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STRENGTHENING OF REINFORCED CONCRETE COLUMNS BY CENTRAL REINFORCING ELEMENT

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ABSTRACT

This study concerns the strengthening of reinforced concrete (RC) columns against earthquake force rather economically. To save human lives as many as possible during severe earthquake, it is necessary to minimize the subsidence of slabs at each floor level as small as possible and behaviors of columns which support slabs have decisive influence. It would be concluded that ordinary RC columns are not dependable for safe structures against severe earthquakes from our past experiences. For this purpose, RC columns with a central reinforcing element such as steel bar, steel H section and steel pipe were taken up. It is expected that this type of RC columns would show higher properties for minimizing the shortening of the length after some shear and bending cracks occurred. To certify the effect of this way of reinforcing, experimental study using specimens of RC short columns of shear span ratio of 2.5 was carried out. To compare the behaviors of columns with central reinforcing and without that, specimens with ordinary reinforcing were also used. The specimens were loaded by both axial and horizonal cycle load and the failure processes to the ultimate state of the member were examined. The effect of axial load and detailing of tie reinforcement were also discussed. As the results of the study, effects of central reinforcing for making higher the earthquake resistant properties of RC columns were observed.

KEYWORDS

RC Columns, Central reinforcing element, Ductility

INTRODUCTION

It is inevitable that during severe earthquake in RC columns many cracks occur. The possibilities of shortening of column length are very high and in the worst case columns collapse completely and slabs which are supported by columns would fall down. It is proposed that as one way of reinforcing RC columns rather economically for above mentioned phenomena to put central reinforcing element in RC columns (Fig.1).

Columns undergo deflection due to axial stress, bending stress, and shearing stress as members of portal

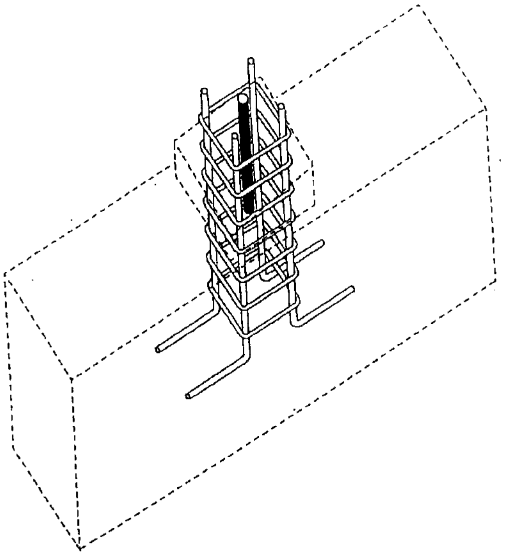
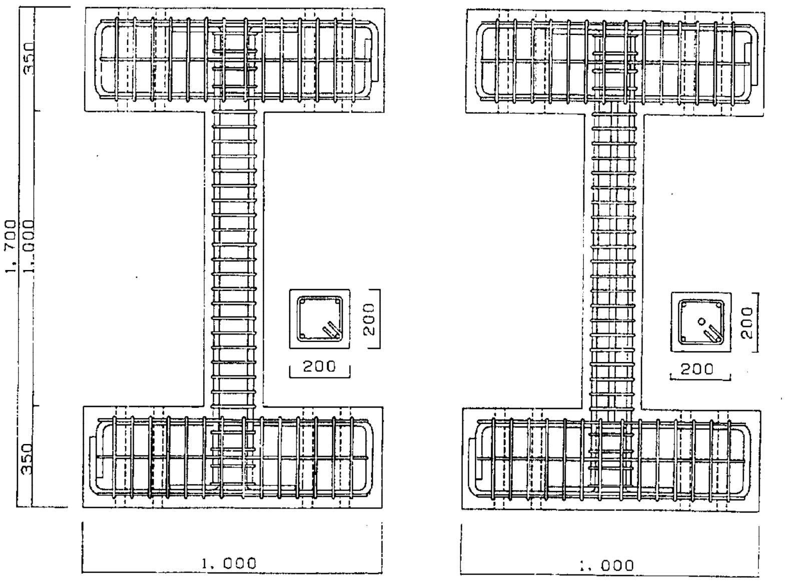


Fig. 1. Axonometric drawin of specimen

frames. Ordinary reinforcing bars are subject to combined axial and bending strain and are rather easy to buckle. But the central reinforcing element is hard to be subject to bending strain and the possibility of buckling is lower than that of peripheral reinforcing element. Therefore it is expected that central reinforcing element would be more effective for preventing the brittle failure of core concrete after shear cracks occurred and therefore the shortening of the length of RC columns. In this study, to certify the effect of this way of reinforcing, experimental study using specimens of RC columns of shear span ratio of 2.5 and The analytical study using the finite element method are carried out. In this report only experimental results are taken up.

EXPERIMENTAL PROGRAM

For all the column specimens, the cross section is $20cm \times 20cm$, the length is $100cm$, the ratio of shear span to depth is 2.5. The configuration of the specimens is shown in Fig.2. The variables which are considered to affect the behavior of reinforced concrete columns subjected to axial load and shear load are as follows:



(a) Ordinary reinforcing type (b) Central reinforcing type

Fig. 2. Test specimen (unit : *mm*)

Table 1. Properties of Specimens

Specimen	Strength of concrete (*kgf/cm^2*)		Axial load ratio	Axial load	Tie ratio	Tie pitch	Tensile steel ratio	Central bar ratio	Section steel ratio
	Compression	Tension	(%)	(*tf*)	(%)	(*mm*)	(%)	(%)	(%)
Series 1									
MB-100-0.4	357.9	30.8	0.4	67.3	1.28	100	1.00	0	2.00
CB-100-0.4	357.9	30.8	0.4	75.3	1.28	100	1.00	1.61	3.61
MB-50-0.4	340.5	30.8	0.4	69.0	1.28	50	1.44	-	2.88
CP-50-0.4	340.5	30.8	0.4	68.6	1.28	50	1.00	1.08	3.08
MB-50-0.2	360.8	30.9	0.2	36.1	1.28	50	1.44	-	2.87
CP-50-0.2	360.8	30.9	0.2	35.8	1.28	50	1.00	1.08	3.07
Series 2									
MB-75-0.2/0.35	384.8	31.6	0.2-0.35	35.7-62.6	0.85	75	1.00	-	2.01
CB-75-0.2/0.35	384.8	31.6	0.2-0.35	40.7-71.3	0.85	75	1.00	2.01	4.02
CH-75-0.2/0.35	384.8	31.6	0.2-0.35	41.5-72.6	0.85	75	1.00	2.33	4.34

(1) Reinforcing element

Series 1

MB: main bar (Pt=1.44% (4-D19), Pc=0%)
CB : central bar (Pt=1.00% (4-D16), Pc=0.97% (1-D29))
CP :central pipe (Pt=1.00% (4-D16), Pc=1.08% (steel pipe φ42.7*mm*×3.5*mm*))

Series 2

Mb: main bar (Pt=1.00% (4-D16), Pc=0%)
CB : central bar (Pt=1.00% (4-D16), Pc=2.01%(a bundle of 4-D16))
CH: central H section (Pt=1.00% (4-D16), Pc=2.33% (H-50×50×5×7))

(2) Tie ratio

Series 1 2-13φ@100 (Pw=1.28%) and 2-9φ@50 (Pw=1.28%)
Series 2 2-9φ@75 (Pw=0.85%)

(3) Axial load ratio ($\sigma_0 = N/F_c \cdot A_c$)

Series 1 0.4 and 0.2
Series 2 0.2 ⇒ 0.35 (The load was increased after deflection angle 2/100-2cycle)

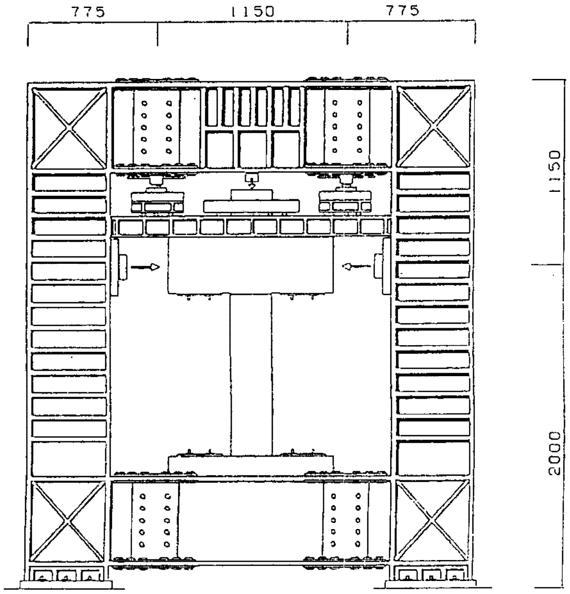


Fig. 3. The loading setup

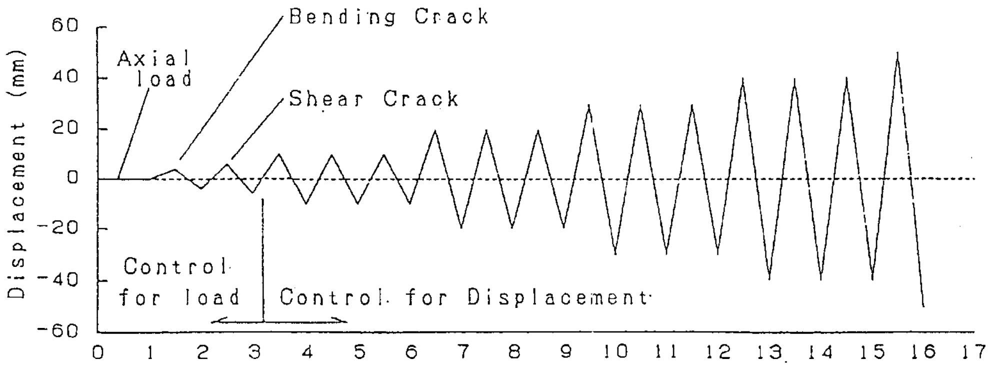


Fig. 4. Loading process

where, "F_c" is compressive strength of concrete, "A_c" is equivalent cross sectional area, "*Pt*" is tensile steel bar ratio, "*Pc*" is center steel bar ratio and "*Pw*" is tie bar ratio.

Specimen names are given in the order of **[reinforcing element] - [tie pitch] - [axial load ratio]**. **[/]** means the change of axial load. Table 1 shows the properties of specimens. The loading setup and the loading process are shown in Fig.3 and Fig.4, respectively.

RESULT OF EXPERIMENT AND CONSIDERATION

Series 1

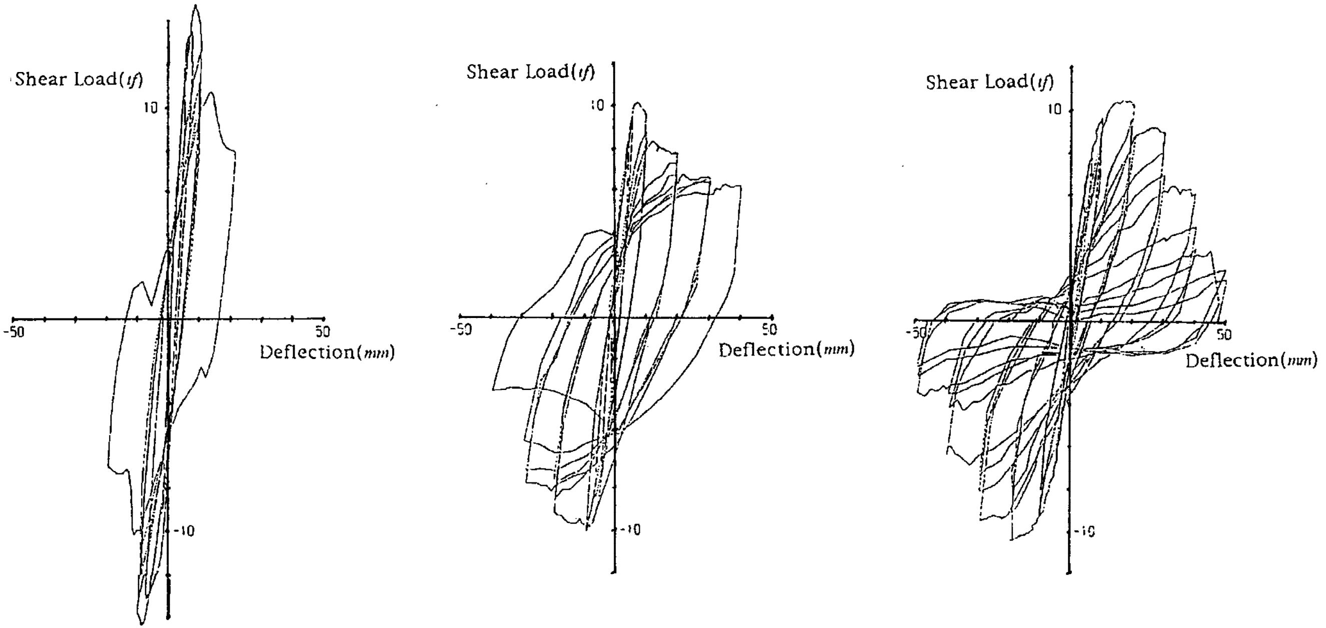
Table 2. shows experimental results.

Fig. 5 shows shear loading-deflection relationship. Central reinforcing element supports axial load at the large deformation after deflection angle 2/100-2cycle, and shows the effects on restraining the shortening of column. Also the central reinforcing element(**CB** and **CP** type) shows the restraining effects of the drop of bearing capability and the accumulate absorption energy for this case becomes larger than that of **MB** type.

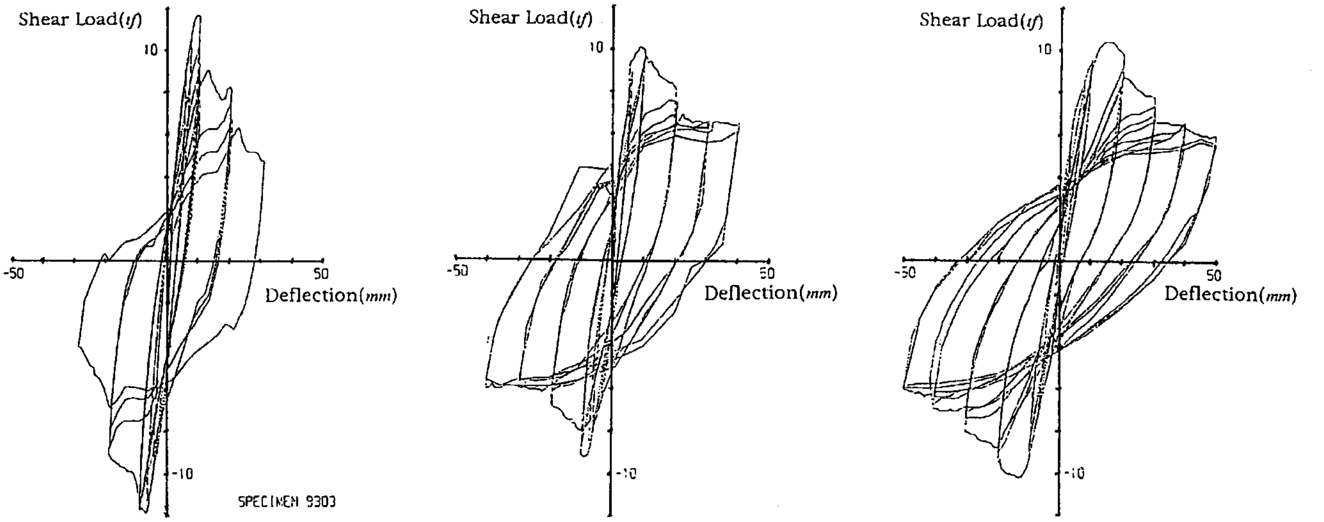
Fig.6 shows strain distribution of central reinforcing pipe of the specimen **CP-50-0.4**. Before concrete fails, central reinforcing element is subject to uniform compressive strain along its length. Then as concrete fails, the compressive strain increases at portions where concrete fails.

Table 2. Experimental results-Series 1

Specimen	Shear load (tf)										
		Displacement/Length									
	Maximum	1/ 100		2/ 100		3/ 100		4/ 100		5/ 100	
MB-100-0.4	14.7	12.7	-13.8	7.9	-6.9	-	-	-	-	-	-
CB-100-0.4	11.7	11.7	-11.7	8.2	-9.0	4.8	-4.0	-	-	-	-
MB-50-0.4	10.2	9.6	-9.9	7.7	-9.1	6.6	-7.7	6.0	-3.3	-	-
CP-50-0.4	10.0	9.9	-8.9	8.0	-6.7	6.4	-5.8	6.4	-5.9	-	-
MB-50-0.2	10.5	9.7	-9.2	10.5	-10.3	8.9	-9.3	6.1	-6.2	3.4	-3.4
CP-50-0.2	10.5	9.5	-8.8	9.7	-9.4	7.7	-9.3	6.6	-6.8	5.9	-6.0



(a) MB-100-0.4 (c) MB-50-0.4 (e) MB-50-0.2



(b) CB-100-0.4 (d) CP-50-0.4 (f) CP-50-0.2

Fig. 5. Shear load-deflection relationship

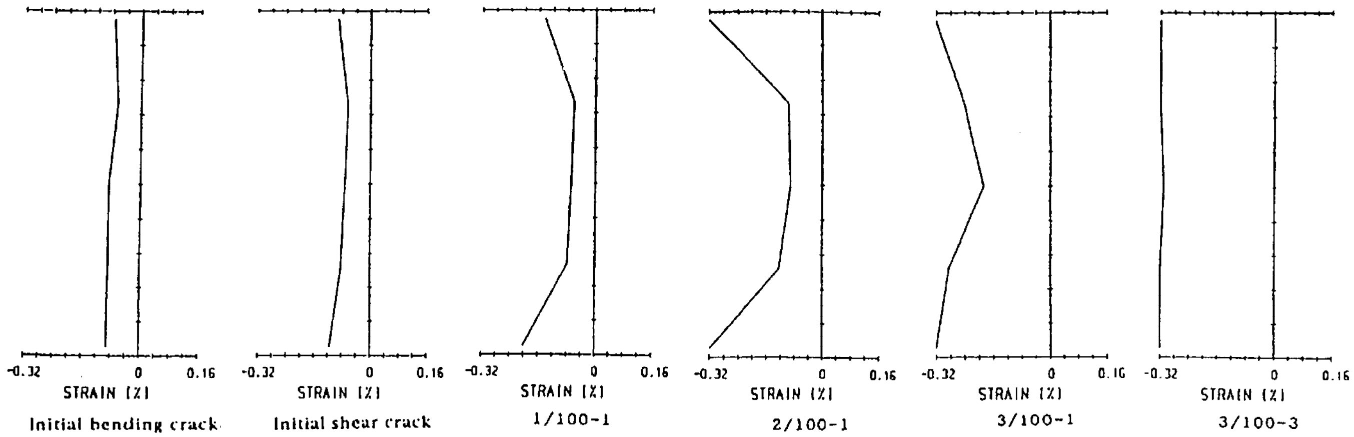
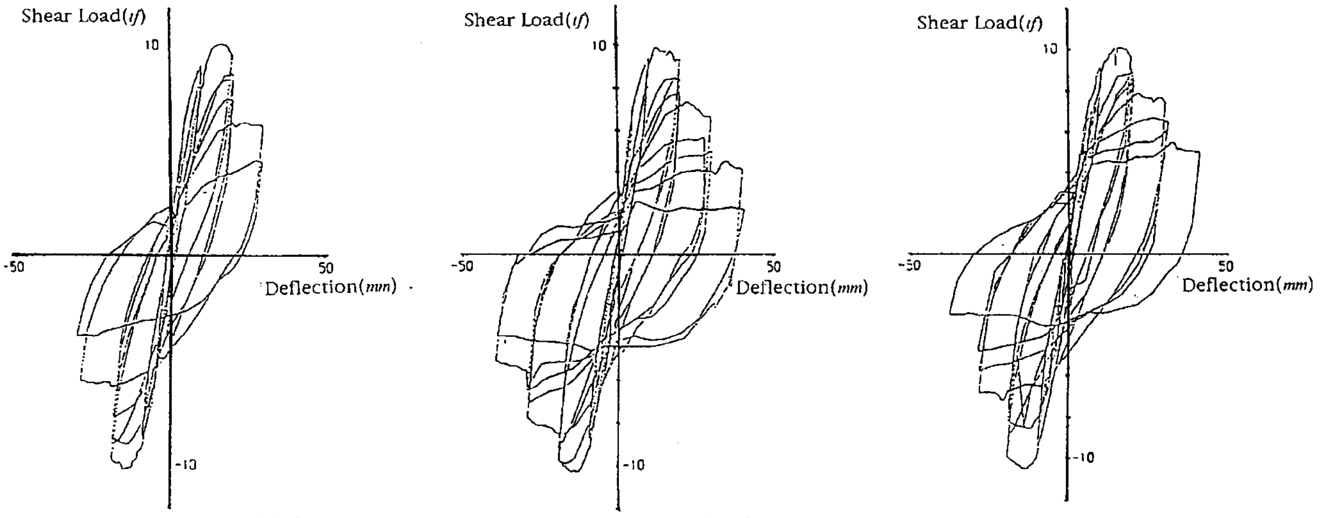


Fig. 6. Strain distribution in central reinforcing of specimen CP-50-0.4

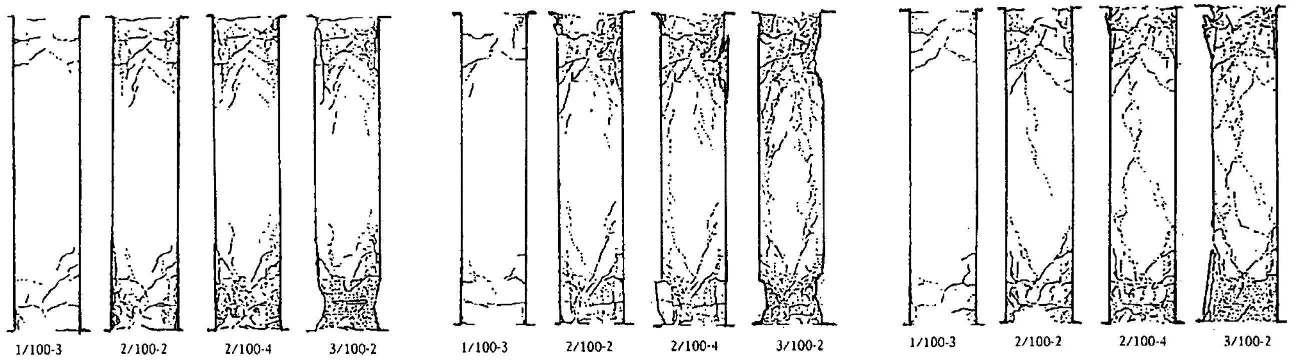
Table 3. Experimental results-Series 2

Specimen	Shear load (tf)										
		Displacement/Length									
	Maximum	1/ 100		2/ 100		3/ 100		4/ 100		5/ 100	
MB-75-0.2/0.35	10.2	9.1	-8.6	9.5	-9.6	6.1	-5.8	-	-	-	-
CB-75-0.2/0.35	10.1	9.4	-8.6	9.3	-9.6	6.5	-7.6	4.2	-5.0	-	-
CH-75-0.2/0.35	10.1	9.2	-9.4	9.7	-9.9	7.5	-6.9	5.0	-2.9	-	-



(a) MB-75-0.2/0.35 (b) CB-75-0.2/0.35 (c) CH-75-0.2/0.35

Fig. 7. Shear load-deflection relationship



(a) MB-75-0.2/0.35 (b) CB-75-0.2/0.35 (c) CH-75-0.2/0.35

Fig. 8. Crack patterns

Series 2

Table.3 shows experimental results.

Fig.7 and Fig.8 show crack patterns and shear load-deflection relationship,respectively. For the specimen of 75*mm* tie pitch, bending and shear cracks occurred in all specimens. The specimen **CB-75-0.2/0.35** showed higher stiffness for larger deformation than the other specimens even though it reached maximum shear load at smaller displacement than that of the other specimens. Cracks occurred mainly in end portions of specimen **MB-75-0.2/0.35** and many bond cracks occurred in specimen **CB-75-0.2/0.35** and shear cracks occurred in the middle portion.

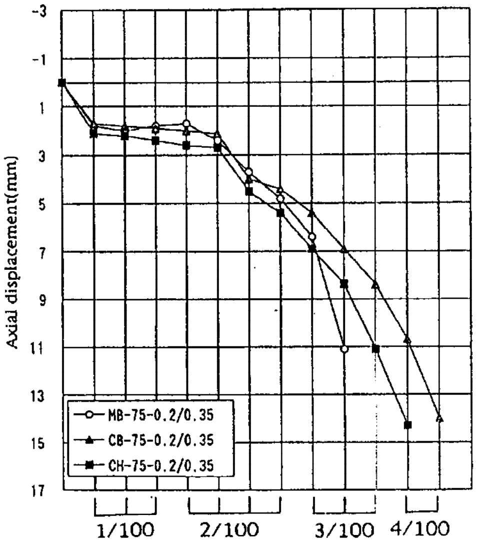


Fig. 9. Shortening of column length for specimen of 75 tie pitch and 0.2/0.35 axial load ratio

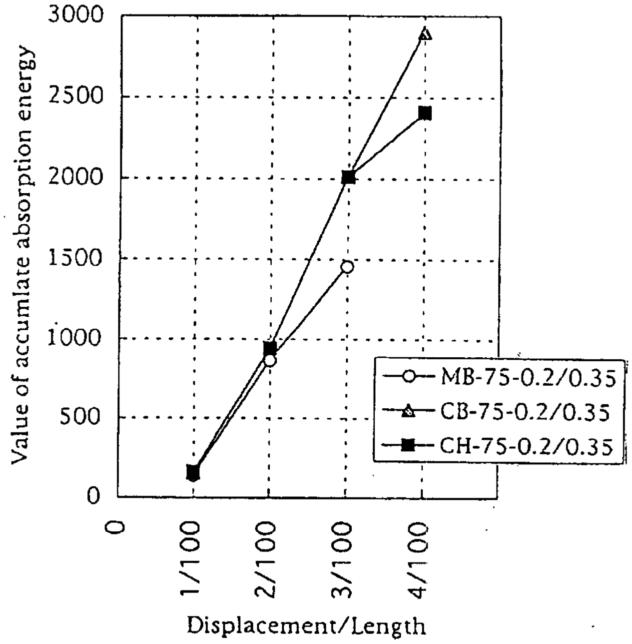


Fig. 10. Accumulative energy absorption for specimen of 75 tie pitch and 0.2/0.35 axial load ratio

Fig.9 shows shortening of column length for the specimens of 75*mm* tie pitch and 0.2/0.35 axial load ratio. At deflection angle 2/100, specially after axial load increase, central reinforcing element becomes effective for resisting the shortening of column length.

In Fig.10 which shows accumulative energy absorption, it is seen that at larger deformation after deflection angle 2/100, central reinforcing element is effective for absorbing energy.

CONCLUSION

As the result of this study for RC columns with shear span ratio 2.5, following results are obtained.

From **Series 1** experiment, it has become clear that central reinforcing elements are rather effective for RC columns which are subjected to large axial force and with higher tie bar ratio.

From **Series 2** experiment in which the axial loading was increased in the process of cyclic shear loading, central reinforcing elements showed rather effective resistance for keeping the original configuration of the column. In this experiment, the specimen with a central reinforcing element of a bundle of 4 steel bars showed the highest ductility. The specimen with central H section reinforcing element was not so ductile as expected.

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