Pullout Test of Headed Reinforcement 2: Deep Embedment

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Abstract

Pullout tests of single headed bars using plain concrete blocks indicate that the embedment depth of $10d_b$ is in general required for the headed bars to develop pullout strength equivalent to 125% of bar yield strength. In this experimental study, test results of multiple headed bars installed in reinforced concrete column sections are presented. Test variables included embedment depth, column main reinforcement ratio, and spacing of column ties. 2D29 bars were pulled out at one time from normal strength concrete. Test results indicated that the embedment depths, column tie spacings, and column main reinforcement ratios all influenced the pullout strengths of the headed bars. When the embedment depth was not sufficient, narrow tie spacings especially resulted in increased pullout strengths of the headed bars. Test results also indicated that the embedment depth of 15 db was sufficient for the closely spaced two headed bars (head-to-head spacing = $6d_b$) to develop pullout strength equivalent to 125% of the bar yield strength.

1. INTRODUCTION

This experimental study investigated the potential use of headed reinforcement in reinforced concrete construction, especially in exterior beam-column joints. The headed reinforcement, or headed bars, is a mechanical device that has a potential to replace standard hooks in the future.[1] By using the headed bars, the steel congestion is typically reduced.[2]

The current study is part of a larger experimental program that was performed to provide the test data necessary to design exterior beam-column joints using the headed bars. Preliminary test results indicated that single D29 bars with small square head (head area = 4 times the bar area) installed in plain concrete (f_{cu} = 30.7MPa) using relatively small embedment depth of $10d_b$ can develop over 125% of bar yield load in tension.[3]

In this study, it was assumed that the headed bars are the main reinforcement of the beams and have been embedded in reinforced concrete columns. As a beam is subjected to moment and

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thereby the rebars are subjected to tension, the headed bars in columns become subjected to pullout force. The pullout performances of the headed bars are likely dependant upon embedment depth, existing column reinforcement (column main bars and ties) among others. Preparation and results of 12 pullout (P/O) tests of D29 headed bars are summarized in this study.

2. PREPARATION FOR TEST

2.1 Materials

Concrete compressive strengths of test cylinders were 30.7MPa and 32.4MPa as shown in Table 1. Grade SD40 (f_y = 420MPa) reinforcing steel was used to fabricate column main reinforcement and ties. The headed bars were fabricated in factory and delivered to the testing laboratory. Bars were threaded at both ends: one end to anchor head and the other end to fix a nut used as testing grip. All headed bars were of SD40 grade steel. Gross area of square head was 4 times the rebar cross-sectional area ($4A_b$) with thickness the same as the rebar nominal diameter (d_b).

2.2 Test Specimens

For a set of eight pullout (P/O) tests, 2D29 headed bar specimens installed in reinforced concrete columns were fabricated. Embedment depth (h_{ef}) was $10d_b$ (290mm). The objectives were twofold: to determine if the headed bars yield in pullout with h_{ef} = $10d_b$; and to evaluate influence of column reinforcement on the headed bar pullout behaviors. Test variables included different column tie spacings (D13 rebars with S_{tie} = $3d_b$, $6d_b$, $9d_b$, and none) and column main reinforcement ratios (D25, ρ_{st} = 0.84% or 1.41%) as summarized in Table 1 and Figs. 1 and 2. Two headed bars were pulled out at one time. It is noted that 5-mm strain gages were installed on headed bars, column main reinforcement, and column ties as shown in Figs. 1 and 2 to investigate the role of column reinforcement on the pullout behavior. Three pairs of strain gages were installed on a headed bar: "head-1" right above head, "head-3" right below surface, and "head-2" in the middle between "head-1" and "head-3." Strain gages on column ties were installed assuming a 45° failure surface. The gages were named as "tie-1," "tie-2,"and so on starting from the pair closest to the headed bar. In addition pair(s) of strain gages was installed on column main reinforcement 60mm away from the headed bar.

Additional six tests of 2D29 headed bars were completed using deeper embedment depth of $15d_b$ sufficient to make the headed bars yield. In this series, the test variables included column tie spacing and main reinforcement ratio as summarized in Table 1. Cross-sections of the reinforced concrete columns are the same as those shown in Fig. 1 except that the strain gages were not used. Average cylinder strength was 32.4 MPa. Fig. 3 shows a reinforced concrete column with D13 ties (S_{tie} = $9d_b$), 6D25 main reinforcement (ρ_{st} = 0.84%), and two headed bars being fabricated.

2.3 Test Setup

Fig. 4 shows the test setup that consisted of steel frames made of H-shape structural steel, a loading block, and a hydraulic cylinder. A high-strength steel rod was used to vertically connect the loading block and the hydraulic cylinder. The headed bars were subjected to pullout as the force from the hydraulic cylinder was applied.

Table 1 Summary of Test Variables and Test Results

Specimen index	f_{ck}, MPa	h_{ef},[1] mm	C_1,[2] mm	S_{head},[3] mm	S_{tie},[4] mm	ρ_{st},[5] %	P_n,[6] kN	$P_n/(A_b*f_y)$[7]	Remarks
C29-10db-2A-L	30.7	290	138	171	87	0.84	457	84.7	strain g.
C29-10db-2C-L	30.7	290	138	171	171	0.84	441	81.8	ditto
C29-10db-2D-L	30.7	290	138	171	261	0.84	363	67.3	ditto
C29-10db-2E-L	30.7	290	138	171	-	0.84	348	64.5	ditto
C29-10db-2A-M	30.7	290	138	171	87	1.41	473	87.7	ditto
C29-10db-2C-M	30.7	290	138	171	171	1.41	478	88.6	ditto
C29-10db-2D-M	30.7	290	138	171	261	1.41	475	88.1	ditto
C29-10db-2E-M	30.7	290	138	171	-	1.41	442	82.0	ditto
C29-15db-2C-L	32.4	435	138	171	171	0.84	730	135	
C29-15db-2D-L	32.4	435	138	171	261	0.84	636	118	
C29-15db-2E-L	32.4	435	138	171		0.84	664	123	
C29-15db-2C-M	32.4	435	138	171	171	1.41	731	136	
C29-15db-2D-M	32.4	435	138	171	261	1.41	772	143	
C29-15db-2E-M	32.4	435	138	171	-	1.41	763	142	

Note: 1. h_{ef} = embedment depth, distance between top of head and concrete surface; 2. C_1 = edge distance, distance between center of head and edge; 3. S_{head} = center-to-center distance between heads; 4. S_{tie} = col. tie spacing, A = $3d_b$, C = $6d_b$, D = $9d_b$, E = none (no ties); 5. $\rho_{st} = A_{st}/(b_{col}*h_{col})$, col. main reinf. ratio; 6. P_n = test result, pullout strength; 7. A_b*f_y = no. of bars * bar cross-sectional area x nominal yield strength in %.

3. TEST RESULTS

3.1 P/O Strengths

Results of eight P/O tests with $h_{ef} = 10d_b$ indicated that the embedment depth of $10d_b$ was not sufficient to make 2D29 headed bars develop stresses equivalent to bar yield load of A_b*f_y as shown in Table 1. In Table 1, P_n ranges between 348kN and 478kN. In terms of $P_n/(A_b*f_y)$, the ratios are between 64.5% and 88.6%. Test results indicated that, in four specimens with ρ_{st} = 0.84%, the column ties influenced the pullout strengths of the headed bars because P_n increases with decreasing S_{tie} in Table 1 and Fig. 5. On the other hand, when ρ_{st} = 1.41%, the test results seem to indicate that the column ties did not significantly influence the pullout strengths in Table 1 and Fig. 5. Average P_n of a set of four tests with ρ_{st} = 1.41% is 467kN while the average of

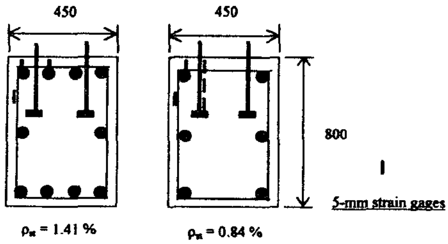


Fig. 1 Cross-Sections of Reinf. Concrete Columns

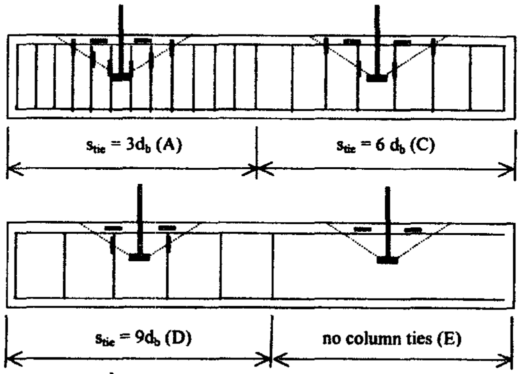


Fig. 2 Positions of Strain Gages

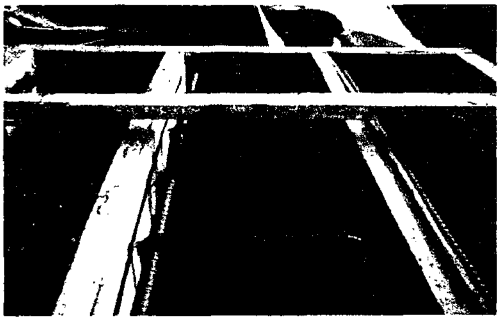


Fig. 3 Test Specimen Fabrication

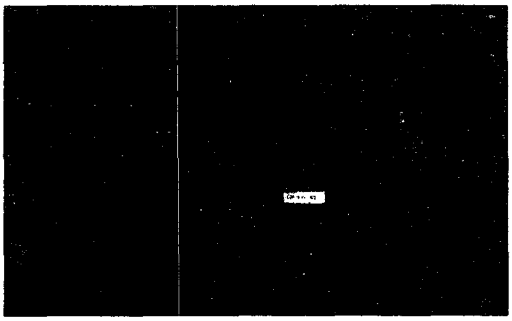


Fig. 4 P/O Test Setup

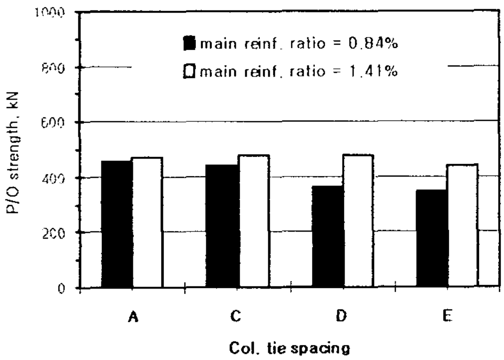


Fig. 5 Test Results: 2D29, h_{ef} = $10d_b$, f_{cu} = 30.7MPa

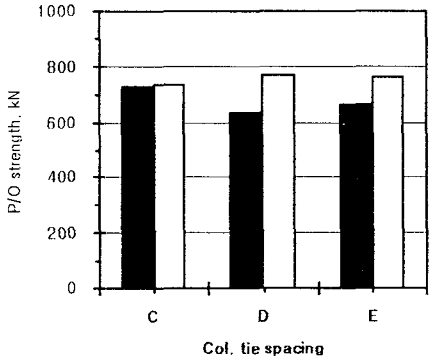


Fig. 6 Test Results: 2D29, h_{ef} = $15d_b$, f_{cu} = 32.4MPa

another set of four tests with ρ_{st} = 0.84% is 402kN. The column main reinforcement seems to have contributed in increasing the pullout strength of the headed bars as there is about 16% difference between two sets of tests.

The embedment depth of $15d_b$ (435mm) was in general sufficient for all headed bars to develop pullout strengths over 125% of A_b*f_y as shown in Table 1. P_n ranges between 636kN and 772kN or 118% and 143% of A_b*f_y. The test results summarized in Fig. 6 indicate that the column ties influenced the pullout strengths of the headed bars when ρ_{st} = 0.84%, but this may not be significant because all headed bars in these tests already yielded in pullout. The test results of 2D29 headed bars in Table 1 and Figs. 5 and 6 reveal the following:

(1) when h_{ef} is sufficient to make the headed bars yield, the column reinforcement do not significantly influence P_n;

(2) when h_{ef} is not sufficient to make the headed bars yield, the column reinforcement, both main reinforcement and ties, can influence P_n;

(3) when h_{ef} is not sufficient to make the headed bars yield and ρ_{st} is "low" (ρ_{st} < 1.4%) at the same time, then the column ties significantly influence P_n: i.e. P_n increases with decreasing S_{tie}.

3.2 Strain Gage Readings

The strain gages were installed on headed bars, column main reinforcement, and column ties for eight specimens with h_{ef} = $10d_b$. Readings determined from the strain gages are shown in Figs. 7 and 8 where the x-axis represent the strains developed in the column main reinforcement, ties, or headed bar while y-axis represent the stresses developed in the headed bar. From the stress-strain diagrams of Figs. 7 and 8, the followings can be observed:

(1) Column main reinforcement start to develop larger strains than ties in the beginning;

(2) Column ties do not exhibit large strains until about 70 % of the peak stress is reached;

(3) Column ties close to the headed bar develop large strains and contribute in increasing the P_n;

(4) Strains developed in the upper part of the headed bar (close to the applied force) are larger than those developed in the lower part (close to head);

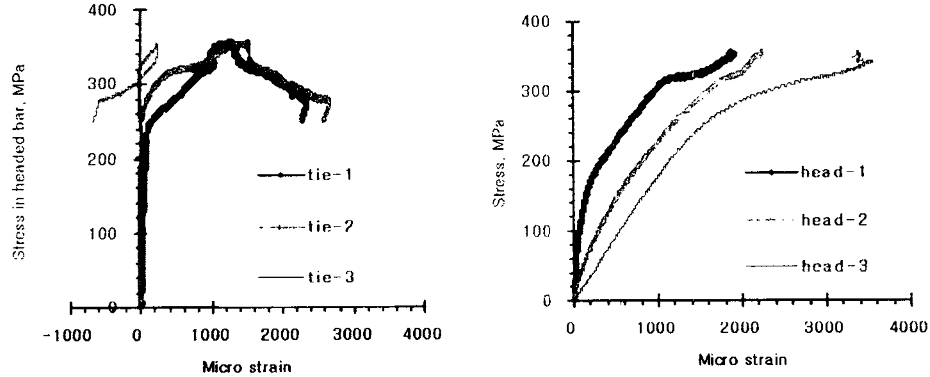
(5) Inside column main bars exhibit larger strains than the outside main bars.

4. CONCLUSIONS

1) The embedment depth of $15d_b$ is sufficient for two closely spaced headed bars (head-to-head spacing = $6d_b$) to develop pullout strengths over 125% of A_b*f_y in normal strength concrete.

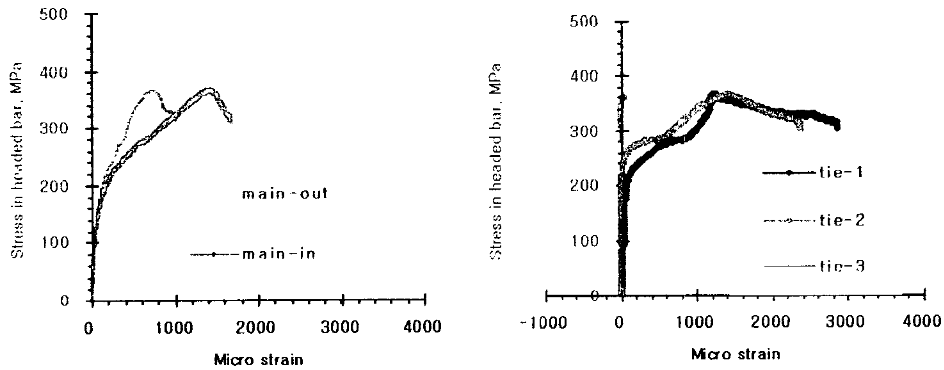
2) When embedment depth is not sufficient to make the headed bars yield, the column reinforcement, both main reinforcement and ties, can influence P_n.

3) Column ties, especially, can significantly help increase the pullout strengths.



(a) column ties (b) headed bar

Fig. 7 Stress vs. Strain: C29-10db-2A-L: h_{ef} = $10d_b$, S_{tie} = $3d_b$, ρ_{st} = 0.84%



(a) column main bars (b) column ties

Fig. 8 Stress vs. Strain: C29-10db-2A-M: h_{ef} = $10d_b$, S_{tie} = $3d_b$, ρ_{st} = 1.41%

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References

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