EXPERIMENTAL RESEARCH ON SHEAR STRENGTH OF SHORT REINFORCED CONCRETE COLUMNS WITH PRESTRESSED HOOPS

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SUMMARY

This paper describes tests on specimens in which prestress into the transverse reinforcement of a reinforced concrete column was introduced. Tests on specimens in which prestress was not introduced were performed for comparison of shear strength. In reinforced concrete structures, the columns which are subjected to axial force develop a three-dimensional compressive stress condition, if it is possible to confine the core concrete laterally by introducing prestress transverse reinforcement, and it is considered that the compressive strength is improved by this method. Hence, it is also possible to laterally introduce prestress into existing columns. Therefore, the idea is considered as a new and effective method for strengthening a column. From the shearing test of reinforced concrete short columns in which prestress is added to the transverse reinforcement, the following facts are indicated. (1) The prestress introduced into the transverse reinforcement is a very effective method for improving the shear strength. (2) It is possible to improve the shear strength by increase of the transverse reinforcement quantity, when prestress was introduced into the transverse reinforcement. (3) It is found theoretically that the formula of evaluation, known as the *New RC Formula,* for shear strength derived for concrete and reinforcement with high strength is agreed well with the experimental results of shear tests.

INTRODUCTION

Under the three-dimensional compressive stress condition of the concrete, it is known that the compressive strength is improved in comparison with the compressive strength of concrete under the uniaxial compressive stress condition. This fact has been observed in past research. Here, the column is always subjected the axial force, which forms the three-dimensional compressive stress condition by the effect of confinement acting on the lateral directions. Also, it seems to be effective in compression members without axial compressive force. Furthermore, the prestress from the lateral direction is considered to be a strengthening method for shear of existing columns. In this study, prestress was introduced into transverse reinforcement of reinforced concrete columns and shear tests were performed on test specimens constructed by this method. It was found from this test that the shear strength of test specimens was enhanced by the confinement effect as the prestress into transverse reinforcement increased

TEST SPECIMEN DESIGNS

Outline of the shearing test

The test specimens were planned as square shaped columns. The 7 specimens with shear span ratio M/QD= 1.25, cross section 120mm×120mm, length 300mm, and about a fifth scale were constructed for the test. End stubs for the loading were established at the portions corresponding to column top and bottom. The changing factors are prestress (0.0 or 1.2GPa) for transverse reinforcement, transverse reinforcement ratio (P_w=0.174**%**: @30mm pitch or P_w=0.087**%**: @60mm pitch), and material of transverse reinforcement (hard steel wire : SW-A or piano wire : SWP-A) with 2 types. Main common factors are longitudinal reinforcement quantity (8-D10 :

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P_g=4.00%), longitudinal reinforcement yield strength (SD785), shape of transverse reinforcement (welding enclosed square type, 98.7mm×98.7mm length) and diameter (ϕ 2.0mm) where it is constant. The concrete mix is shown in Table1, material property of the reinforcement is indicated in Table2, test specimens list is shown in Table3, and the bar arrangement details in test specimens are shown in Fig.1. Antisymmetrical loading without axial force was applied for shear test using the test apparatus with capacity 3MN. The relative displacement was measured by displacement meters installed in the test specimen, as shown in Fig.1. The strain of longitudinal reinforcement and transverse reinforcement were measured in place by strain gauges shown in Fig.1. And, in addition, the compression test was carried for the short column with the same bar arrangement as the shear test specimen.

Method for giving the prestress

Prestress is based on the pretension method which gives the initial tension before the concrete placement done as shown in Fig.2. The initial tension is given by tightening the bolts at four corners. This is reduced after concrete hardening, and then, the lateral pressure is transferred to the core concrete of column. The prestress was transferred to the concrete after the concrete material had awed for 3 days and measured by strain gauges, which were also used for measurement in the shearing test. The initial tensile stress of 1.2GPa in the transverse reinforcement was used so that the prestress become was below the yield strain. The preliminary test was carried out beforehand, because tensile stress loss by relaxation is considered in the shear test, and it was confirmed that an effective stress of 80% of initial tensile stress is ensured in the shear test

Table 1: Concrete mixture

Concrete type	**σ_B** (MPa)	**Fine aggregate (kg)**	**Cement (kg)**	**Water (kg)**	**Water-cement ratio(%)**	**AE water reducing agent(g)**
Mortar (high-early-strength cement)	30	90	30	15	60	360

σ_B :Compressive strength of concrete

Table 2: Properties of reinforcement

Steel type			**Yield strain(%)**	**Yield strength (MPa)**	**Tensile strength (MPa)**	**Modulus of elasticity of steel (GPa)**
Longitudinal Reinforcement	D10	SD785	0.374	777.8	1023.5	207.9
Transverse Reinforcement	ϕ 2.0	SWP-A*	1.067	1790.0	1960.5	206.9
		SWP-A(welded wire) *	0.866	1390.0	1640.5	206.9
		SW-A*	0.800	1250.0	1520.5	206.9
		SW-A(welded wire) *	0.788	1210.0	1350.5	206.9

*0.2%off set

TEST RESULTS

Variation in quantity of prestress of the transverse reinforcement is shown in Table4, shear force-relative deformation curves obtained from the shearing tests are shown in Fig.3 , and the shear test results are shown in Table5. The relationship between maximum shear strength and the transverse reinforcement ratio of each test specimen are shown in Fig.4. A comparison of accumulated energy absorption capacity of prestressed concrete test specimen and reinforced concrete test specimen is shown in Fig.5, where the accumulation energy absorption capacity was calculated by the area surrounded in the shear force-displacement curves

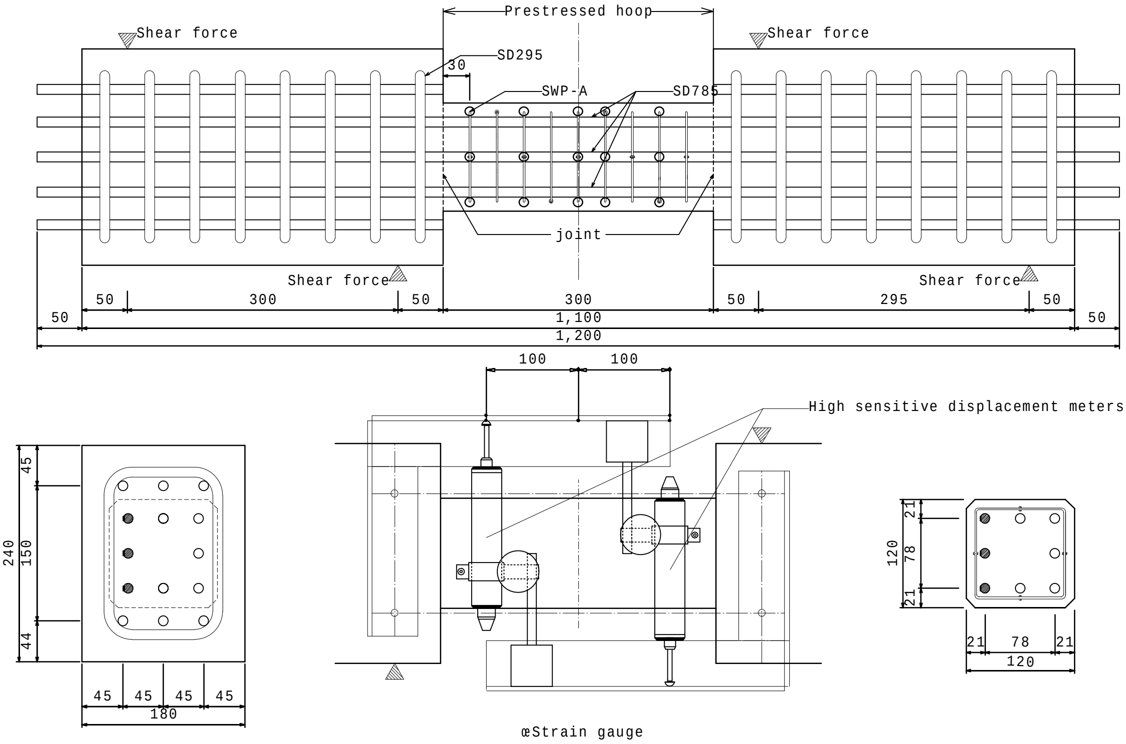


Fig.1: Details of specimen 30-PW-P1-S (unit:mm)

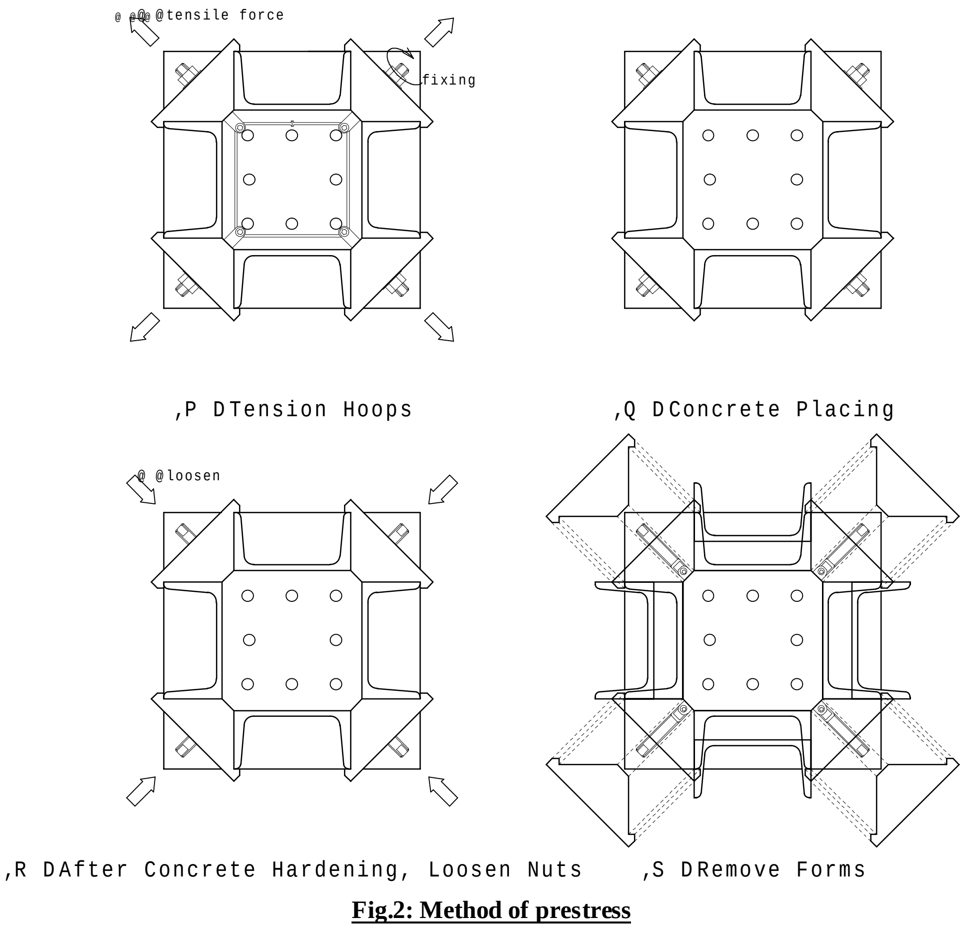


Fig.2: Method of prestress

Table 3: Test specimens

N.O.	Specimen	Type	Shear span ratio *M/QD*	*L* (mm)	Cross Section (mm×mm)	P_g* (%)	P_w** (%)
1	M8-S						?
2	60-SW-P0-S	RC					0.08
3	60-PW-P0-S						0.08
4	60-PW-P1-S	PC	1.25	300	120×120	4.00	0.08
5	30-SW-P0-S	RC					0.17
6	30-PW-P0-S						0.17
7	30-PW-P1-S	PC					0.17

P_g*=A_s/A_c, A_s: Cross-sectional area of the longitudinal reinforcement (mm^2), A_c: Cross-sectional area of the concrete (mm^2) *L:* Length of column
P_w**=a_w/bx, a_w: Cross-sectional area of the transverse reinforcement (mm^2), *b*: Width of column (mm), *x*: Pitch of transverse reinforcement (mm)

Table 4: Yield strength of transverse reinforcement

Specimen	Yield stress σ_{sy} (MPa)	Prestress σ_{sp} (MPa)	Residual tensile stress σ_{sy}? σ_{sp} (MPa)
60-PW-P1-S	1390	1075	315
30-PW-P1-S	1390	910	480

Table 5: Test results

Specimen	Shear strength Q_u (kN)	Displacement at maximum shear strength (mm)	Relative deformation at maximum shear strength R_{max} ($\times 10^{-3}$rad)	K_{ps}*	K_{pc}**
M8-S	18.44	0.58	1.93		
60-SW-P0-S	25.49	1.24	4.12	?	?
60-PW-P0-S	25.33	2.15	7.17		
60-PW-P1-S	37.84	3.67	12.22	1.49	1.14
30-SW-P0-S	29.44	3.39	11.28	?	?
30-PW-P0-S	33.80	3.53	11.77		
30-PW-P1-S	50.74	3.32	10.72	1.50	1.96

K_{ps}**=**Q_{sp}/Q_s
Q_{sp}: Shear strength of prestressed concrete column, Q_s: Shear strength of reinforced concrete column
K_{pc}**=σ_{Bp}/σ_B, σ_{Bp}: Compressive stress of prestressed concrete column

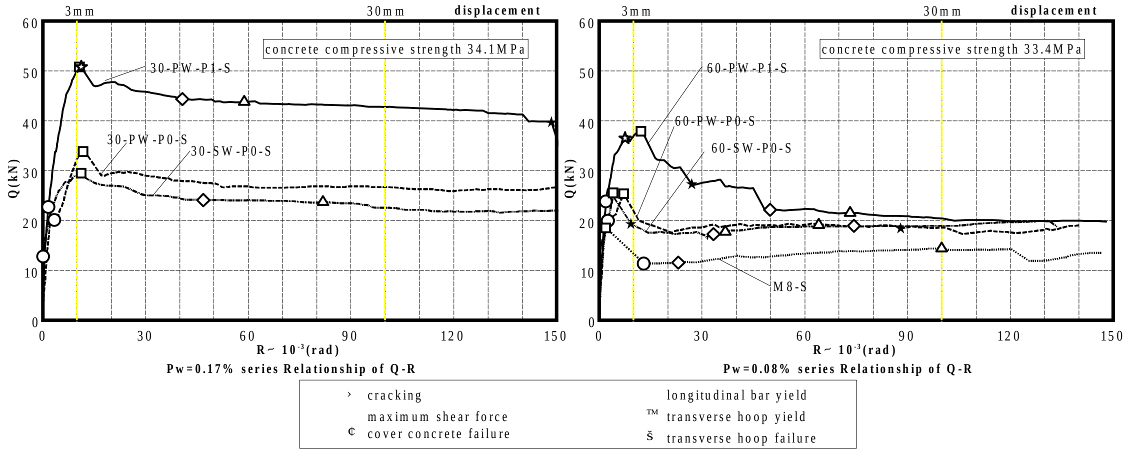


Fig.3: *Q-R* curves

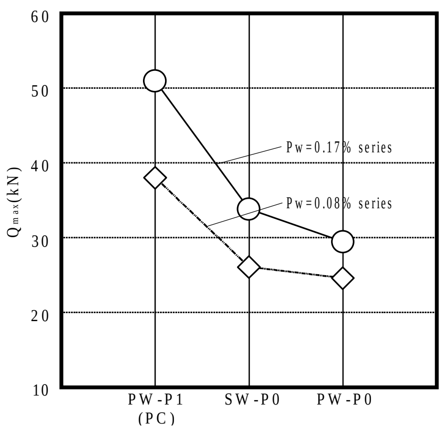


Fig.4: Comparison on maximum shear strength

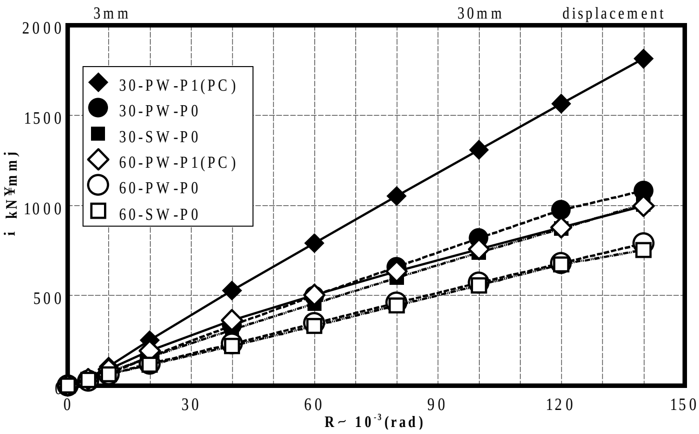


Fig.5: Accumulation absorbed energy

Photo 1: Test specimen 1 (Reinforced Concrete type)

Photo 2: Test specimen 2 (Prestressed Concrete type)

DISCUSSION OF TEST RESULTS

It is observed that the deformation in maximum shearing force is almost equivalent to 11×10^{-3} for the test specimens, 30-PW-P1-S, 30-PW-P0-S, 30-SW-P0-S as shown in Fig.3. However, the transverse prestressed concrete column has improved toughness in the region of large deformations. Especially, large deterioration of shear capacity was not observed until ultimate deformation at 15×10^{-3}*rad* for test specimen with P_w=0.17**%** which was reinforced by a large amount transverse reinforcement. In the comparison with identical transverse reinforcement ratio, the maximum shear strength was highest. At destruction, the shear compression failure in which shear resistance increase after cracking was recognized in all specimens, and great difference could not be observed. In the transverse prestressed concrete test specimen, the rupture of the transverse reinforcement was also confirmed, while it was not confirmed in the reinforced concrete test specimen. It seems that as the test specimen with prestress introduced into the transverse reinforcement possess only a minimal residual tensile strength, and the rupture of transverse reinforcement was caused. That is to say, it is the value $\sigma_{sy}-\sigma_{sp}$ which represents prestress substracted of the transverse reinforcement σ_{sp} from transverse material yield strength σ_{sy}, is considered to be equivalent to the shear resistance of the prestressed concrete columns.

In Fig.4, the shear strength increases for both cases of prestressed concrete and reinforced concrete columns as the quantity of the transverse reinforcement increases. It is indicated that the shear strength of the prestressed concrete test specimen with the identical reinforcement ratio increases about 50% more than that of reinforced concrete test specimen.

And, accumulated energy of prestressed concrete test specimen 60-PW-P1-S is almost equivalent that of the reinforced concrete test specimen 30-PW-P0-S with twice transverse reinforcement ratio to the former, as shown in Fig.5. The result in deterioration of strength in the shear test was good in the region until ultimate deformation while the result of deterioration of strength in the compression test was not good in the region of the high strain. Although an improvement on maximum strength was possible for the compression test when prestress was introduced into transverse reinforcement, the toughness was not good. Otherwise shear strength increased in the shear test, and it displayed better toughness than that of compression test. Paradoxically, it is proven that the effect on confinement appears in the reinforced concrete column test specimen under axial compressive force by the transverse reinforcement the deformation advances considerably. The relation between the improvement in the shear strength and quantity of prestress into the transverse reinforcement was not clarified here because the test was carried out under the constant amount of prestress in the transverse reinforcement.

EXAMINATION OF PAST FORMULAS

Various evaluation formulas for shear strength of reinforced concrete structures often used in Japan are shown in this section and the experimental value is compared with values calculated by these formulas. The formulas estimating the shear strength of past reinforced concrete structures are represented in Fig.6 (a), (b) and (c). The following 3 formulas are shown here; *Modified Arakawa Formula* (7), *Ultimate Shear Strength Formula-A Method* (6), and *New RC Formula* (8). The yield strength of transverse reinforcement is replaced by $\sigma_{sy}-\sigma_{sp}$, in these formulas, because it is decreased by prestress in transverse reinforcement. The ratio K_{pc} of concrete compressive strength to prestress in the transverse reinforcement to uniaxial compressive strength of concrete, is multiply for the concrete compression strength of the shear test specimen. When a value of σ_B is substituted into these formulas, the coefficient K_{pc} is multiplied by the uniaxial compressive strength of concrete. The best results were obtained using the *New RC Formula*.

Eq.1 Modified Arakawa Formula [(7)]

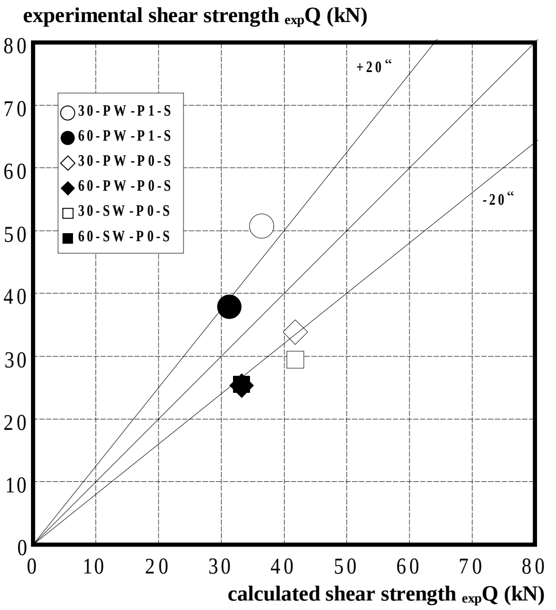
$$Q_{su1} = \left\{ \frac{0.068 \cdot P_t^{0.23}(\sigma_B + 180)}{M/QD + 0.12} + 2.7\sqrt{P_w \cdot \sigma_{wy}} + 0.1\sigma_0 \right\} \cdot b \cdot j \quad \textbf{(kgf)} \ \ldots \qquad \textbf{(a)}$$

Eq.2 Ultimate shear strength Formula (A method) (6)

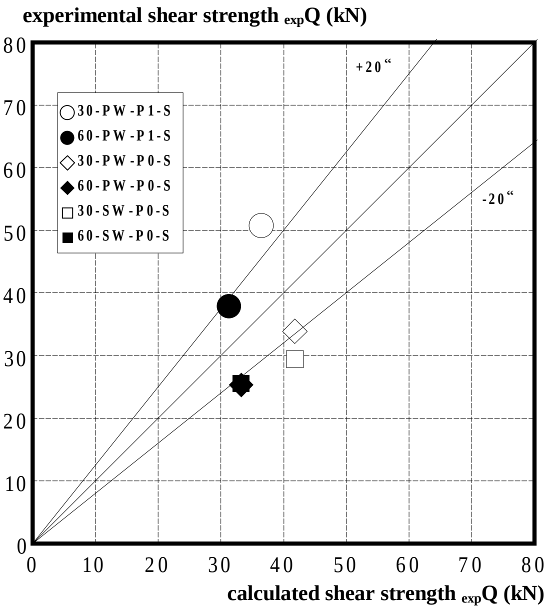
$$Q_{su2} = b \cdot j_t \cdot P_w \cdot \sigma_{wy} \cdot \cot\phi + \tan\theta \cdot (1-\beta) \cdot b \cdot D \cdot \upsilon \cdot \sigma_B / 2 \quad \textbf{(kgf)} \ \ldots \qquad \textbf{(b)}$$

Eq.3 New RC Formula (8)

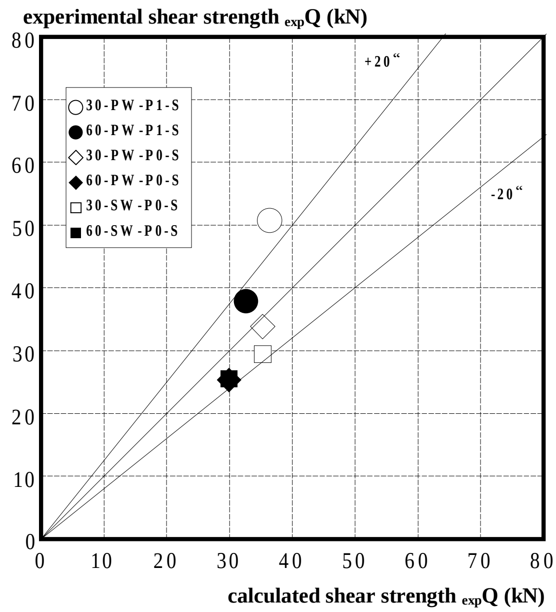
$$Q_{su3} = b \cdot j_t \cdot P_w \cdot \sigma_{wy} \cdot \cot\phi + \alpha \cdot (1-\beta) \cdot b \cdot D \cdot \upsilon_0 \cdot \sigma_B \quad \textbf{(N)} \ \ldots \qquad \textbf{(c)}$$



(a)Modified Arakawa Formula



(b)Ultimate shear strength Formula (*A* method)



(c)New RC Formula

Fig.6: Calculated Formulas

P_t: Tensile reinforcement ratio
B: Width of member

σB: Compressive strength of concrete

M/QD: Shar span ratio

Pw: Transverse reinforcement ratio

σwy: Transverse reinforcement yield strength

σ0: Axial stress

jt: Center distance of longitudinal reinforcement

D: All depth

L: Inner size length

υ_0: Effectiveness factor of concrete compressive strength

ϕ: Concrete compressive lattice of the truss mechanism

CONCLUSION

From the shearing test of reinforced concrete short columns with prestress introduced into transverse reinforcement, the following suggestions are indicated:

1. Introducing prestress into the transverse reinforcement is a very effective method in improving the shear strength.

2. It is possible to improve the shear strength by the increase of the transverse reinforcement, when prestress was introduced into the transverse reinforcement.

3. The prestressed test specimen displayed greater toughness than the reinforced concrete specimen.

4. In the examination of evaluation by formulas for shear strength, it was recognized that the experimental results agreed well with most suitable for the *New RC Formula*.

In the future, research taking into considering the axial force and amount of prestress into transverse reinforcement will be carried out, and these results will be reported.

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