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STUDY ON SHEAR FAILURE PROPERTIES OF REINFORCED CONCRETE SHORT COLUMNS

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SUMMARY

Experimental and analytical study on the shear failure mechanisms of reinforced concrete short columns of shear span ratio of 1.5 was carried out. For experimental study, 27 specimens were used. To investigate the effect of bond between tensile steels and concrete on failure mechanisms, specimens for which the bond at the end portions and the middle portion was cut were used. Also, the effects of axial load and tie ratio on the failure mechanisms were studied. For analytical study, finite element method was applied and by considering bond splitting cracks of concrete surrounding tensile steels, the failure processes until the maximum shear load were followed. As the result of this study, the failure processes and stress condition of reinforced concrete short columns of shear span ratio of 1.5 were more clear.

INTRODUCTION

For aseismic design of reinforced concrete structures, beams and columns are necessary to be ductile enough to make sure the structures should not fail in brittle state under earthquake shear loading. In usual design processes, it is considered that the member should be designed not to be damaged by shear failure. But for the rather short reinforced concrete columns, it can not be said that the member would keep ductile behavior under large deformation or under shear reversal after bending yielding.

In former studies[1,2], the failure properties of reinforced concrete short columns loaded by shear reversals which are affected by axial loading, tie ratio, shear span ratio and so on were investigated.

In this study, experimental study using 27 specimens of reinforced concrete short columns of shear span ratio of 1.5 and analytical study using the finite element method were carried out to discuss the failure processes and the failure mechanisms of short columns.

EXPERIMENTAL STUDY

Experimental Program For all the column specimens, the cross section is 25cmx25cm, the length is 75cm, the ratio of shear span to depth is 1.5 and tensile steel ratio (Pt) is 0.96%. The configuration of the specimens is shown in Figure 1.

The variables which are considered to affect the behavior of reinforced concrete short columns subjected to axial load (N) and shear load (Q) are as follows;

(1)axial load:

(N):15t($24kg/cm^2$:$1/10F_c$),
30t($48kg/cm^2$:$2/10F_c$),
45t($72kg/cm^2$:$3/10F_c$),

(2) tie ratio:

P_w=0.56% - @90mm(2-9φ),
P_w=0.85% - @60mm(2-9φ),
P_w=1.28% - @60mm(3-9φ),

(3) bond condition at middle and end portions of the member: ordinary and cut,

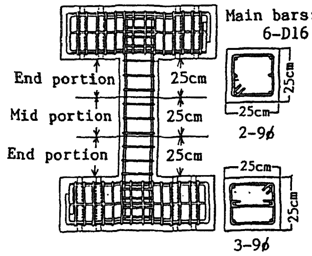

Fig.1 Test specimens.

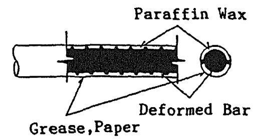

Fig.2
The mechanism to cut bond between steel and concrete.

where "F_c(=$240kg/cm^2$)" is the compression strength of concrete and "P_w" is tie ratio.

To cut bond between tensile steel bars and concrete, tensile steels are coated with wax at first, coated with grease next and finally covered with soft paper as shown in Figure 2. The region of end portions is 25cm length region from the member end and the middle portion is central 25cm length region as shown in Fig.1.

Table 1 shows specimen list. Specimen names are given in the order of [axial load (t)] - [tie ratio (%), tie pitch @ (mm)] - [number of tensile steels and bond condition (B:ordinary, UE:bond cut in end portions, UM:bond cut in middle portion)].

Table 1 Experimemental specimens.

15-0.56@90-6B	15-0.85@60-6B	15-1.28@60-6B	15-0.56@136-6B
30-0.56@90-6B	30-0.85@60-6B	30-1.28@60-6B	45-0.56@90-6B
45-0.85@60-6B	45-1.28@60-6B	45-0.56@136-6B	
15-0.56@90-6UE	15-0.85@60-6UE	15-1.28@60-6UE	30-0.85@60-6UE
30-1.28@60-6UE	45-0.56@90-6UE	45-0.85@60-6UE	45-1.28@60-6UE
15-0.56@90-6UM	15-0.85@60-6UM	15-1.28@60-6UM	30-0.85@60-6UM
30-1.28@60-6UM	45-0.56@90-6UM	45-0.85@60-6UM	45-1.28@60-6UM

The loading process is as follows ; (a) to apply constant axial load, (b) to apply horizontal shear loads of 3t and 6t, (c) to apply horizontal shear loads to cause first visible bending crack, (d) to apply horizontal shear loads to cause first visible shear crack and (e) to apply 3 cycles of shear load for relative horizontal displacements of ±7.5mm (deflection angle of 1/100), ±15.0mm (2/100) and ±22.5mm (3/100).

Result of Experiment To investigate the effect of axial loading and tie ratio, Figure 3 which shows typical shear loading and deformation relationship, and Figure 4 which shows some typical crack patterns for three deflection angles are referred.

Specimens under higher axial load and with lower tie ratio are more brittle than those under lower axial load and with higher tie ratio as seen from Fig.3.

Crack patterns (Fig.4) show that initial bending cracks occur near the member end for all specimens and following bending shear cracks occur at further portions from the end and this portion comes nearer to the middle portion as the axial load becomes smaller. At the ultimate state, specimens under higher axial load or with higher tie ratio tend to be damaged in bond splitting failure.

To see the effects of the bond conditions of tensile steels, Figure 5 which shows shear load and deformation relationships, Figure 6 which shows crack patterns are referred. Comparing ordinary specimens and bond cut specimens, the latter specimens are inferior in ductility to the former ones and after the deformation of the deflection angle 2/100 the declination of the stiffness of members becomes larger. From crack patterns, for specimens in which the bond of tensile steels at the middle portion is cut, shear failure is caused in the middle portion for the case of low tie ratio and bond splitting failure is caused in the middle portion for the case of much tie ratio. For the specimens in which the bond of tensile steels at the end portions is cut, the first bending cracks develop to the bond splitting cracks which occur in the middle portion without any occurrence of bending shear cracks which are caused in ordinary specimens.

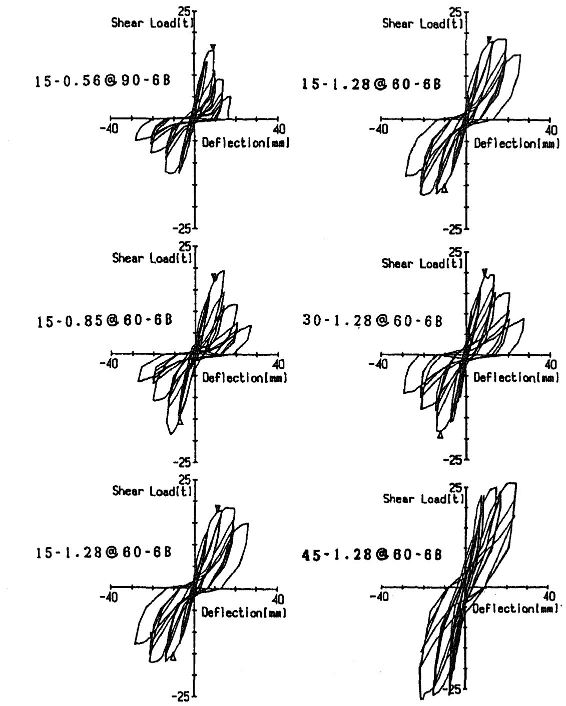

Fig.3 Typical shear loading and deformation relationships.

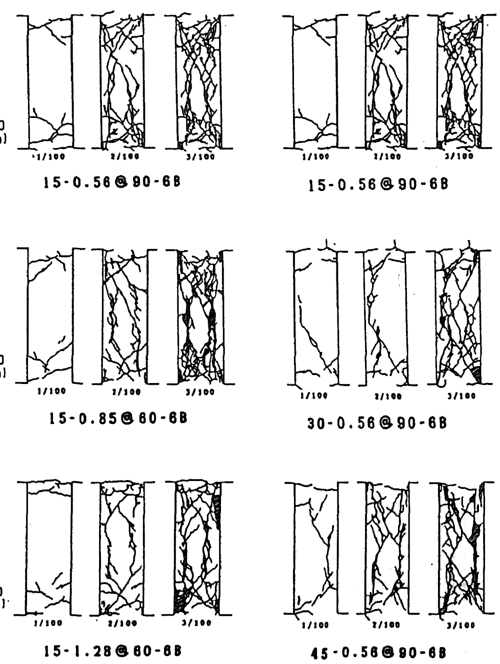

Fig.4 Typical crack patterns for three deflection angles.

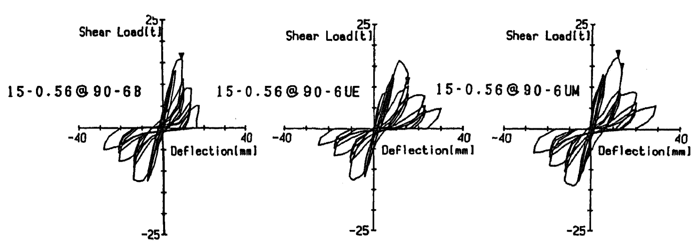

Fig.5 Shear loading and deformation relationships for bond condition.

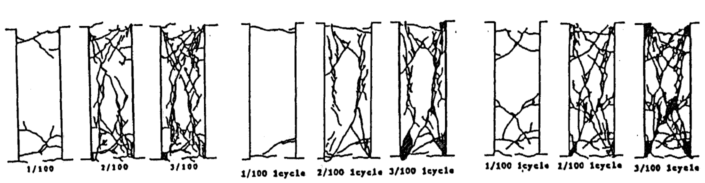

Fig.6 Crack patterns for bond condition.

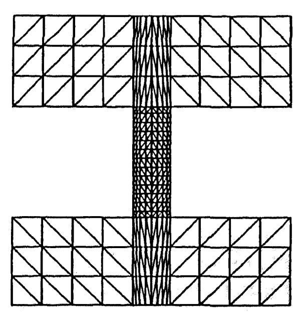

Fig.7 Analytical model.

ANALYTICAL STUDY

Analysis by The Finite Element Method The finite element method is applied for the analytical study. The analytical model is shown in Fig.7 and this model was selected after the actual reinforced concrete specimens which were used in the experiment. Concrete is represented by constant strain triangular elements. And for the behavior of concrete under biaxial stress, the modified incremental orthotropic model is used. Material properties of concrete are shown in Table 2(a). Tensile steels and ties are represented by one-dimensional element. The stress-strain relationship of steel is bi-linear type including the kinematic hardening under cyclic shear loading. Material properties of steel are shown in Table 2(b). Bond link element(Figure 8), which connect concrete and tensile steels, where "K_h" is dowel action stiffness and "K_v" is interface shear stiffness, is used. But perfect bonding between tie and concrete is assumed. Material properties of bond link are shown in Table 2(c).

For reinforced concrete short columns, bond splitting failure is important. Usually, bond splitting failure is represented by increase of stress in bond link. But in this study, we proposed a model called "bond splitting zone" for bond splitting crack. Bond splitting zone represents tensile failure of surrounding concrete of tensile steels. Elements of surrounding concrete of tensile steels have smaller volume than the other elements of concrete due to tensile steels and ties. Figure 9 shows bond splitting zone.

Table 2 Material constant.

(a) concrete

uniaxial compressive strength f_c' (kg/cm²)	250.0
uniaxial tensile strength f_t' (kg/cm²)	36.0
strain for f_c' ε_{cu}	0.0030
initial elastic modulus E_0 (kg/cm²)	215000.0
poission's ratio ν	0.18

(b) steel

yield strength τ_y (kg/cm²)	3780.0
initial elastic modulus E_s (kg/cm²)	2100000.0
modulus after yielding Esy (kg/cm²)	50000.0

(c) bond link

slippage stiffness E_b (kg/cm³)	10000.0

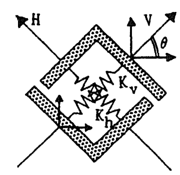

Fig.8 Bond link element.

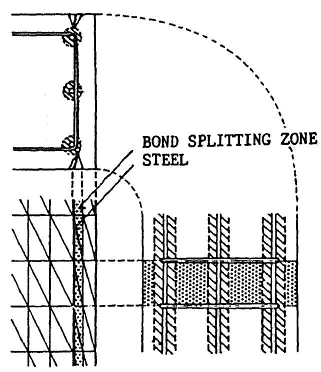

Fig.9 Modeling of oond splitting.

Result of Analysis Figures 10 through 14 are the results for monotonic shear loading. Figures 15 and 16 are some results among those for cyclic shear loading. Figure 10 shows crack patterns of some specimens under different axial loads. Bending cracks occur at smaller shear load for smaller axial load. In the ultimate state, for the specimens of 15t of axial load, bending shear failure is caused, for the specimens of 30t of axial load combined bending shear and bond splitting failure is caused and for the specimens of 45t of axial load bond splitting failure is caused.

Figure 11 shows the distribution of tie stress. The stresses in ties in the middle portion are rather large. These values become larger as the axial loads become larger.

Failure properties in connection with crack pattern are not affected much by the difference of tie ratio, but, distribution of tie stresses is affected. The tie stresses are larger in the middle portion for lower tie ratio and tie stresses are larger in the end portions for larger tie ratio. This shows that specimens with lower tie ratio have the tendency of failure in the middle portion and those with higher tie ratio have the tendency of failure in the end portions.

To compare the behaviors of ordinary and bond cut specimens, Fig.12 for crack patterns, Fig.13 for the distribution of tie stresses and Fig.14 for the stress distribution of tensile steels are shown. From crack patterns, it is observed that for ordinary specimens bending cracks occur first, ensuing bending shear cracks and shear cracks occur and bond splitting failure is caused, whereas for specimens with tensile steels bond of which is cut in the end portions bending cracks occur first and bond splitting cracks occur after small increase of shear and for specimens with tensile steels bond of which is cut in the middle portion bending cracks occur first, bending shear cracks and shear cracks occur next and shear failure in the end portion is caused.

Comparing the stress distributions in tensile steels, for specimens bond of which is cut in the end portions, stress gradient in the middle portion is larger and is smaller in the end portions than those for ordinary specimens. And for specimens bond of which is cut in the middle portion, stress gradient in

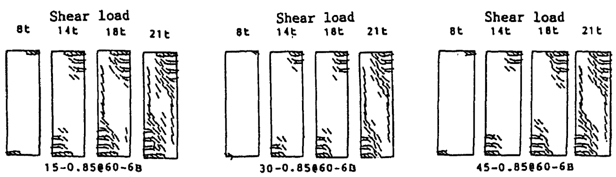

Fig.10 Crack distribution for different axial loads.

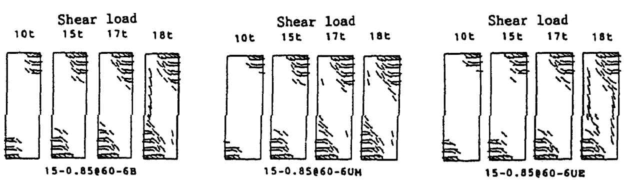

Fig.12 Crack distribution for bond condition.

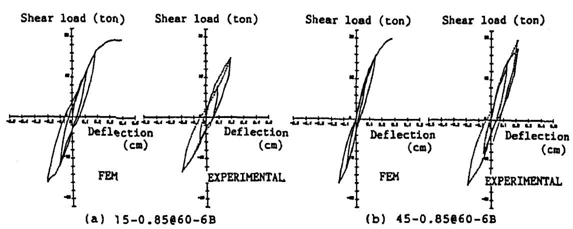

Fig.15 Shear load-deflection relationships for cyclic shear loading.

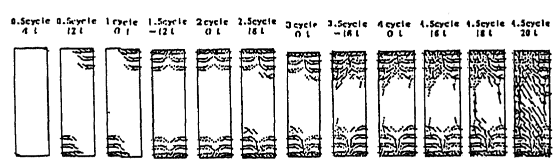

Fig.16 Crack distribution for cyclic shear loading.

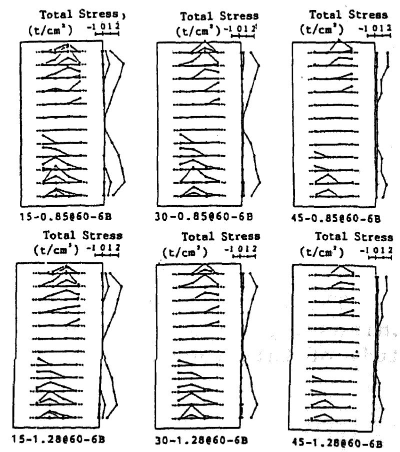

Fig.11 Stresses in tie for tie ratio.

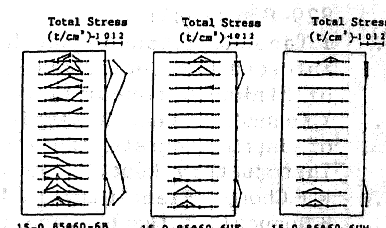

Fig.13 Stresses in tie for bond conditions.

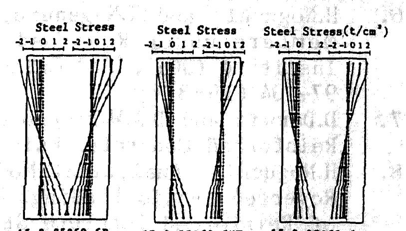

Fig.14 Stresses in tensile steel for bond condition.

the middle portion is smaller and that in the end portions is larger. The effects for distribution of tie stresses by bond conditions are not clear for the present analysis.

To observe the behaviors under cyclic shear loading, Fig.15 for the shear load-deflection relationships and Fig.16 for crack patterns of some specimens are shown with experimental results. Comparing crack patterns and shear load-deflection relationships, the agreement between experimental and analytical results is rather good.

CONCLUSION

Experimental studies and analytical studies on shear failure properties of reinforced concrete short columns with shear span ratio 1.5 were carried out and the failure processes for combined axial and shear load were discussed.

At the first stage of shear failures, bending cracks, bending shear cracks and shear cracks in end portions occur. The patterns are similar to those for specimens bond of which is cut in the middle portion. For further application of shear loading, the crack patterns similar to those for specimens bond of which is cut in the end portions are caused.

It is concluded for reinforced concrete short columns rich tie reinforcement and good bond condition between tensile steels and concrete are very important even in the middle portion of the member to keep the ductility.

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