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A STUDY ON EFFECTIVENESS OF ECCENTRIC ARRANGEMENT OF REINFORCEMENT IN RC COLUMN

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ABSTRACT

In this paper, the authors present a new arrangement of reinforcing bars to improve the ductility in RC base-story exterior columns the axial load to which severely changes during an earthquake. The new method is to arrange more amount of the reinforcement eccentrically so that it works as compression steel when the axial load increases. Consequently it is expected that the compressive stress of the concrete is reduced, and the compressive failure of the concrete is greatly delayed. The effectiveness of this method is confirmed through an analytical and an empirical investigation.

KEYWORDS

RC exterior column; ductility; eccentrical arrangement of reinforcing bars; varying axial force; high axial load

INTRODUCTION

Generally, ductility of RC members is ensured by a flexural failure at both the ends and moreover a tensile yielding of main reinforcements. It is therefore comparatively easy for beams to warrant the sufficient ductility so long as the shear failure can be avoided, however, for columns, particularly the base-story ones of high-rised buildings, it becomes difficult because the relatively high compressive stress due to the axial compression exists, and it often causes the early compressive failure of the concrete even when they fail due to bending.

The bottom end of the base-story columns is allowed to yield at the ultimate stage of the structure in the limit design in use, so it is not too much to say that the seismic performance of the structure is finally dependent on its rotating capacity. The seismic design for the columns is more and more important, considering they have to resist against the dead load of the structure.

In this paper, the authors present a new arrangement of the reinforcing bars to improve the ductility in RC base-story exterior columns in high-rised structures. As they must endure not only a continuous compression but a temporary varying axial force during an earthquake, the severer performance is required.

OUTLINE OF PRESENT METHOD TO ARRANGE REINFORCEMENTS

The outline of the present columns with eccentrically arranged reinforcing bars is illustrated in Fig.1. The present method is to arrange more amount of reinforcements eccentrically and diagonally as shown in Fig.1. When the axial compression increases due to a shearing force of the beams, that is described as the right most column in the figure, the added diagonal reinforcing bars endure a compressive force, and when the axial load decreases (the left most column), they endure a tensile force.

An interaction diagram of a typical section of the present column is compared with the common RC column's in Fig.2. The strengths of the normal type of the section (N), adding central reinforcing bars (C) and adding eccentric reinforcing bars (E) are compared with each other. The axial force (P) and the moment (M) are defined at the geometrical centroid of the sections, and the positive direction of the moment is defined as the eccentric reinforcing bar works in compression. When the axial force decreases, i.e., the moment is negative, the present column shows the largest bending moment under the same axial compression or tension. When the axial force increases, i.e., the moment is positive, the flexural strength of the present column is almost equal to the common RC column's under a certain degree of the axial compression, however, it can be expected that the ductility will be improved because the compressive stress of the concrete will be reduced by the eccentric reinforcements and the compressive failure of the concrete will be delayed as a result. In the following chapters, the ductility of the present column will be discussed.

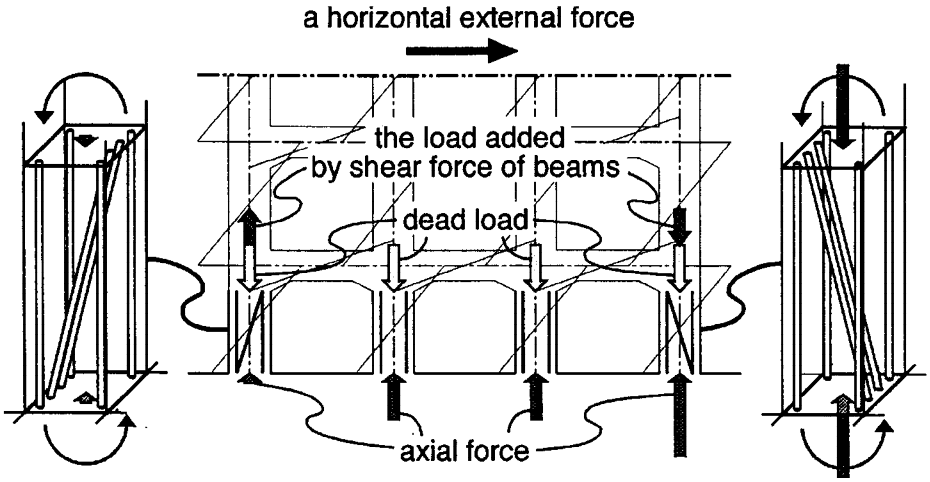
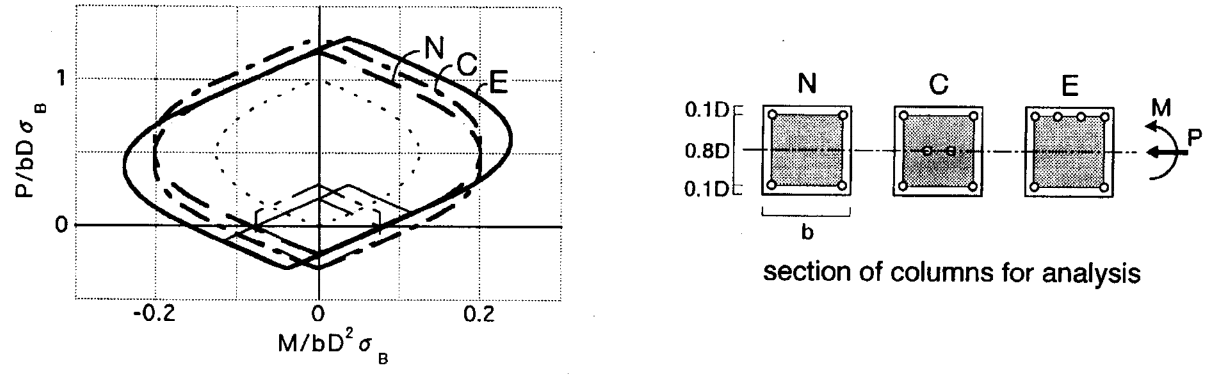


Fig.1. Outline of present column with reinforcement eccentrically arranged



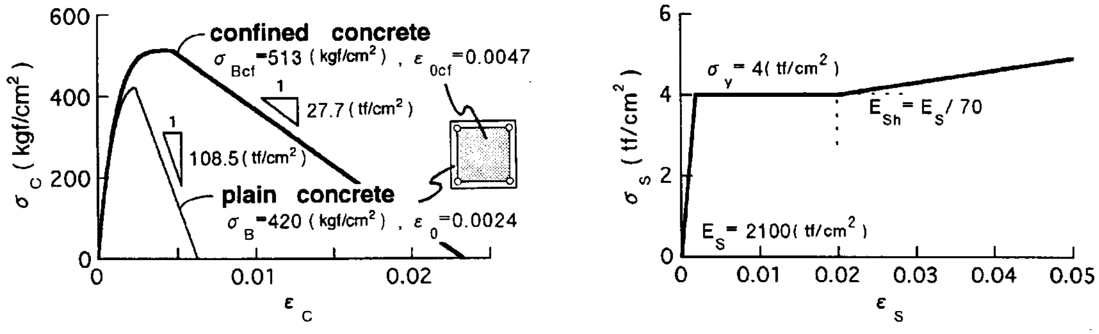
section of columns for analysis

Fig.2. Interaction diagram

Strength and Ductility of Sections

Section analyses were carried out for the same sections as indicated in Fig.2. The ratio of the area of the steel bars to bD was 2% for the section N, and for the section C and E, the steel bars the area of which to bD was 1% were added to the same section as N. The positions of them appear in the figure. Stress-strain relationships for the concrete and the steel were assumed as described in Fig.3. Considering the effect of the hoop confinement, the different properties were given for the concrete inside and outside of the hoop reinforcements as shown in Fig.3(a). The compressive strength of the unconfined concrete was 420kgf/cm^2, and the yield strength of the steel was 4tf/cm^2, regarding the column as the base-story one for a relatively high-rised structure. The moment-curvature relationships were investigated for several constant axial load levels.

Figure 4 shows several obtained moment-curvature relationships when the eccentrically arranged reinforcements work as the tension steel, i.e., the axial compression is reduced due to a horizontal external load. The moment and the curvature are normalized by the dimension of the section and the concrete strength. The section E to which the steel is added eccentrically shows the largest moment for the entire axial load level. Its ductility is poorest in the three sections, however, the difference between them becomes smaller according as the axial compression decreases. Considering the actual axial load ratio due to the dead load is ranged from 0.1 to 0.2, and if the axial load ratio of about 0.1 is changed due to an earthquake, it is more appropriate for discussing the ductilities to compare the behavior of the exterior column with the interior column under the different axial load level, e.g., the section E under the axial load ratio of 0.1 with the section N under 0.2. It can be said that the present exterior column, i.e., the section E has almost the same ductility as the interior column.



(a) concrete

(b) steel

Fig.3. Assumed stress-strain curves for materials

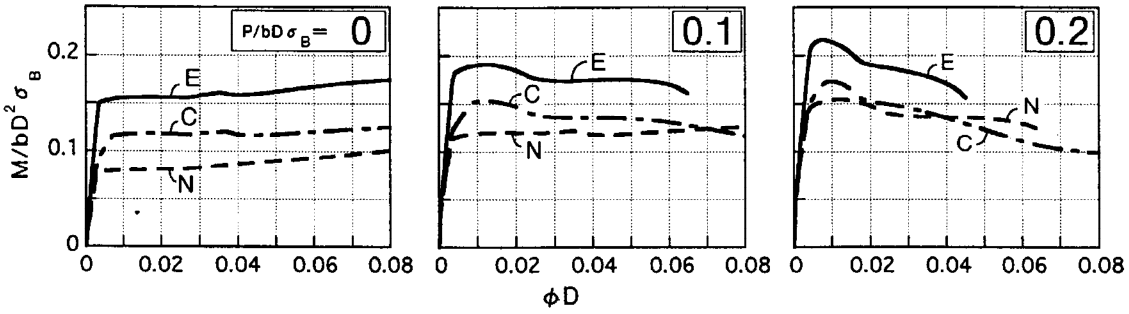


Fig.4. Theoretical moment-curvature relationships when the eccentrically arranged reinforcing bars work as tension steel

In Fig.5, the moment-curvature relationships of the sections are compared with each other, when the eccentrically arranged reinforcements work as the compression steel. The ductility becomes poorer according as the axial load level increases. The eccentrically arranged reinforcements are effective to improve the ductility until a certain degree of the axial load level; 0.3 in this analysis, however, under higher axial load level, they only increase the moment, but have no effect on the ductility. The changes in neutral axis depth according as the curvature increases are described in Fig.6. The solid and the void circles stand for the points that the compression steel and the tension steel yield respectively. The neutral axis of the section E lies shallower than the others in the section for the all axial load levels, however, it becomes deep according to the increase of the axial compression. Under the axial load level that the ductility is improved, the yielding of the compression steel is delayed, however, the steel yields in compression almost at the same time, as the neutral axis depth exceeds about 40% of the entire depth. The ductility can be theoretically improved under such a high axial load level by adding more amount of the eccentric reinforcements.

Applicability of This Method to Members with High Strength Materials

The effectiveness of the present column in which high strength materials are used is discussed in the follows. Using the assumed stress-strain curves for the materials as shown in Fig.7, the similar analysis to the above was carried out. The typical analytical results are illustrated in Fig.8. The axial load ratio ($P/bD\sigma_B$) was 0.4 and constant. The results in the case the concrete strength was 300, 450, 600 kgf/cm^2 are described in the figures form left side in turn. The capital letters N and E appended to the moment-curvature curves mean the normal section and the one to which the eccentric bars are added, respectively. The number adjacent to them means the yield strength of the steel. Comparing the section E with N having the materials of the same strength, it can be said that the eccentrically arranged reinforcing bars improve the ductility in all cases, particularly, the high strength steel bar is effective.

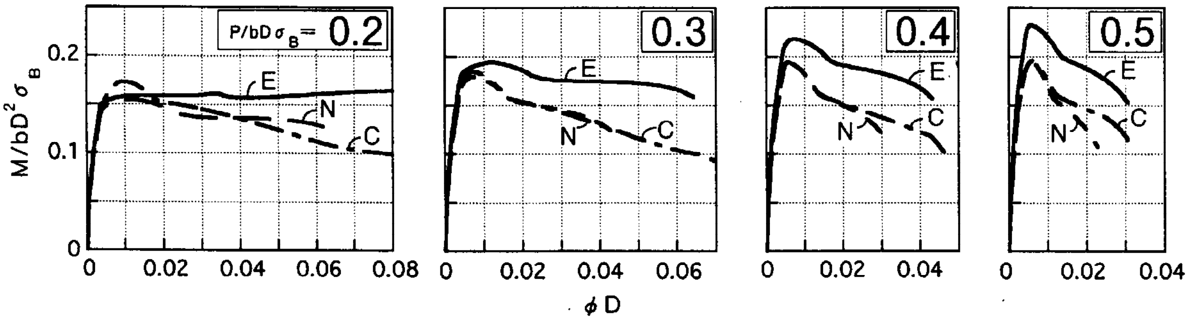


Fig.5. Theoretical moment-curvature relationships when the eccentrically arranged reinforcing bars work as compression steel

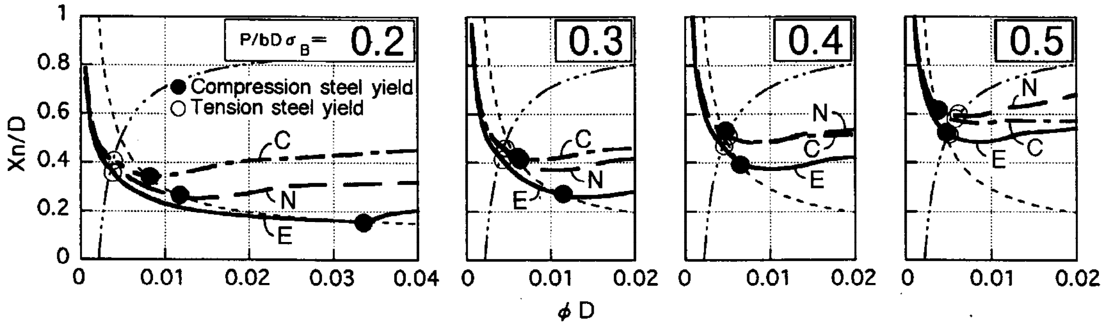
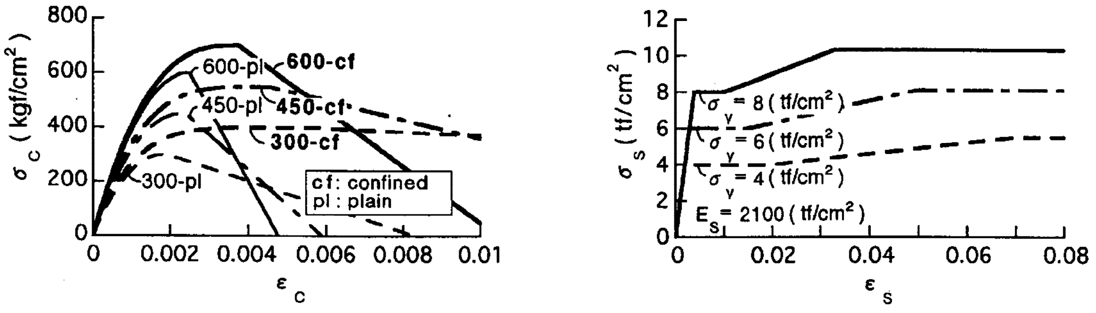


Fig.6. Change in neutral axis depth according as curvature increases

Figure 9 shows the moment-curvature relationships of the section in which the strength of only the additional reinforcements is varied. The strengths of the concrete and the steel bars installed at four corners in advance appear in the figure. The number appended to the curves means the yield strength of the additional steel. The axial load ratio is also 0.4. Using the high strength steel as the additional reinforcements is also effective to improve the ductility of members. As the additional steel bars are installed in a member diagonally, we do not have to give more attention to the bond stress between them and the concrete than the ordinary reinforcements. Therefore relatively high strength steel is expected to be applicable to the eccentric reinforcements regardless of the concrete strength.

EMPIRICAL EXAMINATION ON EFFECTIVENESS OF REINFORCEMENT ECCENTRICALLY ARRANGED

Pure bending tests with a constant axial compression were carried out in order to confirm true effectiveness of the reinforcement eccentrically arranged. Four specimens listed in Table 1 were made and tested. They were



(a) concrete

(b) steel

Fig.7. Assumed stress-strain curves for high strength materials

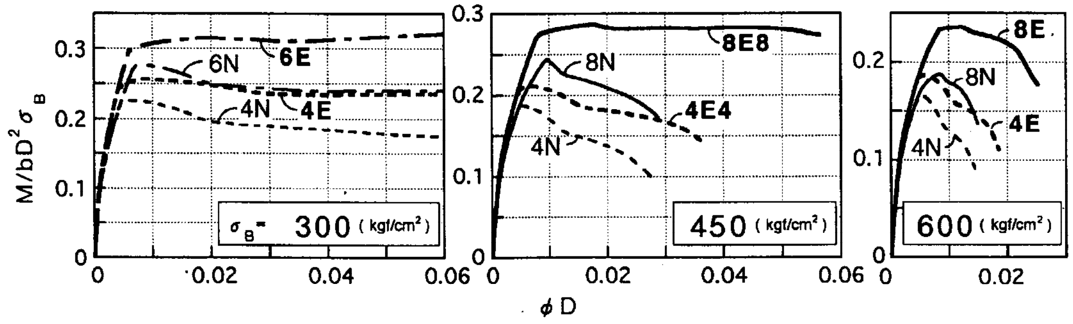


Fig.8. Theoretical moment-curvature relationships for the sections with several kinds of the concrete and the steel

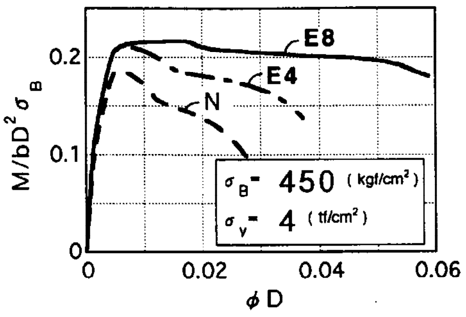


Fig.9. Theoretical moment-curvature relationships for the sections in which the strength of only additional eccentric reinforcement is varied

all short columns having the section of 160mm × 160mm and the clear length of 320mm as illustrated in Fig. 10. The experimental variables were the number of longitudinal reinforcing bars, i.e., the presence or the absence of the additional ones, and the interval of hoop reinforcing bars. The additional reinforcing bars were arranged to the compression side of the section. The compressive strength of the concrete appears in the table, and the yield strength of the longitudinal bars was $3.57 tf/cm^2$. The constant axial compression of 35tf for the specimens CB-*-@30 and 32tf for the ones CB-*-@100 which were equivalent to about 50% of $bD\sigma_B$ were loaded.

The empirical results are indicated in Fig. 11. The upper figure shows the moment-end rotation curves and the lower the change in the axial displacement. All specimens showed their maximum strength near the end rotation of 0.01rad by reason of compressive failure of the cover concrete. As the inner concrete was still able to endure the required compressive stress, the given axial compression was still endured stably, however, the specimens with sparser hoop reinforcements finally became unstable against the axial compression because of the buckling of the longitudinal reinforcing bars. The specimens with the additional eccentric reinforcements showed higher strength, less strength degradation and more delayed unstable behavior against the axial compression than the ones without. The eccentrically arranged longitudinal reinforcements improve the ductility of the members especially with high axial compression. It is also effective to increase hoop reinforcements. Therefore it is considered to be more effective to use them together in members.

Table 1. List of specimens for bending test with axial compression

Specimen	b×D×h (mm)	Longitudinal Reinforcing Bars		Hoop Reinforcing Bars	Compressive Strength of Concrete σ_B (tonf/cm^2)
		Normally Arranged Bars	Eccentrically Arranged Bars		
CB-E-@30	160×160×320	4-D13 (1.98%)	2-D13 (0.99%)	2-6ϕ @30 (1.18%)	287
CB-N-@30			—		279
CB-E-@100			2-D13 (0.99%)	2-6ϕ @100 (0.35%)	257
CB-N-@100			—		257

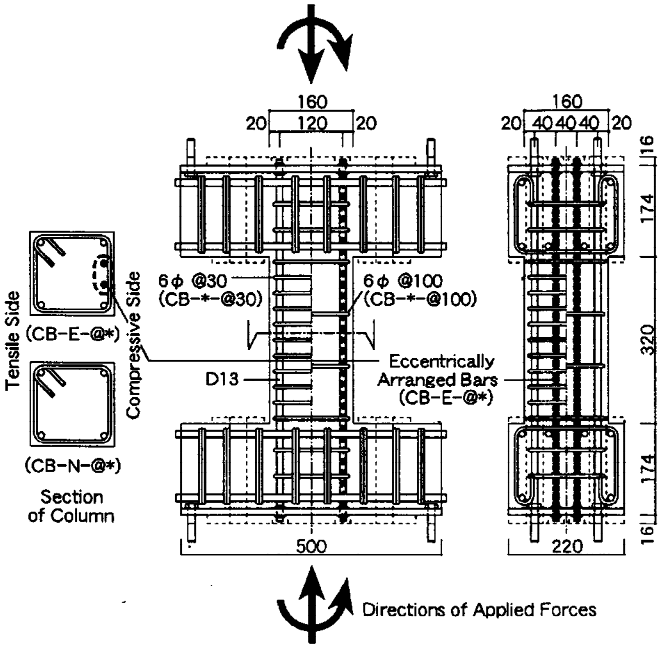


Fig.10. Dimension and detail of splecimens for bending test

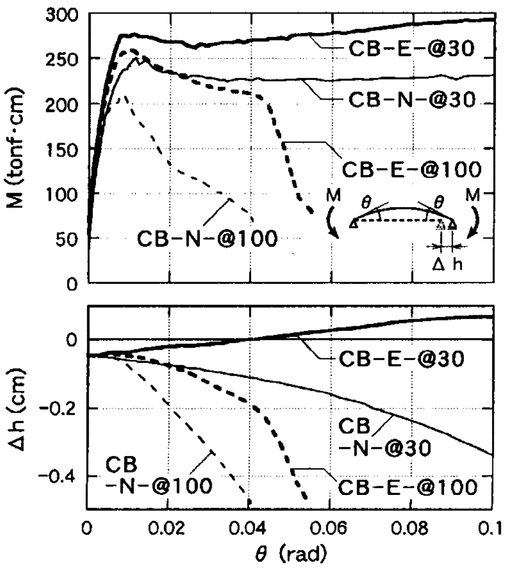


Fig.11. Moment-end rotation curves and change in axial displacement according as end rotation increases

In the next, anti-symmetrical bending tests with a varying axial compression were carried out. The couple of the specimens listed in Table 2 and illustrated in Fig.12 were made and tested. The difference between them was only the position of the additional longitudinal bars, i.e., the ones were arranged diagonally in a member, and another arranged near geometrical centroid of the section so as not to endure the bending moment. The columns with the additional central bars are popular in the exterior ones in high-rised buildings in our country. This experiment is the comparative one of the present arrangement of the reinforcement to the ordinary one's. The specimens had the same section of 160mm × 160mm and the same clear length of 640mm. The compressive strengths of the concrete were almost same as shown in the table, and the deformed bars were the same as the experiment above mentioned. The axial compression of about 60% of bDσ_B was loaded during a positive loading, and during a negative loading no axial compression was applied, imaging the actual behavior of the exterior column, however, the constant axial compression was applied in the experiment because of the circumstances of the loading apparatus, as against the actual changing of the axial compression. The cyclic loading schedule was as follows; two times of positive and negative loading until the end rotation of 0.005, 0.01, and 0.02 rad, three times of the loading until 0.04 rad, and the positive loading until 0.08 rad.

Table 2. List of specimens for cycric shear-bending test with axial compression

Specimen	bxDxh (mm)	Longitudinal Reinforcing Bars			Hoop Reinforcing Bars	Compressive Strength of Concrete σ_B (tonf/cm^2)
		Normally Arranged Bars	Eccentrically Arranged Bars	Central Bars		
VCBS-E	160×160×640	4-D13 (1.98%)	2-D13 (0.99%)	—	2-6φ @30 (1.18%)	263
VCBS-C			—	2-D13 (0.99%)		270

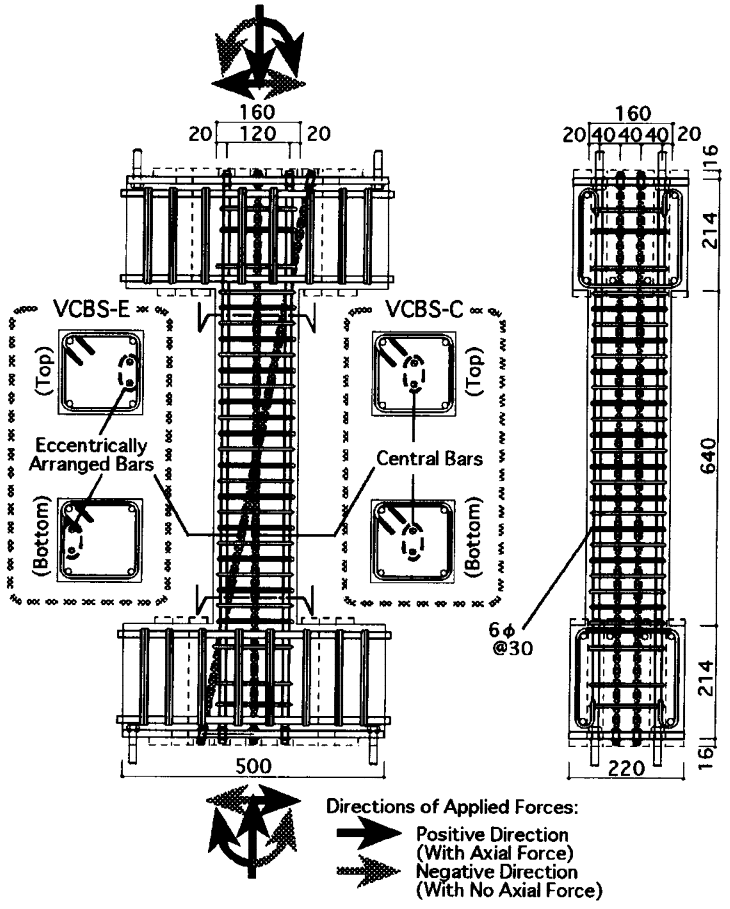


Fig.12. Dimension and detail of a typical splecimen for shear-bending test

The histories of the restoring moment and the axial displacement are described in Fig. 13. The specimen with the eccentric reinforcement reached higher strength during both the positive and the negative loading, but its restoring force characteristic containing the strength degradation during each loop did not differ so much from the one with the central reinforcing bars. As for the axial displacement, the column with the central reinforcing bars always shrank axially during the positive loading, i.e., under the high axial compression and became unstable against the axial compression during the final positive loading, however, the one with the reinforcement eccentrically arranged extended at least after yielding due to bending until the end rotation of 0.04 rad. The axially deforming behavior, i.e., the stabilities against the axial compression of the present column obviously differs from that of the ordinary one.

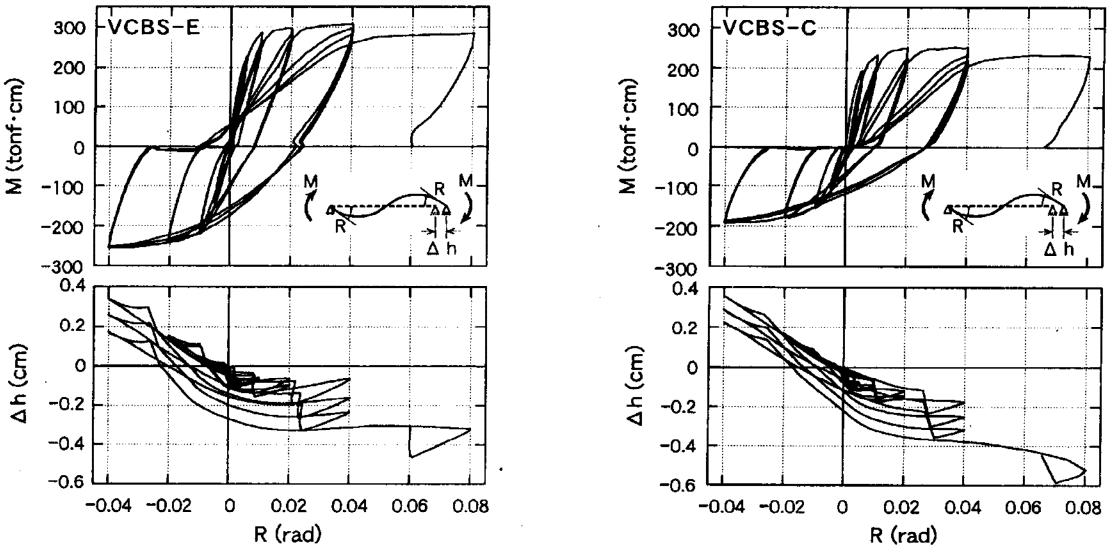


Fig.13. Histories of restoring moment and axial displacement depending on end rotation

CONCLUSIONS

A new arrangement of longitudinal reinforcing bars to improve the ductility in RC exterior columns is presented. Its effectiveness is investigated by means of the section analysis and several experiments. The presented arrangement of the longitudinal reinforcing bars is quite effective to improve the ductility of a member with high axial compression, especially an exterior column in which the axial compressive stress severely changes during an earthquake.

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