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Ultimate strength of composite structure with different degrees of shear connection

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Abstract. Composite beam, which combined the material characteristic of the steel and concrete, has been widely used in the construction of various building and bridge system. For the effective application of the composite beam, the composite action on the composite interface between the concrete element and the steel element should be achieved by shear connectors. The behavioral characteristics of composite beam are related with the degree of interaction and the degree of shear connection according to the shear strength and shear stiffness of the stud shear connectors. These two concepts are also affected by the number of installed shear connector and the strength of composite materials. In this study, experimental and analytical evaluations of the degree of shear connection affected by stud diameter were conducted, and the relationship between structural behavior and the degree of shear connection was verified. The very small difference among the ultimate loads of the specimens depending on the change of the degree of connection was possibly because of the dependence of the ultimate load on the characteristic of plastic moment of the composite beam.

Keywords : degree of shear connection, composite beam, ultimate strength, head stud

1. Introduction

Composite beam, which combined the material characteristic of the steel and concrete, has been widely used in the construction of various building and bridge system. For the effective application of the composite beam, the composite action on the composite interface between the concrete element and the steel element should be achieved by shear connectors. Thus, the shear connectors should be installed to transfer the longitudinal shear force and to resist the vertical force on the composite interface. Therefore, the design of the shear connector in composite beam must take the shear strength and ductility of shear connector into account, since they affect the failure mode and structural behavior of the composite beam.

The behavioral characteristics of composite beam are related with the degree of interaction and the degree of shear connection according to the shear strength and shear stiffness of the stud shear connectors. These two concepts, the degree of shear connection and the degree of interaction, are also affected by the number of installed shear connector and the strength of composite materials. The degree of shear connection can be calculated by the equilibrium of material strength between steel and concrete sections, the degree of interaction can be calculated by the strain distribution and relative slip between steel and concrete materials (Oehlers 1997, EUROCODE-4 2002, Ahn 2008, 2010).

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To evaluate the strength and behavior of the shear connector installed in the composite beam, push-out test and loading test on the composite beam with shear connector are commonly used. Push-out test directly applies shear force to the shear connector, therefore, the shear strength and relative-slip relationship of the composite member can be easily achieved. However the difference between the shear load transfer in real composite beam and the shear forces in push-out test can overestimate the shear strength in composite beam. The loading test on the composite beam indirectly applies the shear force to the shear connector. Therefore, it is difficult to evaluate the shear behavior and shear strength of shear connector because of the differences of behavioral mechanism between the two tests. However, to evaluate the real behavior of the composite beam with the shear connector, the loading test is more reasonable, because it considers the effects of shear conectors on the structural behavior and the failure mode of composite beam (Oehlers 1987, Lam 2005, Ranzi 2007, 2009).

Until recently, there were many experimental research to evaluate the load resistance and behaviors of composite beam with the stud shear connector by push-out tests and loading tests on composite beam. And also numerical research about the influences of stud arrangements, loading condtion, and long-term loading has been performed (Oehlers 1987, 1997, 1999, Shim 2004, Lam 2005, Ryu 2005, Ranzi 2007, Ahn 2008, 2010).

This study describes the effects of degree of the shear connection on composite beam. For this study an experimental and analytical evaluations of the degree of shear connection were conducted. To verify the degree of shear connection the diameters of stud shear connectors were changed. Three composite beam specimens, installed with D13, D16, and D19 studs, were fabricated for the experimental evaluations. Throughout each test, the behavioral change according to the degree of connection has been evaluated, and the behavioral difference has been compared with load-deflection relationship, load-strain relationship, and load-relative slip relationship. And the ultimate load value from numerical evaluation of plastic moment of the composite beam and value from tests were compared. To analytically verify the behavioral change of the composite beam depending on the degree of shear connection, the analytical evaluation with partially shear connected analysis model was conducted. Through the structural analysis, rate of change of the degree of shear connection, yield load of the composite beam, and rate of change of elastic stiffness were numerically compared and evaluated.

2. Shear strength of stud shear connector and composite behaviors

2.1. Shear strength of stud shear connector

To make composite section stud shear connectors are generally used, the designed shear strength of headed stud shear connector were suggested by AASHTO and Eurocode 4. In AASHTO, the ultimate shear strength is determined by Eq. (1). In Eurocode4, the ultimate shear strength is determined by the height of head stud, therefore, the shear strength is decided by the smaller value between them as shown in Eq. (2), and Eq.(3).

$$P_{sh} = 0.50 A_{ck}\sqrt{f_{ck}E_c} \le A_{sc} f_u \tag{1}$$

$$P_{R_d} = \frac{0.8 f_u \pi d^2/4}{\gamma_V} \tag{2}$$

$$P_{R_d} = \frac{0.29\,\alpha d^2 \sqrt{f_{ck}E_{cm}}}{\gamma_V} \tag{3}$$

where, $\alpha = 0.2\left(\frac{h_{sc}}{d} + 1\right)$ for $3 \le h_{sc}/d \le 4$, $\alpha = 1$ for $h_{sc}/d > 4$, A_{sc} is the sectional area of headed stud, f_u is the tensile strength of headed stud, γ_V is the partial factor, d is the diameter of the shank of the stud, 16 mm $\le d \le$ 25 mm, h_{sc} is the overall nominal height of the stud.

2.2. Composite behaviors of composite beam

Composite behaviors can be described by the degree of interaction and the degree of shear connection in the composite beam. The degree of shear connection deals with the equilibrium of the axial strength between the steel element or the concrete element and the shear connection in the composite section as shown in Fig 1. Full shear connection is where the strength of concrete or steel element in composite section is larger than the strength of shear connection, and partial shear connection is where the strength of shear connection is larger than that of composite section's elements. It is full shear connection, when η is larger than 1.0 in the Eq. (4) about the degree of shear connection (Oehlers *et al.* 1997). And the strength of concrete F_c and steel F_s element is determined by Eq. (5), (6).

$$\eta = \frac{\sum P_{sh}}{\sum (P_{sh})_{f_{sc}}} \tag{4}$$

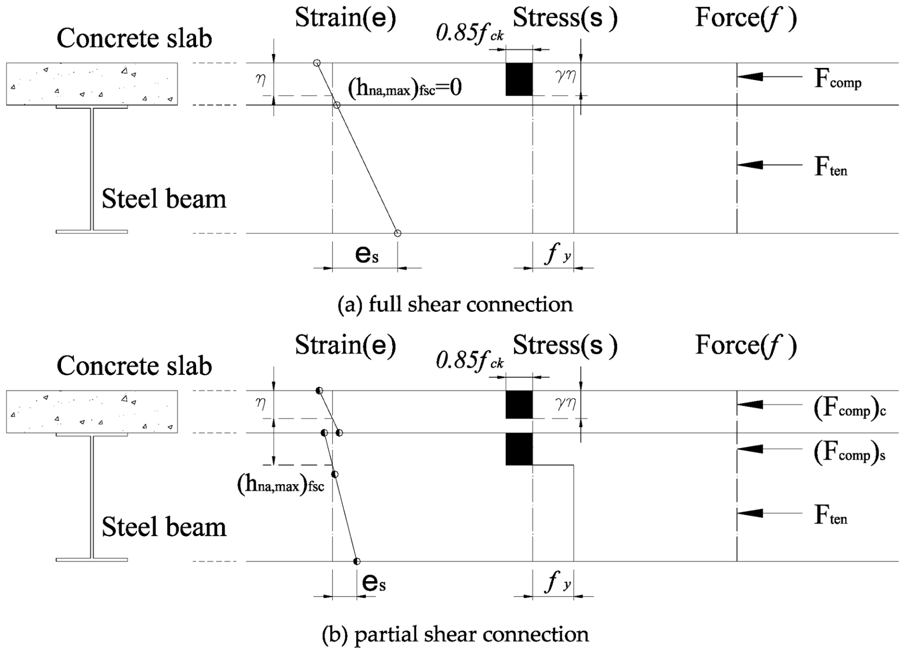


Fig. 1 Degree of shear connection in composite section

$$F_c = 0.85 f_{ck} A_c \tag{5}$$

$$F_s = A_s f_y \tag{6}$$

where, $\sum P_{sh}$ is the available strength of the shear connectors specified, $\sum (P_{sh})_{f_{sc}}$ is the strength of the shear connection, f_{ck} is the compressive strength of concrete element, f_y is the yield strength of steel element, A_c is the area of concrete element in composite section, A_s is the area of steel element in composite section.

The degree of interaction affects the strain distribution in composite section and relative slip at composite interface between the steel element and the concrete element as shown in Fig. 2. For full shear interaction, there is no relative slip at composite interface and the strain distribution in composite section is linear. For partial interaction, there are relative slips and different strain distribution in steel and concrete element due to elastic deformation of shear connector. For full interaction, the ratio of the relative slip at critical or certain point in the composite section should be 0.0 from the Eq. (7) about the ratio of the relative slip in the composite beam. The degree of interaction can be expressed as Eq. (8) (Oehlers 1997).

$$\frac{ds}{dx} = \frac{h}{E_c I_c + E_s I_s} M - \left(\frac{h^2}{E_c I_c + E_s I_s} + \frac{1}{E_c A_c} + \frac{1}{E_s A_s} \right) F = K_1 M - K_2 F \tag{7}$$

$$\zeta = \frac{\sum (P_{sh})_{\max}}{\sum (P_{sh})_{\max, fi}} \tag{8}$$

$$\sum (P_{sh})_{\max, fi} = \frac{K_1 (M)_{\max}}{K_2} \tag{9}$$

where, $\sum (P_{sh})_{\max, fi}$ is the minimum strength of the shear connection for full interaction as expressed in Eq. (9), $\sum (P_{sh})_{\max}$ is the strength of the shear connection at maximum moment in composite beam, $E_c I_c$ and $E_s I_s$ are the sectional properties of steel beam and concrete slab for the flexible behavior of composite beam, $E_c A_c$ and $E_s A_s$ are the sectional properties of steel beam and concrete slab for the axial strength of composite beam. However, the relative slip of the composite interface should be increased according to the flexible deformation of the shear connector. So, the composite beam is designed with

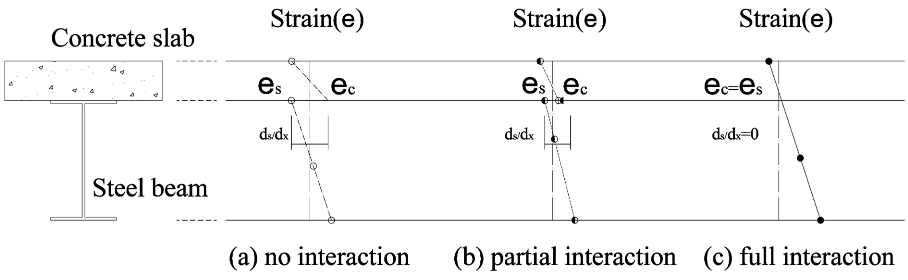


Fig. 2 Interaction behavior of composite beam

full shear connection is commonly assumed to have full interaction.

2.3. Ultimate strength of composite beam according to shear connection

The ultimate strength of composite beam can be determined by the strength of composite member considering the neutral axis in composite section. And the neutral axis of composite section is determined by the compressive force (R_c) at concrete slab and the tensile force (R_a) at steel girder. For the composite beam with full shear connection, the ultimate strengths of composite beams are determined by the location of neutral axis. When the neutral axis is on the concrete slab, the compressive force is greater than the tensile force. The plastic resistance moment can be expressed as Eq. (10). When the neutral axis is on the top flange, the plastic resistance moment can be expressed as Eq. (11). When the neutral axis is on the web, the plastic resistance moment can be expressed as Eq. (12). The plastic resistance moment of the rolled beam can be calculated as Eq. (13) (Liang 2004, AASHTO 2004, Ryu 2005, Silva 2009).

$$M_{pl,R_d} = R_a\left(\frac{h}{2} + h_p + h_c - \frac{R_a}{R_c}\frac{h_c}{2}\right) \tag{10}$$

$$M_{pl,R_d} = R_s\frac{h}{2} + \sum P_{Rd}\left(h_c - \frac{z_{pl,c}}{2}\right) - R_v\frac{(z_{pl,s} - h_c) - t_f^2}{d} \tag{11}$$

$$M_{pl,R_d} = R_c z + M_{pl,a,N-red,Rd} \tag{12}$$

$$M_{pl,Rd-red/Rd} = 1.1M_{pl,Rd}\left(1 - \frac{R_c}{R_a}\right) \le M_{pl,a,Rd} \tag{13}$$

3. Loading test on composite beam with stud shear connector

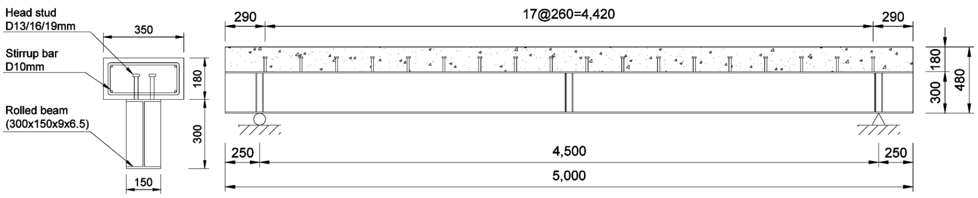
The behaviors and load-resistant characteristics of the composite beams with stud shear connector according to the degree of shear connection and interaction were examined by composite beam loading test. To change the shear connection and interaction of composite beam, the diameter of stud connector in composite beam was changed.

3.1. Composite beam specimens with stud shear connectors

A total of three composite beam specimens were fabricated to examine the behaviors and load-resistant characteristics of the composite beams depending on the degree of shear connection and interaction of composite beams according to the stud diameter. The total length of the composite beam specimens was 5,000 mm and was supported on a 4,500 mm simple span. For the steel part of the composite beam, Rolled beam with compact section, H300 × 150 × 6.5 × 9, was used. The steel grade of the rolled beam was SS400 grad with 180 MPa nominal allowable stress, 200 MPa nominal yield strength, and 250 MPa tensile strength (MOCT, 2005). For concrete part of composite beam, the concrete slab with 350 mm width and 180 mm thickness was used. The designed compressive strength of concrete slab was 30 MPa.

Table 1 Characteristics of the composite beam specimen

Specimens	Diameter of stud (mm)	Number of stud	Stud spacing (mm)	Degree of shear connection	Degree of interaction
D13	13	36	17 × 260	0.85	1.24
D16	16	36	17 × 260	1.30	1.29
D19	19	36	17 × 260	1.88	1.33



(a) Side view (cross section) (b) Front view (elevation)

Fig. 3 Composite beam specimen

Table 1 and Fig. 3 show the dimensions and details of the composite beam specimens. A total of 36 stud shear connectors were welded with 260 mm spacing on the above top flange for every specimen as shown in Fig. 3. To change the degree of shear connection and interaction of composite beam specimens, the diamter of stud connector was changed. In case of D13 specimen, 13 dimater stud connectors were installed. For D16 and D19 specimens, 16 and 19 diamater stud connectors were installed.

From Table 1, D13 specimen with 13mm dimeter stud was designed as partial shear connection of 0.85 shear connection. D16 and D19 specimens were designed with full shear connection of 1.30 and 1.88. The interaction of all specimens was determined as full interaction from interaction values derived by Eq. (8), D13 was 1.24, D16 was 1.29, and D19 was 1.88.

To prevent the local bucking, stiffener was installed at the middle of steel beam at loading section and support section. And prior to concrete pouring, a grease coating was applied on the top flange to minimize the chemical bonding effects of the concrete and the steel interface like push-out specimens.

3.2. Material properties and test programs

The SS400 grad steel and the 30MPa design compressive strength were used in composite specimens. Tensile strength test of steel beam was conducted to confirm the material properties as well as that of stud shear connector slab before the fabrication of composite beam specimens. And also compressive strength tests of concrete slabs were conducted after curing of concrete slabs. For tensile test results of composite beam test specimen, the mean tensile strength was 429.7 MPa, and the measured elongation was 33.3%. Table 2 shows the tensile strength tests of steel of each test specimens.

To determine the compressive strength of concrete, twelve concrete cylinders were prepared. These concrete cylinders were air-cured and standard-cured for 28 days under the same conditions and then tested. The results of compressive strength tests are shown in Table 3.

Loading tests on composite beam specimens were performed at Chung-cheong University with the qualifications of KOLAS (Korea Laboratory Accreditation Scheme). A 3 point bending moment was applied to composite beam specimens using an actuator of 2,000 kN. Loading on composite beam was

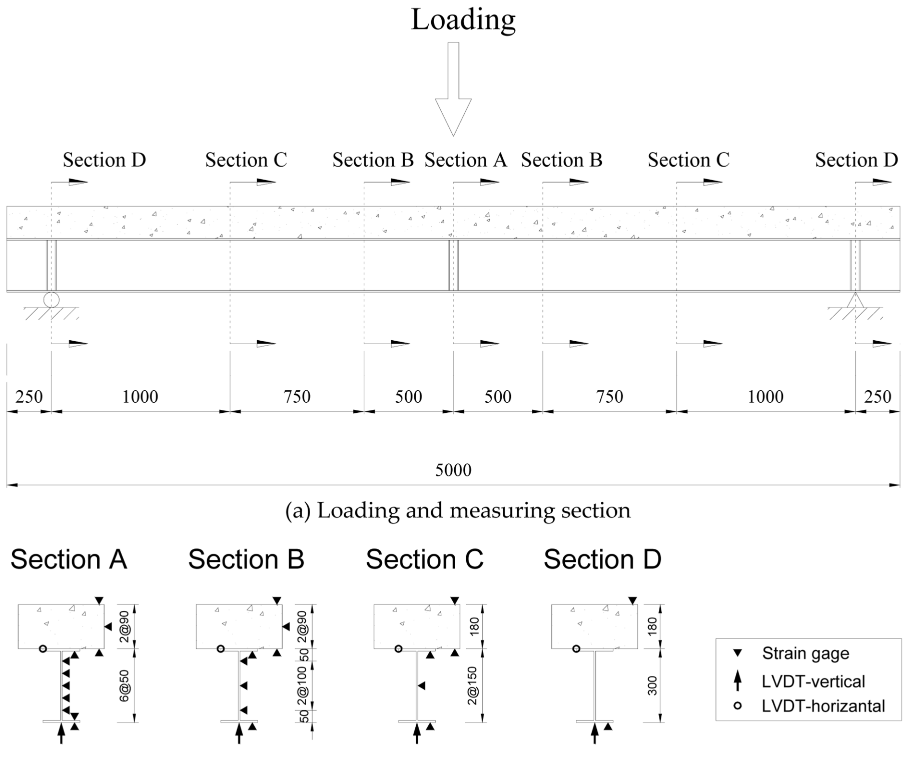
Table 2 Material properties of steel

Specimens		Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Young's modulus
Steel beam	B1	354	438.3	32	2.13 × 105
	B2	347	424.1	35	2.13 × 105
	B3	348	426.8	33	2.13 × 105
	Avg.	349.6	429.7	33.3	2.13 × 105

Table 3 Material properties of concrete

	Compressive strength (MPa)
Design	30.0
Standard curing (28 days)	31.1
At test time	32.0

applied in displacement control with rate of 0.033 mm/sec for nonlinear states of specimens. To compare the behavior and ultimate strength of composite beam strain gages and linear variable differential transforms (LVDTs) were used. In each specimen, 25 strain gages were mounted at the five measured span section A, B, C, and D as shown in Fig. 4, 16 strain gages on the flange and web in steel beam, and 9 strain gages on the concrete slab. The deflections were measured by seven LVDTs located underneath



(a) Loading and measuring section

(b) Location of instrumentation at measuring section

Fig. 4 Load and instrumentation of composite beam test

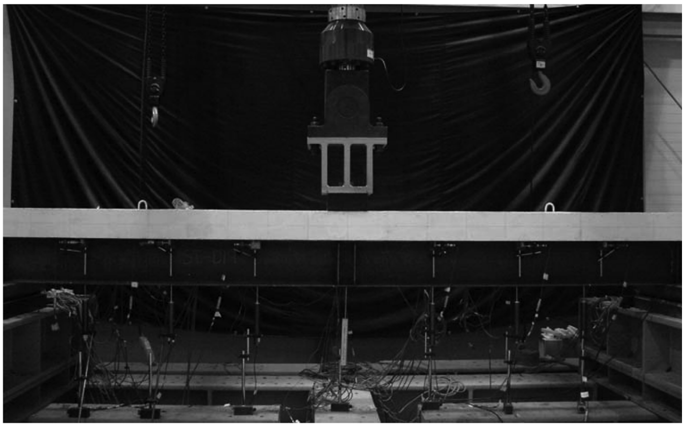


Fig. 5 Load test specimen and test set-up

the bottom flange at the five measured span section A, B, C, and D. and eight LVDTs measured the relative slip between the steel beam and the concrete slab at the eight measured span section B, C, and D. Fig. 4 shows the location of loading and behavioral data collecting instruments. Fig. 5 shows the loading test set-up and the specimens .

4. Loading test results

4.1. Failure modes and load-deflection relationships

The composite beams behaved with the yielding of bottom flange after the linear behaviour with cracking of the concrete slab according to the increase of the loading level after bottom flange yielding. Final failure modes were determined as cracks of concrete slab propagated from initial crack. Fig. 6 shows

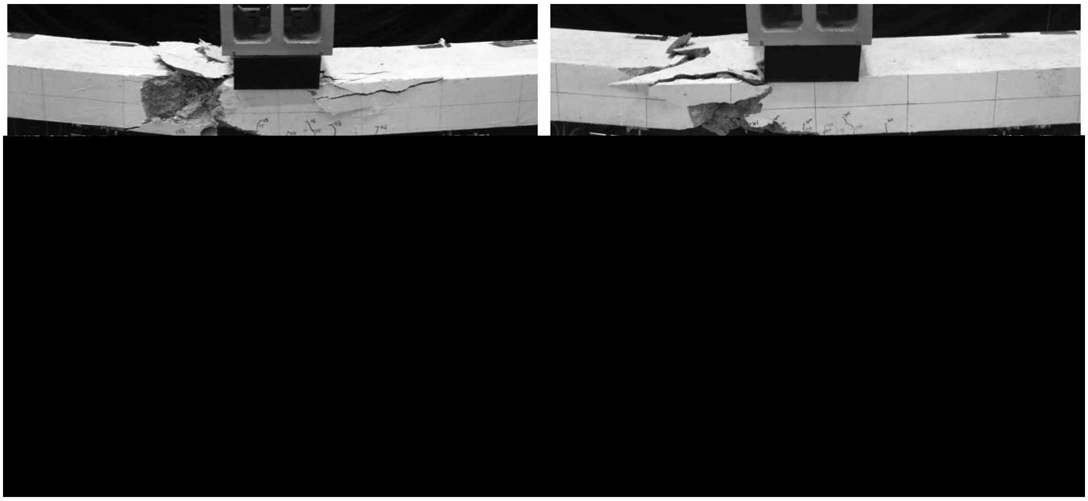


Fig. 6 The final failure modes

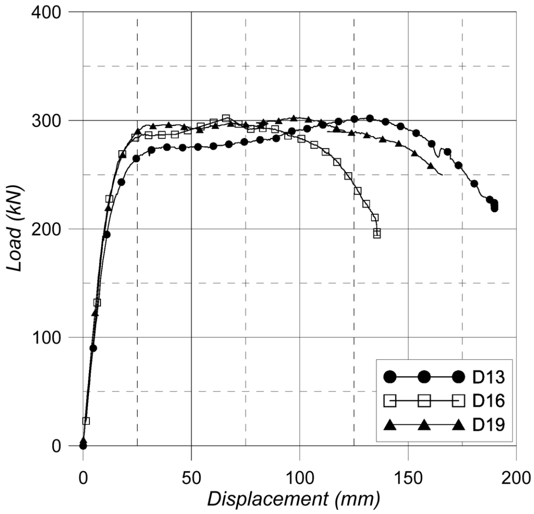


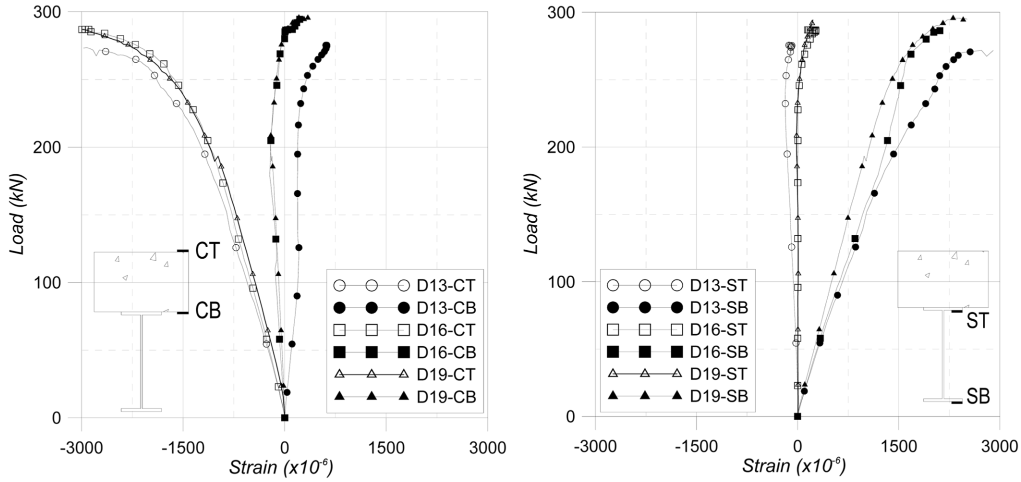
Fig. 7 Load-displacement relationships at center of composite specimens

the final failure modes. Fig. 7 presents the load-deflection curves at center of composite beam specimens. The yield loads varied throughout the specimens. Yield load of 13D was 165.67 kN, 16D was 173.42 kN, and 19D was 214.19 kN. The yield load of specimens increased 4~29% as the degree of shear connection increased. For the stiffness of specimens the slopes of load-displacement relationship were measured at the load 100 kN. As a result of this, 13D of it was 19.18 kN/mm, 16D was 20.39 kN/mm, and 19D was 22.59 kN/mm. The elastic stiffness of specimens increased 6~17% as the degree of shear connection increased. In terms of the ductility of composite beam, it can be varied by the degree of shear connection. As shown in Fig. 6, it can be known that the more ductile behaviour is conducted in 13D than in 19D. This means if the degree of shear connection increases, the ductility of composite beam decreases. For the ultimate strength, however, for 13D it was 302.25 kN, 16D was 302.43 kN, and 19D was 302.41. The ultimate loads of specimens did not change as the degree of shear connection increased.

As a result of this, it can be estimated that the degree of shear connection affect the structural stiffness of the composite beam, but not affect the ultimate strength greatly. The ultimate strength of the composite beam should be determined by plastic neutral axis and plastic moment. The section of the specimens is equal to each other, and the sectional increase of stud shear connector is merely affecting. Therefore if the degree of shear connection is greater than a certain limit, the degree of shear connection does not affect the ultimate strength.

4.2. Load-strain relationships and Load-relative slip relationship

Fig. 8 presents the load-strain curves at the central section of concrete slab and steel beam to evaluate the strain distributions according to shear connector types in the loading test. The load-strain relationships at the bottom flanges of composite beams were shown to be similar with the load-deflection relationships of the composite beam. The composite beam with larger head stud had less strain values than the composite beam with smaller head stud. The full shear specimens, D16 and D19, were designed not to have tensile stress at bottom side of concrete section. Doing the experiments, there was no tensile stress at the same side since the neutral axis of specimen was same with the design section. In



(a) Load-strain curve of concrete slab

(b) Load-strain curve of steel beam

Fig. 8 Load-strain relationships of the composite beams

case of D13 specimen, however, because the neutral axis of D13 specimen was in the concrete section, there was tensile stress at the bottom of concrete section.

Fig. 9 shows the strain distribution at central section of composite beam based on the shear connector diameter before the yield load of the composite beam. For the composite beam with stud, load-strain curve changed linearly before the yield states of the bottom flange. Visible from the Fig. 9, the neutral axis of composite beam also matched the designed location of composite beam. For D13 specimen, tensile stress appears at the bottom of concrete, it is judged to be occurred by the partial interaction behavior of two elements of composite beam. Because unrequested strain may appear due to no consideration of the degree of connection in practical construction, the degree of connection should be considered in designing.

Fig. 10 shows the load-relative curve of composite beam specimens at the support. The shear resistant characteristics of stud shear connector are shown clearly in Fig. 10. For the head stud composite beam specimen, the shear force resisting strength of head stud is small, and has large deformation against shear force, so the relative slip occurred from the early stage of load, and then increased rapidly according to load increase. Thus, the ductility of the beam is also changed as the degree of shear connection varied. In lower degree of shear connection, more ductile behaviour can occur.

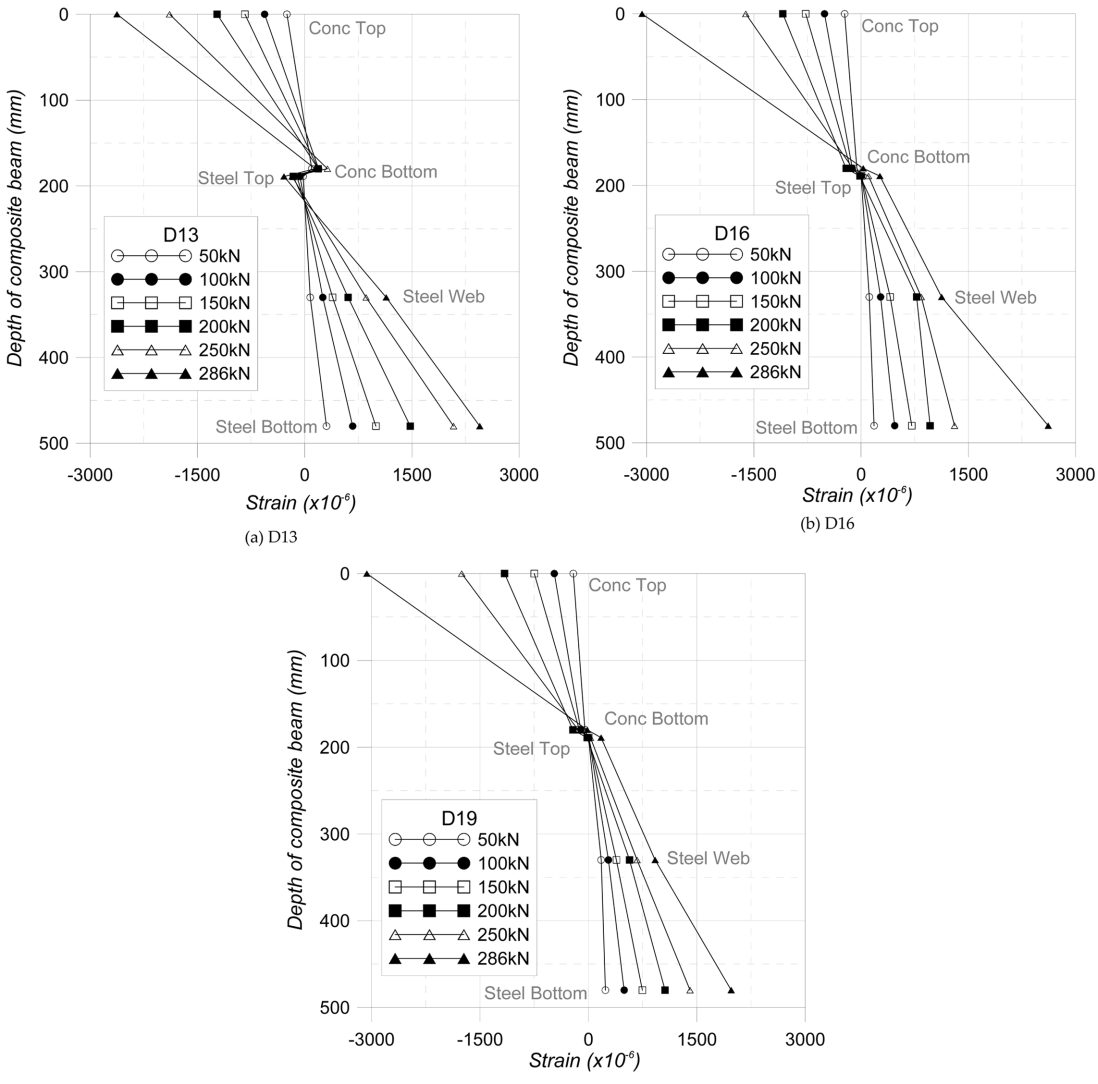
4.3. Ultimate strength

The ultimate strength of composite beam can be evaluated by the rigid plastic analysis between

Table 4 Loading test results

Specimens	Elastic stiffness (kN/mm)	Ratio*	Yielding load (kN)	Ratio*	Ultimate load (kN)	Ratio*
D13	19.18	1.000	165.67	1.000	302.25	1.000
D16	20.39	1.063	173.42	1.047	302.43	1.001
D19	22.59	1.178	214.19	1.293	302.41	1.001

*Ratio = Each case / SCB-D13 : increase ratio as stud diameter



(a) D13 (b) D16 (c) D19

Fig. 9 Load-strain distribution at central section of the composite beams

concrete and steel materials. The shear connector should have sufficient shear strength to resist the shear force on the composite interface. In this study, composite beam specimens were designed to locate the plastic neutral axis on top flange of steel beam, so the plastic moment can be evaluated as Fig. 11. Table 5 presents the comparison test results with analytical results derived from rigid plastic analysis using Eq. (14) and (15). Eq. (14) and (15) are the plastic moment equations of the composite beam at neutral axis located in the top flange and concrete element. Comparison between the test results and analytical results, loading test results on composite beams evaluated greater values than analytical values of plastic moments considering designed and used material properties. And the plastic moments derived from numerical analysis are similar to the ultimate strengths of composite beam tests. After evaluating the effect of the diameter change of head stud toward the ultimate strength of the composite

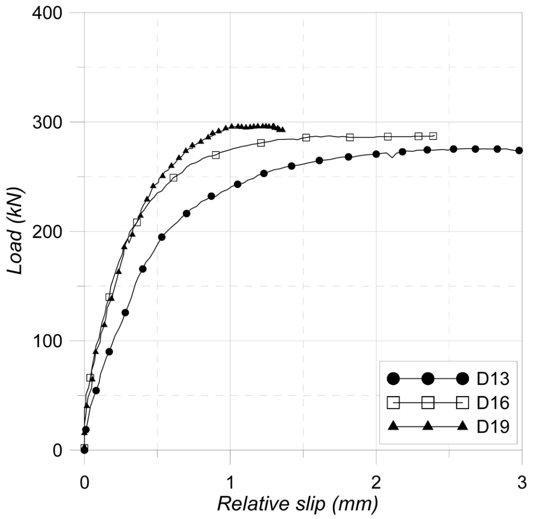


Fig. 10 Load-relative slip relationships at support of composite specimens

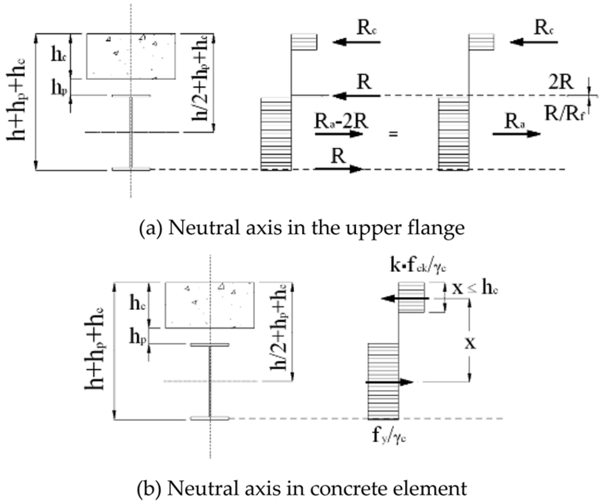


Fig. 11 Plastic moment of composite beam

beam, according to the characteristic of ultimate load which is determined by the effective section and ultimate strength of each element in the composite section, if the degree of shear connection is greater than a certain limit, the degree of shear connection does not affect the ultimate load greatly.

$$M_{pl,Rd} = F_a\frac{h}{2} + R_c\left(\frac{h_c}{2} + h_p\right) - \frac{(R_a - R_c)^2}{4R_f}t_f \tag{14}$$

$$M_{pl,Rd} = R_a\left(\frac{h}{2} + h_p + h_c - \frac{R_a}{R_c}\frac{h_c}{2}\right) \tag{15}$$

Table 5 Ultimate strength

Specimens	By plastic neutral axis (kN)	By experiment (kN)	Ratio*
D13		302.25	1.056
D16	286	302.43	1.57
D19		302.41	1.057

*Ratio = Experiment / Plastic neutral axis

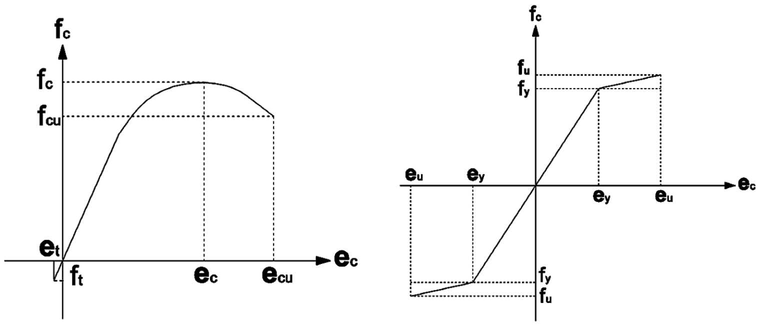
5. Comparison with FE analysis

5.1. Model properties

Analytically to verify the behavioral change of the composite beam depending on the degree of shear connection, structural analysis models representing partial interaction behavior were developed. For this analysis, the commercial FE analysis program LUSAS 14.3 was used. The solid element (HX20) was used for the concrete member and the surface element (QSL8) was used for the steel member. Non-linearity in the analysis material was considered, and an elastic-plastic joint element was assigned as the stud shear connectors. To idealize a real stud's behavior, the elastic-plastic joint element must behave in a bi-linear fashion. The load-displacement relationship results of the push-out test were used as the elastic-plastic joint element. Due to the symmetrical nature of the problem, the left-hand span of the composite beam was only modeled. The stress-strain relationship of the concrete and steel are shown in Fig. 12. For the constitutive models, the concrete crack model was assigned as the concrete section, and the von Mises model was assigned as the steel section. Fig. 13 shows the LUSAS 14.3 analysis model.

5.2. Analysis cases

The standard analysis model used in this study employed the D16 specimen, and the joint elements were arranged accordingly. Table 6 shows the analysis cases. DS-Full signifies no interaction between the bottom of the concrete and the top of the steel girder because the bottom side of concrete and above the top flange share the same elements and nodes without joint elements. DS-100 is an ideal case where the same number of studs is used in the same arrangement, while DS-50 is where half the number of



(a) Concrete material (b) Steel material

Fig. 12 Stress-strain relationship of the materials

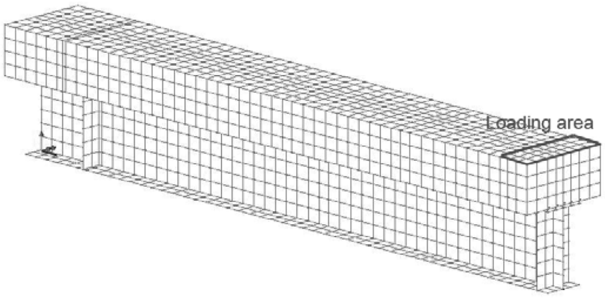


Fig. 13 LUSAS 14.3 analysis model

Table 6 Analysis cases

Name	Number of studs	Degree of shear connection
DS-Full	-	Full*
DS-100	18	1.30
DS-50	9	0.65
DS-0	0	0.00

* Full : without joint elements.

studs was used, and DS-0 is where no joint element was used.

5.3. Analysis results

The loading test and the numerical analysis presented similar results in terms of elastic stiffness and the yield load. Therefore, the numerical analysis accurately represents the actual structural behavior. The behavior of the composite beam changed significantly with the variations of the degree of shear connection. The elastic stiffness of DS-Full was 1.23 times stronger than that of DS-100. Such fact presents that the usual analysis method, which does not consider the degree of shear connection, overestimates the elastic stiffness. For DS-100, DS-50, and DS-0, the elastic stiffness ratios are not proportional to the degree of shear connection ratios, because the stud strength was multiplied by a safety factor when the stud was designed. The stud strength was underestimated, therefore, the degree of shear connection was also underestimated. Through analysis, even if the degree of shear connection of short beams - like the beams subjected from this study - pass a certain critical value, behavior of the girder is barely affected. Fig. 14 presents the load-displacement relationship analysis, and Table 7 presents a comparison of each analysis case.

6. Conclusions

In this study, experimental and analytical evaluations of the degree of shear connection affected by stud diameter were conducted, and the relationship between structural behavior and the degree of shear connection was verified. The three composite beam specimens, D13, D16, and D19, were fabricated with different diameters of stud shear connector for the loading test and three points bending tests. As results of the experimental evaluation, the differences of elastic stiffness, yield load, and ultimate load

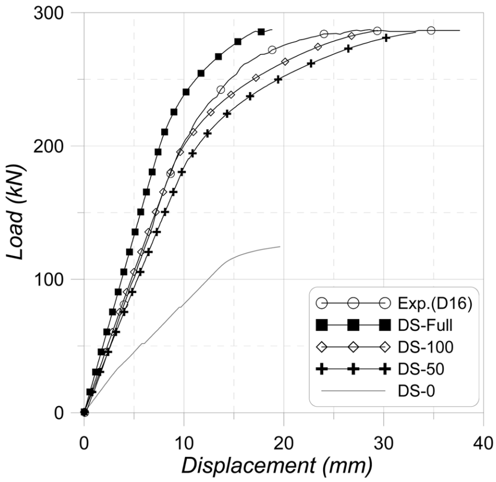


Fig. 14 Load-displacement relationship analysis

Table 7 Comparison of each analysis cases

Name	Elastic stiffness (kN/mm)	Ratio based on DS-100
DS-Full	26.25	1.23
DS-100	21.35	1.00
DS-50	18.90	0.89
DS-0	10.00	0.47

in respect of the degree of shear connection were confirmed. For the specimens with more than 1.0 of degree of shear connection, the tensile stress at the bottom of the concrete section was not observed as it was designed. However, for the specimen with less than 1.0 of degree of shear connection, the tensile stress at the bottom was observed. Since it was partially shear connected, the composite action of beam was affected, and the neutral axis was changed. Finally the elastic stiffness and yield load were decreased due to the partial shear connection. For the ultimate load of the composite beam, the error between the ultimate load value from numerical analysis of the composite beam and the value from the tests was 6-7%, which signified the correspondence of both values. The very small difference among the ultimate loads of the specimens depending on the change of the degree of connection was possibly because of the dependence of the ultimate load on the characteristic of plastic moment of the composite beam. To verify the effect of the degree of shear connection, the FE analysis was conducted through LUSAS 14.3. The similarity between the actual composite beam and the analysis model with an elastic-plastic joint element, which represents the behavior of the stud shear connector, was confirmed. For the analysis four types of analysis model were fabricated depending on the degree of shear connection. As results of the analytical evaluation, for usual analysis model which does not use the joint element the elastic stiffness was greater than the experimental result. For the joint element applied analysis model, the elastic stiffness was less than the experimental result. Even if the ratio of the degree of shear connection is 0.5, the ratio of the elastic stiffness is 0.89, because the actual stud strength is underestimated by multiplying a safety factor when the stud was designed. Shown from the results, the usual analysis model, which does not consider shear connection behavior, overestimates the elastic stiffness of the composite beam, therefore the elastic stiffness of the composite beam is not linearly proportional to the degree of shear connection. Through the loading test and the structural analysis, behavior of the short beams, such as the composite beam from this study, is barely affected when the degree of shear connection pass a certain critical value. Thus, in designing the practical construction, using the degree of shear connection reflected large stud shear connector or perfobond-rib shear connector may contribute to more effective designing, and further evaluation should be conducted regarding this construction.

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