concrete members, and point contacting with 1/3 hardness of the initial hardness typically used for steel members. The yield points according to the foregoing two methods are shown in Table 3.

As seen in Table 3, the two evaluation methods showed some difference according to the shape of the load – displacement curve, but such difference was minimal. Based on the average value of the GSF composite beam with slab, the latter method revealed slightly greater ductility capacity. The ductility index by yield point no.1 was 3.44, and that by yield point no.2 was 3.68.

The ductility index was categorized into two cases: one with no slab and the other with slab. When there was no slab, the average value from the two evaluation methods was 1.7; when there was slab, however, the average value was more than 3.5. The expression "more than" was used because it was difficult to evaluate with the maximum loading point, since the load had been increasing continuously before the unloading.

Table 3. The Yield Points and Ductility Index

Specimen No.		Yield point 1		Yield point 2		Maximum load		Ductility index 1	Ductility Index 2
		mm	kN	mm	kN	mm	kN		
No.01	H-Beam	106	178	97	175	295	191	2.8 over	3.0 over
No.02	B-S750	141	279	167	302	266	325	1.8	1.6
No.03	TB-NS	120	503	104	479	393	613	3.3 over	3.8 over
No.04	TB-S750	115	492	104	472	385	590	3.3 over	3.7 over
No.05	TB-S750-1L	86	431	89	439	376	501	4.4 over	4.2 over

4.4. Effect of the GSF Composite Beam

To review the effect of strength increase in the GSF composite beam, the strength of the h-beam member and increase in strength of the GSF composite beam by the test value and the calculated value were compared (Figure 16). The results were almost identical with the 1.78X difference in strength in strength from the test value and 1.72X difference in strength from the calculated value. Accordingly, the strength of the GSF composite beam may be estimated by using the bending theory Equation as shown in section 3.2. The test result showed that the strength of the GSF composite beam (H-446×199×8×12, As: 8,430mm^2) used in this study was similar to the bending strength of H-606×201×12×20(As: 15,250mm^2) when the comparison was made with only H-beams, and there was a 1.8X difference in the amount of steel.

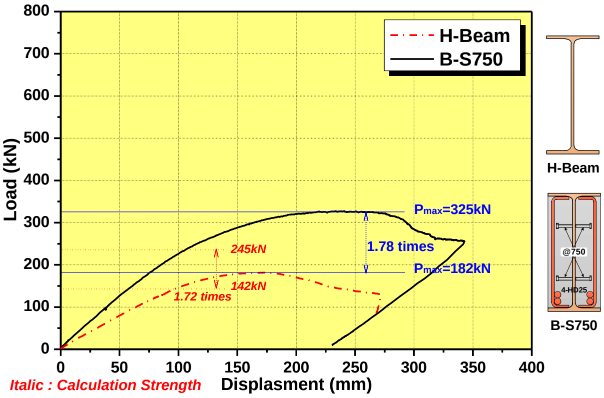


Figure 16. Comparison of GSF beam and H-beam

4.5. Design of GSF Composite Beam

The section detail of the composite beam was summarized based on its test results, i.e., the increase in strength was targeted by arranging bars and placing concrete to the web of an H-beam. The 0.6 L placing length was considered adequate because the placing length and the anchorage length proposed in section 3.2 did not have huge difference in terms of maximum strength with the specimen, with placing executed in all areas according to the test results; the strain of the bars in the anchorage zone was approximately 1/2 of the yield strain.

In case of behavior and strength according to the existence of the shear connecting materials in the web, sufficient adhesive performance was believed to have been secured with the adhesive power of Mullett, D.L only, considering (c) and (d) in Figure 15, which show that the shapes of the bending strength curve and the load – displacement curve almost coincide with each other. Note, however, that the minimum amount of shear connecting materials will be required considering the shock generated when placing was executed on one side of the web and turned upside down during the fabrication of the GSF composite beam in the factory and the damage of the members due to the vibration during the transport. Consequently, two - row 800 mm as the minimum space of shear connecting materials specified in Eurocode 4 was applied. The section details for the design of the GSF composite beam are summarized as follows:

- Placing length: 0.6 L (including anchorage length of the main bar)
- The overlapped joint of the main bar shall be avoided.
- Space between the shear connecting materials of the web: 2@800 (Φ10 or more)
- The use of closed-type shear reinforcing bar shall be avoided, if possible. In case of using the closed-type shear reinforcing bar, sufficient consideration shall be given to the width ratio of the cross section.

5. CONCLUSION

The test was conducted with five specimens to verify the section detail and strength performance of the GSF composite beam. Based on the test results, the condition of cracks and final breakdown, load – displacement relationship, amount of strain at the anchorage zone of the main bar, comparison of H-beam and GSF composite beam, comparison of the standard equation and test value, and ductility capacity evaluation were reviewed. The findings are summarized as follows:

1) The aspects of cracking varied according to the location of the neutral axis. In other words, the depth of the crack differed according to the existence of slab, and typical bending crack appeared. In case of the specimen with placing in all zones, cracks in the diagonal tension shear appeared on the right side of the center zone due to the lack of adhesive power to the concrete.
2) The load – displacement relationship showed a curve of typical bending behavior. The placing length of 0.6L and difference according to the existence of shear connecter had little effect on the behavior of the specimen.
3) The strain of the main bar was around 1/2 of the yield strain at the maximum load, showing that the estimated anchorage length was appropriate.
4) The difference in strength of the GSF composite beam from that of H-beam were 1.78X from the test result and 1.72X from the calculation; thus, they were almost the same. The result suggested that the amount of H-beam could be reduced by 1.8X. Based on the results above, we found out that the evaluation of strength of the GSF composite beam was possible using the theoretical equation of a beam.
5) The ductility index of the GSF composite beam with slab was found to have sufficient ductility capacity of 3.5 or more when evaluated by the maximum load.

The findings above show that the GSF composite beam may be designed based on the placing length setup method considering the anchorage length of the main bar and on the bending theoretical equation of a beam, and that the expected strength of the member was secured considering the fact that the test value was 1.3X or higher when the strength was calculated with a equation.

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