STUDY ON THE PROPERTIES OF REINFORCED CONCRETE COLUMNS WITH CENTRAL REINFORCEMENT

Ortadan Donatılı Betonarme Kolonların Özelliklerinin İncelenmesi.

Yasuo TANAKA[1], *Younggon RO[2] and Tetsuya TOYOTA[3]*

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 earthquakes, 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. For this purpose, RC columns with a reinforcing bar in the central position of the section 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 12 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, 6 pairs of specimens were used. The specimens were loaded by both axial and horizontal cycle load and the failure processes to the ultimate state of the member were examined. The effects of axial load and detailing of tie reinforcement were also discussed. As the results of this study, the effects of central reinforcing for making higher the earthquake resistant properties of RC columns were observed.

INTRODUCTION

It is inevitable that during severe earthquakes 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 total bending deflection as members of portal frames.

1. Prof. Dr., Waseda Univ., Dept. of Architecture, Tokyo, Japan
2. Assistant, Waseda Univ., Dept. of Architecture, Tokyo, Japan
3. Graduate Student, Waseda Univ., Dept. of Architecture, Tokyo, Japan

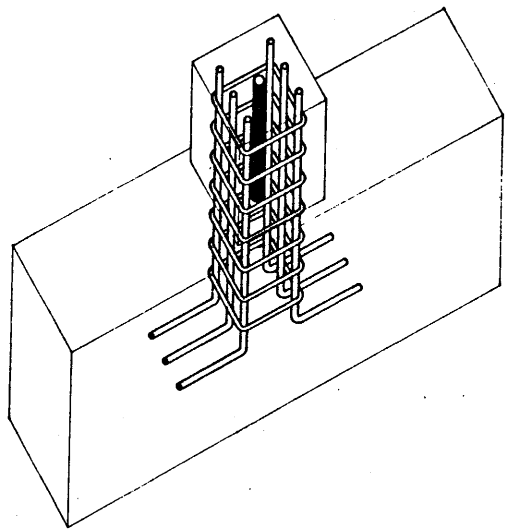


Figure 1. Axonometric drawing of specimen.

Ordinary reinforcing bars are subject to additional bending strain and are rather easy to buckle. But the central reinforcing element is not subject to this additional 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 shortening of the length of RC columns. In this study, a central reinforcing bar is used. But in practical cases, it is expected to use a steel pipe or a steel H–section which has higher buckling resistance than ordinary reinforcing bars.

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 and the main bar ratio (P_t) is 1.00%. The configuration of the specimens is shown in Fig. 2. The variables which are considered to affect the behavior of RC columns subjected to axial load (N) and shear load (Q) are as follows:

(1) Axial load ratio ($\sigma_0 = N/F_c \cdot A_e$)

0.25 and 0.33

(2) Tie ratio (Pw)

0.56%$(2 - 9\phi$ @110), 0.85%$(2 - 9\phi$ @75) and 1.28%$(2 - 9\phi$ @50)

(3) Central reinforcement ratio (P_c)

0.0% and 0.97%($D22$)

where, F_c is compressive strength of concrete and A_e is equivalent cross section area.

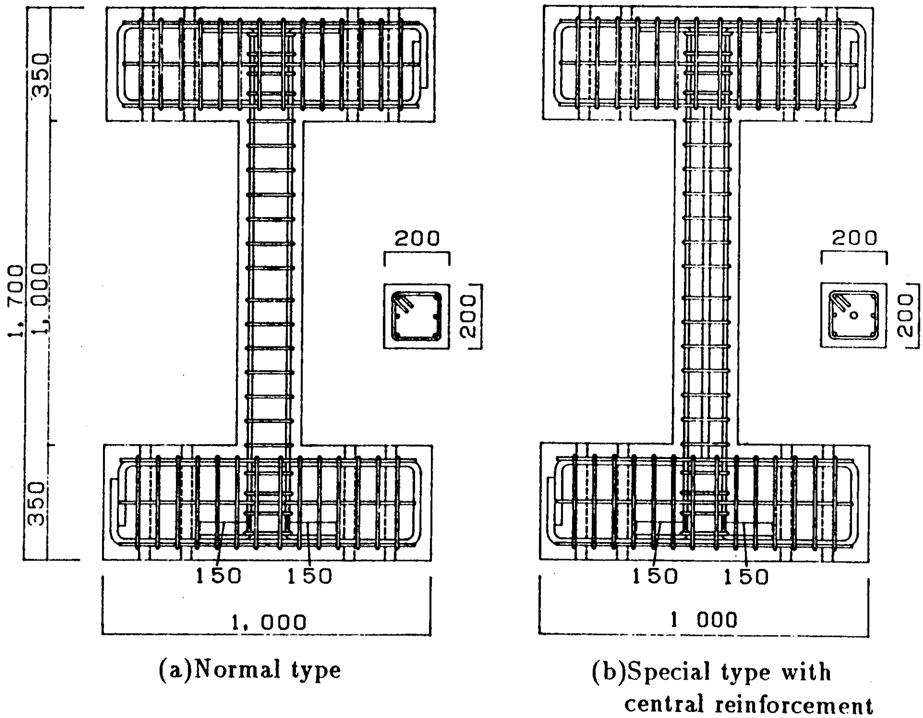


Figure 2. Test specimens.

Table 1. Properties of specimens.

Specimen	Strength of Concrete (kgf/cm²) Compression	Strength of Concrete (kgf/cm²) Tention	Axial load ratio (%)	Tie ratio (%)	Tie pitch (mm)	Tensile steel ratio (%)	Central bar ratio (%)
9201	298.5	25.90	0.25	1.28	50	0.95	-
9202	298.5	25.90	0.25	0.85	75	0.95	-
9203	298.5	25.90	0.25	0.56	110	0.95	-
9204	304.9	26.26	0.33	1.28	50	0.95	-
9205	304.9	26.26	0.33	0.85	75	0.95	-
9206	304.9	26.26	0.33	0.56	110	0.95	-
9207	321.6	27.20	0.25	1.28	50	0.95	0.97
9208	321.6	27.20	0.25	0.85	75	0.95	0.97
9209	321.6	27.20	0.25	0.56	110	0.95	0.97
9210	231.2	21.80	0.33	1.28	50	0.95	0.97
9211	231.2	21.80	0.33	0.85	75	0.95	0.97
9212	231.2	21.80	0.33	0.56	110	0.95	0.97

Table 2. Properties of reinforcement.

	Cross section (cm²)	Yielding point strain (%)	Yielding point strength (kgf/cm²)
D22	3.87	0.206	3556.2
D13	1.27	0.202	3635.8
9φ	0.64	0.180	3195.3

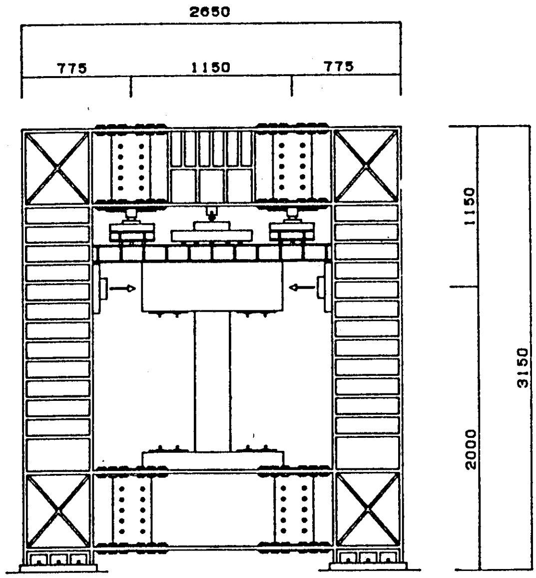


Figure 3. The loading set-up.

Table 1 and 2 show the properties of specimens and reinforcements, respectively. The loading set-up is shown in Fig. 3. The loading process is as follows: (a) to apply constant axial load, (b) to apply horizontal shear load of 3tf, (c) to apply horizontal shear load to cause first visible bending crack, (d) to apply horizontal shear load to cause first visible shear crack, (e) to apply 4cycles of shear load for relative horizontal displacement of $\pm 10mm$ (deflection angle of 1/100), (f) to apply 3cycles of shear load for relative horizontal displacement of $\pm 20mm$ (2/100), $\pm 30mm$ (3/100) and $\pm 40mm$ (4/100) and (G) to apply 1cycle of shear load for relative horizontal displacement of $\pm 50mm$ (5/100) as shown in Fig. 4. The shear loading from the right side is considered as positive loading.

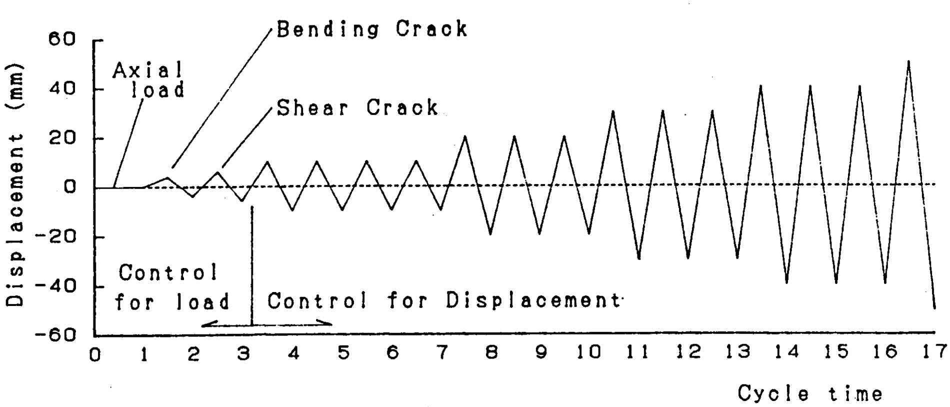


Figure 4. Loading process.

Table 3. Experimental results.

Specimen	Shear load (tf)												
				Displacement/Length									
	Initial bending crack		Maximum	at 1/100 4cycle		at 2/100 3cycle		at 3/100 3cycle		at 4/100 3cycle		at 5/100 1cycle	
9201	6.0	-6.5	10.3	9.0	-9.7	9.1	-9.4	6.7	-6.9	6.3	-6.4	6.1	-
9202	4.9	-4.0	10.5	9.3	-9.4	9.5	-8.9	7.4	-6.8	2.5	-	-	-
9203	5.0	-4.5	10.0	9.5	-9.2	8.0	-8.2	3.5	-3.5	-	-	-	-
9204	6.0	-5.5	11.7	10.8	-9.9	9.7	-8.9	8.6	-7.9	4.8	-4.1	-	-
9205	4.5	-5.5	9.7	9.4	-9.4	8.1	-8.1	4.1	-	-	-	-	-
9206	5.5	-7.0	11.0	9.8	-11.3	8.4	-8.9	-	-	-	-	-	-
9207	5.5	-6.0	11.0	9.9	-10.5	9.7	-8.7	8.3	-7.2	7.6	-7.1	7.3	-6.2
9208	6.6	-5.5	11.9	10.9	-10.4	9.4	-8.8	8.4	-7.4	5.9	-3.1	-	-
9209	5.5	-5.0	10.2	9.7	-9.5	7.9	-8.7	1.8	-	-	-	-	-
9210	6.0	-5.5	10.3	9.4	-8.0	9.5	-7.2	8.7	-4.0	7.0	-5.7	5.9	-5.2
9211	4.5	-4.5	9.3	8.1	-7.2	8.3	-7.1	6.2	-5.1	3.0	-2.2	2.1	-1.0
9212	5.0	-5.0	9.7	8.7	-8.3	6.6	-5.2	3.5	-2.8	0.8	-1.2	0.5	-

RESULT OF EXPERIMENT

Table 3 shows expermental result.

Destruction Properties of Specimens without Central Reinforcement

The crack patterns and shear loading and deflection relationships at the final cycle of loading for member deflection angles are shown in Figs. 5 and Figs. 6, respectively. Cracks are shown by full lines for positive loading, dotted lines for negative loading and shaded portions for the parts of concrete separation from main bars. The broken lines in Figs.6 are shown for considering the ductility properties taking into account the $P - \delta$ effects.

For the specimens of 1.28% tie ratio, the cracks occur concentrically mainly in the end portions and at the final stage of loading, the concrete separations from main bars are observed. It is observed that these specimens show rather high energy absorbing capacity and are ductile.

For the specimens of 0.56% tie ratio, after maximum loading, loadings for 2/100 deflection angle caused longitudinal cracks in the compressive zones and bond splitting cracks in the middle portions and later on concrete separation zones broaden. It is observed from the figures of shear loading and deflection relationships that after longitudinal cracks, the specimens show abrupt declining of its load sustaining capacity and lose its energy absorbing capacity.

The specimens of 0.85% tie ratio show intermediate properties between specimens of 1.28% and 0.56% tie ratios.

Destruction Properties of Specimens with Central Reinforcement

The crack patterns and shear loading and deflection relationships at the final cycle of loading for member deflection angles are shown in Figs. 7 and Figs. 8, respectively. The crack patterns are similar to those for specimens without

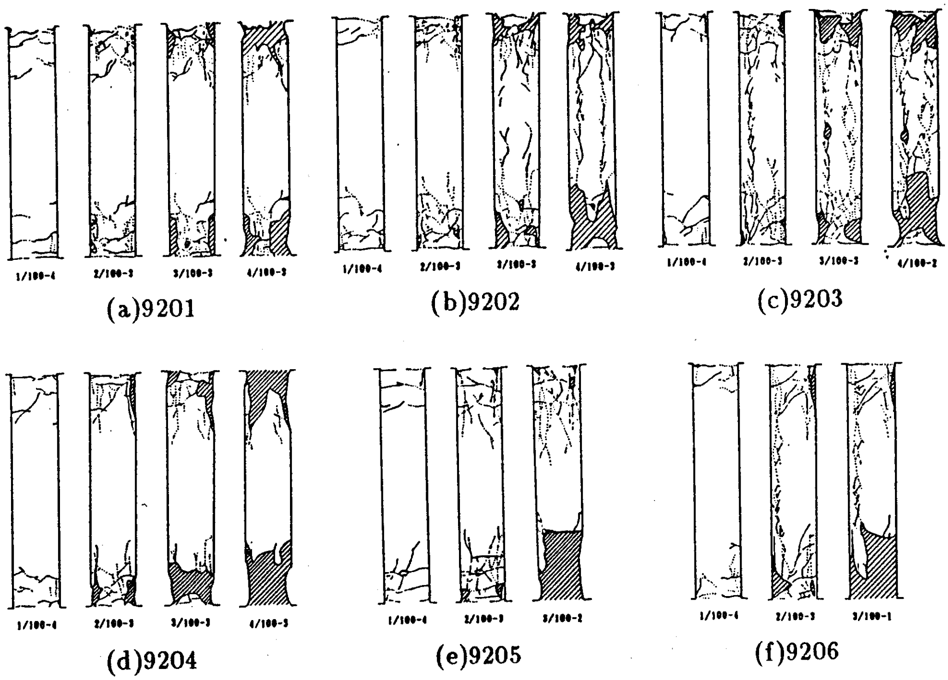


Figure 5. crack patterns.

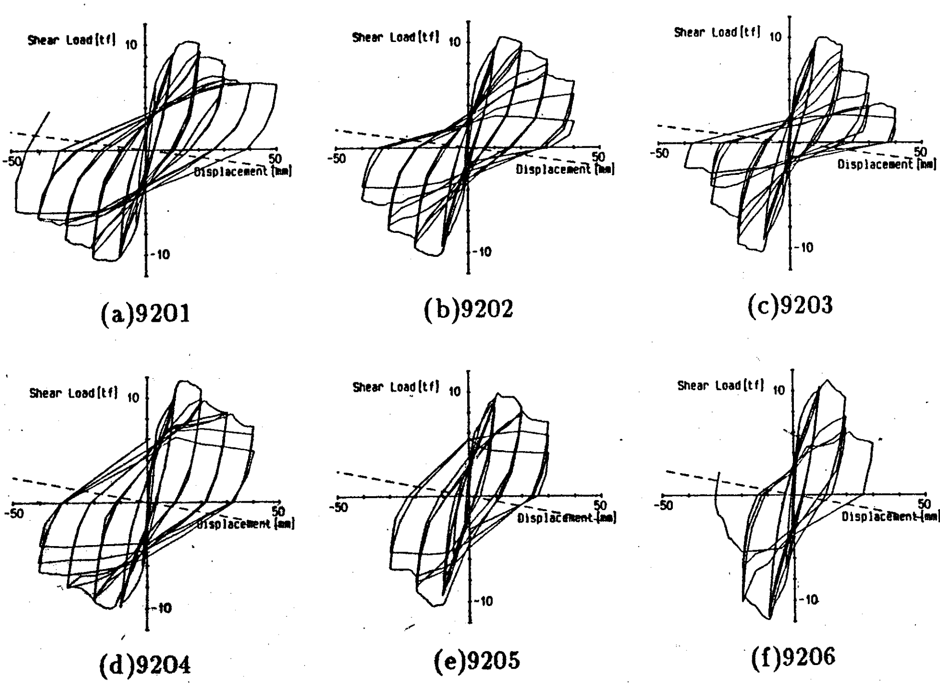


Figure 6. Shear loading and deformation relationship.

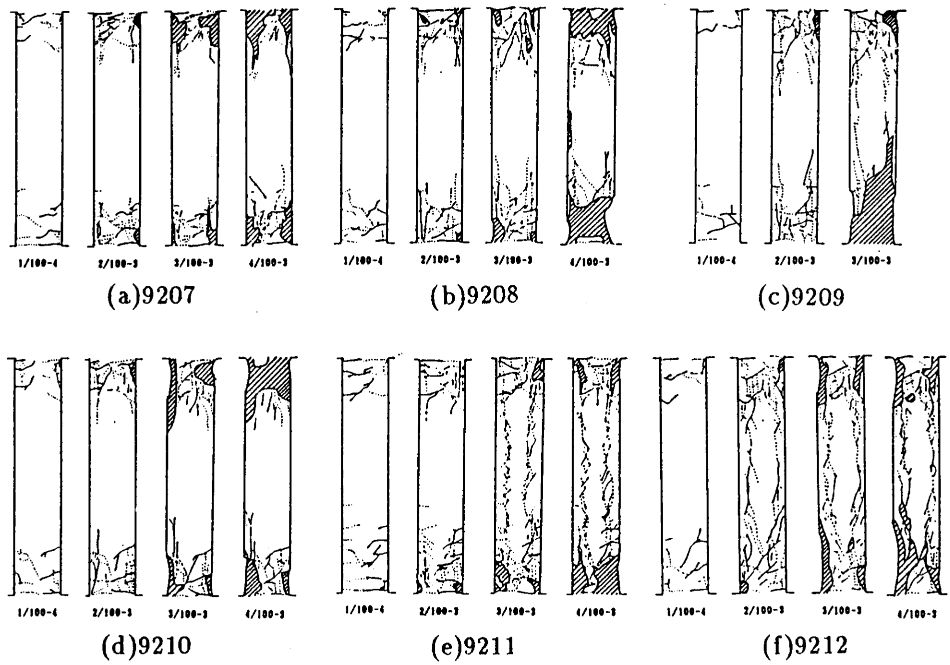


Figure 7. crack patterns.

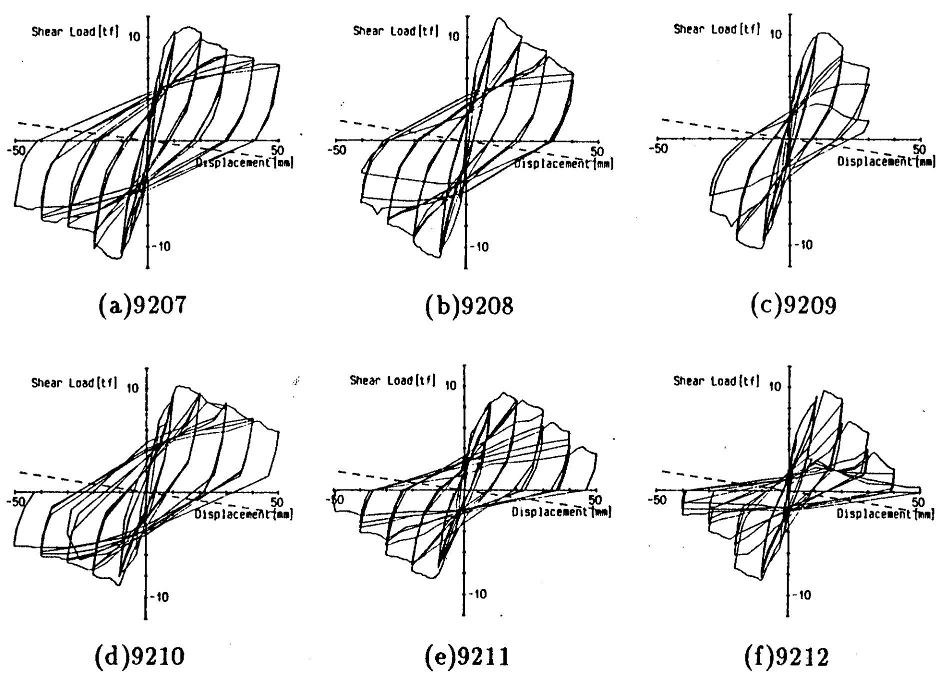


Figure 8. Shear loading and deformation relationship.

central reinforcement. The bond splitting cracks in the central portions occur more as the axial loading become higher.

For specimens of 1.28% tie ratio, after maximum loading, the declining of load carrying capacity is rather smooth and show rather high energy absorbing capacity and rather high ductility even after 5/100 deflection angle.

But for specimens of 0.56% tie ratio, rather abrupt declination of load carrying capacity is observed and rather brittle property is observed.

The specimens of 0.85% tie ratio show intermediate properties of specimens of 1.28% and 0.56% tie ratio.

DISCUSSION

After maximum loading, the relationships between deflection angles and shear loading (Q) and axial displacement (DY) are shown in Figs. 9. In these figures, shear loading and axial displacement are normalized by maximum shear loading (Q_{max}) and axial displacement (DY_{max}) at maximum loading.

It is observed that as shear resistance capacity declines, the axial displacement become larger. As the axial loading becomes larger, the declination of shear resistance capacity and axial shortening become larger.

For the case of 1.28% tie ratio, the specimens with central reinforcement show rather higher ductility and higher resisting capacity of axial loading than those for the specimens without central reinforcement. But in this case both specimens do not collapse completely.

For the case of 0.85% tie ratio, the possibility of complete collapse for both cases becomes higher, and for the case of lower axial loading, no superiority of specimens with central reinforcement over those without central reinforcement is observed. But as the axial loading becomes larger the superiority of the former case for resisting axial loading is observed.

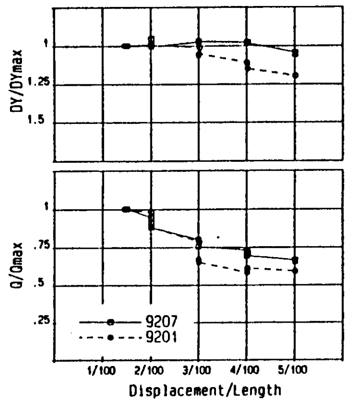
For the case of 0.56% tie ratio, similar tendencies of resisting properties of both types of specimens are observed.

CONCLUSION

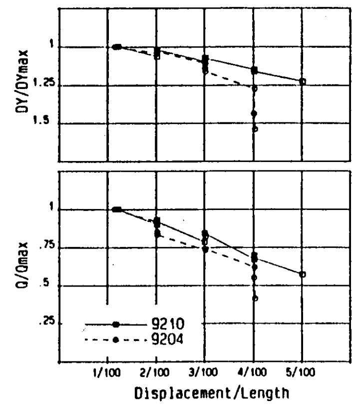
As the result of this study, following results are obtained.

The ordinary specimen without central reinforcement show different properties depending on tie ratio and axial loading. Keeping ductility after bending yielding, the specimens of 1.28% tie ratio fail due to bending compressive collapse at the final stage. The specimens of 0.56% tie ratio show rather brittle property due to longitudinal cracks which occur in the whole part of specimens after bending yielding. The specimens of 0.85% tie ratio show intermediate properties of former two cases. These tendencies become more pronounced as axial loading becomes higher.

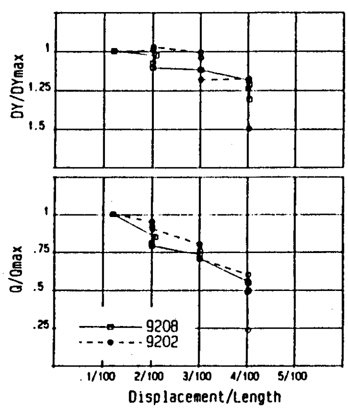
The specimens with central reinforcement show different properties depending on tie ratio and axial loading as the case of ordinary specimens. The effects of



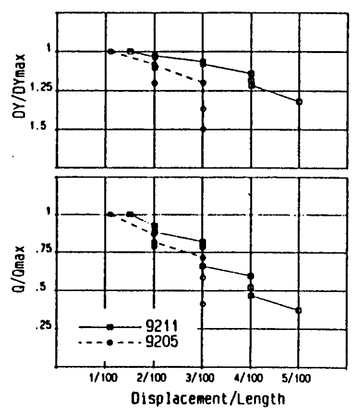
(a)9201 vs. 9207



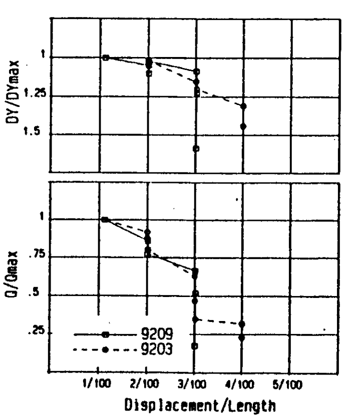
(b)9204 vs. 9210



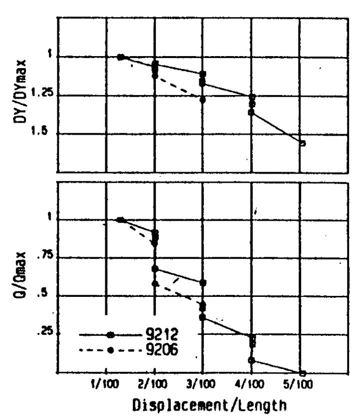
(c)9202 vs. 9208



(d)9205 vs. 9211



(e)9203 vs. 9209



(f)9206 vs. 9212

Figure 9. Deflection angles and shear loading and axial displacement relationshi[p

central reinforcement are observed for the case of higher tie ratios and higher axial loading. For lower tie ratios and lower axial loading, the effects of placing central reinforcement are not expected.

For the case of reinforced concrete columns subjected to large horizontal deflection and large axial force, besides making tie reinforcement higher, to use central reinforcement is effective for keeping the ductility and the resistance for axial force.

Appropriate sectional area and moment of inertia of an area of central reinforcing bar or steel member should be studied further.

Acknowledgement

The authors express their sincere thanks to Messrs. H.Yashiro, S. Miyakoshi, G. Oh and S. Nakagawa.

REFERENCE

1. Y. Tanaka, Y. Ro, N. Sato and H.Yashiro, (1992) *"Study on the Formation of Plastic Hinges and the Failure of Reinforced Concrete Columns"*, Proceedings of 10th World Conference on Earthquake Engineering, pp. 2977–2982.

ORTADAN DONATILI BETONARME KOLONLARIN ÖZELLİKLERİNİN İNCELENMESİ

Yasuo TANAKA - Younggon RO - Tetsuya TOYOTA

Bu çalışma deprem etkisindeki betonarme kolonların oldukça ucuz olarak güçlendirilmesiyle ilgilidir. Şiddetli depremler sırasında mümkün olduğu kadar çok sayıda insanın yaşamını kurtarmak üzere döşemelerdeki sehim mümkün olduğu ölçüde kısıtlanmalı ve bu konuda etkili olan kolonların davranışları üzerinde durulmalıdır. Bu amaçla kesitinin tam ortasında da donatısı bulunan betonarme kolonlarla uğraşılmıştır. Bir ölçüde kayma ve eğilme çatlaklarının ortaya çıkmasından sonra, bu tür betonarme kolonların eksenel boy değişikliklerinin en aza inmesi ve daha iyi özellikler göstermesi beklenmektedir. Bu tür donatı kullanmanın etkilerini belgelendirmek amacıyla, moment - kesme kuvveti oranı 2.5 olan 12 adet betonarme kısa kolon numunesi üzerinde deneysel çalışma yapılmıştır. Ortasında donatı bulunan ve bulunmayan kolon davranışlarını karşılaştırmak üzere altı çift numuneden yararlanılmıştır. Numuneler düşey ve iki yönlü yatay yüklerin etkisinde göçme modlarına ulaşılana dek denenmiştir. Eksenel yük ve etriye donatısının bağlantı detayının etkileri ayrıca tartışılmıştır. Sonuç olarak, ortalarında da donatı bulunduran betonarme kolonların depreme karşı daha iyi davrandığı gözlenmiştir.