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CONNECTION COEFFICIENT OF COMPOSITE BEAM

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Abstract

In the seismic design, beam-to-column connections should prevent early fracture in order to keep enough energy absorption capacity of members after beam yielding. Especially, beam-to-column connection is very important to retain seismic performance of buildings, therefore, the maximum strength of connection is designed by connection coefficient α.

The design formula is defined dealing with bare steel members because all members of building are postulated as bare steel on the calculation of general strength in the present design. That is, composite effect by concrete slab on steel beam is neglected in the calculation. In previous studies of composite beam, it has been already pointed out that strength is greater than bare steel beam by moving the neutral axis to near concrete slab, and plastic deformation is less than bare steel beam.

However, it is not clear that growths of strength of composite beam, and difference of plastic deformation of composite beam between composite beam and bare steel beam. Therefore, according to the connection coefficient of bare steel members, it is hard to judge that composite beam-to-column connection can keep enough energy absorption capacity. In order to judge whether composite beam-to-column connection have enough energy absorption capacity or not, connection coefficient of composite beam are needed. Connection coefficient of composite beam is defined the ratio of the maximum strength to the plastic strength of composite beam. The plastic strength that means strength when plastic hinge created. It also means the changing point from elastic area to plastic area in relationship between moment and deformation such as full-plastic moment in bare steel beam should be clarify its verification. The maximum strength of composite beam is obtained by rectifying the calculation of connection strength based on the study of Tanaka et al.

In this study, a series of cyclic loading test of connection of RHS column and composite beam is conducted. The parameters are two; thickness of column skin plate to consider relation between moment transmission efficiency and hysteresis, and beam width to clear effect of cross-section area between concrete slab and steel beam. The database of composite beam under cyclic loading is constructed not only above tests but also previous studies of experiments in RHS column and composite beam. Moreover, fundamental study of connection coefficient of composite beam regarding strength of material and width-to-thickness ratio of column is also conducted. Through the considerations, following knowledge are obtained;

(1)The plastic strength of composite beam is verified as creating plastic hinge at beam-end and to be appropriate as base of connection coefficient of composite beam.

(2)Connection coefficient of composite beam is obtained as the ratio of the modified maximum strength to the plastic strength of composite beam. The value of connection coefficient of composite beam is less than connection coefficient of bare steel beam, especially it is remarkable in case that moment transmission efficiency of bare steel is low.

(3)In parametric study, connection coefficient of composite beam is affected by the material strength of steel and width-to-thickness ratio of column.

Keywords: Composite Beam, Connection Coefficient, Moment Transmission Efficiency

1. Introduction

In seismic design, the detail of beam-to-column connections should prevent early fracture to retain seismic performance of buildings. In order to guarantee sufficient strength of connection for the strength that it makes plastic hinge at beam edge, the maximum strength of connection is designed by connection coefficient α such as Eq.(1). The formula is stated in Technical criteria references on structure of buildings in Japan[1], and it should be generally used in steel structure for designing safty building against earthquake.

$$ {}_{j}M_{u} \geqq \alpha\, {}_{b}M_{p} \tag{1}$$

here, ${}_{j}M_{u}$ is the maximum strength of connection, α is connection coefficient, and ${}_{b}M_{p}$ is full-plastic moment of beam.

Eq.(1) is defined as a design formula of bare steel beams and connection coefficient should secure more than 1.3. General beam of building is postulated as bare steel on the calculation of strength in the present seismic design, and composite effect by concrete slab on steel beam is neglected. Though it has been already known in previous studies that the strength of composite beam is greater than bare steel beam by moving the neutral axis to near concrete slab, and the plastic deformation of composite beam is smaller than bare steel beam, it have been not reflect in design recommendation. Therefore, it is not clear that composite beam-to-column connection can keep enough energy absorption capacity as bare steel beams. In order to judge whether composite beam-to-column connection have enough energy absorption capacity or not, connection coefficient is useful. However, the connection coefficient of bare steel beam (α) may not match to composite beam. So that, connection coefficient of composite beam defined the ratio of the maximum strength to the plastic strength of composite beam is needed. Here, the maximum strength of composite beam is obtained by rectifying the calculation of connection strength based on the study of Tanaka et al. The plastic strength is that the end of composite beam begin to plasticize such as full-plastic moment in bare steel.
In this study, the connection coefficient of composite beam is considered by a series of cyclic loading test of connection between RHS column and composite beam and database. The parameters of the test are thickness of column skin plate and beam width. The former is to consider relation between moment transmission efficiency and hysteresis, and the latter is to clear effect of cross-section area between concrete slab and steel beam. In order to grasp the trend of connection coefficient of composite beam, database of composite beam under cyclic loading is constructed by previous tests. Based on the consideration, parametric study of connection coefficient of composite beam regarding strength of material and width-to-thickness ratio of column is conducted.

2. Cyclic loading test of connection between composite beam and RHS column

2.1 Specimen

Specimen is T-shape partial frame which consist of RHS column and H-shape beam with concrete slab. It is designed as beam-to-column connection of middle and low rise building. Specimen list is shown in Table 1, and specimen detail is shown in Fig.1. All beam is based on RH-500x200x10x15(SN400B) and all column is □-300x300x16(BCR295). The beam is jointed to column by through diaphragm, beam flange is welded by F.P. and beam web is welded by fillet welding. Scallop is composite annular type based on Japanese Architectural Standard Specification for Steel structure (JASS6), and end tab of beam flange is used solid tab.

Table 1 – Specimen list

Specimen	Beam (SN400)	Panel zone	${}_sM_{pt}$ [kN·m]	${}_s\theta_{pt}$ [rad]	${}_jM_{un}$ [kN·m]	${}_jM_{ut}$ [kN·m]	${}_s\alpha_n$	${}_s\alpha_t$
A-09-200	RH-500×200×10×16	□-300×300×9×16 (SS400・built)	646	0.0062	657	705	1.33	1.09
A-09-150	RH-500×150×10×16		532	0.0062	502	542	1.25	1.02
A-16-200	RH-500×200×10×16	□-300×300×16 (BCR295)	602	0.0056	693	806	1.41	1.34
A-16-150	RH-500×150×10×16		496	0.0057	539	630	1.34	1.27

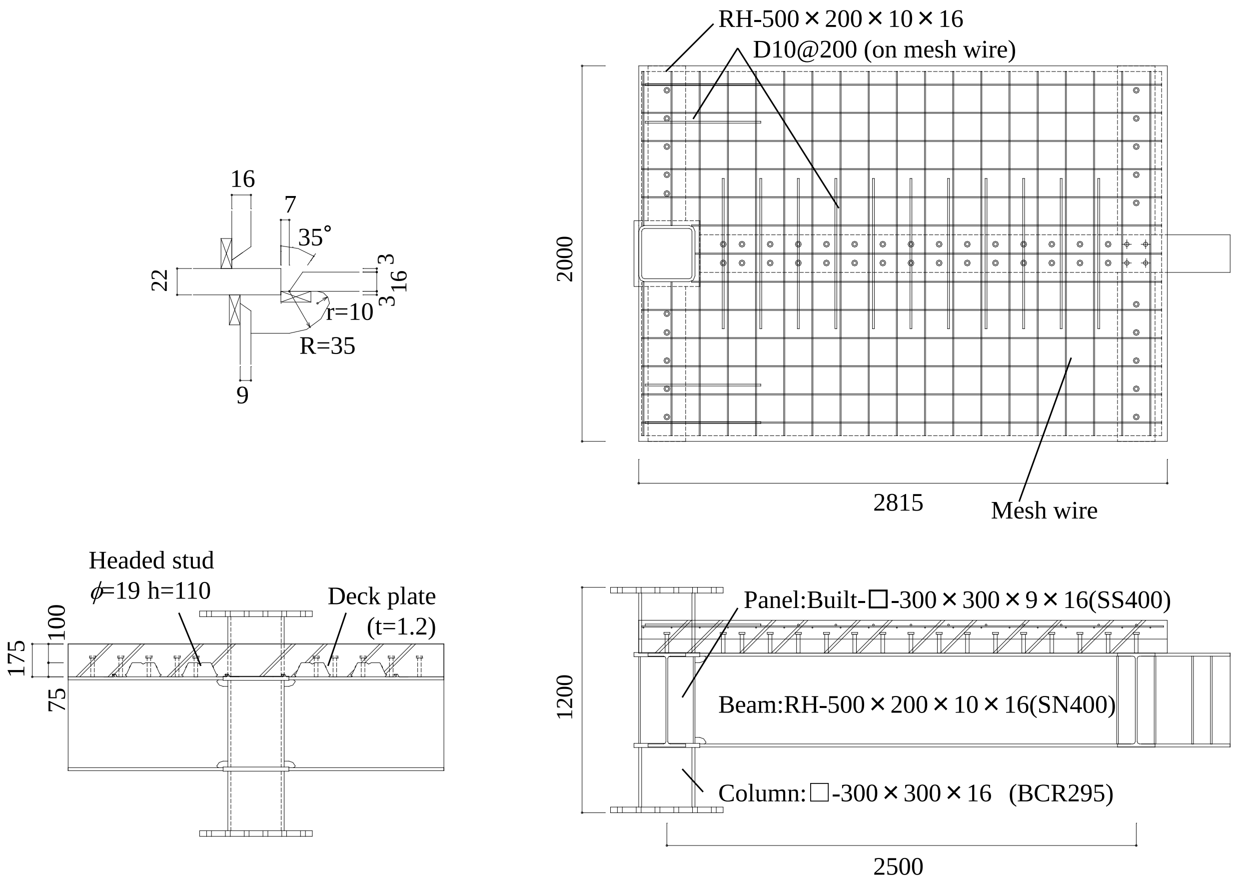


Fig. 1 – Detail of specimen

The width of concrete slab of the specimen is 2,000mm that is twice of effective width of composite beam according to the design recommendation of various composite structures. The concrete slab is used deck plate which has 75mm in height and the deck groove is orthogonal with the direction of beam axis. Headed studs as shear connecter are set up in 150mm intervals and two rows used by 19mm in diameter of shaft part, 110mm in height. It is because that this concrete slab keep fully composite beam.

There are some parameters affected to connection coefficient of bare steel beam; beam size, thickness of column skin plate, material characteristic, welding detail, and so on. In previous studies conducted experiment such as Okada at el, Ishii at el, Tanaka at el, beam size is a critical parameter to composite beam strength because neutral axis is move upward. However, these studies mainly focused on effect of beam height or beam whole size, they didn't focus on beam width itself. The strength of composite beam is affected width of bare steel beam and slab width. The effect of width of bare steel beam in composite beam should be clear to grasp strength in composite beam.

On the other hand, almost specimen of previous studies has thin column skin plate and out-of-plane deformation of column was not occurred. In bare steel beam, Tateyama at el. shows out-of-plane deformation is critical element for maximum strength, however, behavior of composite beam with large out-of-plane deformation is few in previous studies, thus, relation between strength and moment transmission efficiency in composite beam is unclear. Therefore, the parameters of the test are thickness of column skin plate and beam width. In this test, A-16-200 and A-16-150 are set with thin skin plate based on previous studies, and A-09-200 and A-09-150 are set with thick skin plate considering moment transmission efficiency. And there are two specimens of 200mm in beam width and there are two specimens of 150mm in width by cutting flange edge.

Table 2 shows results of coupon test of steel and concrete. Full plastic moment ${}_sM_{pt}$, elastic rotation angle corresponding to full plastic moment ${}_s\theta_{pt}$, the maximum bending strength of bare steel beam-to-column connection ${}_jM_{un}$, ${}_jM_{un}$, and connection coefficient of bare steel beam ${}_s\alpha_n$, ${}_s\alpha_t$ add in Table 1 (here, n shows calculation by official thickness and standard strength (F) of steel, and t shows calculation by measured thickness and results of coupon test) Connection coefficient of bare steel under beam fracture in SN400 grade should keep more than 1.3 in seismic design in Japan. Connection coefficient calculated by official thickness and standard strength ${}_s\alpha_n$ is satisfied, however, connection coefficient calculated by measured thickness and results of coupon test ${}_s\alpha_t$ is about 1.0. Thus, ${}_s\alpha_t$ is not satisfied the value of design recommendation.

Table 2 – Results of coupon test

Member		Average thickness [mm]	σ_y [N/mm^2]	σ_u [N/mm^2]	yield ratio [%]	elogation [%]
Beam flange	A-09-200, 150	15.9	295	425	69.5	32.0
	A-16-200, 150	16.1	272	451	60.2	28.3
Beam web	A-09-200, 150	9.7	360	460	78.3	24.0
	A-16-200, 150	10.1	322	475	67.7	28.8
Column skin plate	A-09-200, 150	9.4	275	421	65.3	31.9
	A-16-200, 150	16.2	407	468	86.8	22.9
Concrete	A-09-200, 150	f_c = 33.8 [N/mm^2]				
	A-16-200	f_c = 20.0 [N/mm^2]				
	A-16-150	f_c = 21.9 [N/mm^2]				

2.2 Test procedure

Test setup shows fig.2. Both column edge of specimen is supported by pin jig on the rigid frame. Load is added vertically by connecting between free end of beam and parallel actuators which have 300kN in maximum strength and 100mm in stroke. The free end of beam is hold between unilateral constraints. Load is controlled by increasing amplitude of beam rotation angle such as 2 ${}_s\theta_{pt}$, 4 ${}_s\theta_{pt}$, 6 ${}_s\theta_{pt}$ after one cycle under elastic area is conducted.

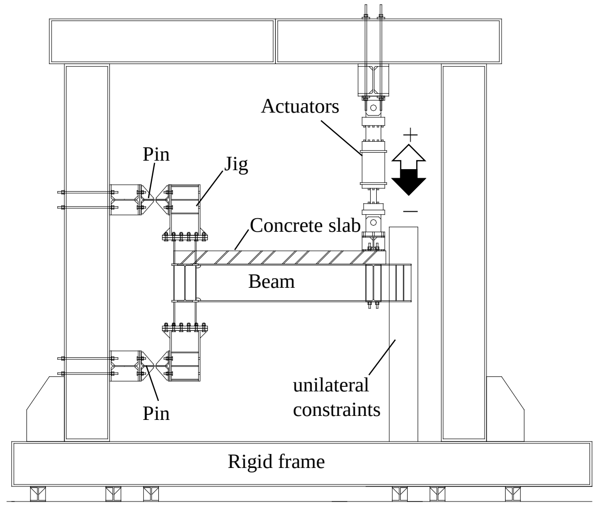


Fig. 2 – Setup

In order to get rotation angle of beam θ, three displacements are measured; vertical displacement of loading point δ, vertical displacement of column face ${}_{c}v$, rotation angle of column face ${}_{f}\theta$. δ, is measured by potentiometer-type displacement transducer and ${}_{c}v$ is measured by spring-type displacement transducer. ${}_{f}\theta$ is obtained by upper and lower horizontal displacement in column face measured by spring-type displacement transducer. Strain gauge glued two section of beam; section-B (70mm from column face) which is section close to fracture near scallop base and section-D (270mm from column face) which is section little far away from column face.

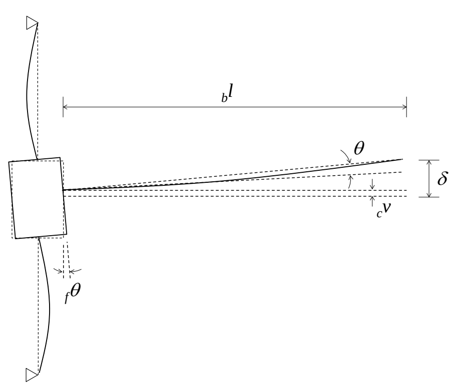


Fig. 3 – Measure of rotation angle

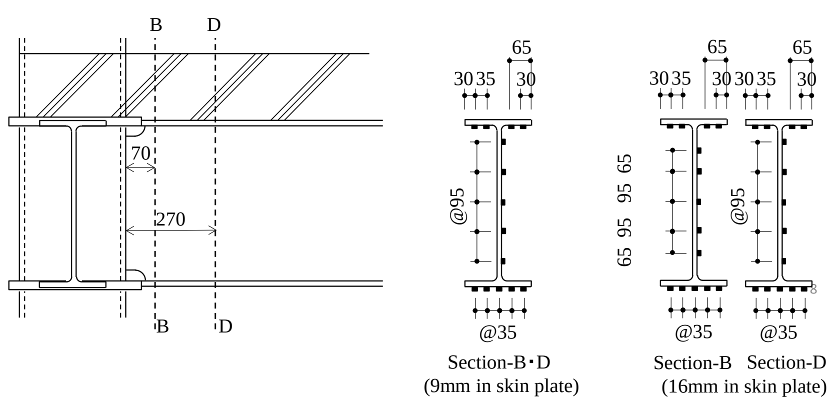


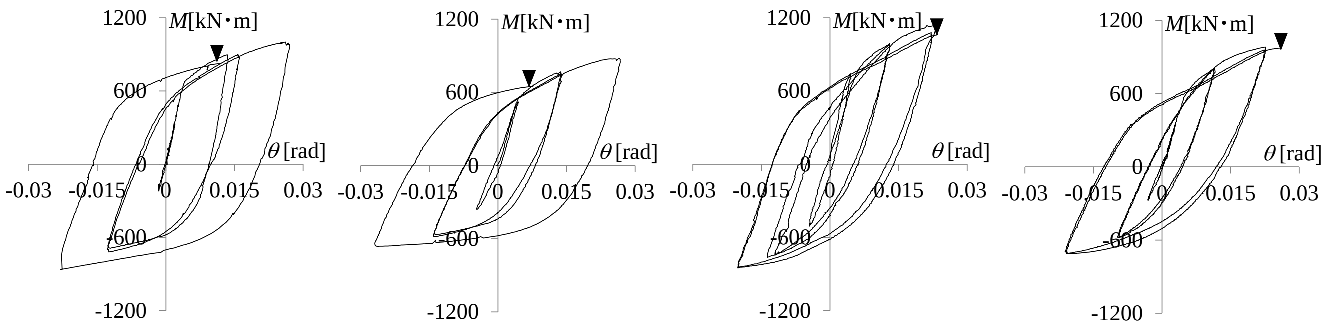
Fig. 4 – Location of strain gauge

2.3 Test results

Fig. 5 shows relation between bending moment M and rotation angle θ in beam edge. M is bending moment of beam edge at column face by multiplying shear force of beam Q by moment arm (2,350mm). The negative hysteresis of A-16-200 and A-16-150 are drown under stroke limit of actuators. Beam fracture is occurred by ductile crake beginning from scallop base of the lower flange under positive bending. Black triangle in Fig.5 shows the point occurring fracture.

Table 3 shows results of each specimen. Elastic stiffness obtained this test ${}_{c}K_{exp}$ which is defined as unloading stiffness at the first cycle is 1.36-1.85 times than elastic stiffness of bare steel beam ${}_{s}K_{t\text{-}cal}$ under positive bending. Here, the ratio of ${}_{s}K_{t\text{-}cal}$ which beam width is 200mm to ${}_{s}K_{t\text{-}cal}$ which beam width is 150mm (K_{200}/K_{150}) is considered under positive bending. In case of bare steel beam, K_{200}/K_{150} is 0.82, in case of composite beam with 9mm in ski plate, K_{200}/K_{150} is 0.72, and in case of composite beam with 16mm in ski plate, K_{200}/K_{150} is 0.60.

Therefore, both beam width and thickness of column skin plate is affected to elastic stiffness. The ratio of maximum strengths of composite beam under positive bending to the maximum strength of bare steel beam ($M_{max}/_jM_{ut}$) is 1.41-1.62. $M_{max}/_jM_{ut}$ of 150mm in beam width is 0.15 smaller than $M_{max}/_jM_{ut}$ of 200mm in beam width. And no difference between $M_{max}/_jM_{ut}$ of 9mm in skin plate and $M_{max}/_jM_{ut}$ of 16mm in skin plate.



A-09-200 A-09-150 A-16-200 A-16-150

Fig. 5 – M-θ relationship

Table 3 – Results of test

Specimen		$_sK_{t\text{-}cal}$ [kN・m/rad]	$_cK_{exp}$ [kN・m/rad]	$\frac{_cK_{exp}}{_sK_{t\text{-}cal}}$	M_{max} [kN・m]	$\frac{M_{max}}{_jM_{ut}}$	θ_{max} [rad]
A-09-200	+	1.04×10^5	1.76×10^5	1.68	1002	1.42	0.0262
	—		1.32×10^5	1.27	862	1.22	0.0230
A-09-150	+	8.53×10^4	1.26×10^5	1.48	877	1.62	0.0265
	—		8.15×10^4	0.96	663	1.22	0.0261
A-16-200	+	1.07×10^5	1.97×10^5	1.85	1137	1.41	0.0236
	—		1.18×10^5	1.11	851	1.06	0.0201
A-16-150	+	8.70×10^4	1.18×10^5	1.36	982	1.56	0.0257
	—		9.58×10^4	1.10	712	1.13	0.0208

2.4 Database of composite beam

Table 4 shows database of composite beam based on previous studies and this test. Data in previous studies means the results concluding not only M-θ relationship but also strain of beam based on cyclic loading test of fully composite beam which occurred ductile fracture. Here, Ex01 means A-09-200, Ex02 means A-09-150, Ex03 means A-16-200, and Ex04 means A-16-150. All specimen is represented middle and low rise building, thus, there are 400mm-600mm in beam height and 300mm-450mm in column width with through diaphragm.

The detail of each item is described in following section.

Table 4 – Database of composite beam

No.	Beam									scallop	Concrete slab				x_n	$_sm_t$	$_cM_{pt-prop}$	$_cM_{ut-cal}$	$_s\alpha_t$	$_c\alpha_t$	$\frac{_c\alpha_t}{_s\alpha_t}$	Ref.
	Material	H_b [mm]	B_b [mm]	t_{bw} [mm]	t_{bf} [mm]	σ_{ybf-t} [N/mm^2]	σ_{ybw-t} [N/mm^2]	σ_{ubf-t} [N/mm^2]	σ_{ubw-t} [N/mm^2]		W [mm]	t_s [mm]	h_r [mm]	f_c [N/mm^2]			[kN・m]	[kN・m]				
	Column									S_r	Stud				Plastic neutral axis		$_sM_{pt}$	$_cM_{u-exp}$				
	Material		B_c [mm]	t_{cf} [mm]	t_{cs} [mm]	σ_{yc-t} [N/mm^2]				[mm]	ϕ [mm]	Number		L [mm]			[kN・m]	[kN・m]				
D01	SM 490	612	202	13	23	386	444	535	551	Old	2500	200	0	26.0	566	0.78	2108	2328	1.15	1.10	0.96	10)
	SM 490		450	22	32	376				35	22	26		3275	Flange-web		1519	2500				
D02	SM 490	596	199	10	15	414	445	556	565	Old	2500	200	0	26.0	566	0.89	1530	1774	1.12	1.16	1.04	
	SM 490		450	22	32	376				35	22	26		3275	Flange-web		1074	1860				
D03	SM 490	612	202	13	23	386	444	535	551	Old	2500	140	0	26.0	566	0.78	1942	2152	1.15	1.11	0.96	
	SM 490		450	22	32	376				35	22	26		3275	Flange-web		1519	2250				
D04	SM 490	612	202	13	23	386	444	535	551	Old	2500	200	0	26.0	566	0.78	2108	2328	1.15	1.10	0.96	
	SM 490		450	22	32	376				35	22	26		3275	Flange-web		1519	2440				
D05	SM 490	612	202	13	23	351	353	522	539	Non	2500	200	0	26.0	566	0.87	1853	2342	1.32	1.26	0.96	11)
	SM 490		450	22	32	376				0	22	26		3275	Flange-web		1328	2650				
D06	SN 400	400	200	7.6	13.1	326	373	454	482	New	2000	100	75	25.1	374	0.56	615	675	1.20	1.10	0.92	12)
	BCR 295		300	9.1	9.1	330				35	19	22		2350	Flange-web		430	681				
Ex01	SN 400	500	200	9.7	15.9	295	359	425	460	New	2000	100	75	33.8	468	0.37	923	905	1.09	0.98	0.90	
	SS 400		300	9.4	16	269				35	19	30		2350	Flange-web		646	1002				
Ex02	SN 400	500	150	9.7	15.9	295	359	425	460	New	2000	100	75	33.8	468	0.37	809	743	1.02	0.92	0.90	
	SS 400		300	9.4	16	269				35	19	30		2350	Flange-web		532	877				
Ex03	SN 400	500	200	10.1	16.1	269	320	451	475	New	2000	100	75	20.0	300	0.80	800	977	1.34	1.22	0.91	
	BCR 295		300	16.2	16.2	407				35	19	30		2350	Web		602	1137				
Ex04	SN 400	500	150	10.1	16.1	269	320	451	475	New	2000	100	75	21.9	330	0.80	705	846	1.27	1.20	0.95	
	BCR 295		300	16.2	16.2	407				35	19	30		2350	Web		496	982				

About prefix subscript of symbol, s means bare steel beam, c means composite beam. About surfix subscript, b means beam, bf means beam flange, bw means beam web, c means column (except for f_c), t means caluculution by results of coupon test

H_b : Beam height B_b : Beam width t_{bf} : Thicknees of beam flange t_{bw} : Thickness of beam web B_c : Column width

t_{cf} : Thickness of column skin plate t_{cs} : Thickness of panel zone jointing orthogonal beam σ_{ybf-t} : Yeild strength of beam flange

σ_{ybw-t} : Yeild strength of beam web σ_{ubf-t} : Tensional strength of beam flange σ_{ubw-t} : Tensional strength of beam web

σ_{yc-t} : Yeild strength of column S_r : Scallop size W : Width of concrete slab t_s : Height of slab constant thickness

S_r : Scallop size W : Width of concrete slab t_s : Height of slab constant thickness h_r : Height of deck plate

f_c : Pressure test strength of concrete L : Bending span x_n : Distance from beam lower flange to plastic neutral axis

$_sm_t$: Dimensionless bending strength of bare steel beam web connection $_cM_{pt-prop}$: Plastic strength of composite beam

$_sM_{pt}$: Full plastic moment of bare steel beam $_cM_{ut-cal}$: Calcuratioin value of maximum bending strength of composite beam cinnection

$_cM_{u-exp}$: Test result of the maximum strength of composite beam $_s\alpha_t$: connection coefficient of bare steel beam

$_c\alpha_t$: connection coefficient of composite beam

3. Plastic strength of composite beam

Full plastic moment of composite beam under positive bending is shown in design recommendation of composite structure, however, this evaluation formula is overestimated as a standard strength of composite beam in plastic design. It is because that plastic neutral axis is near upper flange, thus, upper half of steel beam is not bear stress. We have already shown calculation method of plastic strength as a strength when fully composite beam have plastic hinge based on previous cyclic loading test. And we have also reported that our plastic strength have better correspondence to the beginning to plastic strength at moment and rotation angle relationship then full plastic moment under positive bending. Here, it is considered that this plastic strength method is able to evaluate to each specimen in the database.

$_cM_{pt-prop}$ in Table 4 means calculated value of plastic strength based on stress block balance in Fig.6. The value is obtained by using average thickness and results of coupon test in each specimen. Fig.7 shows moment and curvature relationship at a section about 300mm from column face. Here, moment is calculated by multiplying shear force of beam by distance from loading point to section gluing gauge. Curvature is a straight line connecting average strain of upper flange and lower flange at the section measuring strain. All specimen in Fig.7 shows a good correspondence between $_cM_{pt-prop}$ and positive moment when curvature suddenly increased by progress of plasticizing. Therefore, plastic strength is valid for the strength of fully composite beam when plastic hinge make under positive bending.

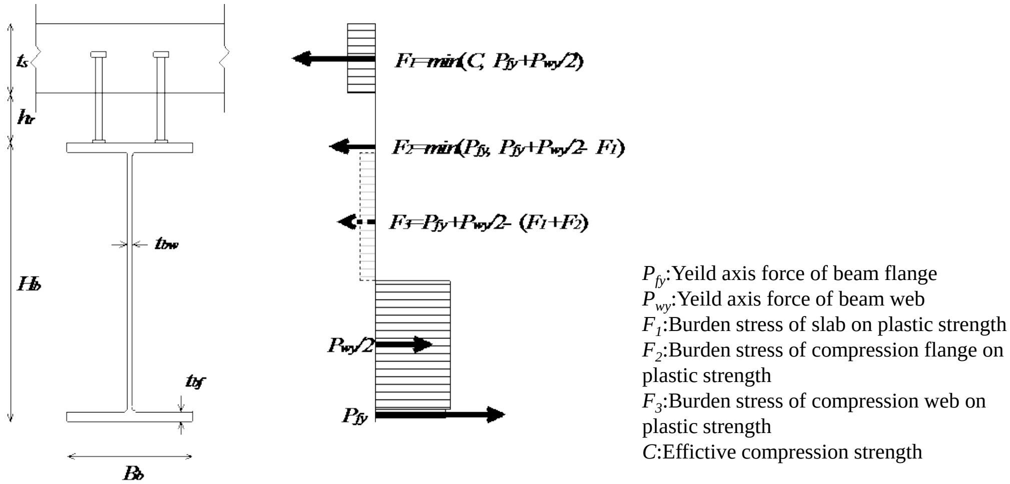


Fig. 6 – Stress Block when plastic strength

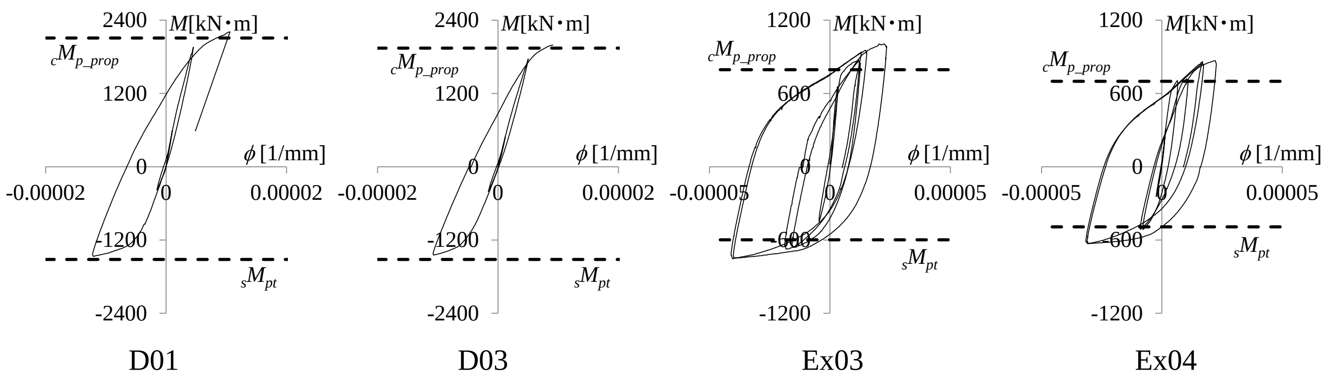


Fig. 7 – Moment and curvature relationships of the database (at section about 300mm from column face)

4. The maximum bending strength of composite beam

The maximum bending strength have been considered in previous studies such as Tateyama et al, Okada et al, Ishii et al, and Tanaka et al. By these studies, evaluation formula is shown reflecting rise of plastic neutral axis by composite effect of concrete slab and effect on out-of-plane of column skin plate. Especially, the formula by Tanaka et al is continuous from design formula of bare steel beam used generally in present structural design to composite beam. In this study, the maximum bending strength is used by correcting the evaluation formula by Tanaka et al to be able to calculate in case of composite beam with scallop. Based on the condition of collapse mechanism by moving plastic neutral axis, the minimum strength is selected as the maximum bending strength ${}_cM_{ut\text{-}cal}$ from each collapse strength of mechanism.

${}_cM_{ut\text{-}cal}$ in Table 4 means calculated value of the maximum bending strength obtained by using average thickness and results of coupon test in each specimen of database. The distance between lower flange and plastic neutral axis x_n and location of plastic neutral axis are also shown in Table 4. A comparison between ${}_cM_{ut\text{-}cal}$ and the maximum strength under positive bending obtained test result ${}_cM_{u\text{-}exp}$ is shown in Fig. 8. Although ${}_cM_{ut\text{-}cal}$ is slightly smaller than ${}_cM_{u\text{-}exp}$, both strength have a good correspondence. Fig. 9 shows a comparison between dimensionless bending strength of bare steel beam web connection which means moment transmission efficiency of web ${}_sm_t$ and ${}_cM_{ut\text{-}cal}/{}_cM_{u\text{-}exp}$. The value of ${}_cM_{ut\text{-}cal}/{}_cM_{u\text{-}exp}$ keeps 0.9 in spite of value of ${}_sm_t$. Therefore, calculation formula of the maximum bending strength based on study by Tanaka et al is verified correspondence to test result even if moment transmission efficiency of web is low.

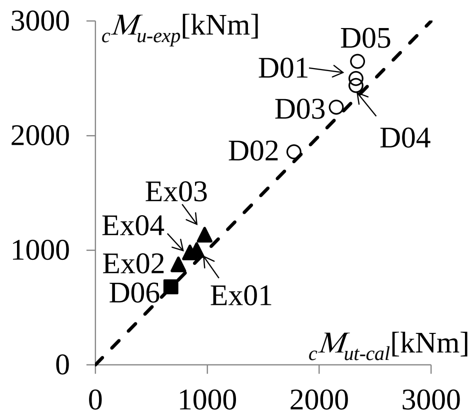


Fig. 8 – Comparison between $_cM_{ut\text{-}cal}$ and $_cM_{u\text{-}exp}$

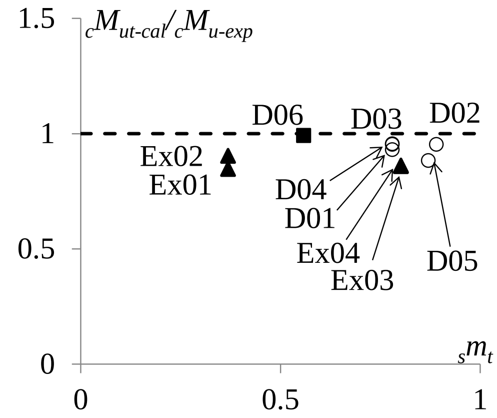


Fig. 9 – Comparison between $_sm_t$ and $_cM_{ut\text{-}cal}/_cM_{u\text{-}exp}$

5. Connection coefficient of composite beam

5.1 Comparison between connection coefficient of composite beam and connection coefficient of bare steel beam

From above chapters, plastic strength and the maximum strength of composite beam are considered. Connection coefficient of fully composite beam is defined as ratio of the maximum strength to plastic strength $_c\alpha$ corresponding to connection coefficient of bare steel beam α. $_c\alpha$ is shown in Eq. (2).

$$_c\alpha = {_cM_{ut\text{-}cal}} / {_cM_{pt\text{-}prop}} \tag{2}$$

Fig.10 shows comparison between connection coefficient of bare steel beam in specimen of database $_s\alpha_t$ and connection coefficient of fully composite beam $_c\alpha_t$ calculated by average thickness and results of coupon test. Generally, $_c\alpha_t$ is slightly smaller than $_s\alpha_t$, especially, $_c\alpha_t$ of Ex01 and Ex02 are significantly less than other specimen. It is because that $_s\alpha_t$ of Ex01 and Ex02 are smaller than other specimen. Thus, connection coefficient of composite beam is small in case that moment transmission efficiency of web is low.

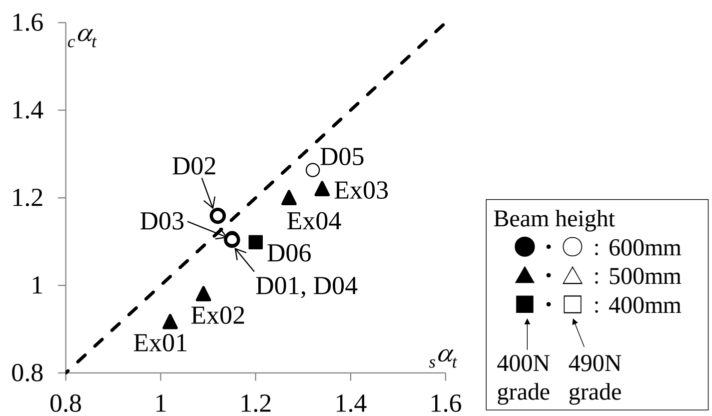


Fig. 10 – Comparison between $_c\alpha_t$ and $_s\alpha_t$

5.2 Consideration of effective elements on connection coefficient of composite beam

In order to understand the condition that connection coefficient of composite beam is smaller than connection coefficient of bare steel beam, preliminary parametric study about effective elements of connection coefficient is conducted. The element of this consideration are combination between beam section and column section, and combination of material stress. Here, column is assumed BCR295, beam is assumed SN400B and SN490B. Combination of beam and column is shown as Table 5 which determine as members used in middle and low-rise buildings. However, the combinations that panel zone or column are significantly weak are removed from consideration objects. In Table 5, ○ means consideration objects in case of SN400B, ◎ means consideration objects in case of SN490B.

Combination of material stress is set two; both column and beam are used standard strengths of each material and used average yield and tension strengths based on previous statistical survey on material stress. In this parametric study, concrete strength is 21N/mm^2, concrete slab is assumed composite deck slab such as chapter 2. As the parametric study, it shows the comparison between connection coefficient of bare steel beam ${}_s\alpha$ and connection coefficient of composite beam ${}_c\alpha$, and it shows the relationship between the ratio of connection coefficient of composite beam to connection coefficient of bare steel beam ${}_c\alpha/{}_s\alpha$ and width-to-thickness ratio of column. Although the plot shapes mean the difference of beam height, the trend of study results are similar by beam height in this consideration. As shown in Fig.11 that means a case of using standard strength as material stress, majorly of connection coefficient of bare steel beam ${}_s\alpha_n$ on SN400B is more than 1.3 and majorly of ${}_s\alpha_n$ on SN490B is more than 1.2. On the other hand, connection coefficient of composite beam ${}_c\alpha_n$ is smaller than ${}_s\alpha_n$ on both SN400B and SN490B. Especially, the difference between ${}_c\alpha_n$ and ${}_s\alpha_n$ is significantly in case that ${}_s\alpha_n$ have relatively small value. Here, the ratio of connection coefficient connection coefficient ${}_c\alpha_n/{}_s\alpha_n$ and width-to-thickness ratio of column B_c/t_{cf} relationship shows negative correlation and the value of almost all plot is under 1.0 regardless of width-to-thickness ratio. A gray break line in Fig.11 and 12 means that the value of having enough plastic deformation capacity in width-to-thickness ratio of column in Japanese design recommendation. In Fig.11, ${}_c\alpha/{}_s\alpha$ on SN400B in case that B_c/t_{cf} is the above value is about 0.9.

As shown in Fig.12 that means a case of using average yield and tension strengths based on previous statistical survey, majorly of connection coefficient of bare steel beam ${}_s\alpha_s$ on SN400B is 0.2 smaller and majorly of ${}_s\alpha_s$ on SN490B is 0.15 smaller than in case of using standard strength as material stress. Also, connection coefficient of composite beam ${}_c\alpha_s$ is smaller than ${}_s\alpha_s$, however, the difference between ${}_c\alpha_n$ and ${}_s\alpha_n$ is relatively small than in case of using standard strength as material stress. ${}_c\alpha_n/{}_s\alpha_s$ and B_c/t_{cf} relationship of Fig.12 also shows negative correlation. The majority value of ${}_c\alpha_n/{}_s\alpha_s$ is greater than the value of ${}_c\alpha_n/{}_s\alpha_n$. The half of plots of ${}_c\alpha_n/{}_s\alpha_s$ is over 1.0 in case that B_c/t_{cf} is less than 20. From above consideration, the difference between ${}_c\alpha$ and ${}_s\alpha$ calculating by average yield and tension strengths based on previous statistical survey is smaller than the values calculating by standard strength as material stress. Moreover, ${}_c\alpha$ is often greater than ${}_s\alpha$ when width-to-thickness of column is small. Therefore, connection coefficient of composite beam is affected by material strength and width-to-thickness of column. This consideration is under constant concrete strength and thickness, thus, it is necessary that more parametric studies about effect elements of connection coefficient of composite beam.

Table 5 – Combination of column and beam

		Column（upper value：width、lower value：thickness）																											
		250				300				350					400				450				500				550		
		6	9	12	16	9	12	16	19	9	12	16	19	22	12	16	19	22	12	16	19	22	12	16	19	22	16	19	22
beam	H-600×200×11×17										○	◎	◎		○	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
	H-500×200×10×16						○	◎	◎	○	○	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎			
	H-450 ×200×9×14					○	○	◎	◎	○	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎							
	H-400 ×200×8×13			○	◎	○	◎	◎	◎	○	◎	◎	◎	◎	◎	◎	◎	◎											

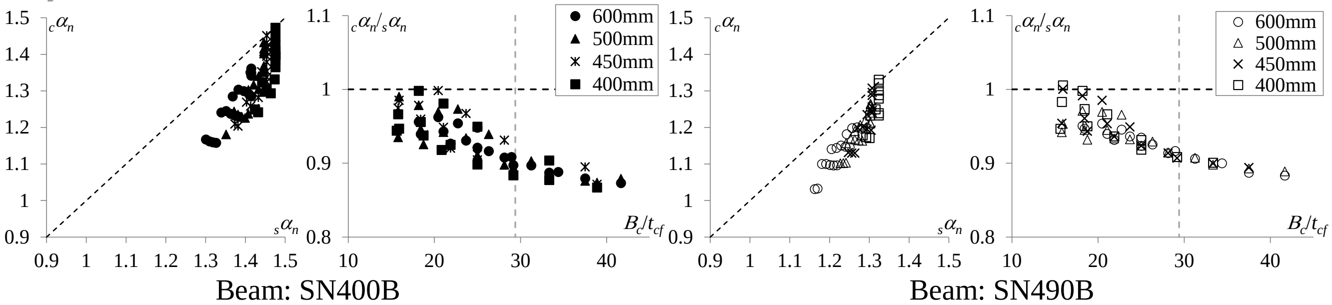


Fig. 11 – Results of parametric study in case of using standard strength as material stress

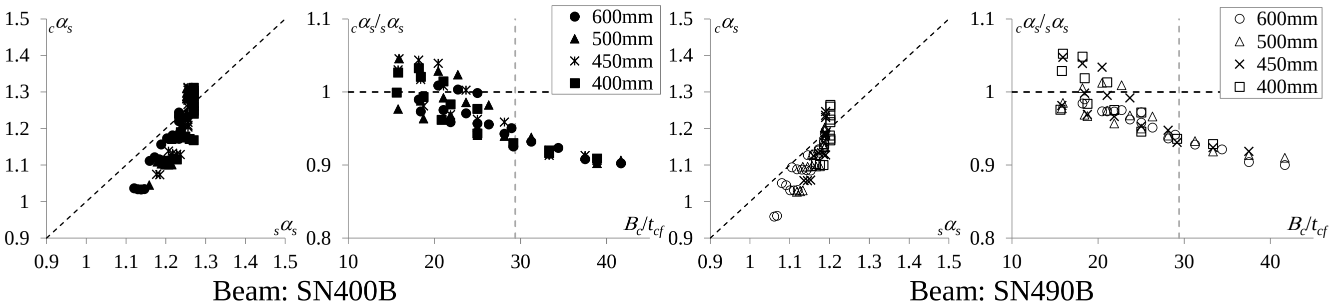


Fig. 12 – Results of parametric study in case of average strengths based on previous statistical survey

6. Conclusion

In the first step of this study, a series of cyclic loading test of composite beam generally used in middle and low-rise buildings was conducted. By obtained results, characteristics of composite beam till ductile fracture is occurred at beam end was comprehended and elastic stiffness is affected by beam width and moment transmission efficiency of web. The second step of this study was construction of database of cyclic behavior of fully composite beam based on previous studies and the above test. In consideration by database, the plastic strength of composite beam is confirmed as the strength when composite beam section make plastic hinge. And the calculated value of maximum bending strength of composite beam based on previous study is corresponded to the maximum moment obtained test results. Therefore, connection coefficient of composite beam is defined as the ratio the maximum strength to plastic strength under positive bending in this study. Connection coefficient of composite beam is slightly small than connection coefficient of bare steel beam, especially, it trend is significantly in case that moment transmission efficiency of web is small.

In order to consider the condition that connection coefficient of composite beam is smaller than connection coefficient of bare steel beam, parametric study about combination of material strength and combination between beam section and column section is conducted. By this consideration, the difference between connection coefficient of composite beam and connection coefficient of bare steel beam calculating by average yield and tension strengths based on previous statistical survey is smaller than the values calculating by standard strength as material stress. Some connection coefficient of composite beam is greater than connection coefficient of bare steel beam when width-to-thickness of column is small.

This paper shows the calculation method of connection coefficient of composite beam and the basic trend of connection coefficient of composite beam. However, in order to determine recommended value of connection coefficient of composite beam in seismic design, it is necessary that more consideration not only other parameters but also a correspondence to plastic deformation capacity. In future work, parametric analytical study of composite beam will be conducted to clear the relationship between effective elements of connection coefficient of composite beam and plastic deformation capacity.

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