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REINFORCING EFFECT OF STEEL PLATE HOOPS ON DUCTILITY OF R/C SQUARE COLUMN

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ABSTRACT

A new transversely reinforcing method is proposed. This method is to confine concrete by steel plate hoops arranged transversely. This paper describes the experimental results of square columns reinforced by the new method. The experimental results concluded that the steel plate hoops improved both axial and lateral deformation capacity of R/C square columns since they confined concrete more effectively than the conventional transversely reinforcing method did.

KEYWORDS

R/C column; transversely reinforcing method; steel plate hoop; deformation capacity; confining effect; ductility; shear failure; bond splitting failure; compressive failure

INTRODUCTION

In order to improve ductility of R/C square columns, it is necessary to confine concrete sufficiently against the dilatation of concrete due to bond splitting failure or compressive failure. In the conventional reinforcing method, cross ties are usually arranged in order to increase resistance capacity to the dilatation of concrete, however, the method is somewhat inconvenient for construction. In this study, the new reinforcing method is proposed. This method is to confine concrete by steel plate hoops arranged transversely. The plate hoops have larger flexural rigidity transversely than the conventional hoops do. Also, this method is convenient for construction since the longitudinal reinforcement bars are arranged accurately.

The aim of this study is to clarify the performance of plate hoops on ductility of R/C square columns based on cyclic lateral loading tests under a constant axial load.

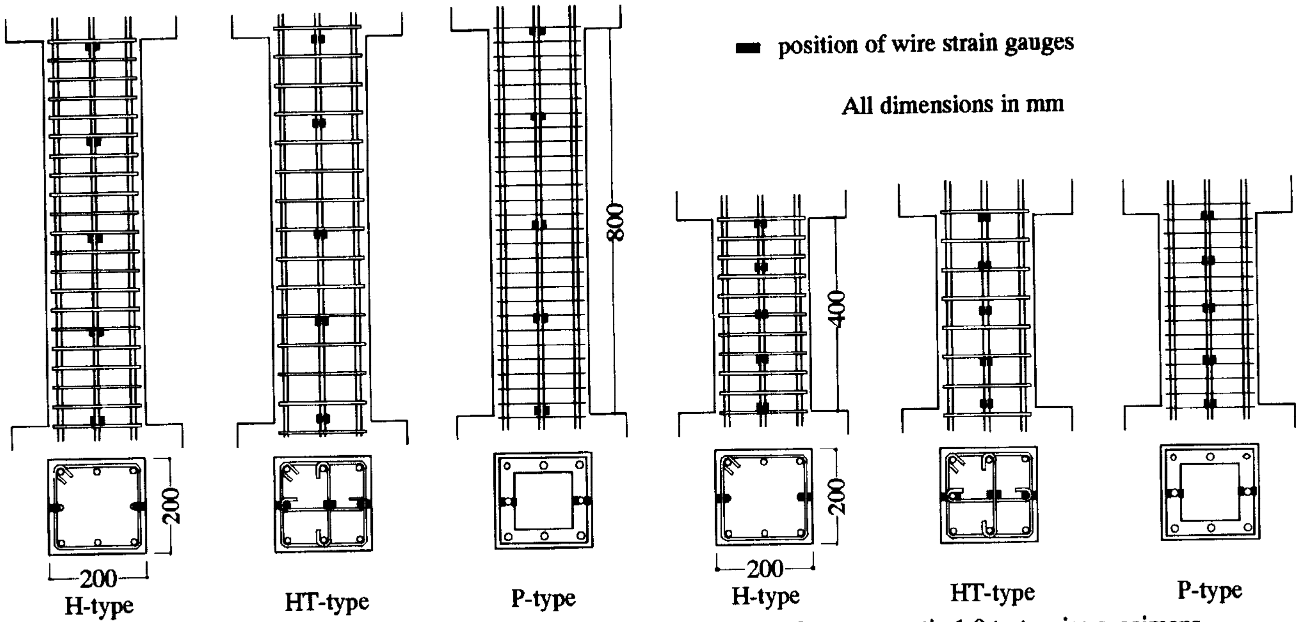
LATERAL LOADING TESTS

Specimens

Figure 1 shows nominal dimensions and arrangement of reinforcement of 1/3 scale model specimens. The properties of test specimens and mechanical properties of materials are shown in Tables 1, 2 and 3, respectively.

Three kinds of transversely reinforcing method were chosen in order to compare their reinforcing effect. They were the H-type specimen reinforced by conventional hoops, the HT-type specimen reinforced by conventional hoops with cross ties and the P-type specimen reinforced by plate hoops. The spacing of hoops was decided so as to be same transversely reinforcing strength, $p_w\sigma_{yw}$, where p_w was reinforcement ratio of hoops and σ_{yw}

was yield strength of hoops. Two kinds of the magnitude of axial load applied and two kinds of shear-span ratio were chosen, respectively. The specimens were so designed as to show flexural yielding at a critical section prior to shear failure by using ultimate strength equations (AIJ,1990,1991) except the shear-span ratio 1.0 specimens subjected to axial load, σ_c/σ_B=1/3, where $\sigma_c = N/(bD)$, N was vertical load, b and D were width and depth of column, respectively and σ_B was compressive strength of concrete.



shear-span ratio 2.0 test series specimens

shear-span ratio 1.0 test series specimens

Fig. 1 Nominal dimensions of test specimens, arrangement of reinforcement and position of gauges

Table 1 Properties of test specimens

Specimen	Shear-span Ratio	Longitudinal reinforcement	Arrangement of hoops	Magnitude of axial load σ_c/σ_B
H -2-1/5	2.0	8-D13 (p_g=2.54%)	2-6ϕ@50 (p_w=0.52%)	1/5
HT -2-1/5			3-6ϕ@75 (p_w=0.52%)	
P -2-1/5			PL-1.6x16@37mm (p_w=0.69%)	
H -2-1/3		8-D13 (p_g=2.54%)	2-6ϕ@40 (p_w=0.65%)	1/3
HT-2-1/3			3-6ϕ@60 (p_w=0.65%)	
P -2-1/3			PL-1.6x16@30mm (p_w=0.85%)	
H - 1-1/8	1.0	8-D13 (p_g=2.54%)	2-6ϕ@20 (p_w=1.28%)	1/8
HT-1-1/8			3-6ϕ@30 (p_w=1.28%)	
P -1-1/8			PL-1.6x16@15mm (p_w=1.69%)	
H -1-1/3		8-D13 (p_g=2.54%)	2-6ϕ@20 (p_w=1.28%)	1/3
HT-1-1/3			3-6ϕ@30 (p_w=1.28%)	
P -1-1/3			PL-1.6x16@15mm (p_w=1.69%)	

Note: p_g = longitudinal reinforcement ratio (= $a_g/(bD)$, a_g = cross sectional area of longitudinal reinforcement)
p_w = transverse reinforcement ratio (= $a_w/(bx)$, a_w = area of a pair of hoops, x = spacing of hoops)

Table 2 Mechanical properties of reinforcement

Bar or Plate	Cross sectional area a (cm^2)	Yield strength σ_y (kgf/cm^2)	Tensile strength σ_u (kgf/cm^2)	Young's modulus E_s (10^6kgf/cm^2)	Elongation (%)
6ϕ	0.26	3715, 3606*	4878, 5250*	2.19, 2.08*	18.5, 24.5*
D13	1.24	3688, 3399*	5394, 4632*	1.86, 2.08*	20.7, 21.8*
PL-1.6	0.26	2738	3705	2.12	33.8

The values marked by * denotes ones used in the shear-span ratio 1.0 test series except the P-type specimens.

Table 3 Mechanical properties of concrete

Specimen	Compressive strength σ_B (kgf/cm^2)	Young's modulus E_s (10^5kgf/cm^2)	Specimen	Compressive strength σ_B (kgf/cm^2)	Young's modulus E_s (10^5kgf/cm^2)
H -2-1/5	235	2.21	H -1-1/8	251	2.25
HT-2-1/5	206	2.15	HT-1-1/8	301	2.50
P -2-1/5	225	2.17	P -1-1/8	244	2.53
H -2-1/3	235	2.21	H -1-1/3	233	2.23
HT-2-1/3	206	2.15	HT-1-1/3	229	2.07
P -2-1/3	190	2.06	P -1-1/3	251	2.53

Loading Setup and Program

The loading setup is shown in Fig. 2. The loading pattern was cyclic pattern with alternating drift reversed as shown in Fig. 3. The constant vertical load applied to specimens was maintained during lateral loading tests.

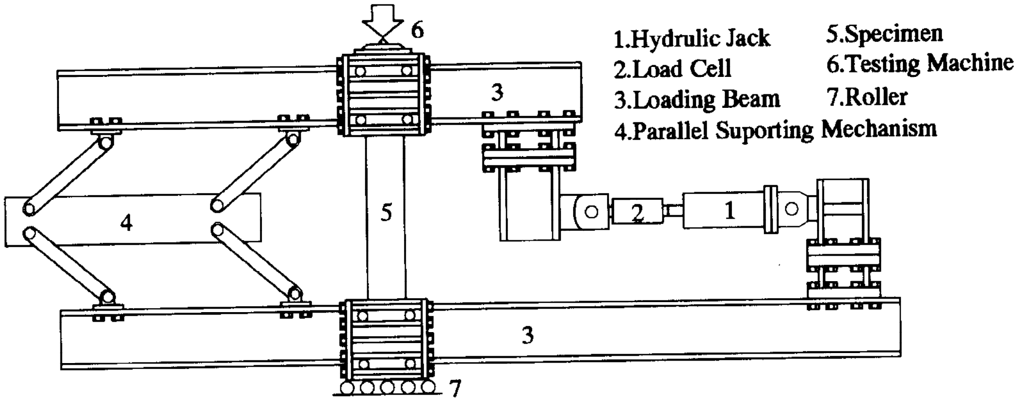


Fig. 2 Loading setup

Measurement System

The lateral and vertical displacements between upper and lower stubs were measured by high sensitive electric transducers (HSETs, 200μ/mm and 500μ/mm) attached to the measurement system shown in Fig. 4. The strains of longitudinal reinforcement bars and hoops were measured by wire strain gauges pasted at the points shown in Fig. 1.

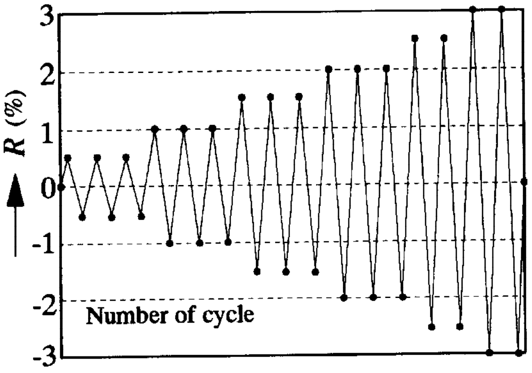


Fig. 3 Loading program

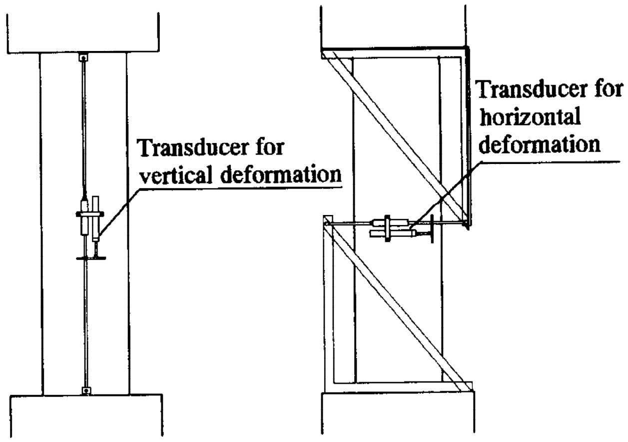


Fig. 4 Measurement system

TEST RESULTS

Figure 5 shows lateral load, Q - drift angle, R, hysteretic response for shear-span ratio 2.0 and 1.0 specimens, respectively. The drift angle, R, was obtained by dividing relative lateral displacement between upper and

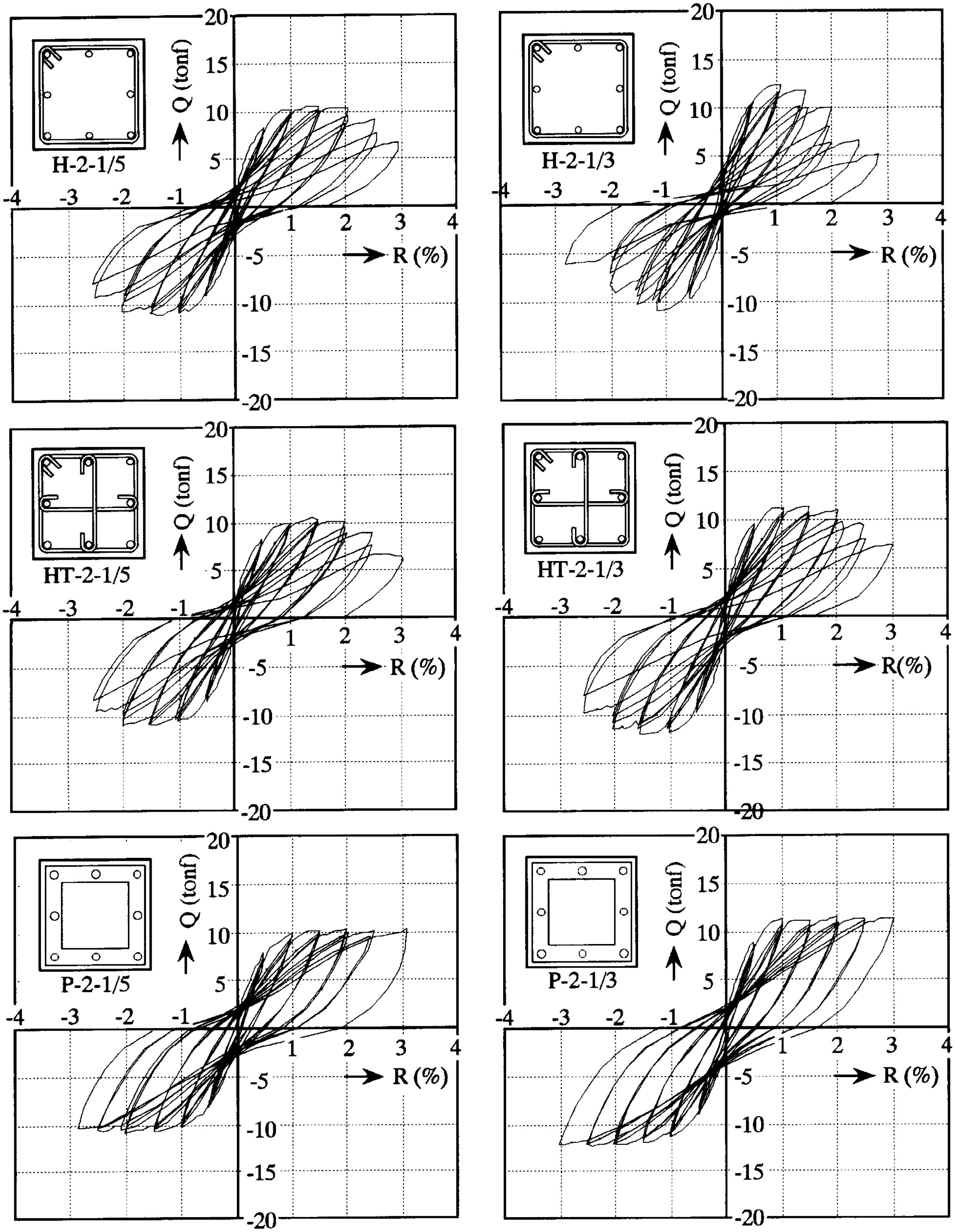


Fig. 5a Lateral load, Q - drift angle, R, relationship for shear-span ratio 2.0 test series specimens

lower stubs by clear height of column. Also, the vertical average strain, ε_v - drift angle, R, hysteretic response were shown in Fig. 6. The test results are summarized in Table 4.

In the shear-span ratio 2.0 test series the longitudinal reinforcement bars began to yield in the vicinity of 1% of drift angle. All specimens showed flexural yielding failure mode. In the low magnitude of axial load, σ_c/σ_B=1/5

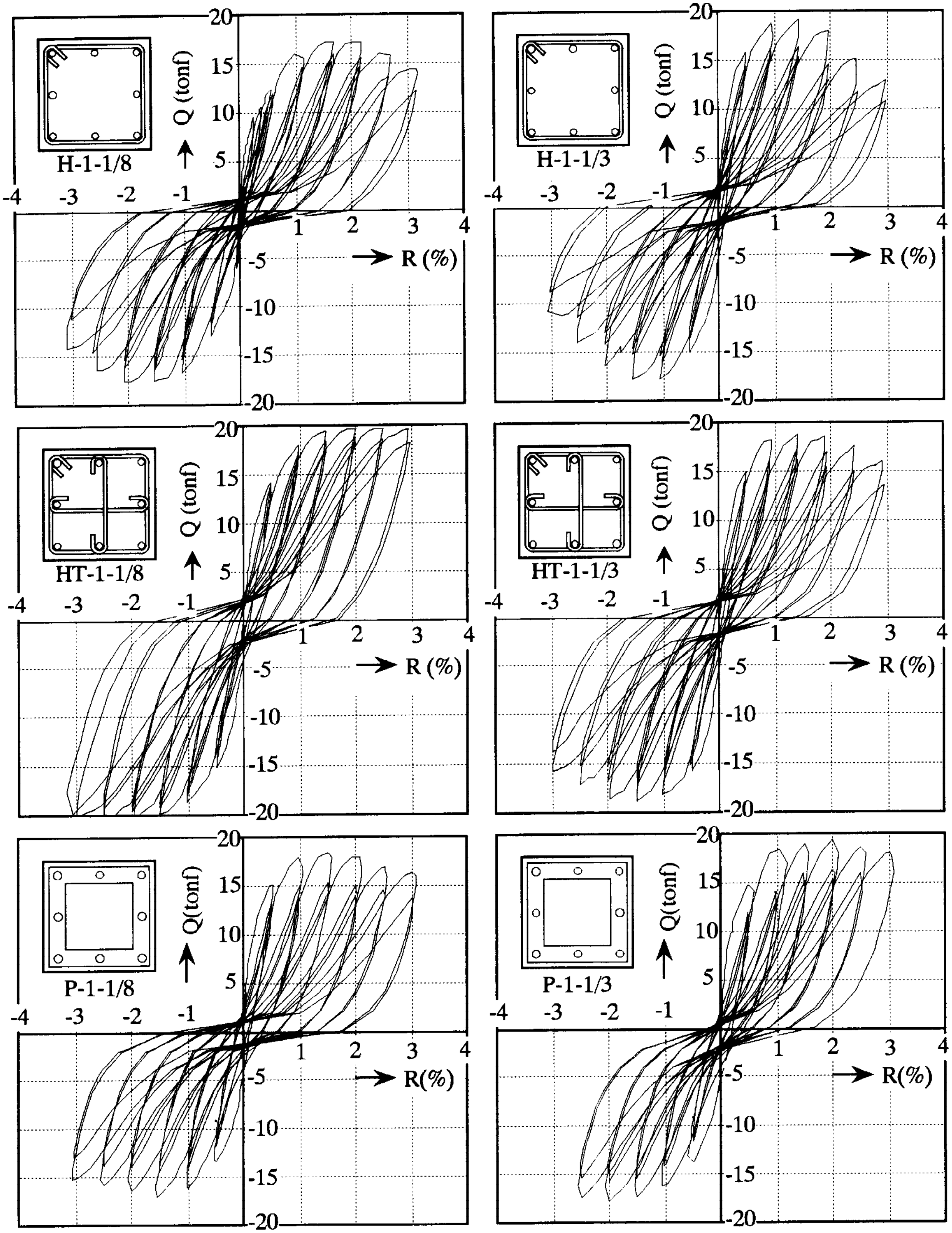


Fig. 5b Lateral load,Q - drift angle, R, relationship for shear-span ratio 1.0 test series specimens

test series, the lateral load carrying capacity of all specimens did not deteriorate until *R* reached 2%. However, the capacity of the H-type and HT-type specimens deteriorated gradually beyond 2% of drift angle since the bond splitting cracks along longitudinal reinforcing bars occurred and spread remarkably. The capacity deteriorated gradually as the elongating rate of column changed slowly or decreased as shown in Fig. 6. This is due to that the shear transfer mechanism capacity due to compressive concrete struts which constituted shear resistance mechanism deteriorated since the bond deterioration due to propagation of bond splitting cracks occurred. On the other hand, the capacity of the P-type specimen did not deteriorate beyond 2% of drift angle. The new reinforcing method improved both the axial and lateral deformation capacity since both the lateral load - deformation hysteretic response and the vertical elongation - lateral deformation one were stable like one characteristic of flexural failure.

In the high magnitude of axial load, σ_c/σ_B=1/3 test series, the capacity of the H-type specimen deteriorated beyond 1% of drift angle. The deterioration was remarkable as *R* increased. The capacity of the HT-type specimen did not deteriorate until *R* reached 2%. However, the deterioration was remarkable beyond 2% of drift angle. On the other hand, the load - deformation hysteretic response of the P-type specimen was stable like one characteristic of flexural failure since the deterioration of the lateral load carrying capacity did not occur even if *R* increased. Also, the vertical elongating rate of the P-type specimen did not change or decrease.

In the shear-span ratio 1.0 test series the predominant action was shear. In the specimens under the axial load, σ_c/σ_B=1/8, the deterioration of lateral load carrying capacity was slight until *R* reached 2%. However, the deterioration of the capacity of the H-type specimen was severe beyond 2% of *R*. Also, the elongating rate of column changed slowly or decreased beyond 2% of *R*. On the other hand, in both the HT-type and the P-type specimens the deterioration of the capacity was slight and the load - deformation hysteretic response were also stable as well as in the shear-span ratio 2.0 test series.

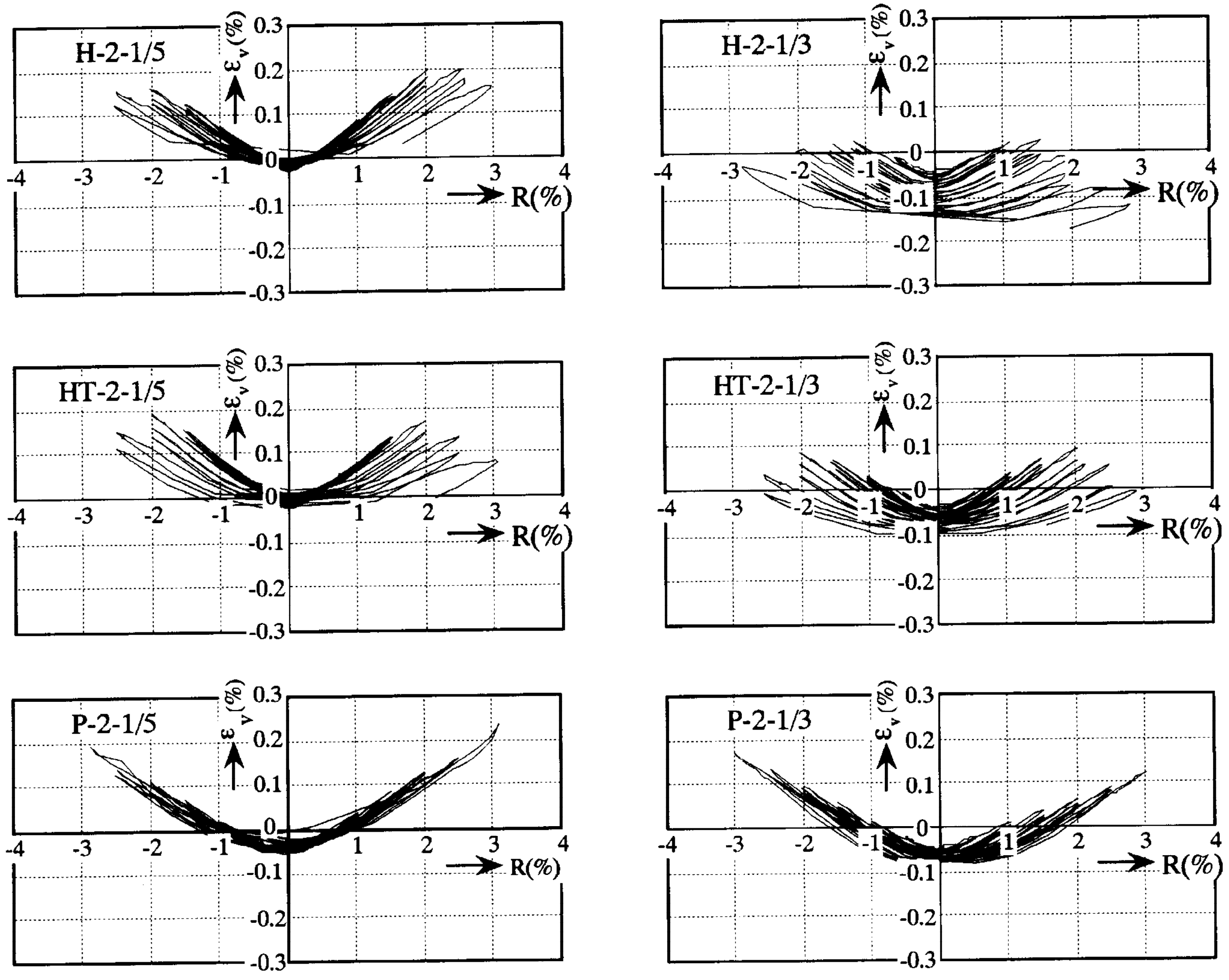


Fig. 6a Vertical mean strain, ε_v - drift angle, *R*, relationship for shear-span ratio 2.0 test series specimens

Table 4 Summary of test results

Specimen	Experiment: Maximum lateral load Q_u (tonf) +	Experiment: Maximum lateral load Q_u (tonf) -	Experiment: Drift angle at peak load R_u (%) +	Experiment: Drift angle at peak load R_u (%) -	Calculation: Flexural capacity Q_{fu} (tonf)	Calculation: Shear capacity Q_{su} (tonf)	Calculation: Bond splitting capacity Q_{bu} (tonf)
H -2-1/5	10.5	11.0	1.50	1.31	9.2	12.5	8.2
HT-2-1/5	10.4	11.0	1.50	1.51	8.8	12.2	7.4
P -2-1/5	10.3	10.8	3.10	2.00	9.1	12.4	8.5
H -2-1/3	12.3	10.9	1.08	1.19	10.7	14.8	8.6
HT-2-1/3	11.4	12.0	1.43	1.43	10.1	14.4	7.8
P -2-1/3	11.5	12.2	2.01	2.41	9.7	13.9	7.9
H -1-1/8	17.4	17.6	2.17	2.08	15.6	20.1	13.6
HT-1-1/8	19.6	20.3	1.98	2.53	16.7	22.2	15.4
P -1-1/8	18.5	16.9	1.52	1.54	16.3	19.8	14.4
H -1-1/3	19.1	17.8	1.44	1.53	20.5	19.3	13.3
HT-1-1/3	18.8	18.8	1.40	1.40	20.3	19.1	13.1
P -1-1/3	19.3	17.9	2.00	2.01	22.1	20.1	15.1

Note:

The calculated values of each lateral capacity were obtained by the ultimate strength equations (AIJ, 1190,1991).

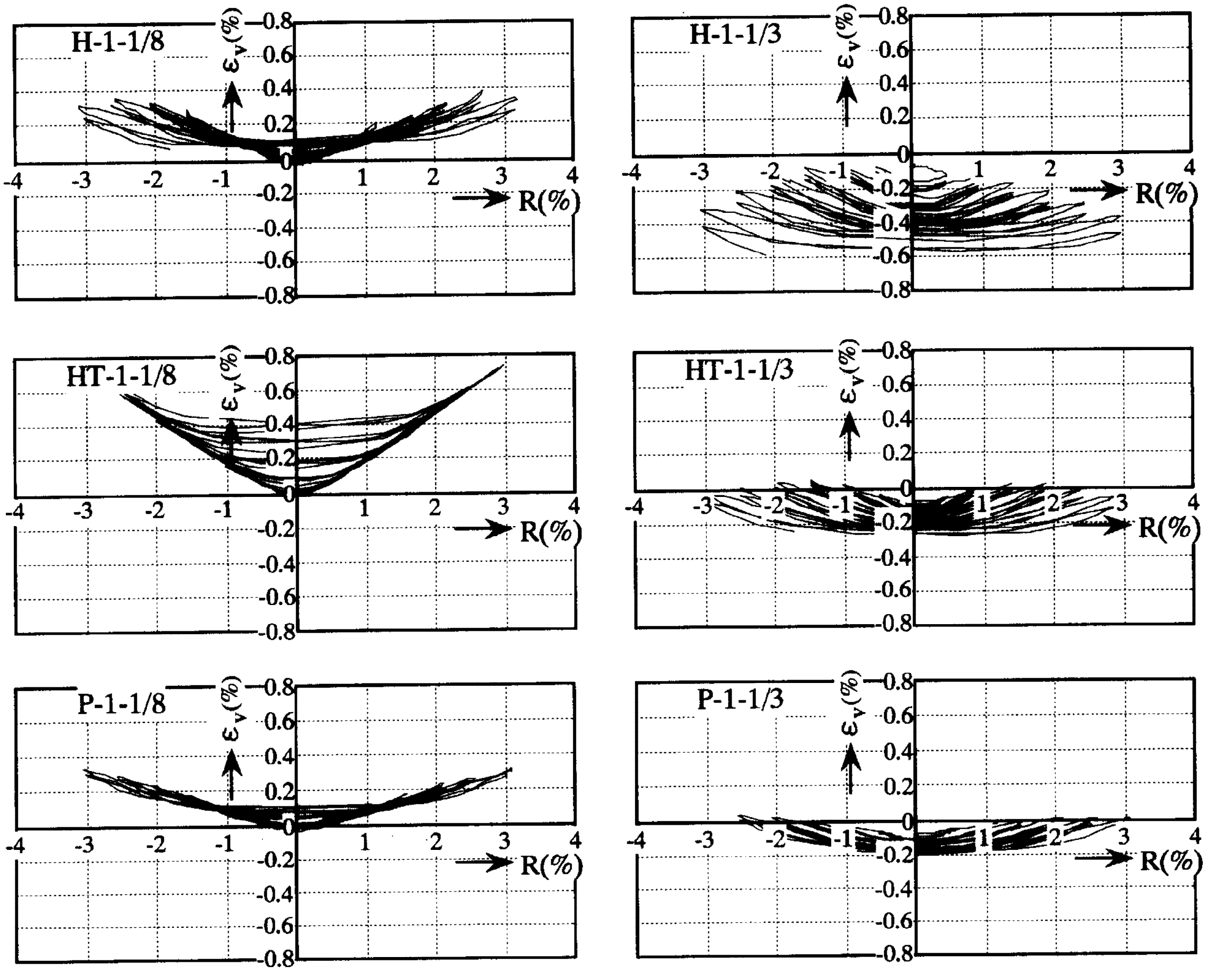


Fig. 6b Vertical mean strain, ε_v - drift angle, R, relationship for shear-span ratio 1.0 test series specimens

In the specimens under the axial load, σ_c/σ_B=1/3, the H-type specimen showed the bond splitting failure mode associated with the propagation of the bond splitting cracks along the longitudinal reinforcement bars. The shortening of column progressed gradually beyond 1.5% of R as shown in Fig. 6.

Both the HT-type and P-type specimens showed the flexural yielding failure mode. The load - deformation hysteretic response was stable and the shortening of column was small. The new reinforcing method improved both the axial and lateral deformation capacity due to the confining effect of steel plate hoops even if the predominant action was shear in case of small shear-span ratio.

CONCLUSION

The lateral loading tests under a constant axial load of R/C square columns reinforced by three kinds of transversely reinforcing method, i.e. the conventional hoops reinforcing method, the conventional hoops with cross ties one and the plate hoops one, were conducted in order to clarify the performance of plate hoops on the ductility of columns. The test results concluded that the plate hoops confined concrete more effectively than the conventional hoops and cross ties did if their transversely reinforcing strength was same and consequently improved both the lateral and axial deformation capacity of square columns.

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