Effects of Steel Fiber Reinforcement and the Number of Hooked Bars at R/C Exterior Joints

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ABSTRACT

An experimental study was performed on the pull-out behavior of 90-deg standard hooks from the exterior beam-column connections. the effects of the number of hooked bars and fiber reinforcement of the joint area were investigated with the following conclusions : (1) Under the pull-out action of hooked bars. the damage and cracking of joint area the number of hooks pulling out from a joint increases; (2) Substitution of the transverse column (confining) reinforcement with steel fibers at the joint region effectively reduces the extent of cracking in exterior joints caused by the pull-out of hooked bars; (3) The pull-out strength and post-peak ductility of hooked bars are adversely influenced by the increase in number of hooks pulling out from an exterior joint. Current hooked bar anchorage design guidelines may be improved by considering the effect of the number of hooked bars on anchorage conditions at the exterior joints; and (4) The strength and ductility of hooked bars under pull-out forces are positively influenced by substituting the conventional confining reinforcement of exterior joints with steel fibers. The application of steel fibers to the exterior joints is an effective technique for improving the anchorage conditions of hooked bars, and also for reducing the congestion of reinforcement in the beam-column connections.

Keywords : pull-out behavior, hooked bars, exterior joints, steel fibers, confining reinforcements

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1. INTRODUCTION

This reinforcement of concrete by short randomly distributed steel fibers results in the following improvements in material behavior (1,2,3,4): (1) increased tensile and flexural, ductility and energy absorption capacity; (2) increased ductility and energy absorption capacity under compression and bearing loads; (3) increased sliding shear resistance across cracks; (4) improved bond of concrete to reinforcing bars(5); (5) controlled cracking and decreased crack width; and (6) reduced spalling of concrete cover under internal outward stresses. The above improvements in concrete behavior resulting from steel fiber reinforcement are particularly beneficial in the exterior joint conditions. Steel fibers can be used to partially particularly beneficial in the exterior joint conditions. Steel fibers can be used to partially substitute the transverse hoops, which are commonly used at relatively high ratios, to provide confinement at exterior joints.

Considering the serious congestion of steel bars at joints, replacement of transverse hoops by steel fibers is a definite advantage for the practicability of the exterior joint construction (1,2,3,6). Besides reducing the congestion of steel, the distinct characteristics of steel fiber reinforced concrete result in the following improvements in joint behavior (1,3,6): (1) increased ductility and energy absorption capacity; (2) reduced crack width and concrete cover spalling, and thus improved structural integrity; (3) reduction of the anchored bar slippage and increase in the beam moment capacity at column face; (4) increased shear resistance; (5)higher stiffness; (6) maintaining the ductility of joints constructed with high strength concrete and steel; and (7) cost savings resulting from the substition of high transverse hoop volumetric ratios by relatively low steel fiber volume fractions.

Research dealt with the effects of two important factors on the pull-out behavior of 90-deg standard hook from exterior joints: the number of bars being pulled out, and steel fiber reinforcement. very limited test data have been reported in the literature to quantify the effects of these important factors.

An experimental study was undertaken in this research to assess the differences in pull-out behavior of single and multiple hooked bars from typical seismic-resistant exterior joints and also to evaluate the effects of substituting transverse hoops with steel fiber in seismic-resistant exterior joints.

2. EXPERIMENTAL PROGRAM

The specimens tested in this study with one, two and three SD40, D25 hooked bars are shown in Figs. 1(a), 1(b) and 1(c). Test results on specimens similar to the one shown in Fig. 1(b) have been reported in Reference(7).

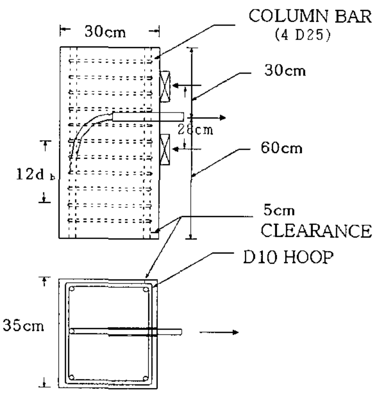
The connection was confined either by transverse hoops according to ACI 318-83(8) (requirements for high-risk seismic zone), or by a combination of transverse hoops and steel fibers. As shown in Fig. 1, the straight lead embedment of hooked bars was covered by a plastic tube. This eliminated the bond resistance along straight embedment length. Pull-out forces were thus resisted only by the 90-deg standard hook. A plastic sheet was placed horizontally at the level of straight lead embedment length, if this bond was not eliminated.

The reinforcement cages of typical specimens with one and two bars are shown in Figs. 2(a) and 2(b), respectively.

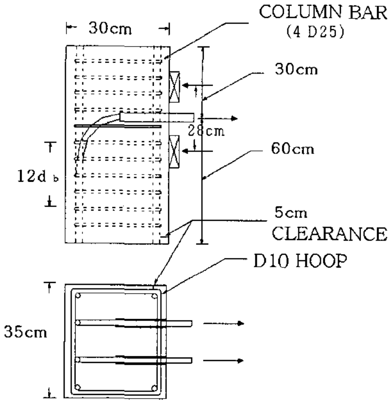
The compression zone of the beam-column interface was simulated with a steel plate pushed against column face.

Type IA portland cement and aggregates with a maximum particle size of 19mm were used in the concrete mixes of this experimental study. in the fibrous mixes, a fraction of portland cement was substituted with Type F fly ash. A superplasticizer was also used in the fibrous mixes. The steel fibers used in this study were straight-round with length of 51mm and a diameter of 0.9mm, having an aspect (length-to-diameter) ratio of 57. All the reinforcing bars used in this experimental investigation were SD40, and the average of their actual yield strengths measured in tension tests was 524MPa.

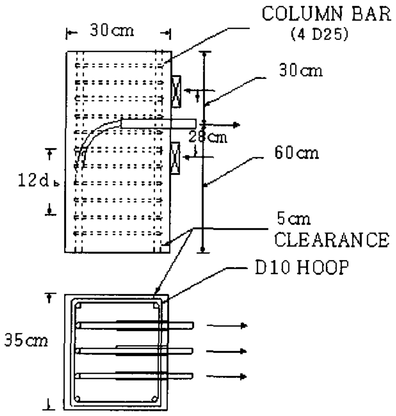
The plain concrete and fiber reinforced concrete mix proportions used in this study are shown in this Table 1, which also presents the inverted slump cone time (a measure of the workability of fibrous mixes which decreases as workability increases) and compressive stress-strain relationships for the fibrous concrete used in this study are shown in Fig. 3.



(a) Single Bar Pull-out

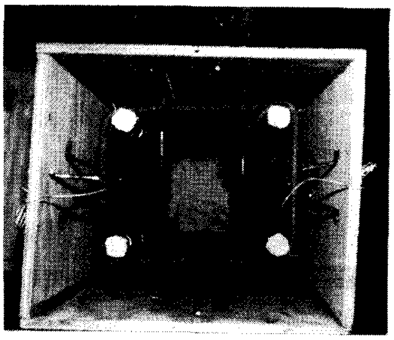


(b) Double Bar Pull-out

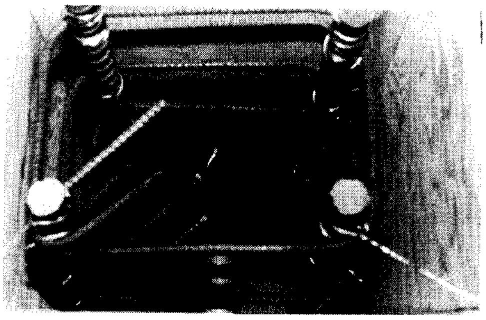


(c) Triple Bar Pull-out

Fig.1 Hook Test Specimens



(a) Single Hooked Bars



(b) Double Hooked Bars

Fig.2 Reinforcement Cage of Typical Hook Test Specimens

Table 1 Mix Proportions of plain and Steel Fiber Reinforced Concrete Mixes(1 psi=0.0069 MPa)

$\frac{W}{C+F}$	$\frac{(S+G)}{(C+F)}$	$\frac{S}{G}$	$\frac{SP}{(C+F)}$
0.6	3.5	1.0	0.0
0.5	4.0	1.0	0.005
0.5	4.0	1.0	0.005

$\frac{F}{(C+F)}$	Vf (%)	Inverted Slump Cone Time	Concrete Comp. Strength
0.0	0.0	----	28(MPa)
0.3	1.0	10(sec.)	36(MPa)
0.3	2.0	15(sec.)	42(MPa)

Note;W = water; C=cement; F=fly ash; S=fine aggregate; G=coarst aggregate; SP=liquid superplasticizer; an Vf=fiber volume fraction.

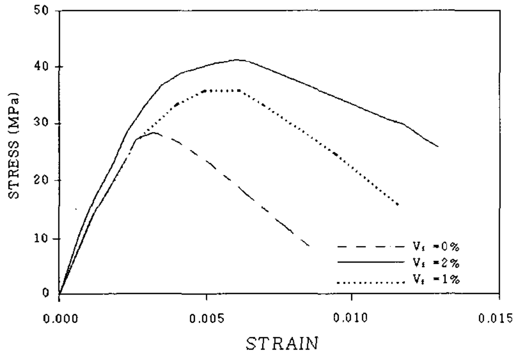


Fig.3 Compressive Stress-Strain Relationship of the Plain and Fibrous Concrete

The specimens were moist-cured inside their molds at 20±3℃ and 100% relative humidity for 7 days before being demolded and exposed to the regular laboratory environment. The specimens were tested at the age of 28±2 days.

Table 2 presents a summary of the test program performed on hooked bar anchored in conventional and fibrous reinforced concrete specimens. Information on the number of hooked bars, lateral confinement provided in conventional specimens 1 and 2 of Table 2 satisfied the requirements of ACI 318-83(8) for seismic-resistant beam-column connection. The confinement reinforcement of specimens 1 and 2 was substituted with steel fiber reinforcement in specimens 4, 5, 6 and 7. Specimen 3 was confined by both the confined by both the conventional hoops and fibers at relatively high ratios, in order to investigate the convinced confining effects of these two reinforcement techniques. Specimens 8 and 9 together with specimens 1 and 2 were designed bars on their pull-out behavior.

Table 2 Test Program on Hooked Bars in Conventional and Fibrous Specimens

Specimen	Reference	Hooked	Lateral Confinement	Fiber Volume Fraction
1	Author	3D25	D10@75mm	0%
2	Author	3D25	D10@75mm	0%
3	Author	3D25	D10@75mm	2%
4	Author	3D25	D10@100mm	2%
5	Author	3D25	D10@150mm	2%
6	Author	3D25	None	2%
7	Author	3D25	D10@100mm	1%
8	Author	1D25	D10@75mm	0%
9	Author	1D25	D10@75mm	0%
10	7	2D25	D10@75mm	0%
11	7	2D25	D10@75mm	0%

The test data generated on hooked bars in this study actually complement those reported in Reported in Reference 4 on the pull-out behavior of two hooked bars from conventional reinforced concrete joints (Fig. 1b). Table 2 also presents information on the test specimens of Reference(4) the results of which were used in this study (specimens 10 and 11 in Table 3). Fig. 4 presents the test set-up used in this study. Two hydraulic actuators bearing on the concrete column applied the pull-out force. The load was measured by two load cells located on the actuators. Two electrical displacement transducers were installed on each anchored bar at 100mm from column face. The pull-out displacements at the end of hook bends (point A in Fig. 4) were obtained by substracting the extension of anchored bar between point A and displacement transducer (measured in tension tests of bars) from the average measurement of two transducers. Loading was monotonic and quasi-static, applied in a displacement-controlled manner. The experiment was continued until the observation of extensive cracking in specimens and large pull-out displacements. The load cells and displacement transducers used in this study had maximum error of less 1% the measured values.

3. EXPERIMENTAL RESULTS

Pull-out of multiple (two or three) hooked bars from the conventional confined concrete specimens simulating exterior joints resulted in the damage process described below :

(1) Radial splitting cracks appeared at the exit on the face of specimens (Fig. 5a), nothing that the splitting cracks norma to hooked bar planes were generated artificially by the placement of a plastic sheet inside the specimen. The radial splitting cracks in the hooked bar plane on the other hand seem to have been generated by the bearing of the hook bend against concrete :

(2) Cracks appeared on the sides of specimens, extending along the hooked bars, with a tendency to separate the concrete inside the hook bend from the remainder of the specimen block (Fig. 5b) : and

(3) The confined concrete specimens expanded laterally under the increasing pressure of the hook bend, which resulted in spalling of concrete cover (Fig. 5c).

At the same amount of confinement, the extent of cracking and damage in specimens with three hooked bars was observed to be more serious than specimens with two hooked bars (compare the appearance after failure of the three-bar specimen No. 1 of Table 2 in Fig. 6(a) with that of the two-bar specimen No. 10 of Table 3 in Fig. 6(b). In the conventionally confined specimens 8 and 9 of Table 3, with a single hooked bar, only minor cracks appeared at the bar exit point or on the sides of specimens, as shown in Fig. 6(c). The hooked bars in these specimens could not be pulled out, and yielding of anchored bars always dominated the failure of single-bar specimens under pull-out forces. Comparison of the crack intensities in specimens with different number of hooked bars clearly indicates that the increase in the number of closely spaced hooked bars adversely influences anchorage conditions in exterior joints.

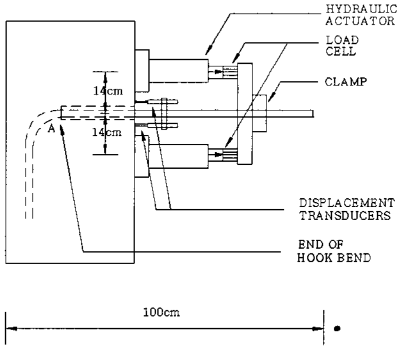


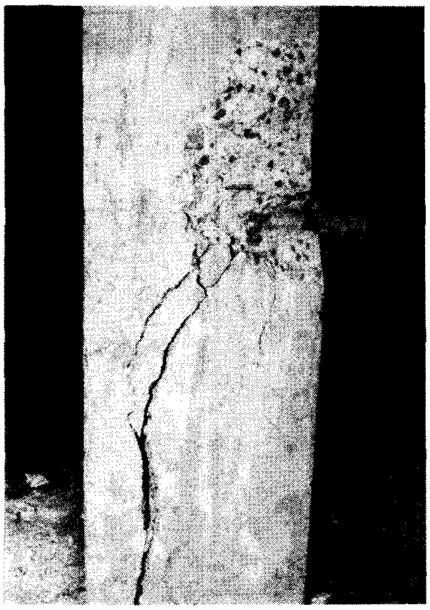
Fig.4 Test Set-Up and Instrumentation

(a) Radial Cracks

Fig.5 Conventionally Confined Specimens under Multiple Hooked Bar Pull-Out(con'd)

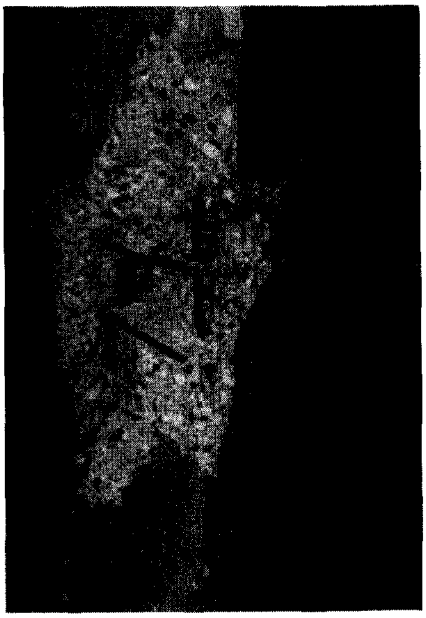
(b) Side Cracks

Fig.5 Conventionally Confined Specimens under Multiple Hooked Bar Pull-Out(con'd)



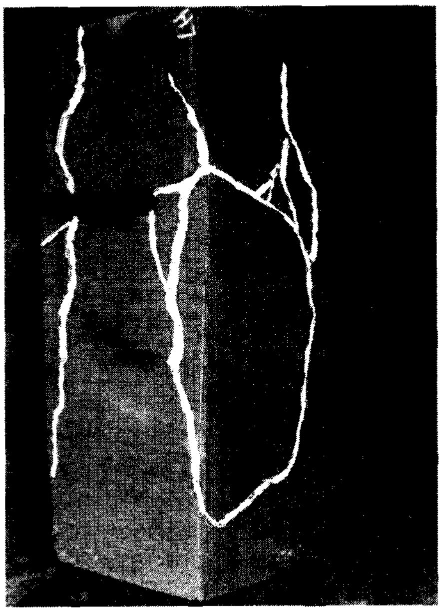
(c) Spalling of Concrete Cover

Fig.5 Conventionally Confined Specimens under Multiple Hooked Bar Pull-Out.



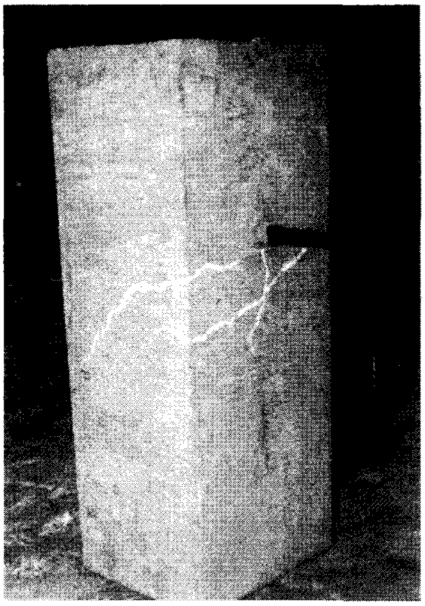
(a) Three Hooked Bars

Fig.6 Cracking in Specimens with Different Number of Hooked Bars(con'd)



(b) Two Hooked Bars

Fig.6 Cracking in Specimens with Different Number of Hooked Bars(con'd)



(c) One Hooked Bars

Fig.6 Cracking in Specimens with Different Number of Hooked Bars

The fibrous concrete specimens (No.3 to 7 in Table 2 showed much less cracking and significantly better anchorage conditions under pull-out forces, when compared with comparable conventional specimens. The first cracks which appeared in fibrous specimen where the radial one at the bar exit points, and were sometimes followed by cracks appearing on the sides of specimens extending along hook bends. No significant widening of these cracks or lateral expansion of specimens where observed in hook pull-out tests of fibrous specimens. Except in one case with low fiber volume fraction and no lateral confinement (specimen No. 6 in Table 2) shown in Fig. 2(a), failure of anchored bar was dominated by bar yielding with minor anchorage damage. The typical comparison between the crack intencities after failure of specimen No. 6 of Table 2 with fiber and no lateral confinement shown in Fig. 7(a), and specimen No. 1 of Table 2 without fibers but with a large confining reinforcement ratio shown in Fig. 7(b) is indicative of effectiveness of steel fibers enhancing the anchorage conditions of hooked bars at exterior joints.

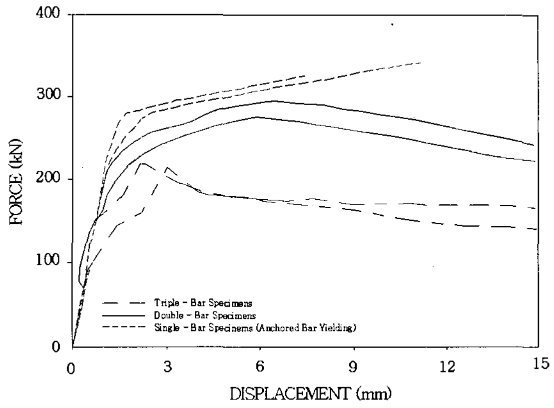
The hook pull-out force-displacement relationship for conventional reinforced specimens with different number of anchored bars (specimens 1, 2, 8, 9, 10 and 11 in Table 2) are shown in Fig. 8(a). This Fig. clearly indicates that the anchorage conditions in similar specimens are adversely affected by the increase in number of hooked bars being pulled out. the While the single-bar specimens fail dominantly by yielding of the anchored bar, those with double- and triple-bar pull-out fail mainly due to anchorage loss. Strength and ductility of the hooked bar pull-out behavior are observed to drop with the increase in number of bars. It seems appropriate to modify current hooked bar anchorage design requirements to account for the important effects of the number of hooked bars on anchorage performance.

The effects of fiber reinforcement on pull-out force displacement relationships in triple-bar specimens (No.1 through 7 in Table 2) are shown in Fig. 8(b). All the fiber reinforced specimens, even the one with no transverse hoops, are observed to have higher strength and better ductility than the non-fibrous specimens with conventional confinement. In all the fiber reinforced specimens, the pull-out force practically reached the anchored bar yield force. In the confinement condition with D10 transverse hoops @ 150mm spacing, only a slight drop in pull-out resistance is observed when the transverse hoop spacing is increased at a constant fiber volume fraction. No significant effect of fiber reinforcement on the initial pull-out stiffness could be observed.

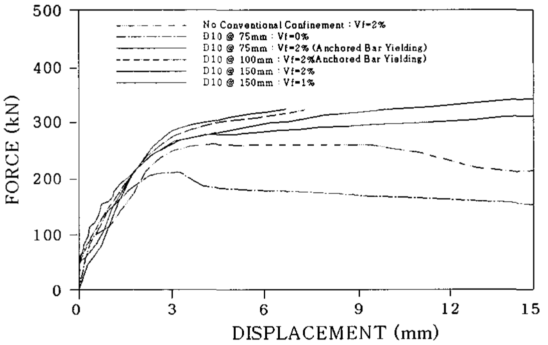
(a) Fibrous Specimens

(b) Conventionally Confined Specimens

Fig.7 Cracking of Fibrous and Conventionally Confined Specimens



(a) Specimens with Different Fiber Number of bar



(b) Specimens with Different Fiber Volume Fractions and Confinement Conditions

Fig.8 Hook Pull-out Force-Displacement Relationship

The above discussions on the effects of fiber reinforcement on hooked bar pull-out behavior are indicative of the potentially significant performance and economic advantages of using steel fibers in exterior beam-column connections. The reduction in transverse steel area resulting from fiber reinforcement also leads to reduced congestion of steel fibers in the joint area, which is an important factor in improving the practicality of joint congestion.

4. SUMMARY AND CONCLUSIONS

An experimental study was performed on the pull-out behavior of 90-deg standard hooks from exterior beam-column connections. The effects of the number of hooked bars and fiber reinforcement of joint area were investigated. It was concluded that:

(1) Under the pull-out action of hooked bars, the damage and cracking of joint area tends to be more extensive as the number of hooks pulling out from a joint increases;

(2) substitution of the transverse column (confining) reinforcement with steel fibers at the joint region effectively reduces the extent of cracking in exterior joints caused by pull-out of hooked bars;

(3) the pull-out strength and post-peak ductility of hooks are adversely influenced by the increase in number of hooks pulling out from an exterior joint. Current hooked bar anchorage design guidelines may be improved by considering the effect of the number of number of hooked bars on anchorage conditions at exterior joints: and

(4) The strength and ductility of hooked bars under pull-out forces are positively influenced by substituting the conventional confining reinforcement of exterior joints with steel fibers. Application of steel fibers to exterior joints seems to be an effective technique for improving the anchorage conditions of hooked bars, and also for reducing the congestion of reinforcement in beam-column connections.

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