CONSIDERATION OF EARTHQUAKE DESIGN FOR REINFORCED CONCRETE COLUMNS OF TALL BUILDINGS

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SYNOPSIS

The KS column was newly developed as the column system of tall reinforced concrete buildings, taking into consideration the simplicity of construction works as well as the aseismatic effects. This paper describes earthquake resistant properties of KS column, their comparison with the aseismatic effects of the conventional lateral reinforcements of columns, the application of the tecnology to the practical construction works and researches on aseismatic characteristics of KS columns in the lower stories of tall buildings in structural experiments.

INTRODUCTION

As a matter of common practice in Japan, buildings of pure reinforced concrete structure are not regarded as safe enough against earthquakes as those of steel or composite reinforced concrete structure. Pure reinforced concrete structure have been traditionally forbidden for the framework of buildings of 7 stories or more and 20 meters higher.

Both the Tokachi-oki (1968) and San fernando (1971) earthquake revealed, in fact, the defects of reinforced concrete structure; some of them were damaged severely during the earthquakes. The most striking feature of the damages resulting from these earthquakes was the shear failure of reinforced concrete columns.

Our studies were made as one series of research and development work on high-rise reinforced concrete buildings. This paper describes experimental results of the experiments on the newly devised column which was developed in consideration of not only the earthquake resistant effects but also the simplicity of construction as the column system of high-rise reinforced concrete buildings.

ASEISMATIC BAR-ARRANGEMENT SYSTEMS OF COLUMNS

In realization of tall buildings of reinforced concrete structure in Japan, first of all, reinforced concrete columns strong enough to have sufficient earthquake resistance should be developed. Judging from the damages of reinforced concrete columns caused by the Tokachi-oki earthquake (1968), it was recognized that the conventional types of lateral reinforcement would have to be improved fundamentally to increase the earthquake resistance against many repetitions of cyclic lateral forces as experienced during the destructive earthquakes. The authors tested each of the specimens shown in Fig.1 with different lateral reinforcement types of reinforced concrete to research their aseismatic behaviour.

The hooped column was the conventional type of reinforced concrete columns in Japan. The tied column and spiral column, which are more effective in confinement of the core concrete and longitudinal bars, are supposed to be better aseismatic than the hooped column. However both the tied column and spiral column have a few difficulties in the construction works in which the tied column showes complexity in placing lateral reinforcements, which in the spiral column, construction of the beam reinforcing bars through the column is difficult. A new arrangement type of column reinforcement combining the spiral and square hoops was devised to make good these defects, and the divice was named as KS column. The bar arrangement of the KS column

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was shown in Fig.2.

The authors compared in experiment to the aseismatic properties of reinforced concrete columns, using the light weight aggregate concrete with high strength (designed compressive strength $Fc=360\ kg/cm^2$) with varied types and amount of lateral reinforcement. In this test, the authors intended to research the restoring force characteristics of the columns used in tall reinforced concrete buildings against the alternately repeated lateral force in the range of plastic deformation at rotation angle R=1/100 rad to keep constant stress $\sigma_n= N/BD=1/3Fc=120\ kg/cm^2$ during tests. In Fig.3 the hooped column showed a very significant reduction of restoring force by shear failure due to increasing repeated cycles. On the other hand, tied column and the spiral column showed not so large reduction of restoring force even after many cycles of alternately repeated distortion in plastic range and the pattern of bending failure to maintain the ductile characteristics. And the KS column was found in the experiment to have the same aseismatic properties as those of the tied column and the spiral column.

EARTHQUAKE DESIGN OF KS COLUMNS IN THE SHIINACHI BUILDINGS

The Shiinamachi building, built in January 1974, was 18 stories high and represented the first trial of a tall reinforced concrete building in Japan. Fig.4 showed the outline of transverse framing of this building. The building structure was designed to be composed of uniform open frames which were ductile moment resisting frames consisting the ductile members of which the shear capacity surpassed the bending one. The columns of this building were unified KS column of which dimensions were all 60 cm square, except 8 side columns for longitudinal framings. They were intended to uniform the stiffness of framing and to rationalized the works of forming. The reinforcement arrangement was made up of 12 axial bars, 4 corner bars of column with square hoops and the other 8 bars with spiral hoop.

The exterior columns of the lower stories in the transverse framing of this building, of which the tower ratio was comparatively large, are subject to too much tension force due to destructive earthquakes. Though in general the resistant behaviour of lateral force when the columns of reinforced concrete structure catch the tensile force has not known adequately, the exterior columns of Shiinamachi building were provided with two PC bars 32 mm in diameter in the center of the column section with an aim at reluxing extremely tensile force which was supposed to develop in destructive earthquakes. One was placed in the column passing through the 1st floor to the 6th floor and the other in the column passing through the 1st floor to the 4th floor. The effective prestressing force of each bar introduced at the beam bottom of the 1st floor was designed to be 45 tons so that the axial tensile stress of the exterior column in destructive earthquakes could be reduced to below 20 kg/cm^2.

The aseismatic safety of the exterior column by the induction of the prestressing force was confirmed in structural experiments. The specimens shown in Fig.5 were $1/\sqrt{2}$ scaled models against the proto type which was the exterior column of transverse framings at the 2nd story. The experiments were made on two specimens for comparison, one (specimen NO.1) being a prestressing column built in accordance with the design, and the other (specimen NO.2) being a pure reinforced concrete column as non-prestressing. In testing the specimens, conducted by testing set up and loading procedure as shown in Fig.6 and Fig.7, the condition of an exterior column recieving stress in earthquakes was simulated. At first, sustained load(N_L)designed was applied to the column, and next, designed axial load(N_K) caused by overturning effects brought about by alternate lateral shear force was applied alternately to it variedly.

A load deflection curve of specimen NO.1 is shown in Fig.8. The results from this experiment are summarized as follows:

i) There were no cracks under the compressing axial load simulated till the load was increased to one half times of the design load.

ii) On the other hand, when the axial force in tension was increased to tow times of the designed force, many flexural and tension cracks were found, but no significant damages by shear force were seen.

iii) The prestressing column was preferable to non-prestressing one, because the former maintained the higher strength and stiffness and less cracks were found on the former.

EARTHQUAKE RESISTANT CHARACTERISTICS OF KS COLUMNS

With the aim of researcing the ductile properties of the KS column, a total of 13 specimens were tested for properties of columns in the lower stories of tall reinforced concrete buildings (see Table 1, Fig.9 and Fig.10). This experiment chose 4 facters that affect the earthquake resistance of a column--the applying axial load, the kind of concrete, the ratio of lateral reinforcement and loading directions. The results of these experiments shown in Fig.11 and Fig.12 may be summarized as follows:

APPLYING AXIAL LOAD The columns receiving tensile axial force(N=-70 ton) showed increasing the load capacity and maintained enough ductility with increasing deformation after the yielding of tensile bars. The column receiving compressive axial force below N=140 ton corresponding to axial load N_B on equilibrium of ultimate bending capacity based on ACI Code showed a little capacity decay after the maximun strength was reached, and the sufficient ductile resistance can be expected. Otherwise, the columns receiving large axial force (N=210 ton, 280 ton) seemed remarkably to decay the capacity with the increase of applying axial load, and too much ductility can not be expected.

KIND OF CONCRETE In case of compressive columns with lateral reinforcement ratio Pw=0.9%, it became clear that both the strengh and stiffness rose evidently and ductility became better after the maximum capacity was attained by changing light weight aggregate concrete to the normal concrete.

LATERAL REINFORCEMENT RATIO In the case of the columns with the normal concrete receiving the axial force N=140 ton and 280 ton, it was found that the maximum capacity incresed a little, but the restoring force characteristics improved remarcably after the maximum capacity was attained.

LOADING DIRECTION In case of the column with light weight aggregate concrete whose axial load of N=140 ton, the column under biaxial load of both bending and shearing was below in the maximum capacity than the column with uniaxial load, but the ductility was rather better.

CONCLUDING REMARKS

The column systems of tall reinforced concrete buildings should maintain strong earthquake resistance and, at same time, arrange the bars properly the practical work with certainty. The KS column, restraining 4 corner bars with square hoops and the other bars with spiral hoops, was newly devised in the structural system of reinforced concrete columns for tall buildings, and it was confirmed in the construction of the Shiinamachi building and through many structural experiments that it is excellent the simplicity of construction works and the earthquake resistance.

Even though the structural framing of tall reinforced concrete buildings is designed so that the beams yeild before columns, it should be away to prevent the collapse of a tall building in destructive earthquakes of unexpectedly strong force to design the column to give it as high a ductility as possible.

REFERENCE

1. T.Hisada and others,"Earthquake Design Considerations in Reinforced Concrete Columns", Earthquake Engineering and Structural Dynamics, Vol.1, 79-91(1972).
2. K.Muto, T.Hisada, T.Tsugawa and S.Bessho,"Earthquake Resistant Design of 20 Story Reinforced Concrete Buildings", 5WCEE,Rome, June 1973.

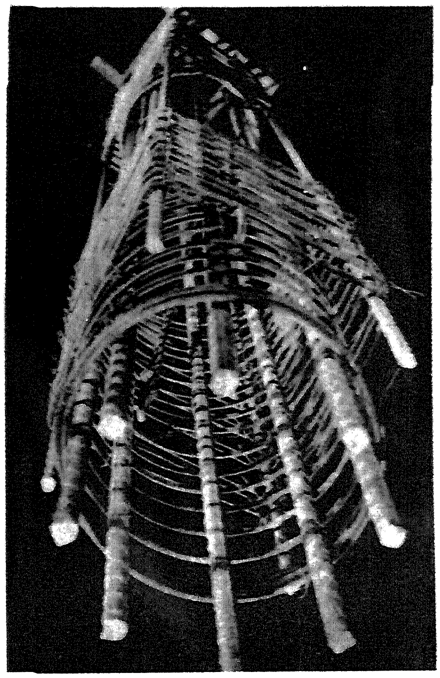
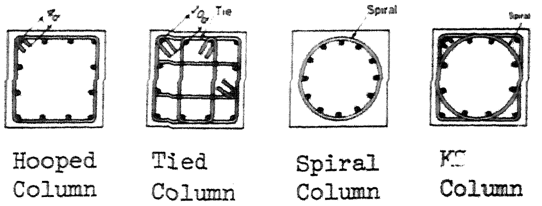


Fig.2 Bar Arrangement of KS Column



Hooped Column Tied Column Spiral Column KS Column

Fig.1 Tested Lateral Reinforcement Systems

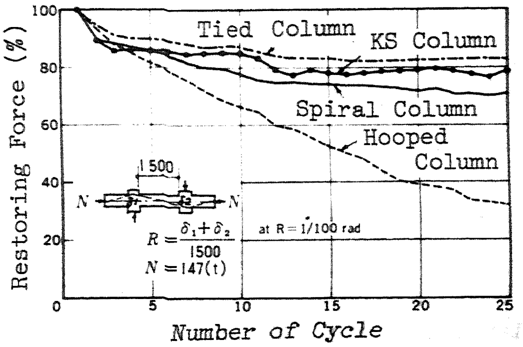


Fig.3 Restoring Force Decay of Each Column for Cyclic Deformation

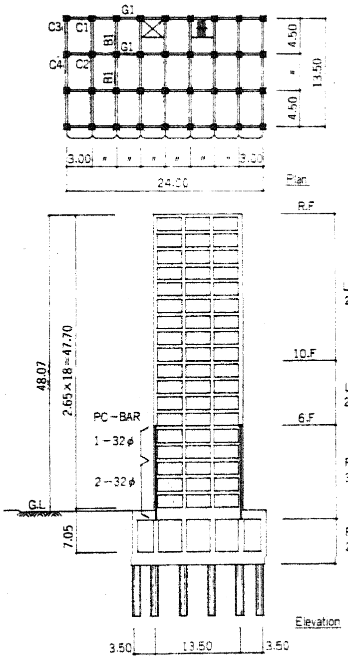


Fig.4

Outline of The Transverse Framing of Shiinamachi Build.

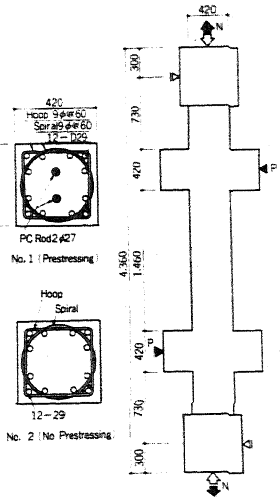


Fig.5

Test specimens for Exterior Columns

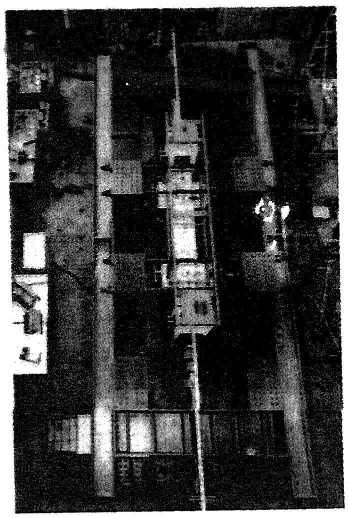


Fig.6 Testing Set-up

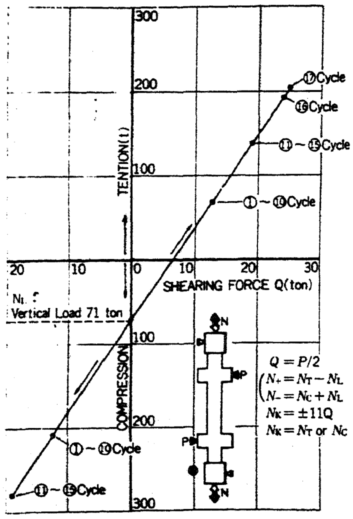


Fig.7 Loading Procedures

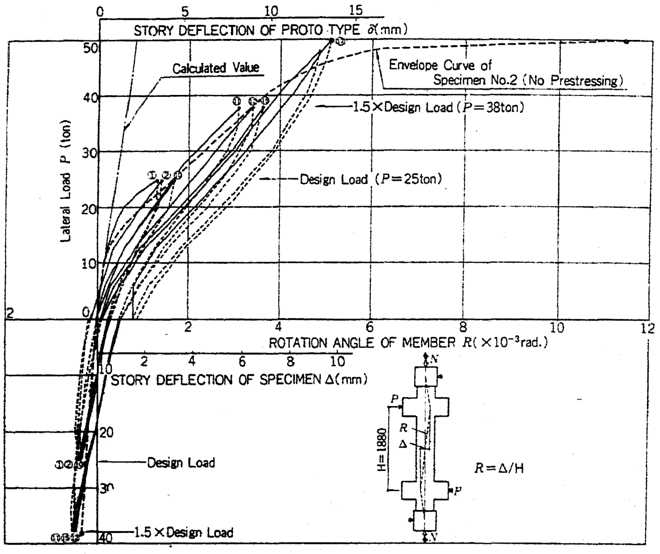


Fig.8 Load-deflection Curve of Exterior Column Specimens

Table 1
List of Specimens to Investigate The Earthquake Resistant Properties of KS Columns

Mark	Design Value				
	Kinds of Concrete	Transverse Reinforcement Ratio P_w (%)	Type of Loading	Axial Load	
				N (ton)	N/BD (kg/cm²)
APW0. 9NT070	Light-weight	0.9	→□	-70	-57
APW0. 9NC070	〃	〃	〃	70	57
APW0. 9NC140	〃	〃	〃	140	114
APW0. 9NC210	〃	〃	〃	210	171
APW0. 9NC280	〃	〃	→□	280	229
BPW0. 9NC140	〃	〃	→◇	140	114
BPW0. 9NC280	Light-weight	〃	→◇	280	229
CPW0. 9NC070	Normal-weight	〃	→□	70	57
CPW0. 9NC140	〃	〃	〃	140	114
CPW0. 9NC210	〃	〃	〃	210	171
CPW0. 9NC280	〃	〃	〃	280	229
CPW1. 2NC140	〃	1.2	〃	140	114
CPW1. 2NC280	Normal-weight	〃	→□	280	229

Axial reinforcement ratio : $P_g=\frac{A_s}{BD}=2.8\%$

Shear arm ratio : $\frac{a}{D}=\frac{M}{QD}=1.5$

Designed compressive strength $Fc=300$ kg/cm^2

Designed yield strength $\sigma y=3.5$ ton/cm^2

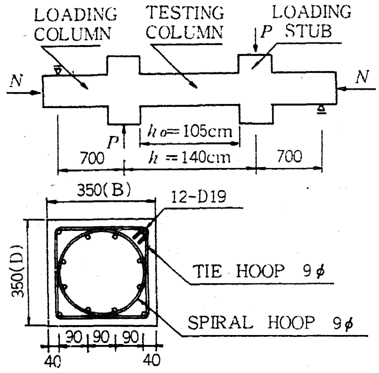
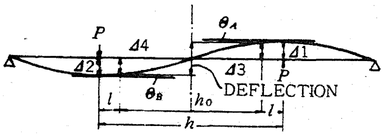


Fig.9 Outline of Test Specimens



$$\Delta_T=\Delta_1+\Delta_2-\frac{h}{2}(\theta_A+\theta_B)$$

$$=\Delta_1+\Delta_2-\frac{h}{2l}\{(\Delta_1-\Delta_3)+(\Delta_2-\Delta_4)$$

Fig.10

Measuring Method for Structural Deformation

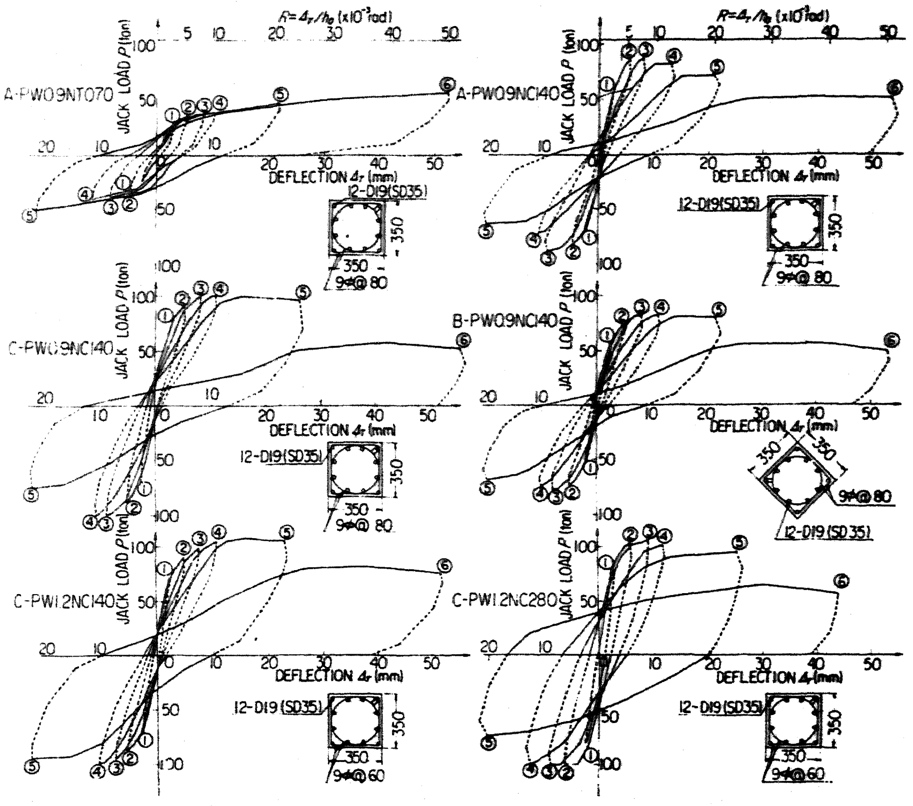


Fig.11 Load-deflection Curves of Typical Specimens

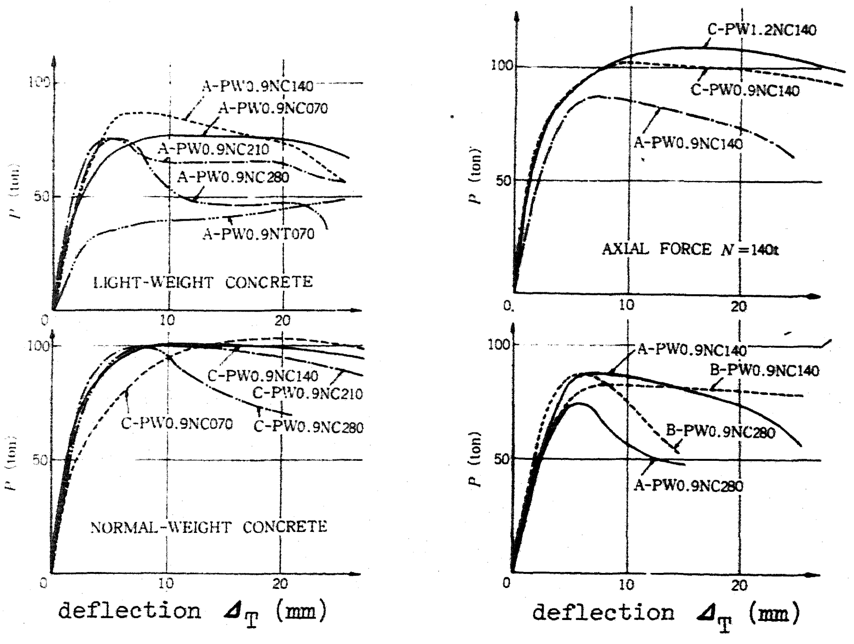


Fig.12 Comparison of Enveloped Load-deflction Curves