Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.IV)

6-4-12

A NEW WAY FOR IMPROVING THE SEISMIC BEHAVIOR OF REINFORCED CONCRETE SHORT COLUMN

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SUMMARY

The horizontal cyclic loading tests of 3 short column specimens, prove that short column segmented into 4 separate columns by diaphragm boards can be transformed into long column both in its stress behavior and failure mode. Shear failure is transformed into flexural failure, shear strength is not affected, flexural strength decreases slightly, but the deformability is obviously improved.

INTRODUCTION

Earthquake lessons prove that short column failure is an important factor causing collapse of frame building. Worldwide investigations had been made to improve the seismic behavior of short column, such as using special type reinforcement, steel fibre concrete and steel-concrete composite structure.Ineffectiveness due to very small shear to span ratio of column (m<1.5) and complication in construction are the defects of above measures.

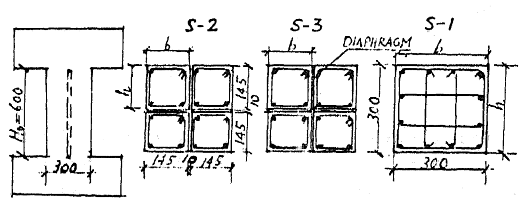


Fig.1 Dimension of Specimens

The method suggested in this paper is to separate the rectangular column between upper and lower beams into 4 smaller columns of equal sections, the column section within the region of beam-column joint is not separated (Fig.1).The shear to span ratio is doubled,even very short column can be transformed into long column. The aseismic behavior is much improved.

Description of Experiment Three test specimens including S-1 ordinary short column for comparison, S-2 segmented short column using asbestoes diaphragm boards, and S-3 segmented short column using gypsum diaphragm boards. Dimensions of specimens and reinforcement details are shown in Fig.1 and Table.1.

The test was carried out on a quasi-static testing foudation. A loading set with 4 hinged bars was adopted (Fig.2)

Table 1

Specimens	R(test) Kg/cm^2	b x h mm mm	Ho mm	Reinforcement	μ %	Hoop	μ_t%
S-1	346	300x300	600	12 ϕ10	1.16	8-70 4 bars	2.30
S-2	262	145x145	600	4 ϕ10	1.88	4-70 2 bars	0.76
S-3	235	145x145	600	4 ϕ10	1.88	6-70 2 bars	1.70

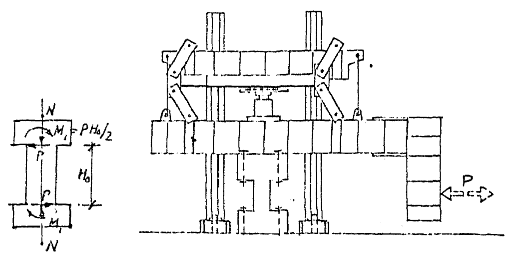


Fig.2 Loading Set

The cyclic loading procedure is shown in Fig.3. The first cycle corresponds to the initial crack level, flexural cracks firstly appeared on S-2, S-3. The

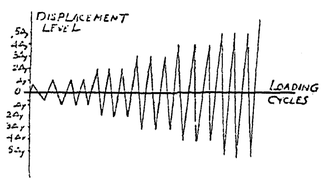


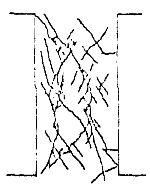
Fig.3 Loading Program

second cycle corresponds to the yielding of longitudinal steel at the end of column, after that the loading was controlled by the relative horizontal displacement between ends of column. There are three cycles for each displacement level.

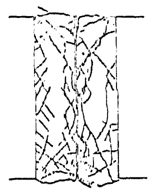
Test Results

1. Failure Mode. Diagonal shear cracks appeared firstly on S-1, followed by yielding of longitudinal reinforcement at the lower end of column, finally, sudden failure occured due to crushing of concrete by shear compression and buckling of longitudinal reinforcement. Maximum horizontal load reached 45t. The crack pattern of shear-compression failure is shown in Fig.4.

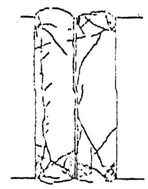
Under horizontal loading, longitudinal cracks firstly appeared along the diaphragm board of the segmented column S-2,S-3. Four small columns were acting simultaneously according to the behavior of long columns. With the increasing of horizontal cyclic loading horizontal flexural cracks firstly appeared at both ends of column, plastic hinges were nearly formed simultaneously with shear cracks on both ends. The final failure was caused by successive degradation of strength due to crushing of concrete at the regions of plastic hinges. The flexural compression failure modes of S-2,S-3 are shown in Fig.5 and Fig.6.



Crack Pattern
S-1 Fig.4



Crack Pattern
S-2 Fig.5



Crack Pattern
S-3 Fig.6

Bond failure cracks appeared along longitudinal reinforcement of S-2,S-3, this is owing to high reinforcement ratio of the small column (μ=1.88%). Vertical splitting cracks were found on S-3 at final stage due to comparatively high compressive stress ratio σ_o/R_a=0.60. σ_o is the compressive stress, Ra is the design strength of concrete under axial compression.

2. Strength and Deformation (1) The internal force and displacement of specimin under horizontal loading are shown in Fig.7.

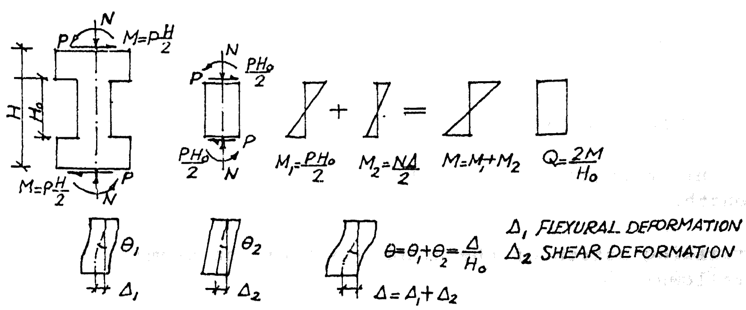


Fig.7 Internal Force and Displacement of Specimen

The tested ultimate shear strength, ultimate flaxural strength and displacement are shown in Table.2.

Table.2

Spacimen	R_{test}	R_w^b Kg/cm²	R_a	$R_g(\phi 10)$	N t	σ_o/R_a	τ_s/R_a	Q_s=P t	Q_j t	$M_s=M_1+M_2$	M_j t-m	Δ_s mm
S-1	346	301.4	200.3	3490	90	0.50	0.272	45	43.71	14.45	11.86	7
S-2	262	230	152.2	3490	55	0.42	0.232	24.3	15.26	(7.29) 7.70	(5.16) 8.90	15
S-3	235	206.5	134.5	3470	67.5	0.60	0.297	26.7	22.74	(8.04) 8.62	(5.29) 9.30	18

In Table.2:

Q_s--Max.value of tested shear;

Q_j--Max.value of computed shear. The sum of the shear strength of 4 small column is adopted for S-2, S-3;

M_s--Max.value of tested bending moment. The figures in the parenthesis are M_1 values (Fig.7);

M_j--Max.value of computed bending moment. The value in the parenthesis represents the sum of the flexural strength of four small columns;

σ_o/R_a -- compressive stress ratio of column section;

τ_s--tested value of average shear stress;

Δ_s--tested value of retative horizontal displacement of column ends at the stage of max. tested loading;

(2) Strength of Segmented Short Column.

From Table 2, it can be seen the tested values of shear strengths of S-2,S-3 are higher than computed values. Flexural strengths are slightly lower than those computed as an integral section, but are greater than the summation of the flexural strength of four separate columns. In general, the shear strength and flexural strength of segmented short column are all greater than those computed as the summation of individual small columns. The reasons are:

a.Shear transfer by the restraining action of diaphragm board.

Except from flexural action of four individual columns, the restraining action of the diaphragm board increases the flexural strength of the segmented column, it is included in the tested value M_s(Fig.8)

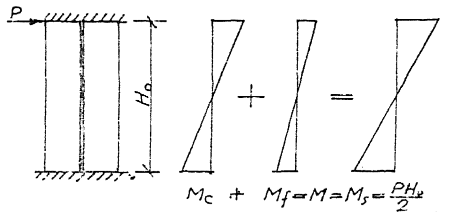


Fig.8 Restraining Action of Diaphragm

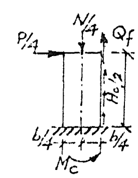


Fig.9

b.The diaphragm board itself participates in the ultimate shear strength and flexural strength.

The restraining action of the diaphragm board on segmented column can be computed as follows:

Fig.9 designates an isolated part of segmented column. Q_f is total shear along diaphragm board.

$$Q_f=\frac{3}{2}\beta\frac{P}{b^2}\,\frac{b}{2}\,\frac{Ho}{2}=\frac{3}{8}\beta\,\frac{PHo}{b}$$

Restraining moment due to diaphragm board:

$$M_f=\frac{Q_f b}{4}=\frac{3\beta}{32}PHo$$

Moment at the end of small column:

$$M_c=\frac{PHo}{8}-M_f=\frac{PHo}{32}(4-3\beta)$$

is the coefficient of integral effect of segmented column. $\beta=1$, for integral column. $\beta=0$, for segmented column without diaphragm board.

Coefficient β of S-2,S-3 can be approximately obtained from tested value M_1.

S-2 $\quad M_f=\frac{M_s}{4}-\frac{M_j}{4}=\frac{7.29}{4}-\frac{5.16}{4}=0.53\text{t-m.}$

$$=\frac{32M_f}{3PHo}=\frac{0.53x32}{3x24.3x0.6}=0.39.$$

S-3 $\quad M_f=\frac{8.01}{4}-\frac{5.29}{4}=0.68\text{t-m.} \qquad \beta=\frac{0.68 \text{ x } 32}{3x26.7x0.6}\approx 0.45$

From the above analysis, we find the integral coefficient coefficent varies with material of the diaphragm board. When β =0.39, the moment reduction factor:

$$\frac{M_c}{M} = \frac{2M_c}{PH_o} = 1 - \frac{3\beta}{4} = 0.70$$

(3) Deformation of Segmented Column

The tested horizontal relative displacements Δ_s at maximum loading stage are listed in Table 2. Even under the condition of lower strength of concrete, the deformability of segmented column is 2.14-2.57 times larger than that of ordinary column.

The tested P-Δ hysteretic curve (horizontal loading/relative displacement of column ends) are shown in Fig.10,11,12. The maximum horizontal displacement Δ max of S-2 is 21.19mm, ductility factor μ_Δ=4.81. Δ max. of S-3 is 23.67mm, μ_Δ=5.68. The shape of hysteretic loops designates adequate energy dissipating behavior of S-2,S-3. Comparatively, S-3 is better than S-2, this explains gypsum board

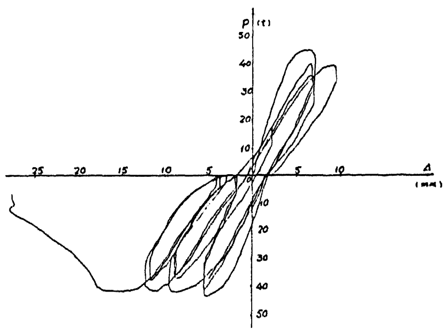


Fig.10 P-Δ curve S-1

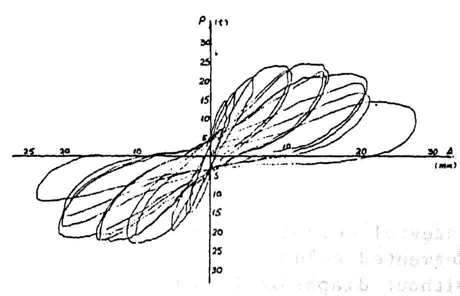


Fig.11 P-Δ curve S-2

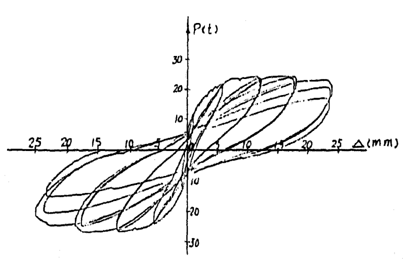


Fig. 12 P-Δ curve S-3

possesses better energy dissipation behavior than asbestoes board.

The flexural and shear deformation and the additional deformation due to N-Δ effect are considered in computing the displacement of segmented column in elastic stage. The coefficient β should be considered in computing displacement due to horizontal loading. The displacement angle due to total displacement can be calculated by following formula.

$$\frac{\Delta}{H_o} = \frac{P(4-3\beta)\ (16H_o^2+9.6b^2)\ (Eb^4+4N\ H_o^2)}{16E^2b^8}$$

Δ --Relative displacement of column ends including displacement due to N-Δ effect;
P --Total horizontal loading;
N --Total axial load on column;
E --Modulus of elasticity of concrete;
β --Coefficient of integral effect due to disphragm boards;
b --Overall width and depth of segmented column.

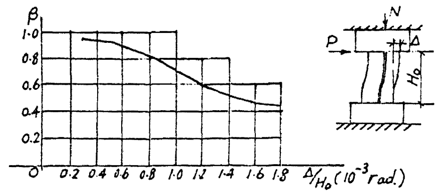


Fig.13 $\beta - \frac{\Delta}{H_0}$ Relationship

Fig.13 shows the relationship of $\Delta/H_0 \sim \beta$ at elastic stage, the intergral effect decreases with the increasing of displacement. β=0.96-0.43 corresponds to displacement angle 0.3‰—1.7‰. value decreases steadily at elastic-plastic stage. From strength analysis β value at stage of ultimate moment is about 0.4. Test shows the rigidity and integrity of segmented column can be maintained at a certain extent during minor earthquake, while at major earthquake adequate deformability satisfies the requirement of seismic design.

The rigidity factor λ is the ratio between the rigidity of segmented column and rigidity of integral column. $\lambda = \frac{1}{4-3\beta}$

Integral column β =1, λ =1
Segmented column
without diaphragm board β =0.4, λ =0.35

Segmented column
without diaphragm board β =0, λ =0.25

CONCLUSION

1.Segmented short column with diaphragm board can transform short column into long column and possesses adequate behavior of strength, deformability and energy dissipation.

2.Segmented column with gypsum diaphragm board behaves better than that with asbestoes diaphragm board.

3.The shear strength of segmented column is not lower than integral column, while its flexural strength is slightly lower than integral column.

4.The coefficient of integral effect β decreases with the increasing of deformation, at yielding stage β =0.40, the corresponding coefficient of rigidity degradation λ=0.35.