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EVALUATION OF DEFORMABILITY OF R/C BEAM WITH AN OPENING AT BEAM-END REGION

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SUMMARY

To establish the opening reinforcement method of the reinforced concrete beam where the opening exists in the beam-end region, loading tests were carried out. The beam adopted a reinforcing method that combined diamond opening reinforcement, stirrup beside opening, and U-shaped diagonal reinforcement. Experimental factors were opening diameter, opening position, amount of the opening reinforcement, concrete strength and main reinforcement strength. The relationship of the experimental factors and maximum strength, deformation capacity was examined. This paper discusses the relationships of deformation capacity and reinforcement coefficient of opening, and proposes an equation to evaluate the lower bound of the deformation capacity.

INTRODUCTION

Openings for ventilation equipment pipes are installed in beams of the reinforced concrete (R/C) condominium building. In this case, it is desirable to install the opening at beam-end region to secure added open space. But it is known that inappropriate reinforcement for the opening causes brittle fracture in an earthquake, when an opening is established at beam-end region. Therefore, the opening is generally installed in the region that separates over the beam depth from the beam-end, and the pipe is passed outside as shown in Figure 1(a). The installation of a large drop ceiling to conceal the pipe is needed constricting room space.

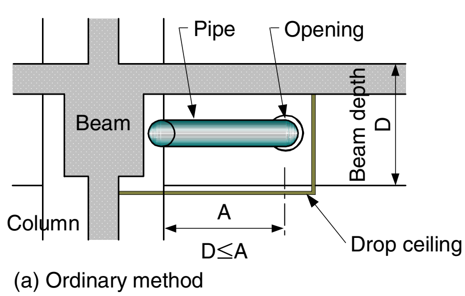

Fig. 1 Situation of ventilation equipment pipe and opening

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To solve this, loading tests of RC beams were carried out to establish the opening reinforcement method as shown in Figure 2 which was able to secure necessary strength and ductility on the structural design even if the opening was installed at the beam-end region as shown in Figure 1(b). In this paper, the relationship of experimental factors and maximum strength, deformation capacity is examined, and it proposes the evaluation equation of the lower bound of the deformation capacity that considers the effect of the reinforcement for opening at beam-end region.

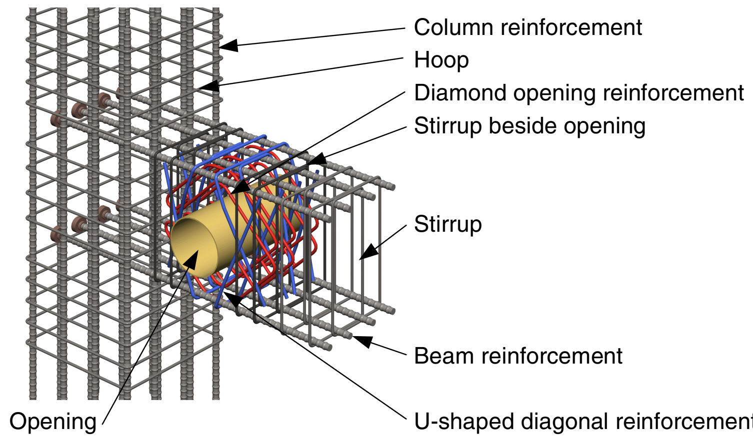


Fig. 2 Opening reinforcement method

LOADING TEST PLAN

Specimens

Table 1 shows the parameters of the test specimens. Figure 3 shows the details of specimens. Specimens consisted of the F_c24 series and F_c48 series. Concrete specified design strength of F_c24 series was 24N/mm^2, and that of F_c48 series was 48N/mm^2. Total number of specimens was 20, and scale size was about 1/2. In 18 of 20 specimens, openings that had a diameter (H) from D/4 to D/3 were installed in positions of from D/3 to D/2 from beam-end (D: beam depth), and opening center position was D/24 in eccentricity in the direction of the beam depth from the center of the beam in 2 of the 18 specimens. The remaining two were conventional RC beam specimens without openings for a structural performance comparison. Shear reinforcement for openings consisted of ready-made diamond opening reinforcement and stirrup in the area of reinforcement for opening (hereafter, stirrup beside opening). For prevention of buckling of the main reinforcing bars of beams and for securing ductility and shear strength of beams, in the upper and lower parts of the opening U-shaped diagonal reinforcement was arranged in diagonal direction. However, U-shaped diagonal reinforcement was not arranged in one of the beam specimens with openings. In each specimen, it was planned that the calculated value of shear strength in the reinforcement area for opening as calculated by the modified Hirosawa's equation would exceed the calculated value of shear force at beam-end by flexural ultimate strength equation of Architectural Institute of Japan (hereafter A.I.J.) (A.I.J.[1]). The main experimental factors were opening diameter, opening position, amount of the diamond opening reinforcement, amount of the stirrup beside opening, and amount of the U-shaped diagonal reinforcement. These reinforcement ratios obtained by equation (1) ~(3) are shown in table 1. In these tests, the bond length of U-shaped diagonal reinforcement was extended from the opening center to 15d_b (d_b: reinforcing bar diameter), because bond performance of the U-shaped diagonal reinforcement was secured by referring to past experimental results (Arakawa [2]).

Table 1 Parameter of test specimens

Series	Specimen	F_c (N/mm^2)	Beam Arrange.	Beam p_t (%)	Opening*1 Dia.	Opening*1 Trans. Dir.	Opening*1 Verti. Dir.	Stirrup beside Opening Arrange.*2	Stirrup beside Opening p_v (%)	Diamond Opening Reinforcement Arrange.*3	Diamond Opening Reinforcement p_d (%)	U-shaped Diagonal Reinforcement Arrange.*4	U-shaped Diagonal Reinforcement p_b (%)
(1)	L6-0	24	6-D19 [SD345]	1.67	-	-	-	-	-	-	-	-	-
	L6-5-4L-N				D/3	D/3	Center	4-D6×2 [SD295A]	0.53	S6×2	0.37		
F_c24(2)	L6-5-6L									S6×3	0.56	4-D6	0.34
	L6-5-6M				D/3.5								
	L6-5-6S				D/4								
	L6-5-4M				D/3.5					S6×2	0.37		
	L6-5-4S				D/4								
F_c24(3)	L6-5-6SE-B1				D/4	D/3	Center +D/24	4-D6×2 [SD295A]	0.48	S6×3	0.51	6-D6	0.46
	L6-5-6SF					2×D/3	Center		0.53		0.56	4-D6	0.34
	L6-5-6M-B1				D/3.5	D/3						6-D6	0.51
F_c24(4)	L8-12-8M-B2		8-D19 [SD345]	2.28	D/3.5	D/3	Center	4-D10×2 [SD295A]	1.18	S6×4	0.75	4-D10	0.76
	L8-12-8M-B3											4-D8	0.53
	L8-8-12M-B3							4-D6×3 [SD295A]	0.80	S8×4	1.17		
F_c48(1)	H6-0	48	6-D19 [SD490]	1.67	-	-	-	-	-	-	-	-	-
	H6-5-9S-B2				D/4	D/3	Center	4-S6×2 [KSS785]	0.53	S8×3	0.88	4-D10	0.76
	H6-5-12S-B2									S8×4	1.17		
	H6-5-9S-B1									S8×3	0.88	6-D6	0.51
	H6-5-9SE-B2						Center +D/24		0.48		0.79	4-D10	0.69
F_c48(2)	H8-12-8M-B2		8-D19 [SD490]	2.28	D/3.5	D/3	Center	4-S10×2 [KSS785]	1.19	S6×4	0.75	4-D10	0.76
	H8-8-12M-B2							4-S6×3 [KSS785]	0.79	S8×4	1.17		

*1: Opening position of transverse direction means the distance from beam-end to opening center,
D: Beam depth, *2: Half the reinforcement of opening, *3: SD785, *4: SD295A

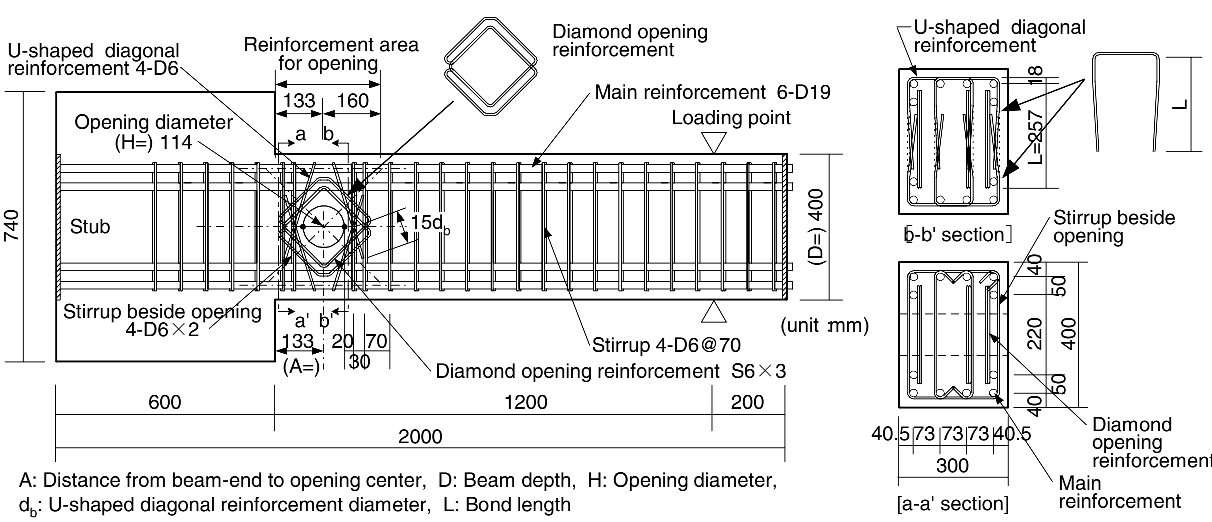


Fig. 3 Specimen shape, dimension, and reinforcement arrangement (Example of L6-5-M6)

Mechanical properties of materials

Table 2 shows the mechanical properties of the concrete, and Table 3 shows the ones of the reinforcing bars.

Table 2 Mechanical properties of concrete

Series	Compressive Strength	Secant Modulus	Tensile Strength
	(N/mm^2)		
F_c24(1)	24.4	24.7	2.42
F_c24(2)	27.1	25.4	2.65
F_c24(3)	28.9	27.3	2.34
F_c24(4)	24.6	23.9	2.34
F_c48(1)	54.6	32.2	3.69
F_c48(2)	35.6	30.0	3.49

Table 3 Mechanical properties of reinforcing bars

Series	Main Re-bar	Stirrup, Stirrup beside Opening				Diamond Opening Reinforcement		U-shaped Diagonal Reinforcement		
	D19	D6	D10	S6	S10	S6	S8	D6	D8	D10
	(N/mm^2)									
F_c24(1)	375 560	381 513	- -	- -	- -	981 1126	- -	- -	- -	- -
F_c24(2)	367 587	329 503	- -	- -	- -	905 1096	- -	329 503	- -	- -
F_c24(3)	371 534	361 528	- -	- -	- -	977 1148	- -	361 528	- -	- -
F_c24(4)	375 552	367 519	362 506	- -	- -	905 1121	938 1110	- -	417 573	362 506
F_c48(1)	538 690	- -	- -	882 1068	- -	- -	993 1162	361 528	- -	364 500
F_c48(2)	538 690	- -	- -	833 1056	915 1083	905 1121	938 1110	- -	- -	362 506

Upper row: Yield strength Lower row: Tensile strength

Loading method

A cantilever-type loading procedure was used. Hydraulic jack was installed at the position of the inflection point of beam, and the loading was applied in a vertical direction to the axis of the beam specimen by displacement control. The loading was reversed in two cycles each at drift angle (R) that was ±(5, 10, 20, 30, 40, 50)×10^{-3} rad, and monotonous loading was applied to R=+100×10^{-3} rad.

TEST RESULTS AND DISCUSSION

Evaluation standard of deformability

In this study, the relationship of the rotation angle (R_p) of the beam-end region's plastic hinge area and the drift angle (R) were considered. R=40×10^{-3} rad was set as a drift angle which was enough to ensure R_p=20×10^{-3} rad used for structural design. This value of drift angle was assumed to be the standard, and the deformability of specimens was evaluated.

Maximum strength (Q_{max}) and deformation capacity (R_u)

Table 4 shows the calculated values and experimental values of maximum strength, and the experimental values of deformation capacity (R_u). Moreover, Figure 4 shows the Q_{max}-Q_{mu} relationships, and Figure 5 shows the Q_{max}/Q_{mu}-Q_{su1}/Q_{mu} relationships. Q_{max} is the experimental value of maximum strength, and Q_{mu} is a calculated value by flexural ultimate strength equation of A.I.J. (Eq. (4)) (A.I.J. [1]). Q_{su1} is a calculated value of the shear strength of reinforcement area for opening by modified Hirosawa's equation (Eq. (5)) (A.I.J. [1]). R_u is a deformation capacity that is defined as drift angle on the envelope curve of the Q-R curve when the load decreases to 80% of maximum strength.

Table 4 Maximum strength and deformation capacity

Series	Specimen	Calculated Value Q_{mu} (kN)	Experimental Value Q_{max} (kN)	Experimental Value R_u ($\times 10^{-3}$ rad)	Exp/Cal Q_{max}/Q_{mu}
F_c24 (1)	L6-0	166	198, -199	53, -49	1.19, -1.20
	L6-5-4L-N		174, -177	21, -20	1.05, -1.07
F_c24 (2)	L6-5-6L	163	196, -199	41, -35	1.20, -1.22
	L6-5-6M		202, -202	43, -42	1.24, -1.24
	L6-5-6S		201, -212	49, -46	1.23, -1.30
	L6-5-4M		194, -200	42, -39	1.19, -1.23
	L6-5-4S		204, -207	42, -45	1.25, -1.27
F_c24 (3)	L6-5-6SE-B1	164	192, -204	44, -45	1.17, -1.24
	L6-5-6SF		193, -186	44, -42	1.18, -1.13
	L6-5-6M-B1		195, -194	46, -49	1.19, -1.18
F_c24 (4)	L8-12-8M-B2	216	261, -270	67, -50	1.21, -1.25
	L8-12-8M-B3		258, -265	60, -47	1.19, -1.23
	L8-8-12M-B3		256, -265	67, -50	1.19, -1.23
F_c48 (1)	H6-0	238	270, -278	100, -50	1.13, -1.17
	H6-5-9S-B2		272, -283	100, -50	1.14, -1.19
	H6-5-12S-B2		278, -283	100, -50	1.17, -1.19
	H6-5-9S-B1		271, -286	75, -50	1.14, -1.20
	H6-5-9SE-B2		274, -284	100, -50	1.15, -1.19
F_c48 (2)	H8-12-8M-B2	310	332, -342	61, -48	1.07, -1.10
	H8-8-12M-B2		334, -342	67, -50	1.08, -1.10

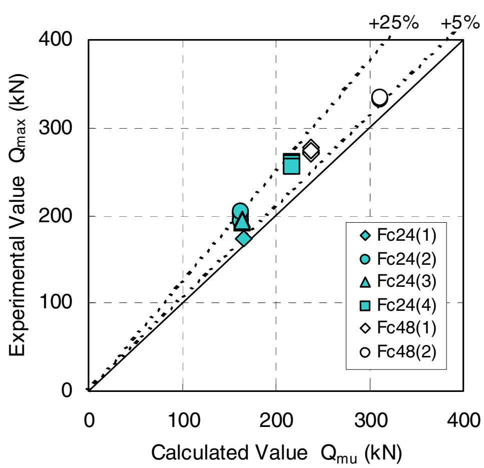


Fig. 4 Q_{max} - Q_{mu} relationship

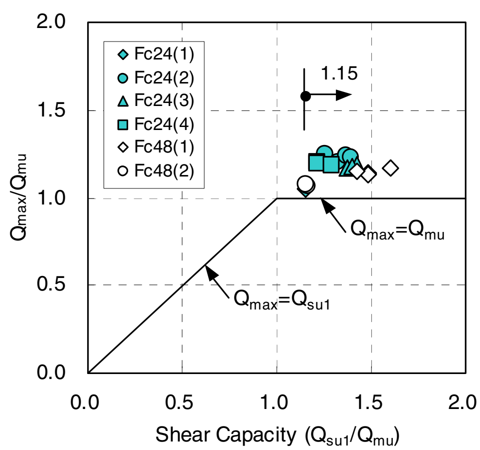


Fig. 5 Q_{max}/Q_{mu} - Q_{su1}/Q_{mu} relationship

Figure 4 indicates that experimental values exceed the calculated values by about 5% to 25% regardless of differences in material strength and differences in the amount of the opening reinforcement including the

U-shaped diagonal reinforcement. Figure 5 indicates that the experimental values of the maximum strength exceed the calculated values by the flexural ultimate strength equation on all specimens when the shear capacity is greater than 1.15. Thus the flexural ultimate strength equation finds the experimental strength to be on the safety side for beam with an opening in the beam-end region.

Relationship of each experimental factor and Q-R curve

Influence of opening diameter

For L6-5-6L, L6-5- 6M, and L6-5-6S of which opening diameter (H) is D/3, D/3.5, and D/4, the Q-R curve is shown in Figure 6(a)~(c), and the envelope curve is shown in Figure 6(d). In the D/3 specimen, the load decreased from R=30×10^{-3} rad. R_u was 38×10^{-3} rad on average in positive and negative direction. On the other hand, R_u was greater than 40×10^{-3} rad in specimens of opening diameters of D/3.5 and D/4. The opening diameter influences the deformation capacity, even if shear capacity (Q_{su1}/Q_{mu}) is about 1.32. It is now understood that securing deformability is difficult in openings of diameter D/3 though secure deformability is obtained in D/3.5 or less.

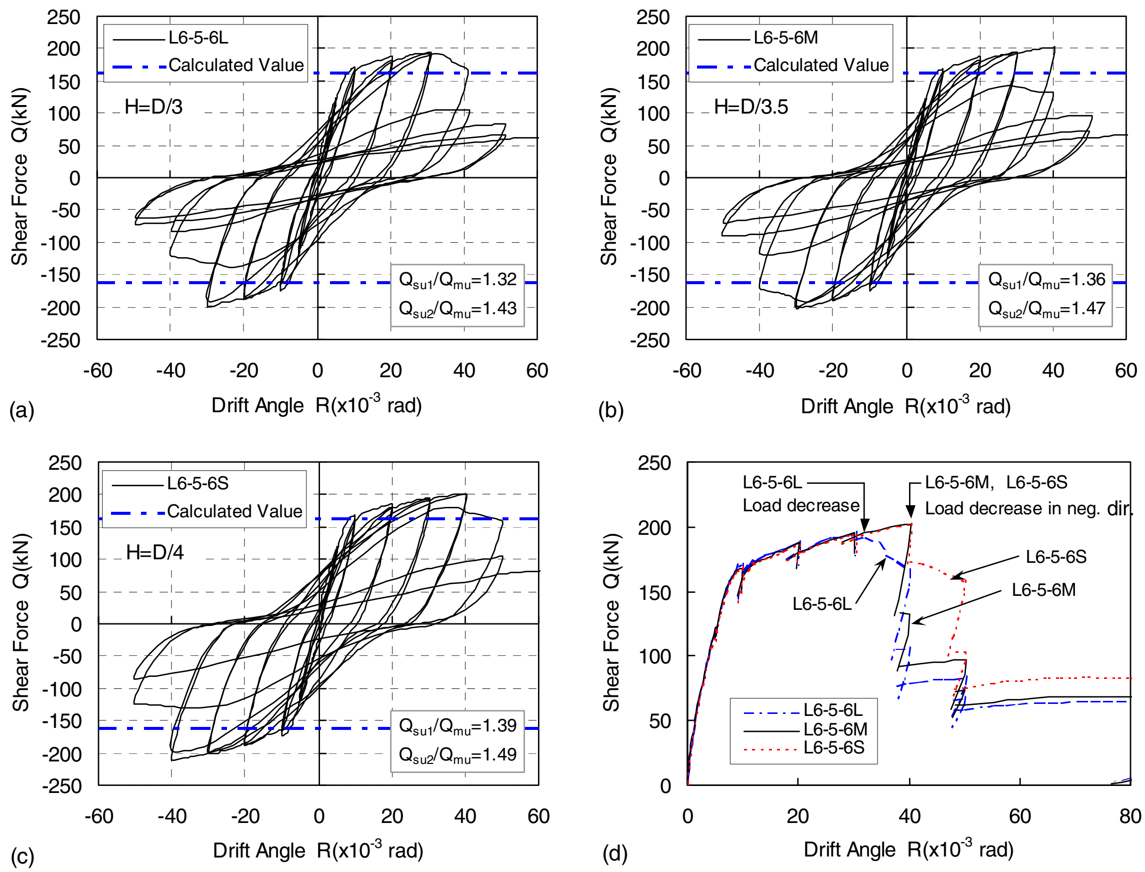


Fig. 6(a)~(d) Shear force - drift angle curve

Influence of eccentricity of opening

Figure 6(e) shows the Q-R curve of L6-5-6SE-B1 of which opening center position is D/24 in eccentricity in the direction of the beam depth, though the opening diameter is the same as L6-5-6S. The eccentricity of D/24 corresponds to D/3 in edge distance length (D_e). The deformation capacity was greater than 40×10^{-3} rad. The experimental value of flexural ultimate strength was greater than the calculated value. As such, distance of eccentricity (e) hardly influences deformability and strength.

Influence of horizontal position of opening

Figure 6(f) shows the Q-R curve of L6-5-6SF in which opening center position is 2D/3 away from the beam-end, though the opening diameter is the same as L6-5-6S. The load decrease of L6-5-6SF was greater than the one of L6-5-6S after the second cycle of $R=40\times10^{-3}$ rad. However, R_u was greater than 40×10^{-3} rad. Moreover, the experimental value of the flexural ultimate strength was greater than the calculated value. Differences in deformability and strength of both specimens were not found.

Comparison of effects of stirrup beside opening and diamond opening reinforcement

Figure 6(g) and (h) show the Q-R curves of H8-12-8M-B2 and H8-8-12M-B2 of which $p_v\sigma_{vy}$ and $p_d\sigma_{dy}$ are reversed, although the amount of opening reinforcement is almost the same with ($p_v\sigma_{vy}+p_d\sigma_{dy}$) of both specimens from 17.0 N/mm^2 to 17.2 N/mm^2. The load decrease in H8-8-12M-B2 of which $p_d\sigma_{dy}$ was greater than the one of H8-12-8M-B2 was small after $R=40\times10^{-3}$ rad cycle. A difference on load decrease was found. As a result, when the opening reinforcement of a constant amount is arranged, it is more effective to increase the amount of diamond opening reinforcement compared to the amount of stirrup beside opening. The method of calculating each reinforcement ratio is shown in Figure 7.

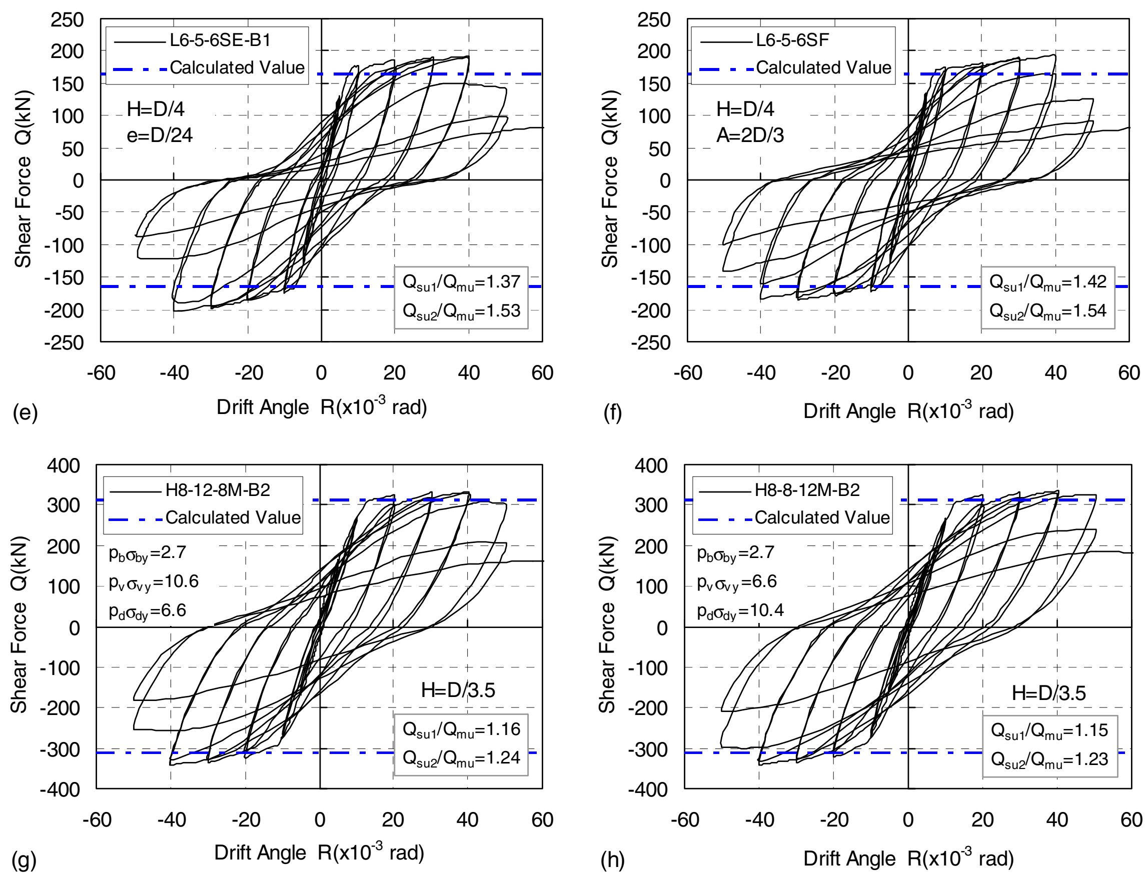
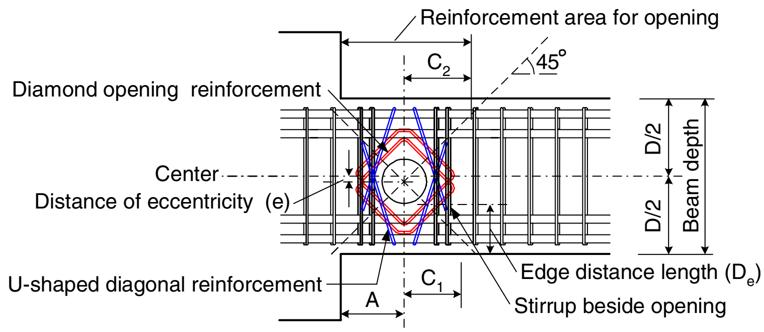


Fig. 6(e)~(h) Shear force - drift angle curve



$$p_v = min\left(\frac{a_{v1}}{b \cdot C_1}, \frac{a_{v2}}{b \cdot C_2}\right) \tag{1}$$

$$p_d = \frac{\sqrt{2} \cdot a_d}{b \cdot C_2} \tag{2}$$

$$p_b = \frac{a_b\left(sin\,\theta_b + cos\,\theta_b\right)}{b \cdot C_2} = \frac{\sqrt{2} \cdot a_b\, sin\left(\theta_b + 45\right)}{b \cdot C_2} \tag{3}$$

p_v: Stirrup beside opening ratio, a_{v1}: Cross sectional area of stirrup beside opening in C_1, a_{v2}: Cross sectional area of stirrup beside opening in C_2, p_d: Diamond opening reinforcement ratio, a_d: Cross sectional area of diamond opening reinforcement in C_2, p_b: U-shaped diagonal reinforcement ratio, a_b: Cross sectional area of a pair of U-shaped diagonal reinforcement in C_2, θ_b: Angle of U-shaped diagonal reinforcement (θ_b=75°), b: Beam width, A: Distance from beam-end to opening center

Fig. 7 Calculation method of reinforcement ratio

Relationship of deformation capacity and amount of each reinforcement

Relationship of deformation capacity and amount of U-shaped diagonal reinforcement

Figure 8 shows the relationship of deformation capacity (R_u) and ratio of the amount of the U-shaped diagonal reinforcement to the shear stress at the flexural ultimate strength ($p_b\sigma_{by}/\tau_{mu0}$). Hereafter, $p_b\sigma_{by}/\tau_{mu0}$ is called U-shaped diagonal reinforcement coefficient. Because U-shaped diagonal reinforcement was arranged like bundled reinforcing bars, the U-shaped diagonal reinforcement of 6-D6 was not able to demonstrate anchor performance and the deformation capacity of the specimen was small. However, the deformation capacity tended to increase in other specimens as the U-shaped diagonal reinforcement coefficient increased. When U-shaped diagonal reinforcement coefficients were greater than 0.83, R_u was greater than 40×10^{-3} rad. Moreover, even if the amount of the opening reinforcement was the same, when a specimen of which the amount of the U-shaped diagonal reinforcement $p_b\sigma_{by}$=0 N/mm^2 was compared to a specimen of $p_b\sigma_{by}$=1.12 N/mm^2, a difference of 20×10^{-3} rad was discovered in R_u. The effect of the U-shaped diagonal reinforcement to the deformation capacity is found.

Relationship of deformation capacity and amount of stirrup beside opening

Figure 9 shows the relationship of R_u and ratio of amount of the stirrup beside opening to the shear stress at the flexural ultimate strength ($p_v\sigma_{vy}/\tau_{mu0}$). Hereafter, $p_v\sigma_{vy}/\tau_{mu0}$ is called a stirrup beside opening coefficient. Though a relationship of R_u and the stirrup beside opening coefficient was not found, in this test, R_u was greater than 40×10^{-3} rad when amount of U-shaped diagonal reinforcement ($p_b\sigma_{by}$) was above 1.12N/mm^2 and stirrup beside opening coefficient was above 1.29.

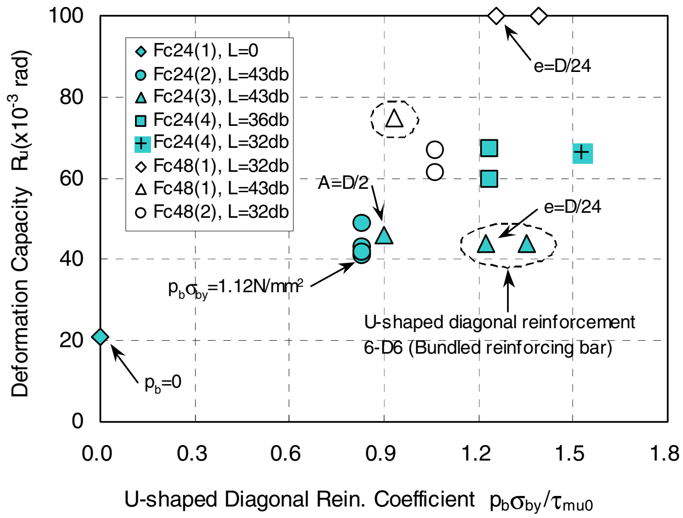


Fig. 8 R_u - $p_b\sigma_{by}/\tau_{mu0}$ relationship

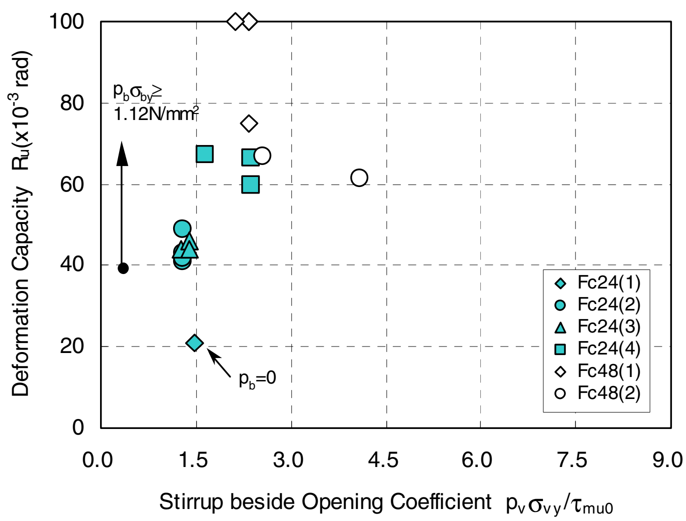


Fig. 9 R_u - $p_v\sigma_{vy}/\tau_{mu0}$ relationship

Relationship of deformation capacity and amount of diamond opening reinforcement

Figure 10 shows the relationship R_u and ratio of the amount of the diamond opening reinforcement to the shear stress at the flexural ultimate strength ($p_d\sigma_{dy}/\tau_{mu0}$). Hereafter, $p_d\sigma_{dy}/\tau_{mu0}$ is called diamond opening reinforcement coefficient. Increases in the diamond opening reinforcement coefficient resulted in a linear relationship to R_u. In this test, R_u was greater than 40×10^{-3} rad when the amount of U-shaped diagonal reinforcement ($p_b\sigma_{by}$) was above 1.12N/mm^2, and diamond opening reinforcement coefficient was above 1.86.

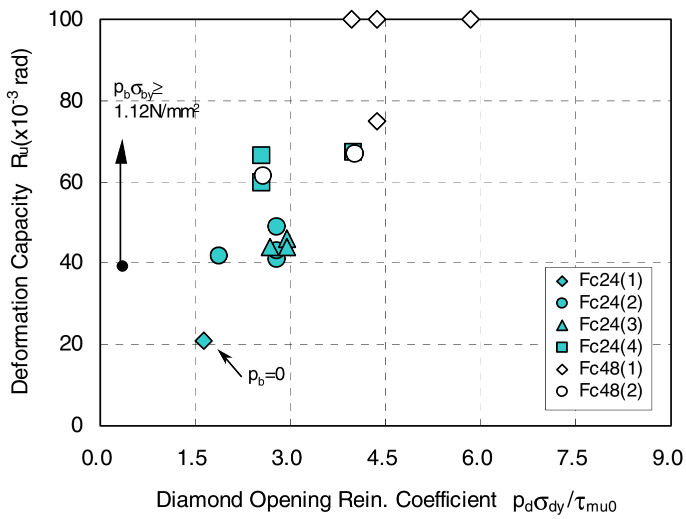


Fig. 10 R_u - $p_d\sigma_{dy}/\tau_{mu0}$ relationship

Relationship of deformation capacity and amount of opening reinforcement

Figure 11 shows the relationship of R_u and ratio of the amount of the opening reinforcement (sum of the amount of stirrup beside opening and amount of the diamond opening reinforcement) to the shear stress at the flexural ultimate strength ($(p_v\sigma_{vy}+p_d\sigma_{dy})/\tau_{mu0}$). Hereafter, $(p_v\sigma_{vy}+p_d\sigma_{dy})/\tau_{mu0}$ is called opening reinforcement coefficient. In this test, when the opening reinforcement coefficient is above 3.16, R_u was greater than 40×10^{-3} rad. Increases in the opening reinforcement coefficient resulted in a linear relationship to R_u.

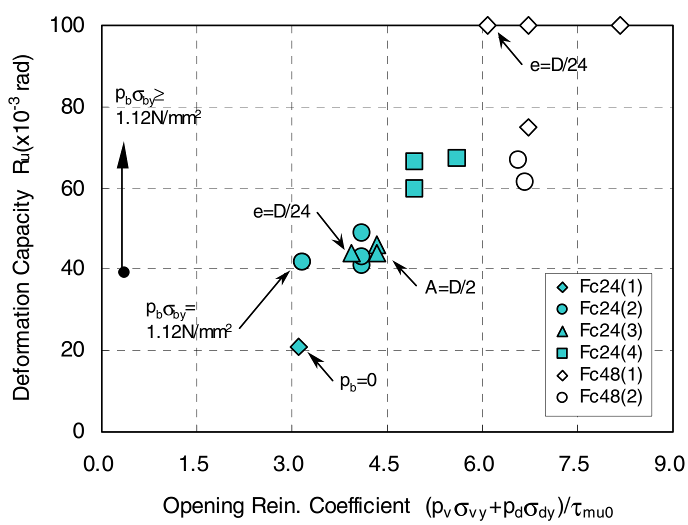
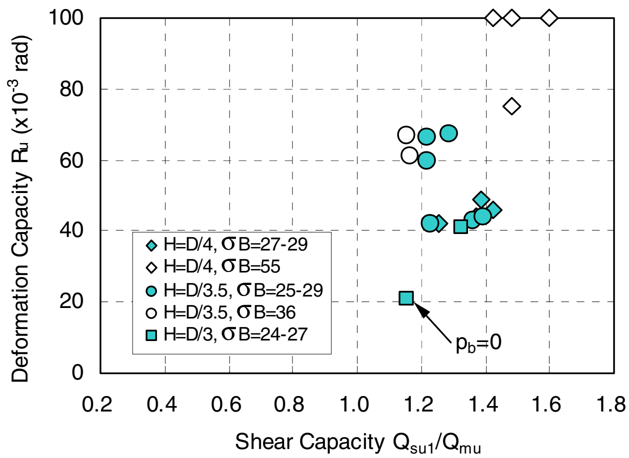


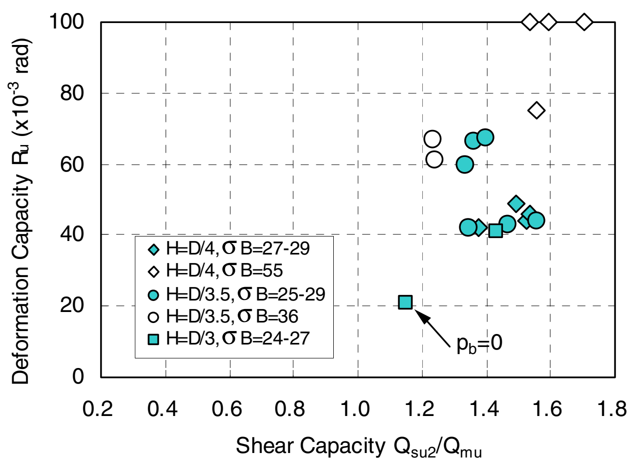
Fig. 11 R_u - $(p_v\sigma_{vy+}p_d\sigma_{dy})/\tau_{mu0}$ relationship

Relationship of deformation capacity and shear capacity

Figure 12 shows the R_u-Q_{su1}/Q_{mu} relationship and the R_u-Q_{su2}/Q_{mu} relationship. Q_{su1} is a shear strength that is obtained by modified Hirosawa's equation without considering the effect of the U-shaped diagonal reinforcement to shear strength of reinforcement area for opening. Q_{su2} is a shear strength that is obtained by modified Hirosawa's equation (Eq. (6)) which considers that the U-shaped diagonal reinforcement contributes to the increase of the shear strength of reinforcement area for opening. In this test, when Q_{su1}/Q_{mu} was above 1.15 and Q_{su2}/Q_{mu} was above 1.23 as the shear capacity, shear failure in the area near opening of the beam-end region did not occur. The deformation capacity was greater than 40×10^{-3} rad. However, a clear relationship of R_u and Q_{su1}/Q_{mu}, R_u and Q_{su2}/Q_{mu} is not found, and it is understood that evaluating the deformation capacity correctly only by shear capacity is difficult.



(a) U-shaped diagonal reinforcement effect not considered



(b) U-shaped diagonal reinforcement effect considered

Fig. 12 Relationship of deformation capacity and shear capacity

Flexural ultimate strength equation and shear strength equation used for strength calculation

As mentioned above flexural ultimate strength equation is shown in equation (4), and shear strength equations are shown in equations (5) and (6).

(a) Flexural ultimate strength equation of A.I.J.[1]

$$Q_{mu} = 0.9 a_t \sigma_y d / a \tag{4}$$

(b) Shear strength equation of A.I.J.[1] .... (Modified Hirosawa's equation)

$$Q_{su1} = \left\{ 0.053 p_t^{0.23} (\sigma_B + 18)(1 - 1.6H/D)/(M/Qd + 0.12) + 0.85\sqrt{p_v \sigma_{vy} + p_d \sigma_{dy}} \right\} bj \tag{5}$$

$$Q_{su2} = \left\{ 0.053 p_t^{0.23} (\sigma_B + 18)(1 - 1.6H/D)/(M/Qd + 0.12) + 0.85\sqrt{p_v \sigma_{vy} + p_d \sigma_{dy} + p_b \sigma_{by}} \right\} bj \tag{6}$$

a_t: Cross sectional area of beam main reinforcement, σ_y: Yield strength of beam main reinforcement, d: Beam effective depth, a: Shear span length, p_t: Ratio of beam main reinforcement, σ_B: Concrete compressive strength, H: Opening diameter, D: Beam depth, σ_{vy}: Yield strength of stirrup beside opening, σ_{dy}: Yield strength of diamond opening reinforcement, σ_{by}: Yield strength of U-shaped diagonal reinforcement, (σ_{vy}, σ_{dy}, $\sigma_{by} \leq 25\sigma_B$), j=7d/8, b: Beam width

Proposal of evaluation equation of deformation capacity

It is difficult to evaluate the deformability of beam with opening at the beam-end region correctly only by the shear capacity. However, the influence of the opening diameter, and the effects of stirrup beside opening and the diamond opening reinforcement have already been considered in Q_{su1} as obtained by the modified Hirosawa's equation. If the index that considers the effect of the U-shaped diagonal reinforcement is introduced into Q_{su1}, the deformability of the beam with opening in the beam-end region can be evaluated. The introduced index is a product of the shear capacity and the U-shaped diagonal reinforcement coefficient ($Q_{su1}/Q_{mu} \times (p_b \sigma_{by}/\tau_{mu0})$). This is called a deformability index. Figure 13 shows the relationship of deformation capacity and deformability index of these experimental specimens. Among specimens shown in this figure, the anchor performance of the U-shaped diagonal reinforcement was not demonstrated in specimens that had U-shaped diagonal reinforcement (6-D6) arranged like bundled reinforcing bar and the deformation capacity of the specimens was smaller than that of other specimens. Therefore, when the evaluation equation of the deformation capacity is set, it uses the lower bound value from relationships of deformation capacity and the deformability index, but it excludes the values for bundled reinforcing bar specimens. Thus equation (7) is obtained.

$$R_u = 20 e^{0.6 (Q_{su1}/Q_{mu})(p_b \sigma_{by}/\tau_{mu0})} \tag{7}$$

To verify the validity of this equation, past experimental results (Kurosawa [3], [4]) of the specimens with opening reinforcement method which were almost the same as ones of our test specimens are shown by triangle symbols in this figure too. The experimental value is in the neighborhood of or exceeds the calculated value of the obtained deformation capacity evaluation equation and thus validates equation (7). This equation is, however, constrained by $\tau_{mu0}/\sigma_B \leq 0.073$ and $D_e \geq D/3$, which were confirmed by the test, and applies to a beam with an opening that has arranged U-shaped diagonal reinforcement with sufficient anchor performance.

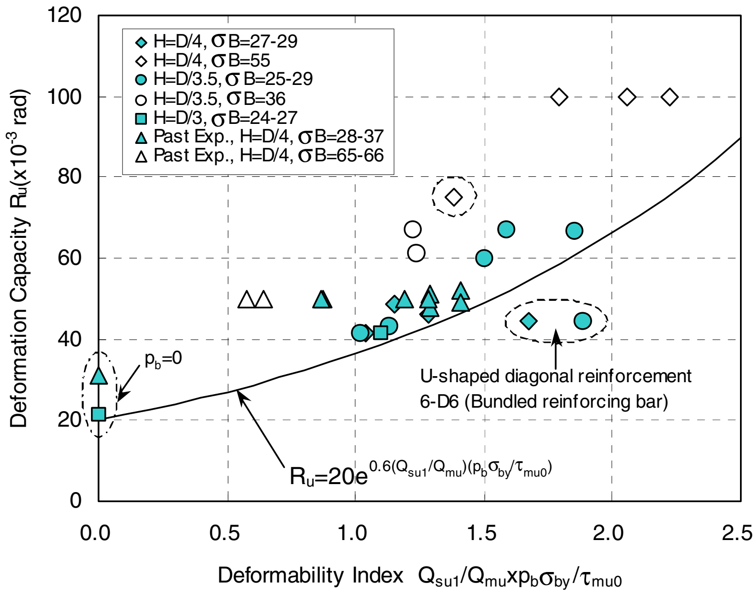


Fig. 13 Relationship of deformation capacity and deformability index

CONCLUSIONS

The results obtained from the test on beam with opening at the beam-end region are summarized as follows.

(1) A linear relationship of the deformation capacity and the U-shaped diagonal reinforcement coefficient, and one of the deformation capacity and the opening reinforcement coefficient is found.

(2) Though the deformation capacity was greater than 40×10^{-3} rad, when shear capacity (Q_{su2}/Q_{mu}) was greater than 1.23, it is difficult to evaluate the deformation capacity only by the shear capacity.

(3) It is possible to evaluate the lower bound of the deformation capacity of the beam with opening that adopts this opening reinforcement method by the proposed equation (7).

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