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SEISMIC STRENGTH OF SMALL SIZE STEEL ENCASED REINFORCED CONCRETE COLUMNS WITH HIGH STRENGTH MATERIALS

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ABSTRACT

Described are the seismic behavior of a new SRC(steel encased reinforced concrete) column using a small size steel, high strength concrete(60MPa) and high strength hoops(900MPa). Fourteen SRC column specimens were tested. Experimental results showed the effectiveness of high strength hoops for both increasing shear carrying capacity and improving the ductility of such small size steel encased high strength concrete columns. No separation of the concrete section by the small steel seems to be brought when subjected to lateral load in the direction of strong axis, although separation of the concrete section can not be ignored in the direction of week axis. The shear strength of the new SRC columns is evaluated using truss and arch analogy.

KEYWORDS

SRC column, small size steel, high strength concrete, high strength hoop, shear strength, flexual strength, cyclic loading, loading direction

INTRODUCTION

In last decade, high strength concrete(specified compressive strength 40 to 50MPa) and high strength hoops(yield strength 700 to 1300MPa) have been widely used in high-rise(25 to 40 stories) reinforced concrete(R/C) structures in Japan. High strength concrete are also used in steel encased reinforced concrete(SRC) structures, not widely as compared with R/C structures. Recently, higher strength concrete(60MPa) are being used not only in R/C structures(Aoyama et al., 1994) but also in concrete filled steel tubular structures(Yonezawa et al., 1993). Utilization of high strength materials brings structural advantages, such as small member section, high stiffness and strength, long span and reduction of amount of materials. The authors have been studying on a new SRC column to utilize high strength materials in SRC structures(1994a, 1994b, 1995a, 1995b). This new SRC column has following features, 1)a small size steel encased reinforced concrete, 2) using high strength concrete (50 to 60Mpa) and 3)high strength hoops(900Mpa). This SRC column is developed in order to have high shear carrying capacity and ductile performance under seismic loading.

Table 1. List of specimens

Specimen		Hoop(4 ϕ)			Pw· σ wy
Loading in strong axis	Loading in week axis	Spacing(mm)	Ratio,Pw(%)	Type	(kg/cm ^{2})
SRC-20-A-R	SRC-20A			A	59.9
SRC-20-B-R	SRC-20B	@20	0.63	B	30.0
SRC-20-C-R	SRC-20C			C	109.1
SRC-50-A-R	SRC-50A	@50	0.25	A	23.8
SRC-50-B-R	SRC-50B			B	11.9
SRC-100-A-R	SRC-100A	@100	0.125	A	11.9
SRC-100-B-R	SRC-100B			B	6.0

Table 2. Mechanical properties of hoop reinfmt., main reinfmt. and steel plates(kg/mm ^{2})

	Hoop reinfmt.(4 ϕ)			Main reinfmt.	Steel plates	
	A	B	C	(D13)	P-5(web)	P-7(flange)
Yield strength	95.1	47.6	173.1	33.5	37.0	32.3
Tensile strength	102.4	49.9	198.6	51.2	47.9	46.2

Table 3. Mechanical properties of concrete(kg/cm ^{2})

Specimen	Comp. strength	Splitting strength	Specimen	Comp. strength	Splitting strength
SRC-20-A-R	605	42	SRC-20A	617	39
SRC-20-B-R	578	34	SRC-20B	617	39
SRC-20-C-R	657	43	SRC-20C	617	39
SRC-50-A-R	612	47	SRC-50A	655	41
SRC-50-B-R	659	36	SRC-50B	659	37
SRC-100-A-R	640	42	SRC-100A	655	41
SRC-100-B-R	635	40	SRC-100B	655	41

SEISMIC LOADING TEST

Specimens

Fourteen column specimens, listed in Table 1, were provided and tested. Each specimen was subjected to cyclic and reversal bending moment and shear force under constant axial force (50tonf). Half seven specimens were tested under the loading direction of the strong axis of tha steel. The other seven specimens having the same parameters as former ones were tested under the loading direction of the week axis of the steel. The concrete section of the specimens was 200x200mm. The steel section was 100x50x5x7mm, and the ratio of the height of steel section to that of concrete section was 1/2 in the direction of the strong axis of the steel and 1/4 in the direction of the weak axis, respectively, and was smaller than that of ordinary SRC columns used in Japan. The ratio of clear-height to depth of the column specimen was set as 2.0 mainly focusing on the shear strength. As test parameters, three different strengths of hoop bars, as shown in Fig.1, were adopted. The tensile yield strengths hoop bars were 930MPa (referred to as Hoop A), 450MPa(Hoop B) and 1700MPa(Hoop C). Welded closed hoops were provided for Hoop A and B, and spiral hoops were provided for Hoop C. The hoop spacing was set as 20mm, 50mm and 100mm, corresponding to the hoop reinforcement ratio of 0.63%, 0.25%and 0.125%,

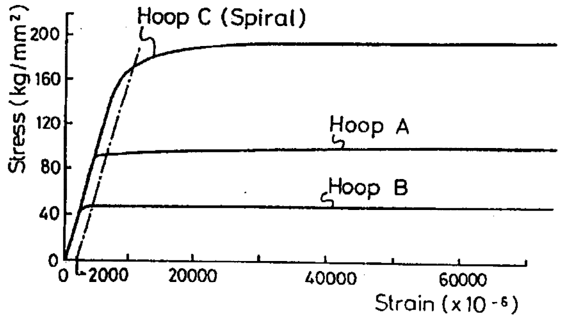

Fig. 1. Stress-strain curves of hoop bars

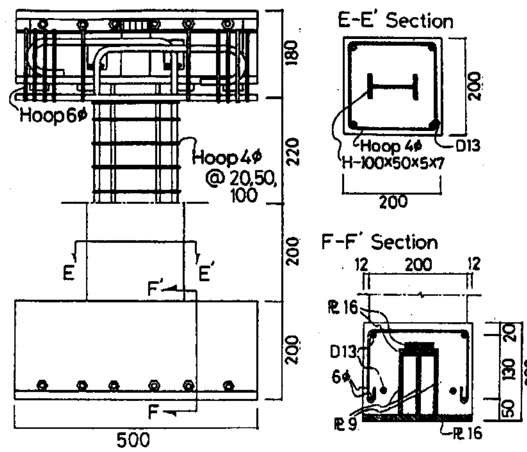

Fig. 2. Detail of specimen

respectively. A detail of a specimen is shown in Fig.2. Mechanical properties of hoop reinforcements, main reinforcement and steel plates are shown in Table 2. Table 3 shows mechanical properties of concrete. Normal concrete with coarse aggregate having a nominal maximum diameter of 10mm was used.

Test Results

Loading Direction of the Strong Axis. Load-deflection curves under the loading direction of the strong axis are shown in Fig. 3. Comparing the specimens having different hoop spacing, smaller hoop spacing, in other words, larger hoop ratio gave lager shear carrying capacity and more ductile behavior. Also comparing the specimens having the same hoop spacing but different strength of hoop reinforcement, higher hoop strength brought higher shear strength in case of specimens having larger hoop spacing 100mm. In case of specimens having smaller hoop spacing 20mm and 50mm, higher hoop strength gave more ductile behavior, although the effect of hoop strength on shear strength of columns was not clearly observed. Only specimens SRC-20-A-R and SRC-20-C-R failed in shear at large deflection after flexural yielding. All other specimens failed in shear before flexural yielding.

Loading Direction of the Week Axis. Load-deflection curves under the loading direction of the week axis are shown in Fig. 4. The test results are similar to those of the loading direction of the strong axis mentioned above, that is, larger hoop ratio gave higher shear strength and more ductility. However, no specimen developed its flexural strength, even in the case of the specimen SRC-20A and SRC-20C

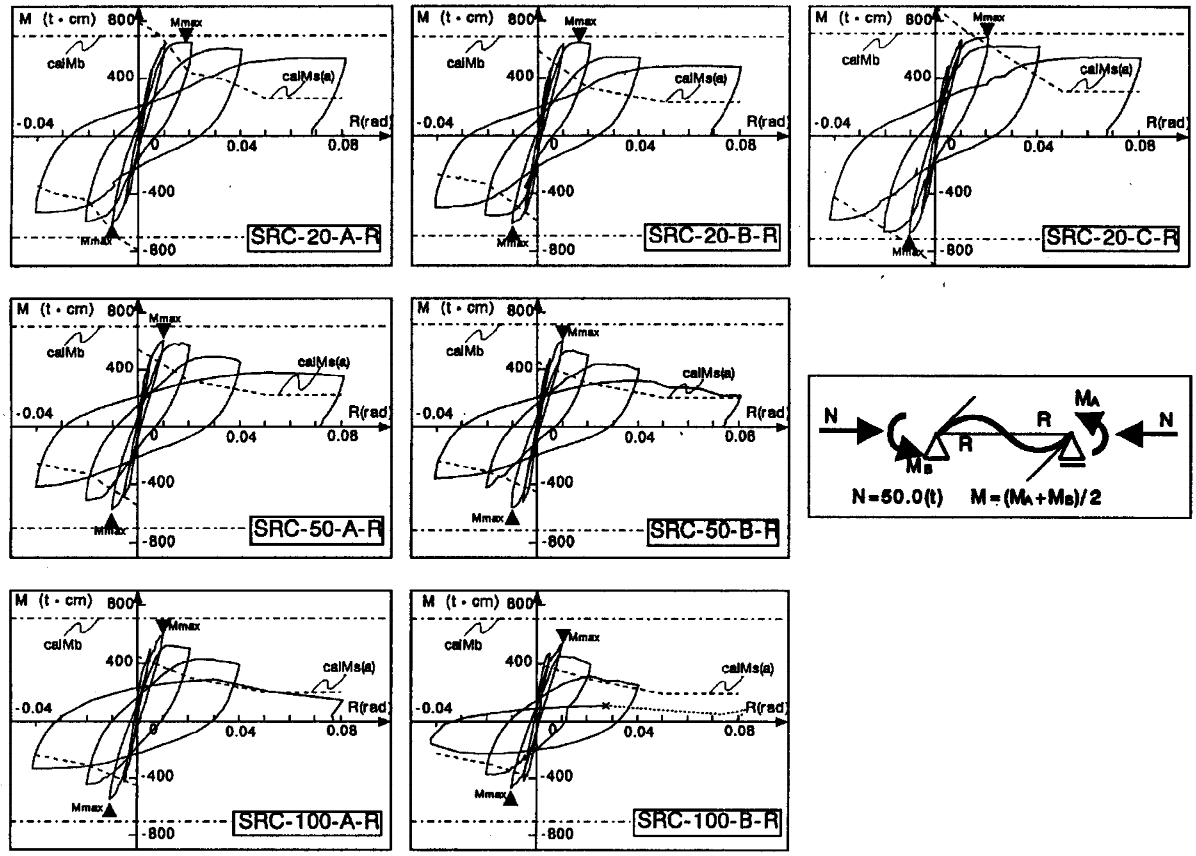

Fig. 3. Load-deflection curves under loading direction of the strong axis

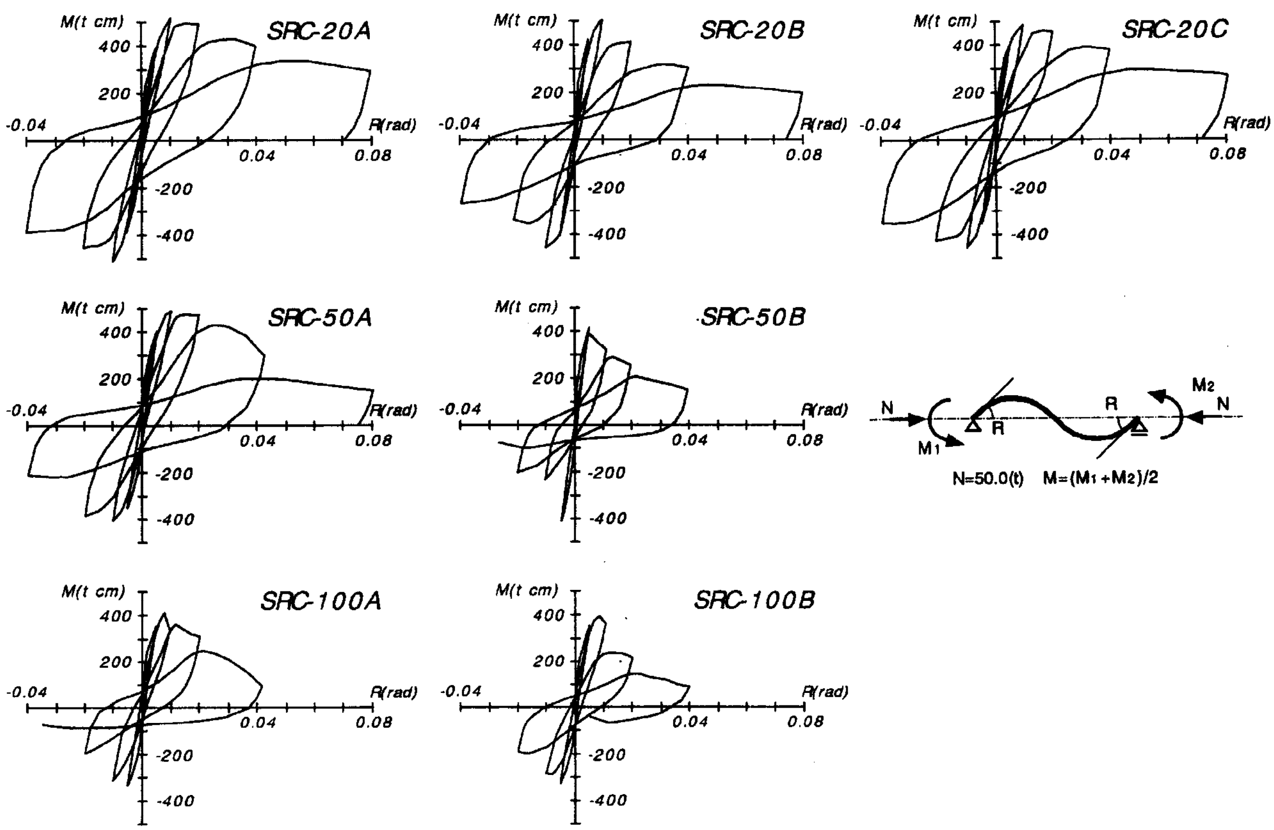

Fig. 4. Load -deflection curves under loading direction of the week axis

identical to the specimens SRC-20-A-R and SRC-20-C-R, respectively, which developed the flexural strength under the loading direction of the strong axis. Comparing the specimens having the same parameters,but with different loading direction, the lateral load carrying capacity in the direction of the week axis was clearly smaller than that of the strong axis. This test result is discussed later.

DISCUSSION ON RESULTS

Strain in Hoop Reinforcement

Fig. 5 shows strain developed in high strength hoop reinforcement(Hoop A) of the specimen SRC-50-A-R and SRC-100-A-R. High strength hoops did not yield at the maximum load, but yielded at large deflection, indicating that the effectiveness of high strength hoops depends on the deflection.

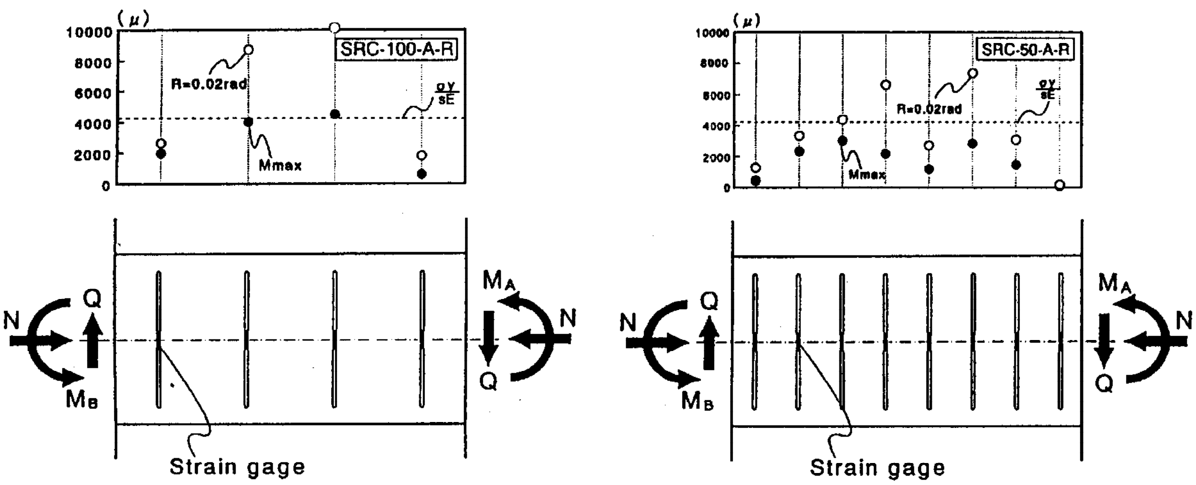

Fig. 5. Strain developed in hoop reinforcement

Shear Force carried by Small Steel

Fig. 6 shows shear force developed in small steel at the top, center and bottom of the column under the loading direction of the strong axis. The Qby and Qwy in Fig. 6 are shear capacity determined by the full plastic moment of the steel section and the shear yielding capacity of the steel web, respectively. Shear force developed in the steel was not constant along the member axis, and shear force at the center was larger than those at column ends. It is indicated that shear force of the columns was transferred from concrete to steel, and again steel to concrete. It should be noted that the small size steel carried the shear force at least Qby without regard to failure mode.

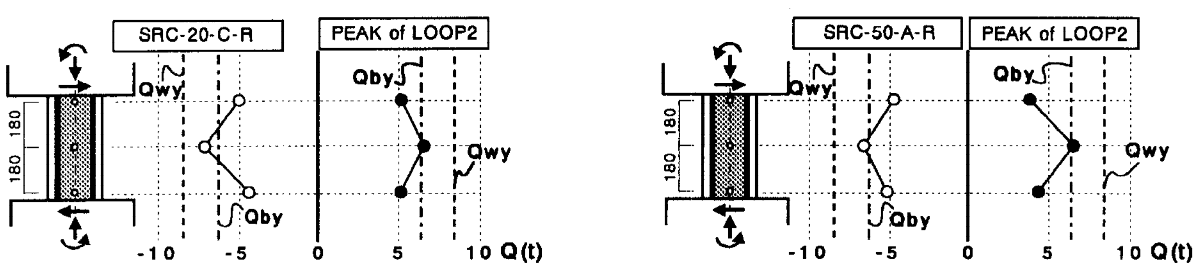

Fig. 6. Shear force developed in steel (loading in the strong axis)

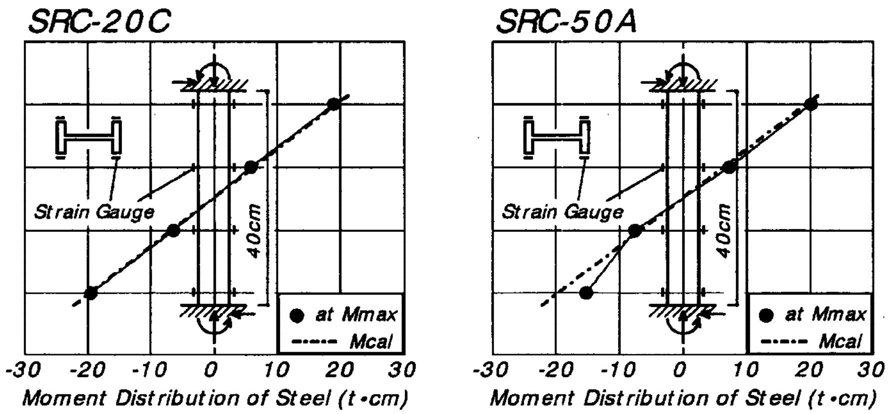

Fig. 7. Moment developed in steel (loading in the week axis)

Fig. 7 shows moment distribution along the member axis of the columns under the loading direction of the week axis at maximum lateral load. The small steel developed its full plastic moment at the column ends. The moment distribution along the member axis is almost linear, indicating that small steel carried shear force determined by the full plastic capacity in the week axis.

Maximum Strength

Flexural Strength. The flexural strength of the columns were estimated by using superposed method(AIJ Standard, 1987) and compared with the test results. In the method, it was assumed that 1)Concrete, steel and reinforcing bar had rigid-plastic properties, 2)Concrete had no tension strength,but had full cylinder compressive strength, and 3)Steel and reinforcing bar had full yield strength in both tension and compression. Fig. 8 shows the moment(M)-axial force(N) interaction and the test results. The calculated flexural strength calMb slightly overestimated the experimental strength exM. It is indicated that the compressive stress of concrete stress block for the calculation of flexural strength was overestimated or could not be assumed as cylinder strength. Based on the test results, the effective compressive stress of high strength concrete of 60MPa was estimated as 0.8 times the cylinder strength.

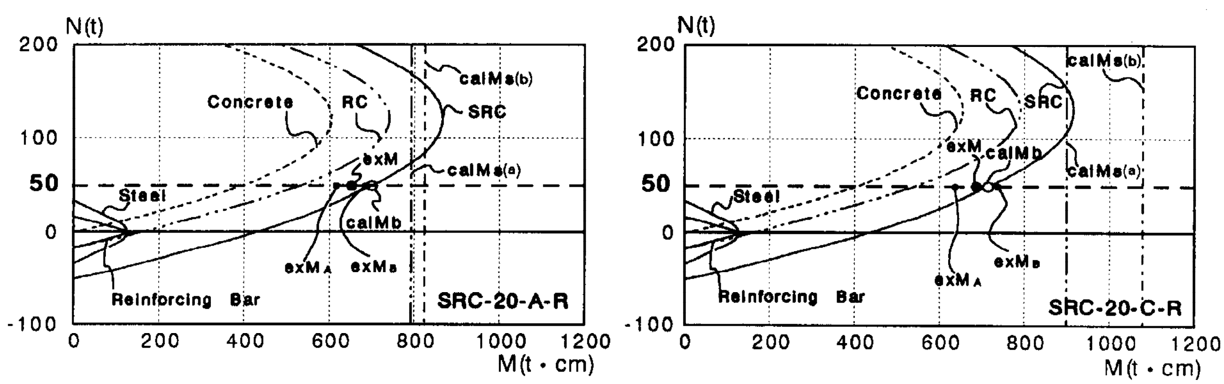

Fig. 8. M-N interaction and test results

Shear Strength. As mentioned before, the specimens having high strength hoops, Hoop A and C,with spacing 20mm(SRC-20-A-R and SRC-20-C-R) developed the flexural strength when subjected to lateral load in the direction of the strong axis. On the other hand, when subjected to lateral load in the direction of the week axis, the specimens having the same hoop reinforcement(SRC-20A and SRC-20C) failed in shear, and their maximum strengths were approximately 75% of the flexural strength. The encased small size steel developed its full plastic moment and carried shear force coressponding to the full plastic moment without regard to the loading direction, as mentioned before. It is indicated that separation of the concrete section by the small size steel could be ignored in the loading direction of the strong axis, but should be taken account in the loading direction of the week axis.

Based on the test results mentioned above, the shear strength of the columns were estimated by using truss and arch analogy. In the estimation, following assumptions were adopted. 1)The strength of SRC is sum of strengths of R/C and Steel . 2) The steel carries shear force corresponding to its full plastic moment. 3)The strength of R/C is estimated by the truss and arch analogy method, referred to Method A of the AIJ design guidelines(1990). 4)The concrete section is divided to four parts , as shown in Fig. 9, in case of the loading direction of the week axis. For the parts 1 and 2, truss and arch mechanism is taken into account. Only arch mechanism is considered for the parts 3 and 4.

Fig. 10 shows the comparison of the analytical and experimental results. The calculated shear strengths agreed well with the test results, although the analytical strengths slightly underestimated the test results, indicating that the analytical method can be used in design practice in conservative manner.

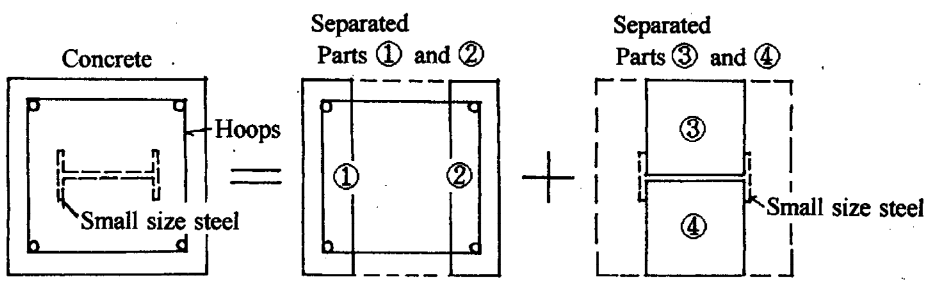

Fig. 9. Model for separation of concrete section by small steel under the loading direction of the week axis

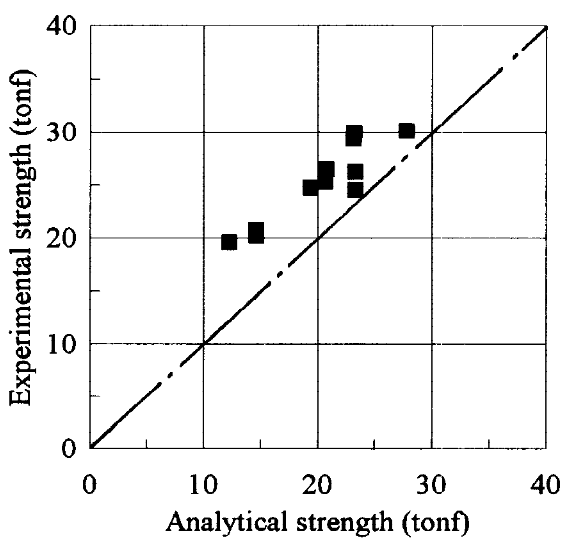

Fig. 10. Analytical and experimental strength

CONCLUSIONS

Test on small size steel encased high strength concrete (60MPa) columns using high strength hoops(900MPa to 1700MPa) were carried out to examine their seismic performance, and following conclusions were drawn.

1)High strength hoops were quite effective to increase shear strength and improve the ductility of small size steel encased high strength concrete columns. The shear strength of the columns increased as the capacity of hoop reinforcement ($Pw \cdot \sigma wy$, where Pw : ratio of hoop reinforcement, σwy : tensile yield strength of hoop reinforcement) increased, although the shear strength were not increased in proportional to the capacity of hoop reinforcement.

2)The encased small size steel worked quite effectively in carrying shear force when the columns were subjected to shear in the direction of the strong axis. No separation of the concrete section by the small steel seems to be brought.

3)When subjected to shear in the direction of the week axis, however, separation of the concrete section by the small steel must be considered in the estimation of the shear strength in such direction.

4)The shear strength of the columns using 60MPa high strength concrete and 900Mpa high strength hoops was estimated by the truss and arch analogy with good agreement.

5)The effective compressive stress of concrete stress block for calculation of the flexural strength of the columns with 60MPa high strength concrete should be assumed as 0.8 times cylinder strength.

REFERENCES

Aoyama,H., Hiraishi,H. and Fujitani,H.(1994). Feasibility study on New RC and enforcement plans. Concrete Journal, JCI,Vol.32,No.10,Oct.,pp.55-61.

Design guidelines for earthquake resistant reinforced concrete buildings based on ultimate strength concept. (1990). AIJ.

Standard for structural calculation of steel reinforced concrete structures(1987). AIJ.

Takiguchi,K., Nagashima,T. and Umebayashi,k.(1994a). Strength of small size steel encased reinforced concrete columns with high strength materials. J. of Structural & Construction Eng., AIJ. No.458,pp.145-152.

Takiguchi,K., Nagashima,T. and Irei,T.(1994b). Strength of small size steel encased reinforced concrete columns with high strength materials under cyclic loading. J. of Structural & Construction Eng., AIJ. No.466,pp.155-163.

Takiguchi,K. and Nagashima,T.(1995a). Strength of small size steel encased reinforced concrete columns with high strength materials. EASEC-5. Gold Coast,Qeensland,Australia,25-27,July,1995

Takiguchi,K., Nagashima,T. and Ootomo,T.(1995b). Strength in the direction of week axis of small size steel encased reinforced concrete columns with high strength materials. J. of Architectural Eng., AIJ. No.1,pp.103-107.

Yonezawa,t.,(1993). Bottom-up concreting into steel tube columns filled with ultra-strength concrete using silica fume. Concrete Journal. JCI. Vol.31,No.12. pp.22-33/