論文 Shear Resistant Behavior of Beam with High Strength Concrete under Monotonic Loading

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ABSTRACT : Six reinforced concrete beams were tested in order to investigate the shear resistant behavior of high strength concrete. The experimental variables are concrete compressive strength (target strength of 1,000 kgf/cm^2 and 300 kgf/cm^2) and shear reinforcement ratio(p_w= 0, 0.3, 0.6, 0.8, and 1.0%). All the beam specimens were subjected to monotonically loaded to failure to get more fundamental data of shear strength. Test results showed that the experimental shear strength was close to the calculated one by AIJ Structural Design Guidelines[1] and the shift stress of longitudinal bars due to truss action was observed along the clear span except the compression zone.
KEYWORDS: shear strength, shear reinforcement, high strength concrete, truss and/or arch resisting mechanism, effectiveness factor for the compressive strength of concrete.

1. INTRODUCTION

Shear strength provisions for reinforced concrete members in building codes have been changed gradually from experimental to theoretical approach. One of the typical examples of theoretical shear strength is superposition of truss and arch resisting mechanisms, which is adopted in Design Guidelines for Earquake Resistant Reinforced Concrete Buildings of AIJ, 1990[1]. In this concept, the top and bottom stringers should be strong enough to assure the compression failure of diagonal concrete strut and the sufficient anchorage strength should be provided for arch support.

One of the objectives of this paper is to clarify whether the AIJ shear criterion is also effective to the members with 1,000kgf/cm^2 class high strength concrete. Almost all of the shear tests of RC member in Japan have been limited to repeated reversed loading. It is very important, however, to investigate

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more basic behavior of the RC members under the monotonic loading to failure without any repeated reversed loading is still needed. So, in this research monotonic loading test was adopted, and test results were compared with the repeated reversed loading data (author's former test)[4].

2. OUTLINE OF EXPERIMENT

2.1 TEST SPECIMEN

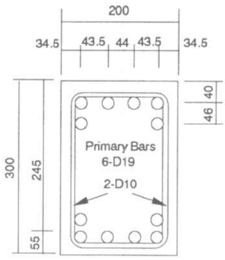


Fig. 1 Cross section of specimen and arrangement of longitudinal bars (mm)

Six test specimens have same shape (1,300 mm clear span) and same cross section (200 mm width and 300 mm total depth) as shown in Fig. 1 and Fig.2. Six high strength longitudinal bars (σ_y=7,420 kgf/cm^2) were doubly laid at top and bottom of the section so as to precede the shear failure rather than flexural failure. The test varaibles were concrete compressive strength (target strength of 1,000 kgf/cm^2 and 300 kgf/cm^2) and the amount of shear reinforcement (p_w=0, 0.3, 0.6, 0.8, 1.0%). The properties of specimens together with the real concrete strength (compressive strength σ_B and splitting tensile strength σ_t) are also shown in Table 1.

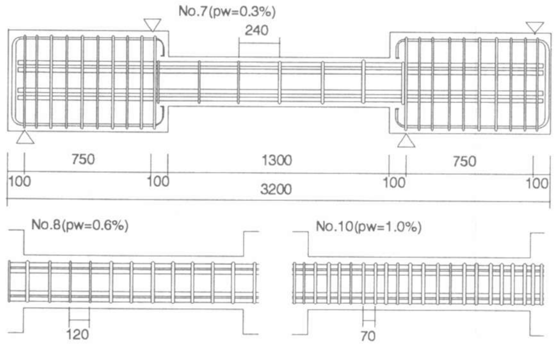


Fig. 2 Detail of shear reinforcement (mm)

Table 1 Properties of specimen

Specimens	Transverse Reinf.			Concrete Strength (kgf/cm²)		Cross Section b x D (cm)	Longitudinal Reinf.
	Bars & Pitch	P_w(%)	σ_{wy} (kgf/cm²)	σ_B	σ_t		
No.6		0	3470	993	47.2	20x30	6-D19 Pc=Pt= As/bD=2.87% σ_y=7420 (kgf/cm²)
No.7	2-D10@240	0.3					
No.8	2-D10@120	0.6					
No.9	2-D10@ 90	0.8		979	47.6		
No.10	2-D10@ 70	1.0					
No.11	2-D10@120	0.6		310	25.5		

*) The number follows the author's former test [4]

2.2 MATERIAL

Table 2 Mix proportioning of concrete

Specimens	W/C (%)	S/A (%)	Unit Quantity (kg/m³)					
			W	C	S	G	Silica Fume	Super-plasticiser
No.6~10	30	42	165	525	699	988	25	11
No.11	58	45	233	400	747	912		

Normal portland cement, natural river sand and crushed stone with maximum size of 20 mm were used for concrete. Silica fume and super water reducing plasticiser were used for 1,000 kgf/cm^2 class high strength concrete. The mix proportion for high strength concrete (No.6~10) and normal concrete strength (No.11) are presented in Table 2. The 10 mm diameter deformed bar (σ_{wy} =3,470 kgf/cm^2) was used for shear reinforcement.

2.3 LOADING APPARATUS AND MEASURING

The loading apparatus is shown in Fig.3. At the both end of the specimen, the very stiff stub was provided, of which height two times of that in the clear span. Loading and supporting points were both located within the stub so as to prevent confining the longitudinal bar in the clear span. The loading pattern was selected so that the anti-symmetric bending moment distribution could occur. The strain of every shear reinforcement and strain distribution of longitudinal bars were measured by foil strain gages. The deformation of clear span was also measured as the relative displacement of each measuring frame at the end stub as shown in Fig.4.

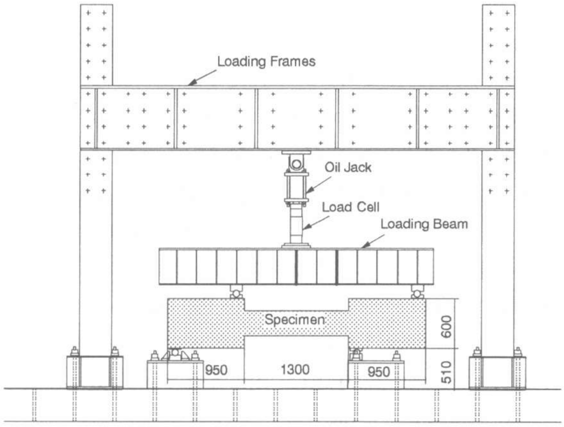


Fig.3 Loading apparatus

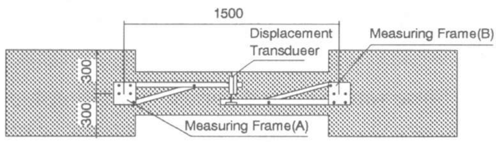


Fig.4 Detail of measuring frame

3. TEST RESULTS AND DISCUSSIONS

3.1 MAXIMUM SHEAR FORCE

Summary of test results are shown in Table 3. All specimen resulted in shear failure as was expected (Q_{exp}<Q_f). Shear capacity Q_s and its detail (Q_t carried by truss and Q_a carried by arch) by AIJ-A method were also shown in the table. The following equation proposed in New RC Report[5] was used as the effective compressive concrete strength of diagonal concrete strut.

$$\nu_0 \sigma_B = 3.68 \sigma_B^{0.667} (kgf/cm^2) \quad (1)$$

Experimental shear force(Q_{exp}) is very close to the AIJ's shear capacity(Q_s). It can be said that the effective concrete compressive strength by Eq.(1)

Table 3 Test results

Specimens	σ_B (kgf/cm²)	P_w (%)	Flexural Capacity (Calculated Value) Q_f (tf)	Shear Capacity by AIJ [1]			Maximum Shear Force (Measured Value) Q_{exp} (tf)	Q_{exp}/Q_s
				Total Shear Force Q_s (tf)	Shear Force carried by Truss Q_t (tf)	Shear Force carried by Arch Q_a (tf)		
No.6	993	0	35.76	11.02	0	11.02	11.35	1.03
No.7		0.3		18.38	8.92	9.46	17.28	0.94
No.8		0.6		25.75	17.85	7.90	24.85	0.97
No.9	979	0.8	35.70	30.56	23.80	6.76	31.57	1.03
No.10		1.0		35.47	29.75	5.72	34.73	0.98
No.11	310	0.6	32.03	19.80	17.85	1.95	21.72	1.10

is also available to 1,000 kgf/cm^2 high strength concrete member. Fig.5 shows the relationship of the shear force and shear reinforcement degree with non dimensional expression (devided by effective concrete compressive strength $\nu_0 \sigma_B$). Solid circles(●) presents the results of this paper (monotonic loading to failure) and white circles(○) presents the former test results (repeated reversed loading)[4]. Test results shows that the shear strength surely decreases due to the repeated reversed loading. Every test result was plotted lower than the theoretical line differing the consideration in Table 3.

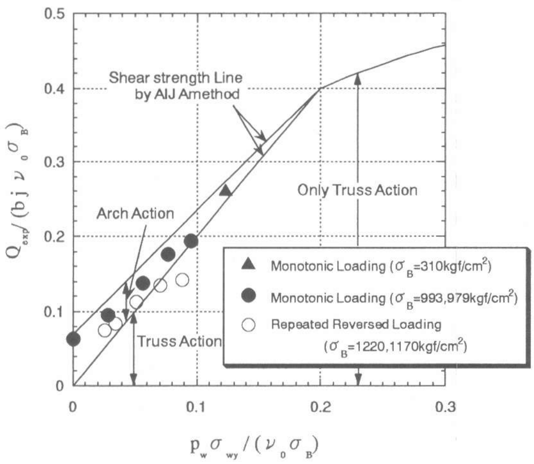
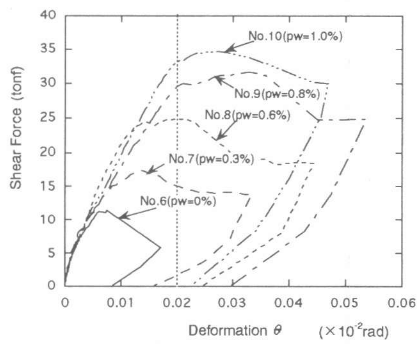


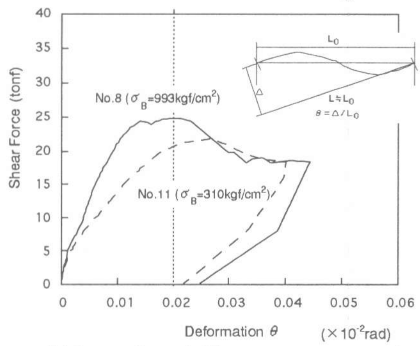
Fig.5 Shear strength - shear reinf. degree relationship

3.2 SHEAR FORCE - DEFORMATION RELATIONSHIP

Shear force versus deformation relationship of all specimens is shown in Fig.6. The deformation (θ) was defined as the measured displacement (Δ) divided by the span (L_0) as shown in Fig.6(b) . Fig.6(a) shows the influence of the amount of shear reinforcement on shear force-deformation relationship under same concrete strength. Stiffness is almost same irrespective of the amount of shear reinforcement. As increasing of shear reinforcement, not only the shear strength but the ductility of the specimens are greatly improved. Fig.6(b) shows the influence of concrete strength only (other condition is quite same between No.8 and No.11). It can be seen from the figure that increasing the concrete strength by three times results in an increasing of shear strength by only 15% and results in rather bad ductility.



(a) Comparison of different content stirrup and same concrete strength



(b) Comparison of different concrete strength and same content stirrup

Fig. 6 Shear force - deformation relationship

3.3 STRESS IN SHEAR REINFORCEMENT AND CRACK PATTERN

Fig.7 shows the stress distribution of shear reinforcement along with the clear span and the crack pattern of typical specimens. As increasing of the amount of shear reinforcement, the yielding zone spread to each end. But, there always remains the unyielding zone at the neighborhood of stub.

3.4. STRESS DISTRIBUTION OF LONGITUDINAL BARS

Fig.8 shows the measured stress distribution(bold line) of the longitudinal bars (upper side of top bar). To make the explanation easy, there are also shown the stress distribution due to the flexural theory only (dashed line) and the stress distribution after the shift to tension side by truss action $Q_t \cot \phi /2$ (solid line), where Q_t is shear force carried by truss and ϕ is the degree angle of diagonal strut[2,3]. The measured stress distribution scatter fairly, but it can be seen that the stress distribution shift to tension side in tension zone and is close to original dashed line in compression zone.

4. CONCLUSIONS

From the previous discussions and test results, the following conclusions can be drawn :

1. The experimental shear strength of reinforced concrete beam with high strength concrete is close to the calculated one from truss and arch actions due to AIJ Structural Guidelines by using the effectiveness factor for compressive strength of concrete of New RC. version;
2. In the scope of this study, the shear strength is mostly affected by shear reinforcements rather than influence by the concrete strength;
3. The shift stress to tension side of longitudinal reinforcement was obtained along the clear span, except in the compressive stress zone.
4. The failure of the specimen is mostly the crushing of diagonal compression strut and the main diagonal crack inclination is smaller than 45 degree.

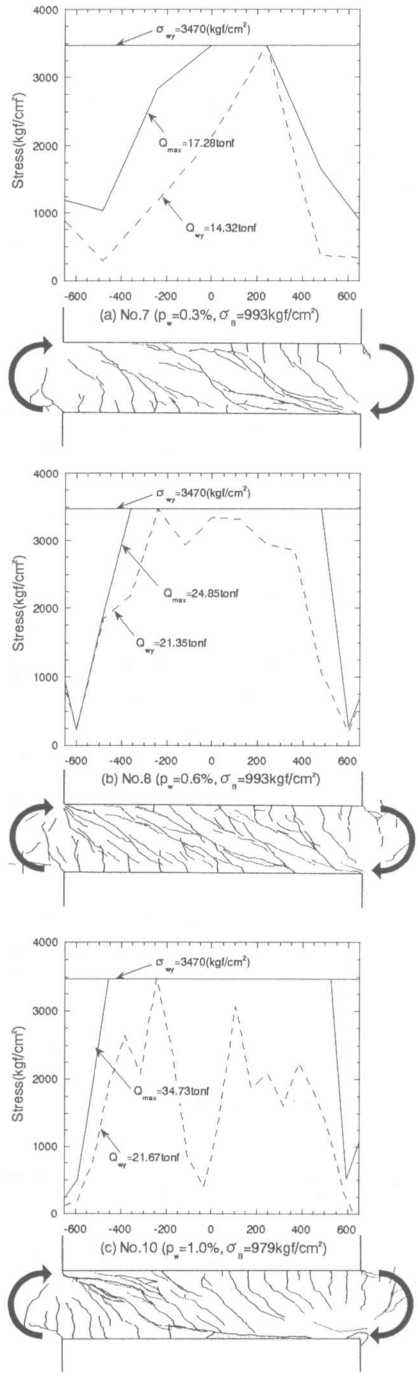


Fig. 7 Stress distribution of shear reinforcement and cracks

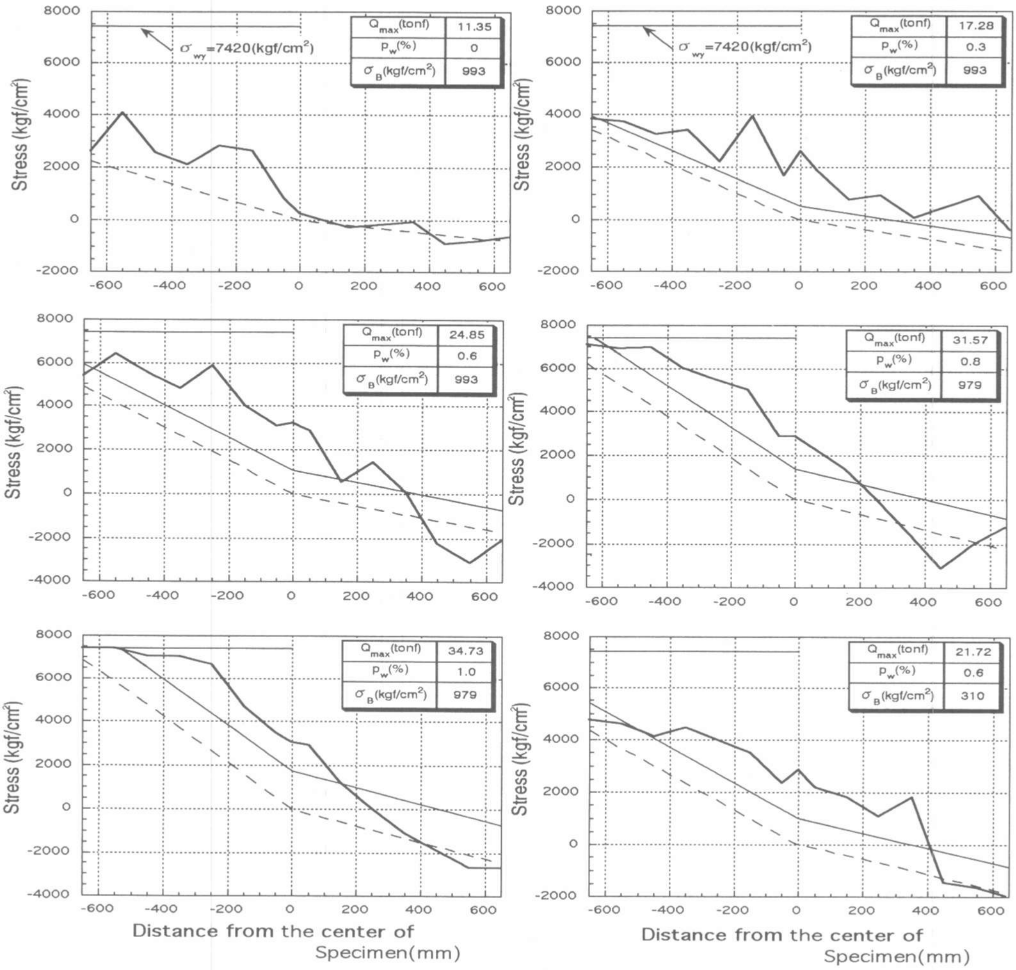


Fig. 8 Stress distribution of longitudinal bars

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