KCI CONCRETE JOURNAL
Vol.14 No.2, June 2002, pp.86-91

Behavior of Mechanical Anchorage of Bars Embedded in Concrete Blocks

Young-Chan You [1)*], Keun-Do Choi [1)], Keung-Hwan Kim [1)], and Li-Hyung Lee [2)]

[1)] *Korea Institute of Construction Technology, Korea*
[2)] *Dept. of Architectural Engineering, Hanyang University, Korea*

(Received January 28, 2002; Accepted May 13, 2002)

Abstract

This paper presents an experimental study to investigate the behavior of mechanical anchorage of reinforcing bars in concrete members. Three kinds of mechanical anchorage which are a kind of headed reinforcements are considered in this study. Total seven specimens were prepared to consider the effects of anchoring methods (Type A, Type B and Type C) and anchorage lengths of the reinforcing bars ($14d_b$, $12d_b$, $9d_b$). Pullout tests conforming to ASTM were carried out to assess the effects of several variables on anchoring strength of bars. Based on the test results, it was concluded that the behavior of the specimen anchored by the mechanical anchorage with the anchorage length of $12d_b$, is as good as, or better than that of the specimen anchored by 90-degree standard hook.

***Keywords:** anchorage, anchorage length, beam-column joint, bond (concrete to reinforcement), bond stress, embedded length, hooked bars, mechanical anchorage, pullout test, slip, headed reinforcement*

1. Introduction

Generally speaking, 90-degree standard hooks specified in national building code [8)] are the simplest and the most effective anchoring method in the construction of precast concrete building structures. A series of studies concerning anchoring strength of standard hooks has been made by many researchers (Hamad et al,[1)] Jirsa and Marques,[2)] Clark and Johnston,[3)] Altowaiji et al,[4)] Minor and Jirsa,[5)] Hribar and Vasko [6)]). But, the use of standard hooks often leads to steel congestion in beam-column joints, making fabrication and construction difficult. The use of larger diameter reinforcing bars has been considered as a solution to avoid the steel congestion in such joints. But geometric limitations such as larger bend diameter and lengthy hook extension often restrict the use of them.

Furthermore, the interference of bottom bars embedded in precast beam at the beam-column joint panel zones is another problem in precast concrete construction. Usually the development length of the standard hook, namely l_{dh}, is longer than half the column width. So, bar interference is happened at the middle of beam-column joint panel zone. In these cases, the use of mechanical anchorage, which is a kind of headed reinforcements, has obvious advantages in the ease of fabrication, construction and concrete placement. Also, the shorter development length of headed reinforcement can eliminate the possibilities of bar interference of precast beam at the beam-column joint. Moreover, Wallace et al showed the improved performance of the beam-column joints using headed reinforcements based on the experimental results of two exterior and five corner joint specimens tested as part of an extensive experimental program(Wallace et al [7)]).

The main purpose of this experimental study is to examine the possibilities of mechanical anchorage to the development of the reinforcing bar in concrete construction. Three types of mechanical anchorage including 90-degree standard hook were examined in this study.

2. Experimental work

2.1 Materials

Air-entrained concrete was supplied by a local ready-mix

* *Corresponding author*
Tel.: +82-031-9100-364; Fax.: +82-031-9100-392
E-mail address: ycyou@kict.re.kr

Table 1 Material properties of concrete

Design strength (MPa)	W/C (%)	Compressive strength (MPa)			Slump (mm)
		7 day	14 day	28 day	
23.8	52.0	16.3	20.1	24.0	145.0

Table 2 Material properties of reinforcing bar

Bar size	Yield strength (MPa)	Young's modulus (MPa)	Tensile strength (MPa)	Elongation percent (%)
D22	454.4	2.16×10^5	689.2	20

plant. Type I portland cement and 25 mm nominal maximum size coarse aggregate were used. Table 1 summarizes the concrete compressive strength f_{ck} for each day. Compression cylinders, ϕ 100×200 mm were prepared for each specimen. A concrete compressive strength of 24.0 MPa and a reinforcement yield stress of 420 MPa were used for design purposes. ASTM A615, Grade 60 (nominal), No. 7 reinforcing bars were used for all specimens. All No. 7 test bars were from the same production lot and had a yield strength of 454.4 MPa.

2.2 Mechanical anchorages

Four kinds of anchorages were examined to study the effects of the anchoring methods; 90-degree standard hook, screw-threaded headed reinforcement (Type A anchorage), mechanical anchorage composed of screw-type coupler and perforated plate (Type B and C anchorage respectively) as shown in Fig. 1.

Type A mechanical anchorage was composed of female screw (diameter = 35 mm, thickness = 6.5 mm) and circular steel plate (diameter = 75 mm, thickness = 4.0 mm) welded at the end of the female screw to increase the anchoring strength as shown in Fig. 1(b) and Fig. 2(a) Reinforcing bar, in this case, was screw-threaded to connect with the female screw. Type B mechanical anchorage was composed of screw-type sleeves, coupler (diameter=40 mm, thickness =3.5 mm) and rectangular steel plate (100× 65× 10 mm) as shown in Fig. 1(c) and Fig. 2(b). The inner groove of the screw-type sleeves is intended to grip the ribs of the reinforcing bars, and transfer the bar stress to the screw-type coupler and perforated plates. Reinforcing bar, in this case, was not screw-threaded. Type C mechanical anchorage is composed of two sets of the component of Type B mechanical anchorage. They are inter-connected by bolts and nuts through the rectangular steel plates as shown in Fig. 1(d) and Fig. 2(c).

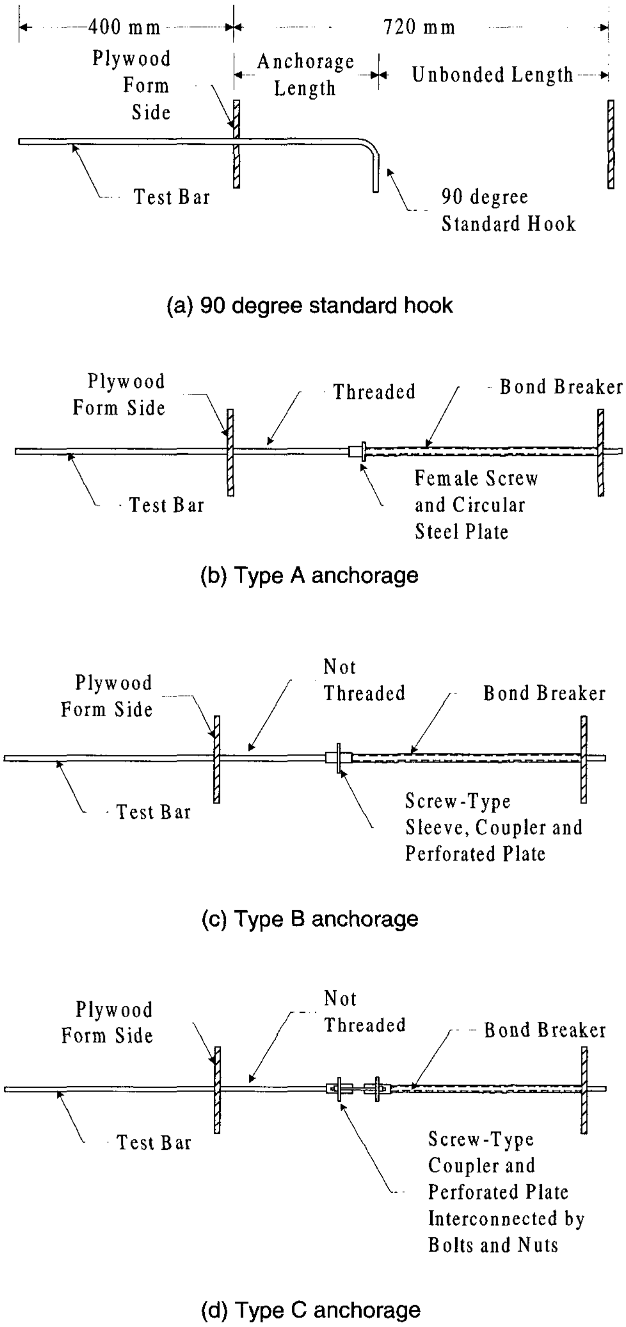
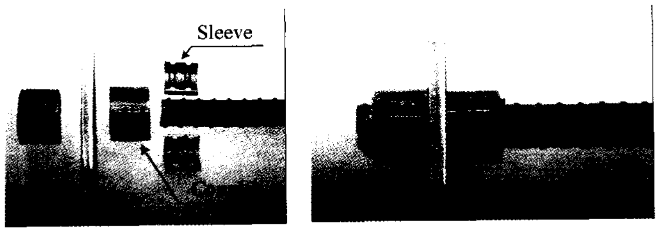


Fig. 1 Details of anchorages

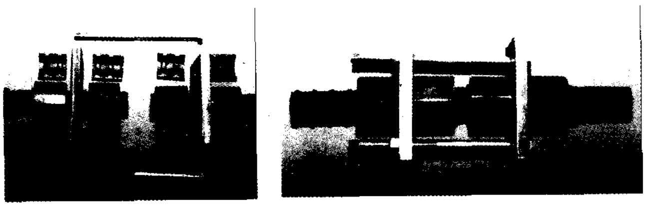
2.3 Test specimens

The concrete block in which reinforcing bars are embedded simulates the panel zone of the reinforced concrete beam-column joint. Overall dimension for the specimens are shown in Fig. 3. Each face of the concrete block was reinforced by No. 2 wire meshes to prevent possible brittle failure of concrete blocks itself. The length of the concrete block was chosen to eliminate confining stresses at the anchorage region produced by the axial reaction of vertical tie rods. In this figure, 'b' means bonded length and, in the same way, 'u' means unbonded length.

(a) Type A anchorage



(b) Type B anchorage



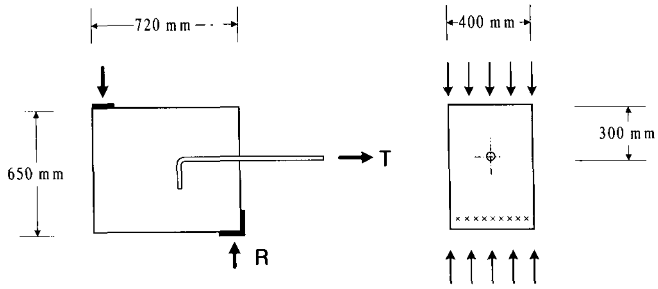
(c) Type C anchorage

Fig. 2 Types of mechanical anchorage

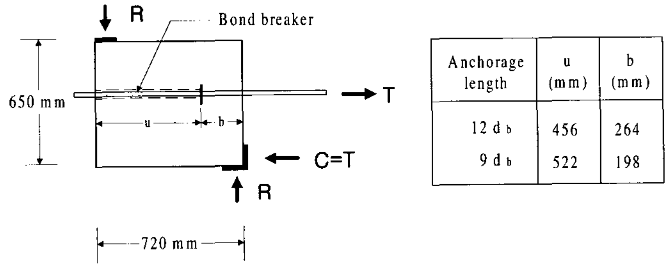
The test bar was No. 7 (22 mm) deformed bar, 1220 mm long, and was embedded to be pulled out from the concrete block. 25 mm diameter polyvinyl chloride (PVC) pipes were used as a bond breaker to limit the bonded length. Table 3 summarizes the details of the seven specimens tested in this study. In the specimen notation, **HOOK** means standard hook, and **FORM** means Type A anchorage. Also **SP** means single plate in Type B anchorage and, in the same way, **DP** means double plate in Type C anchorage.

According to ACI 318-95 [8] Chapter 12 requirement, the basic development length in tension for Grade 60 (420 MPa) hooked bars is ;

$$l_{hb} = \frac{1200\, d_b}{\sqrt{f_{ck}}}\ in. = \frac{100\, d_b}{\sqrt{f_{ck}}}\ mm \qquad (1)$$



(a) 90 degree standard hook



(b) Mechanical anchorage

Fig. 3 Overall dimension of test specimens

Where f_{ck} are in terms of psi for l_{hb} in *in*. and in MPa for l_{hb} in *mm*. For the given materials f_{ck} = 24.0 MPa, f_y = 420.0 MPa, the development length, l_{dh} for the 90-degree standard hook is $14 d_b$ after being multiplied by applicable modification factors. Two different anchorage lengths of $9 d_b$ or $12 d_b$ were used for each test specimen of Type A, B, and C anchorage.

2.3 Test set-up and procedures

The test set-up shown in Fig. 4 and 5 was constructed to apply pullout loads to the reinforcing bar embedded in concrete blocks (Donahey and Darwin [9,10]). A hydraulic actuator was directly attached at the front end of the reinforcing bar. The vertical tie rods were set at the other end of the concrete block to prevent it from overturning caused by the pullout loading. Vertical reactive force was also applied

Table 3 Details of test specimens

Series no.	Specimen notation	Anchorage length (d_b)	f_{ck} (MPa)	Bar	Anchorage type		
					Thread	Plate	Bolts
90 degree standard hook	HOOK-14	14	23.8	No.7	×	×	×
Type A	FORM-12	12	23.8	No. 7	O	C	×
	FORM-9	9	23.8	No. 7	O	C	×
Type B	SP5C-12	12	23.8	No. 7	×	R	×
	SP5C-9	9	23.8	No. 7	×	R	×
Type C	DP5C-12	12	23.8	No. 7	×	2-R	2-B
	DP5C-9	9	23.8	No. 7	×	2-R	2-B

C = ccular steel plate, ϕ 75× T4 mm, R = rctangular steel plate, 100× 65× 10 mm, B = iterconnecting bolts, ϕ 4× L135 mm

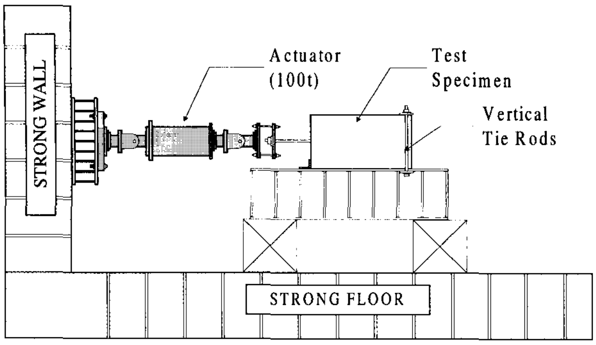


Fig. 4 Loading frame details

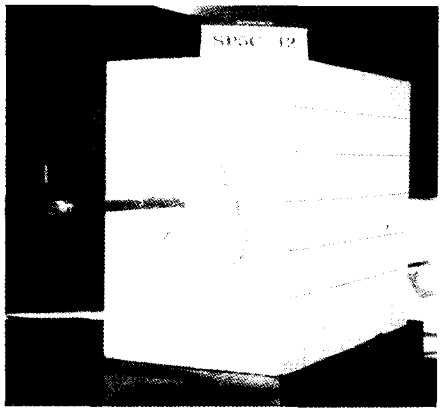
Fig. 5 Test set-up

to keep the loaded end of the specimen perpendicular to the pulling force.

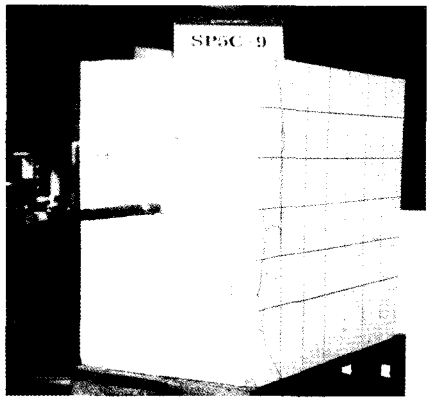
Two sets of linear variable displacement transducers (LVDTs) were attached at each end of the concrete block to measure the relative displacement of the reinforcing bar to the concrete block ; lead slip and end slip. The bar slip measured at the front end of the concrete block is termed "lead slip", and the slip measured at the other end of the concrete block is named "end slip" in this study. The strains in the reinforcing bar and connecting bolts in Type C anchorage were measured by electric wire strain gages. A pre-loading was applied to stabilize the loading grips and reading apparatus. Pull-out loads were applied under load control at 25.0 kN/min before yielding of reinforcing bar and under displacement control at 6 mm/min after yielding. Load, lead slip, and end slip were recorded during the tests. A test was terminated when the anchored bar was pulled out of the concrete block excessively.

3. Evaluation of experimental results

The primary purpose of this study is to evaluate the performance of the mechanical anchorages which is a kind of a headed reinforcement in reinforced concrete beam-column joint regions. Direct comparisons of failure crack patterns, anchoring strengths and load-slip curve of each specimen with 90-degree standard hook were made to evaluate the performance of mechanical anchorage. Specimen behaviors and performances were discussed in the following subsections. Conclusions were based on the observed behaviors as well as comparative evaluations. The ultimate loads listed in Table 4 represent the anchoring strength of each specimen. The anchoring strengths of specimens with Type A, B and C mechanical anchorage were compared with those of the specimen with 90-degree standard hook.



(a) Conical crack



(b) Radiating cracks

Fig. 6 Failure type of specimens

3.1 Final crack patterns

In nearly all the tests, the sequence of cracking and subsequent failure followed a similar pattern for the whole stage of loading. First cracking occurred at the front face of the concrete block with cracks radiating outward from the bar. As the applied load increased, two types of cracks were observed; cracks making a circle centering around the bar as shown in Fig. 6(a), and cracks radiating diagonally outward from the bar as shown in Fig. 6(b).

The former crack pattern was shown in the case of the specimen with 90-degree standard hook and specimens with mechanical anchorage whose anchoring length is $12d_b$. The final failure was governed by the bar fracture and no harmful damage on the concrete block was found. These

Table 4 Summary of test results

Specimen notation	Anchorage length (d_b)	Load at lead slips of (kN)			Ratio of (2)/(1) at lead slips of			Yield		Ultimate load (kN)	Final failure mode
		0.12mm	0.41mm	1.27mm	0.12mm	0.41mm	1.27mm	Slip(mm)	Load (kN)		
HOOK-14 (1)	14	74	111	142	-	-	-	0.93	143	219	F
FORM-12 (2)	12	24	110	156	0.31	0.99	1.11	0.98	148	222	P
FORM-9 (2)	9	45	131	159	0.60	1.18	1.12	0.75	150	180	T
SP5C-12 (2)	12	40	107	151	0.54	0.96	1.06	0.78	152	209	P
SP5C-9 (2)	9	45	104	123	0.61	0.94	0.87	3.22	152	157	T
DP5C-12 (2)	12	26	079	155	0.34	0.71	1.09	0.87	141	198	P
DP5C-9 (2)	9	71	110	117	0.96	0.99	0.78	2.67	149	150	P

F = bar fracture, P = bar pullout , T = splittng failure of concrete block at excessive slip

crack patterns shows that it has sufficient anchorage strength. The latter crack pattern, on the other hand, was shown in the case of the specimen with the anchorage length of $9d_b$. The progresses of the radiation crack are as follows. The larger conical cracks in the specimens whose anchoring length were $9d_b$ expanded over the width of the concrete block, causing excessive tensile stress at the front end of concrete blocks. When the tensile stress become greater then tensile strength of the concrete, the front end of the concrete block become split, resulting in radiation cracks. These crack patterns represent the shortage of anchoring strength in this study. The final failure of these specimens was governed by the splitting of the concrete.

3.2 Slip and anchorage length

The ultimate loads listed in Table 4 represent the anchoring strength of each specimen. The anchoring strength of Type A, B, and C anchorage whose anchorage length is $12d_b$ is higher than $1.25f_y$, reaching 91-102 % of the anchoring strength of the specimens with 90-degree standard hook, where f_y is the yield strength of the reinforcing bar. And, the overall performances, such as slip at each loading stage, yield slip and yield load of the specimen with the standard hook are equivalent to those of the specimens with a mechanical anchorage whose anchoring length is $12d_b$. Also a similar failure modes between 4 specimens are observed. So, it is recommended that the mechanical anchorage of Type A, B, and C be embedded at least $12d_b$ into the joint core. Also, it should be noted that shorter anchorage length may not be possible for Type A and B anchorage due to the possibility of the splitting failure of the beam-column joint.

A summary of measured slip behavior is also listed in Table 4. Applied loads at lead slip of 0.12, 0.41, 1.27 mm were chosen. Load at slip of 0.41 mm was selected because it is in the range suggested as a permissible crack width in beams (Hamad et al,[1] Jirsa and Marques [2]). At the same

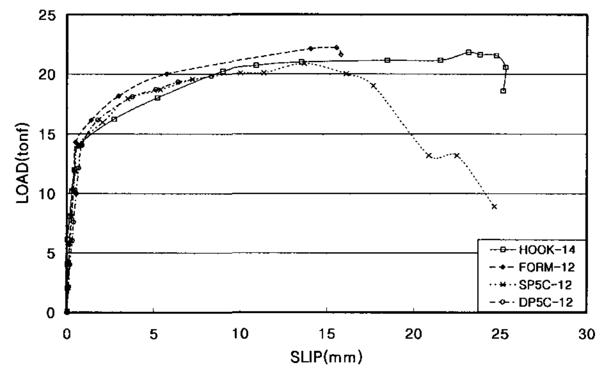
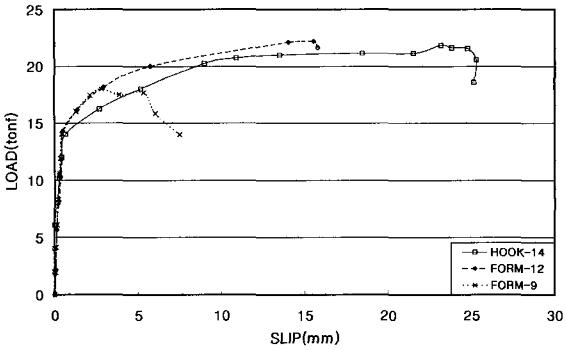


Fig. 7 Load-slip curve of specimen with different anchorage

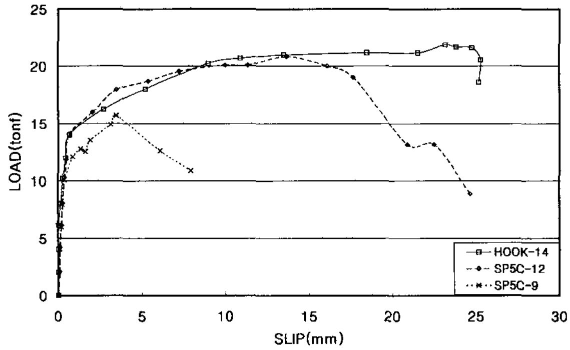
times, load at slip of 1.27 mm was selected because it is in the range suggested as a ultimate crack width in beams. The observed loads at 0.41 mm slip provides a measure of the serviceability of the anchored bar if it is assumed that the crack width at the beam-column joint is about equal to the slip of the anchored bar (Marques and Jirsa,[11] ACI Committee 318 [8]). The ratio of the observed load at 0.41 mm slip of Type A, B, and C anchorage to that of the 90-degree standard hook range 0.94-1.18 except the specimen DP5C-12, meaning sufficient serviceability of mechanical anchorage. Also, the ratio of the observed load at 1.27 mm slip of Type A, B, and C anchorage with the anchorage length of $12d_b$ to that of the 90-degree standard hook range 1.06-1.11, meaning sufficient anchoring strength of mechanical anchorage.

3.3 Load-slip curve

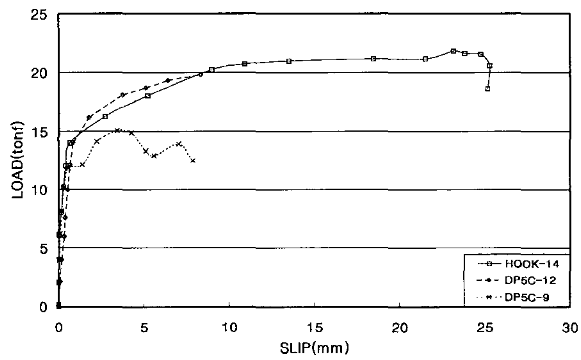
Fig. 7 shows load-slip curves for three specimens with the same anchorage length of $12d_b$ compared with that of the specimen with 90-degree standard hook. Also, Fig. 8 shows the load-slip curves for the seven specimens with the same types of anchorage; Type A, Type B, and Type C anchorage compared with that of the specimen with 90-degree standard hook.



(a) Specimen with type A anchorage



(b) Specimen with type B anchorage



(c) Specimen with type C anchorage

Fig. 8 Load-slip curve of test specimen

As shown in Fig. 7, the performance of the specimen with mechanical anchorage whose anchoring length is $12d_b$ may be equivalent to that of the specimen with standard hook. This trend also can be observed in Fig. 8. As shown in this figure, initial stiffness, yield slip and yield load, and maximum load of four specimens are equivalent to each other. Based on the load and slip measurements from the tests, therefore, it is concluded that Type A, Type B and Type C anchorage with the anchorage length of $12d_b$ is viable option in place of standard hook.

On the other hand, in the case of the specimen with shorter anchoring length of $9d_b$, a poor performance in slip and anchoring strength were observed even though the initial behavior before yield load is somewhat similar to that of the specimens with the standard hook.

4. Conclusions

Seven reinforced concrete blocks with embedded reinforcing bars were constructed and tested to examine the viability of mechanical anchorages which are composed of screw-type sleeve, coupler and perforated plate. The mechanical anchorage systems with shorter development length, proposed in this study can eliminate the bar interferences of RC beam at the beam-column joint. Based on the test results, the following conclusions were drawn.

(1) The anchoring strength and the overall performance of the specimen with type A, B and C are almost equivalent to the performances of the specimen with standard hook.

(2) A minimum anchorage length of $12d_b$ is recommended for the development of anchoring strength of Type A, B, and C anchorage in this experimental study (No. 7 bar).

(3) The additional researches such as beam-column joint tests are needed to prove the viability of the mechanical achorage. Also, the additional studies are needed to formulate the size and thickness of the couplers and plates as a function of the bar size.

REFERENCES

1. Hamad, B. S., Jirsa, J. O., and D'Abreu de Paulo N. I., "Anchorage Strength of Epoxy-Coated Hooked Bars," *ACI Journal*, Vol. 90, No. 2, 1993, pp.590-606.
2. Jirsa, J. O. and Marques, J. L. G., "Study of Hooked Bar Anchorages in Beam-Column Joint," *ACI Journal*, Vol. 72, No. 5, 1975, pp.198-209.
3. Clark, C. R. and Johnston, D. W., "Early Loading Effects on Bond Strength," *ACI Journal*, Vol. 80, No. 6, 1983, pp. 532-593.
4. Altowaiji, W. A. K., Darwin, D., and Donahey, R. C., "Bond of Reinforcement to Revibrated Concrete," *ACI Journal*, 1986, Vol. 83, No. 6, pp.1035-1042.
5. Minor, J. and Jirsa, J. O., "Behavior of Bent Bar Anchorage," *ACI Journal*, Vol. 72, No. 4, 1975, pp.141-149.
6. Hribar, J. A. and Vasko, R. C., "End Anchorage of High Strength Steel Reinforcing Bars," *ACI Journal*, Vol. 66, No. 11, 1969, pp.875-883.
7. Wallace, J. W., McConnell, S. W., Gupta P., and Cote P. A., "Use of Headed Reinforcement in Beam-Column Joints Subjected to Earthquake Loads," *ACI Structural Journal*, Vol. 95, No. 5, 1998, pp.590-606.
8. ACI Committee 318, "*Building Code Requirements for Structural Concrete (ACI 318-95) and Commentary (ACI 318R-95)*," American Concrete Institute, 1995.
9. Donahey R. C. and Darwin D., "*Effects of Construction Procedures on Bond in Bridge Decks*," SM Report, No. 7, University of Kansas Center for Research, Kawrence, 1983.
10. Donahey, R. C. and Darwin, D., "Bond of Top-Cast Bars in Bridge Decks," *ACI Journal*, Vol. 82, No. 1, 1985, pp.57-66.
11. Marques, J. L. G. and Jirsa, J. O., "A Study of Hooked Bar Anchorages in Beam-Column Joint," *ACI Journal*, Vol. 72, No. 5, 1975, pp.198-209.