Experimental Study on Shear Strength of Reinforced Concrete Continuous Deep Beams with Web Opening

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ABSTRACT :
Reinforced concrete continuous deep beams were tested to evaluate the shear strength with the various location of web opening. In total 5 specimens with the circular web opening have been cast and tested in the laboratory. From the test, it has been observed that the specimens with web opening have about 90 % of shear strength of the specimen without web opening. In general, the span with web opening is less stiff than the span without web opening, and in DB#4 specimen two spans have the same shear strength, stiffness, deflection. Web opening in the deep beam with shear span-depth ratio of 1.0 can be located not in the compressive strut area but tensile area, but in this case adequate reinforcement should be provided around the opening to avoid the crack width becoming wider and fail.

KEYWORDS:
Continuous Deep Beam, Web Opening, Shear Strength

1. INTRODUCTION

In the modern high-rise reinforced concrete buildings, deep beams are used as transfer girders. Generally bending moment governs the behavior of ordinary beams, but in deep beams, the shear force governs the behavior. In the reinforced concrete design code of AIK(4) or ACI 318-99(1), there are specipic standards on these beams. But in practice, deep beams may have web openings for essential service ducts and pipes, so particular standards are necessary to be prepared.
ACI code and Korea building code read that the nominal shear strength of reinforced concrete is divided two portion: one is from concrete, the other is from web reinforcement (vertical, horizontal, diagonal reinforcement). See Eq.(1.1, 1.2).

$$V_u = \phi V_n \tag{1.1}$$

$$V_n = \left(V_c + V_S\right) \tag{1.2}$$

In shear design for beams, we can calculate the nominal shear strength(Vn) to the given load and section of member, and exclude the concrete portion(Vc), then we can get the reinforcement portion(Vs) that is used for the design of reinforcement in concrete beams. Eq.(1.3) can be used for simplified design method. In detailed method, Eq.(1.4) can be used for ordinary beams and Eq.(1.5) for deep beams without openings.

$$V_c = 0.53\sqrt{f_{ck}}\, b_w d \tag{1.3}$$

$$V_c = \left(0.50\sqrt{f_{ck}} + 176\rho_w \frac{V_u d}{M_u}\right) b_w d \tag{1.4}$$

$$V_c = \left(3.5 - 2.5\frac{M_u}{V_u d}\right)\left(0.50\sqrt{f_{ck}} + 176\rho_w \frac{V_u d}{M_u}\right)b_w d \qquad (1.5)$$

All the above equations are for the beams without web openings, and there is no equation in ACI or Korea building code for the shear strength of deep beams with web openings. Moreover most of previous researches on ordinary or deep beams with web openings are for the cases of simply supported beams(6)(7)(8). In this paper, total 5 reinforced concrete continuous deep beams have been tested to find the effect of web openings on shear strength. 2-span continuous deep beams with various locations of opening have been tested under 2 concentrated loads.

2. EXPERIMENT

2.1. Design of Specimen

Table 2.1 shows the characteristics of 5 specimens. All specimens are supported at center(width:40cm) and both ends(width:20cm), and there are two loading points(width:30cm) at the center of both spans.

Table 2.1 Specifications of deep beams (Unit: cm)

Specimen	Shear span- depth ratio(a/h) (Left span, Right span)	Clear span (Left, Right)	Depth	Diameter of openings	Location of opening
DB#1	(1, 1)	(200 ,200)	100	-	-
DB#2	(1, 1)	(200, 200)	100	30	Right discontinuous end
DB#3	(1, 1)	(200, 200)	100	30	Left discontinuous end
DB#4	(1, 1)	(200, 200)	100	30	Right discontinuous end Left continuous end
DB#5	(1.5, 1)	(250, 200)	100	30	Left discontinuous end

Specimen DB#1 is basic specimen without opening, the others have circular opening whose diameter is 30cm. Main parameter of test is the location of opening, it is located avoiding compressive strut.
Deep beams are reinforced by D10 vertical stirrup only in shear span. 4-D16 steel bar is embedded in 2 layers as main tensile reinforcement. Table 2.2-2.3 show the test results of concrete and reinforcing steel used in producing the specimens.

Table 2.2 Compressive test of concrete (kgf/cm^2)

Concrete (28days)	
Design stress	210.0
Test compressive stress	242.2
Test tensile stress	19.4
Elastic modulus	2.33E+05

Table 2.3 Tensile test of steel bar (kgf/cm^2)

	Yield stress	Tensile stress	Elastic modulus
D10	3577.2	4705.5	1.82E+06
D16	4431.5	6618.1	2.06E+06
D22	3880.0	5984.3	1.83E+06

2.2 Test and Measurement

200tf oil jack and loading beam are used for 2-point loading. LVDT is installed under bottom sides of both span to find relation between loading poing and maximum displacement point. Many wire strain gages are set up.

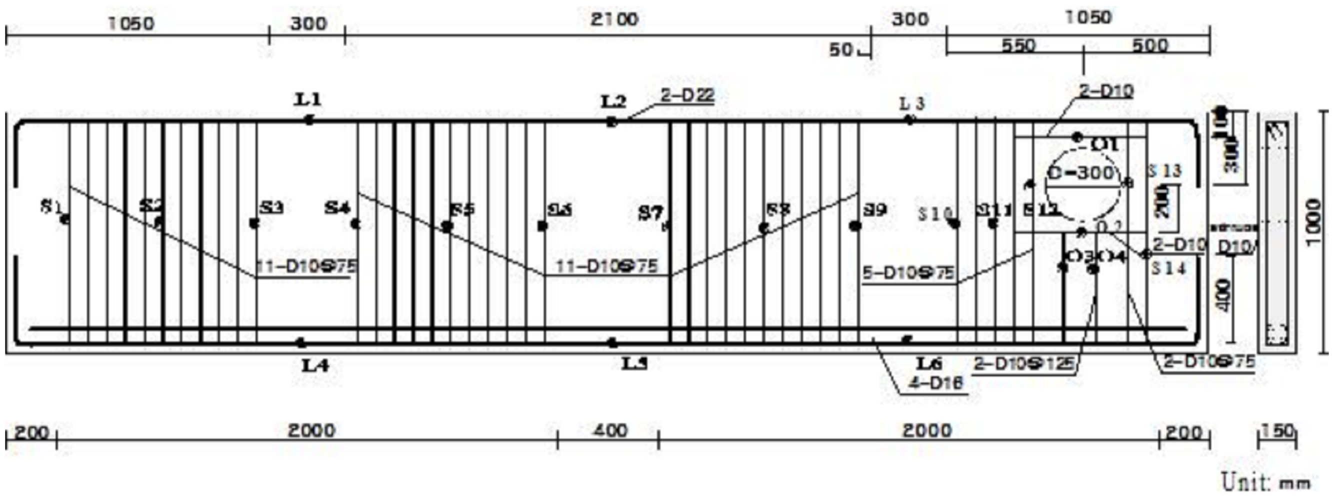

Fig. 2.1 Detail of specimen (DB#2)

3. TEST RESULTS

3.1 Maximum Load

Table 3.1 shows initial cracking load and maximum load of each specimen. In standard(5) or code(1), the nominal shear strength of reinforced concrete beam is obtained by equation $V_n = 0.18\left(10 + \frac{l_n}{d}\right)\sqrt{f_{ck}}b_w d$ for $2 \le l_n/d \le 5$. In case of specimen DB#1 without opening, V_n=46.82tf by equation for one shear span, so maximum load is 187tf for four shear span, and the test result is 183tf, which is 97.7% of load by equation. Maximum load of specimen with opening is about 90% of maximum load of DB#1.

Table 3.1 Initial cracking load and maximum load (Unit:tf)

Specimen	P_{cr}	P_{oc}	P_{sc}	P_{max}	P_{cr}/P_{st}^*	P_{oc}/P_{st}	P_{sc}/P_{st}	P_{max}/P_{st}
DB#1	65	-	75	183	0.355	-	0.410	1.000
DB#2	47	52	65	159	0.257	0.284	0.355	0.869
DB#3	57	62	74	168	0.311	0.399	0.404	0.918
DB#4	40	50	68	168	0.219	0.273	0.372	0.918
DB#5	49	56	74	169	0.268	0.306	0.404	0.923

Pcr = initial cracking load at tension extreme, Pco = load of cracking around opening
Psc = shear cracking load, Pmax = maximum load
Pst = maximum load of specimen DB#1 = 183tf

3.2 Cracks and Failure

By Table 3.1, we can say that the initial cracking load is largest in DB#1 without opening, smallest in DB#4 with two openings. First of all, initial tension cracks appeared, and diagonal cracks through openings came out, and then diagonal cracks keeping out openings appeared. In accordance with increasing load, the cracks propagated to fail.

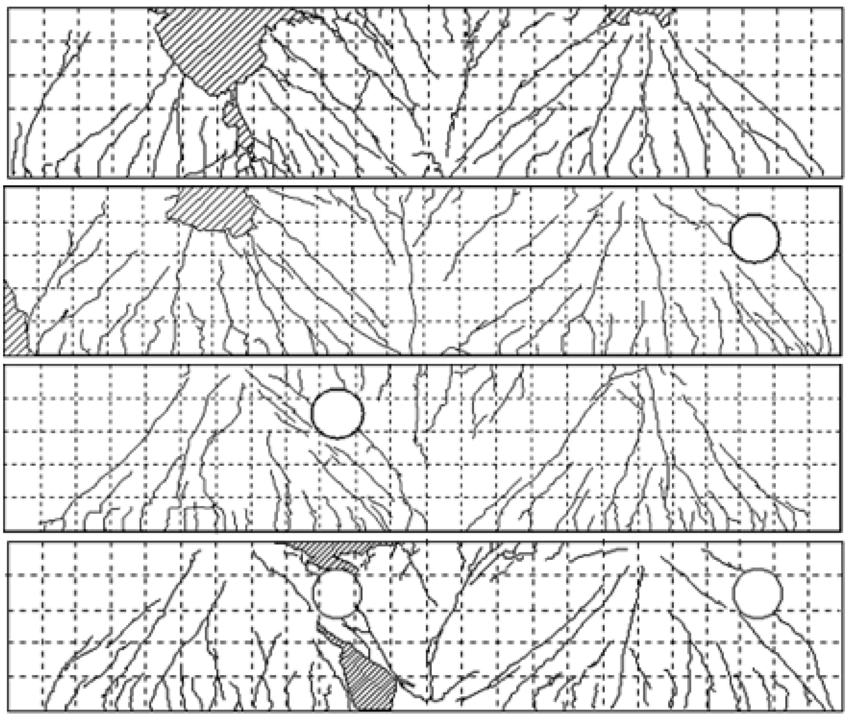

Fig. 3.1 Final failure (DB#1-DB#4, respectively)

3.3 Load-Deflection Curves in Specimen

Fig. 4 displays load-displacement curves. Deflection is larger in the span with opening. All the specimens show the brittle failure.

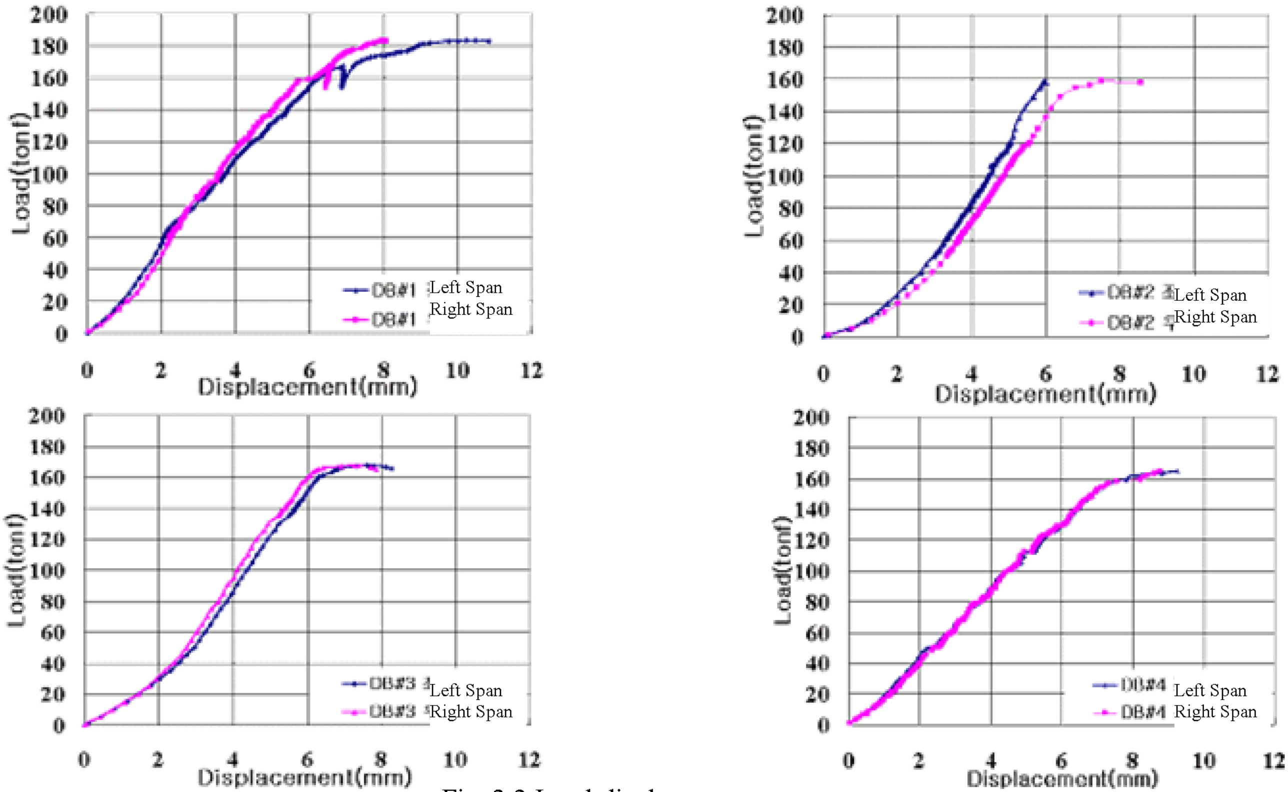

Fig. 3.2 Load-displacement curves

3.4 Load-Strain Curves in the Reinforcements

The nominal shear strength of reinforced concrete is obtained at a/2, that is, critical section. Fig. 3.3 shows strains of stirrup in the critical section at discontinuous end of span with opening, Fig. 3.4 shows that of continuous end. These reveal that critical sections are exposed compressive stress to the failure.

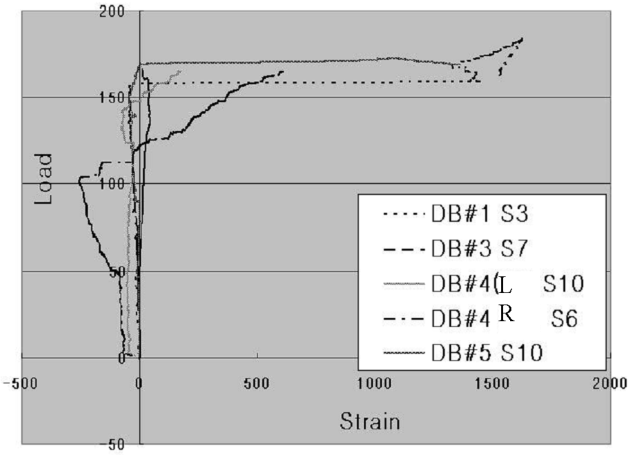

Fig. 3.3 Strain at critical section
($*10^{-6}$, Discontinuous end)

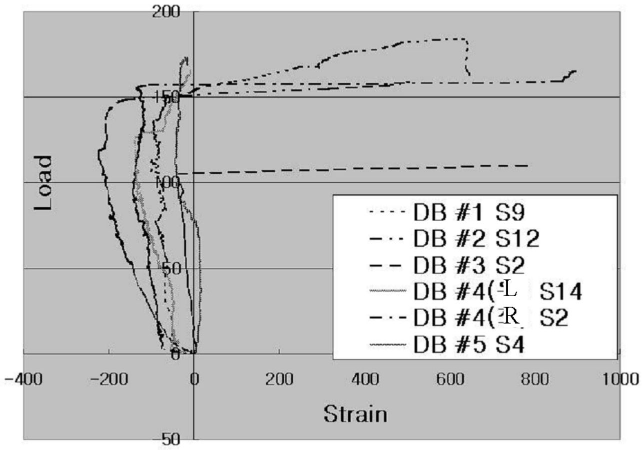

Fig. 3.4 Strain at critical section
($*10^{-6}$, Continuous end)

4. CONCLUSIONS

From the test of reinforced concrete continuous deep beams to find the effect of locations of opening, we can conclude as follows.

1) The shear strength of deep beams without opening calculated from equation $V_n = 0.18\left(10 + \frac{l_n}{d}\right)\sqrt{f_{ck}}b_w d$ specified in ACI and Korea building code is 98% of test result.
2) The shear strength of deep beams with opening, whose diameter is 0.3 times of depth, is 87-92% of test result of deep beam without opening.
3) Generally the slope of load-displacement curve is steeper in the span with opening than in the span without opening, and the result of DB#4 show that the shear strength, stiffness and deflections are have no difference regardless of locations of opening.
4) If opening was located in the tension region, that is, beside of strut at discontinuous end, it is necessary to reinforce properly around the opening to avoid propagation of crack.

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