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ANCHORAGE BEHAVIOR OF BENT BAR IN EXTERIOR BEAM-COLUMN JOINTS UNDER SEISMIC LOADING

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SUMMARY

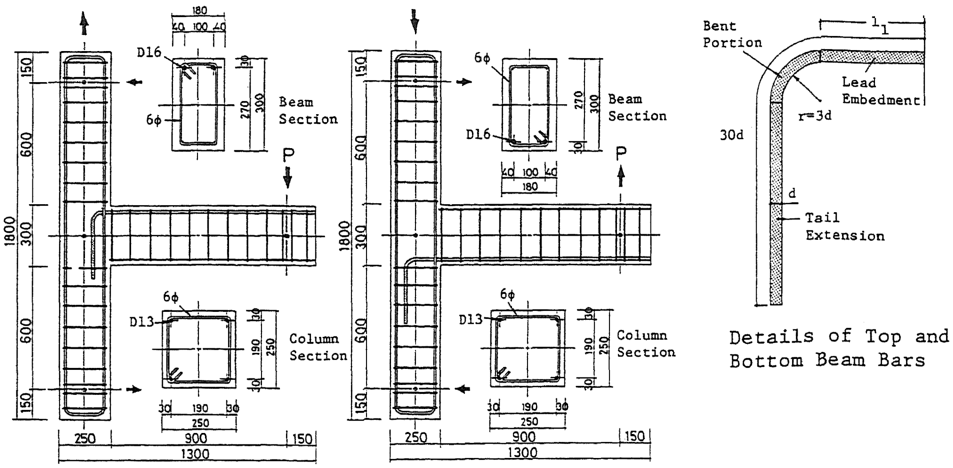
The effects of the straight lead embedment, the transverse reinforcement and column axial compression on the strength and behavior of 90° bent-down anchorages in exterior beam-column joints were clarified experimentally. Furthermore, considering these test results, reinforcing bar details, using transverse bars provided at the bent portion of the beam bars and vertical bars at the inner face of the joints, were proposed to improve the performance on the strength and behavior of 90° bent-down anchorages of top and bottom bars with short lead embedment length. Effectiveness of proposed details was clarified experimentally.

INTRODUCTION

In AIJ Standard for Structural Calculation of Reinforced Concrete Structures, bond length of beam bars in exterior joints is recommended, in Recommendation for Detailing and Placing of Concrete Structures, the point at the start of bent-down for both top and bottom beam bars is recommended [1, 2]. However, they are not theoretical. The object of this study was to investigate the performance on the strength and behavior of 90° hook anchorage for top and bottom bars in more realistic stress conditions. This study consisted of two test series, test series I and II. In test series I , the effects of lead embedment, the transverse reinforcement and column axial compression on the strength and deformation behavior of 90° bent-down anchorages were studied [3, 4, 5]. In test series II, considering the test results in test series I, reinforcing bar details were proposed to improve the performance of 90° bent-down anchorage of top and bottom bars with short lead embedment length. Effectiveness of proposed details was studied.

TEST SERIES I

The overall dimensions of the specimens and the reinforcement details are shown in Fig. 1. A total of twenty-three specimens were tested. All specimens were designed so as to prevent the shear failure of beam-column joints. The same specimen configuration was used for all tests. The 25×25 cm columns were reinforced with four D13 longitudinal column bars. The 18×30 cm beams were reinforced with two D16 longitudinal beam bars. The beams were singly reinforced. Bond length l_b (lead length + bend length + tail length, 30d) and radius of bend r (r = 3d) were common for all specimens. the tail length of the beam bar was extended to the length of more than 12d. The specimens with only top and bottom bars were referred to as the " A series " and " U series ", respectively. The 6 ∅ closed



Details of Top and Bottom Beam Bars

A Series U Series

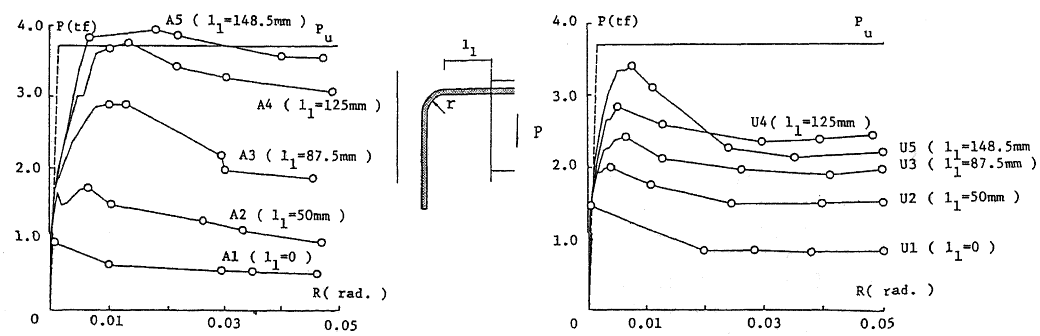
Fig. 1 Details of Test Specimens

ties were spaced at 10 cm outside of the joints. The column was pin-supported at one end and roller-supported at the other. The load was applied at the end of the beam. The loading was repeated once. Mechanical properties of materials were listed in Table 1.

<u>Influence of lead embedment</u> The lead embedment lengths l_1 were 0, 50, 87.5, 125 and 148.5 mm for each top or bottom bars. The transverse reinforcing bars were not provided in the joints.

Load-deflection curves are shown in Fig. 2. The ordinate represents the applied load at the end of the beam. The abscissa gives the deflection of the beam relative to the column at the load point. P_u denotes the calculated ultimate flexural strength of the beam. For specimens A4 and A5, flexural strength was developed. However, flexural strength was not developed for other specimens.

Fig. 3 shows the relationships between the measured stress f_u at the critical section and distance l measured from the critical section to the center of the vertical tail. The anchorage strength of the bent bars is dependent on the lead embedment. The bent bar anchorage strength of the bottom bar is smaller than that of the top one for the same lead embedment length. The bent bar anchorage strength can not be estimated only by bond length. ■-----■ denotes values of f_u calculated from the recommendations proposed by Jirsa and Marques[6], and □—·—□ shows ones proposed by Pinc., Watkins and Jirsa[7]. In this study, the Jirsa and Marques equation was very conservative. On the other hand, the Pinc., Watkins and Jirsa equation was in better agreement for top bars. However, anchorage strengths of bottom bars were approximately 70% of the values calculated by the Pinc.,



Top Bars Bottom Bars

Fig. 2 Influence of Lead Embedment Length

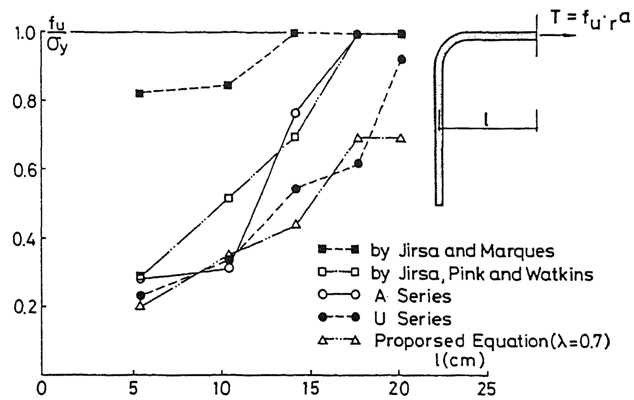


Fig. 3 Comparison of Proposed Formula with Test Results

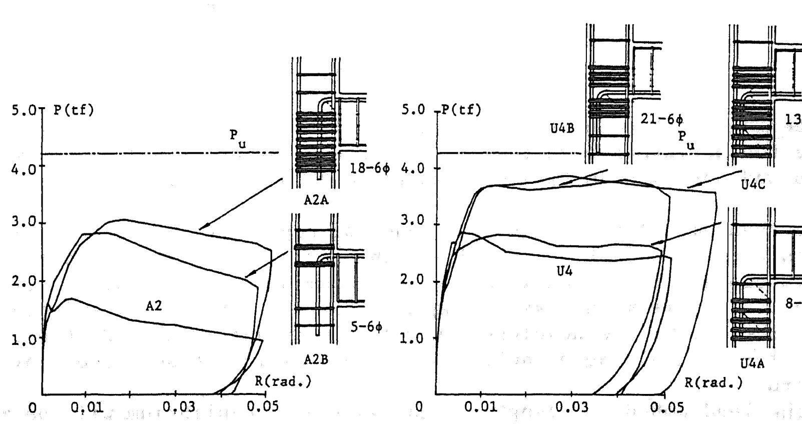
Watkins and Jirsa equation.

Influence of transverse reinforcement The lead embedment lengths for A and U series were 50 mm and 125 mm, respectively. The details of the transverse reinforcement in the joint area is shown in Fig. 4.

Fig. 4 shows the envelope curves of load-deflection curves. Flexural strength was not developed for all the specimens. However, the maximum loads for all the specimens were larger than the maximum ones for specimens U4 and A2. Therefore, the transverse reinforcing bars were effective for the anchorage strength. Particularly, the transverse reinforcing bars placed at the bent portion were effective in increasing the anchorage strength of the hook. On the other hand, the transverse reinforcing bars placed at the tail extension portion acted for preventing the anchorage strength from deterioration after the attainment of the maximum load.

Influence of column axial load The lead embedment lengths for the A and U series were 50 mm and 125 mm. The applied axial load was 0%, 10% and 20% of the ultimate compressive strength of the column. The transverse reinforcing bars in the joint were not provided.

Fig. 5(a) shows the envelope curves of load-deflection curves. Fig. 5(b) shows the relationships between the maximum loads and the applied axial ones. The ordinate represents the ratio of the maximum load to the calculated ultimate flexural load of the beam. The anchorage strength increases with the axial load.



Top Bars (l_1 = 50 mm) Bottom Bars (l_1 = 125 mm)

Fig. 4 Influence of Transverse Reinforcement

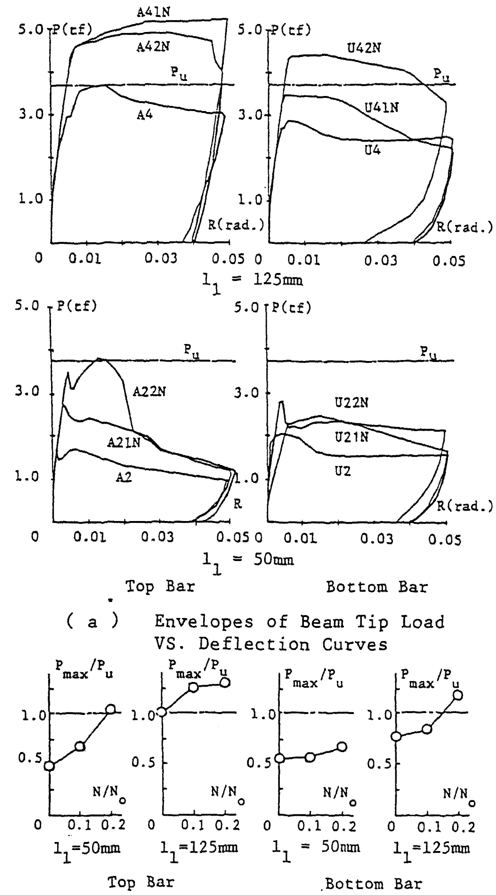
Table 1 Mechanical Properties of Materials

Series	No.	Specimen	Concrete F_c (kgf/cm²)	Concrete F_t (kgf/cm²)	Reinforcing bars ø	σ_y (kgf/cm²)	σ_{max} (kgf/cm²)	ϵ_u	Maximum load P_{max} (tf)
Test series I	1	A1	362	33.8					0.96
	2	A2	362	33.8					1.73
	3	A3	362	33.8					2.89
	4	A4	299	30.7	D16	3389	5032	19.5	3.76
	5	A5	362	33.8	D13	3786	5630	18.7	3.94
	6	U1	337	28.8	6ø	2347	3544	40.9	1.50
	7	U2	349	23.1					2.02
	8	U3	346	33.5					2.44
	9	U4	349	23.1					2.85
	10	U5	346	33.5					3.42
	11	A2A							3.15
	12	A2B			D16	3900	5140	25.0	2.83
	13	U4A	290	27.0	D13	4080	5950	24.0	2.84
	14	U4B			6ø	1762	2887	43.5	3.82
	15	U4C							3.89
	16	A21N			D16	3864	5653	16.3	2.75
	18	A41N	247	34.6	D13	4321	6177	25.2	5.23
	20	U21N			6ø	1743	2896	43.5	2.36
	22	U41N							3.48
	17	A22N	245	21.9	D16	3459	5221	21.0	3.83
	19	A42N	267	20.2	D13	3528	5332	18.8	4.89
	21	U22N	254	21.9	6ø	2347	3544	40.9	2.49
	23	U42N	254	21.9					4.43
Test series II	24	A2-1	291	23.2					4.34
	25	A2-2	310	34.5	D16	3779	5047	21.6	4.73
	26	U2-1	291	23.2	D13	3717	5213	19.3	5.13
	27	U2-2	305	32.2	D10	3817	5669	15.3	5.42
	28	U4-1	310	34.5	6ø	2347	3544	40.9	4.49
	29	U4-2	334	35.6					4.89

* * * *

- Applied axial load 1N : $0.1N_o$, 2N : $0.2N_o$ (N_o : Compressive strength of column)
- Detail of reinforcement -1 : case 1, -2 : case 2
- 1 : l_1 = 0, 2 : l_1 = 50mm, 3 : l_1 = 87.5mm, 4 : l_1 = 125mm, 5 : l_1 = 148.5mm
- A : A series, U : U series

F_c : Compressive strength, F_t : Tensile strength
σ_y : Yield stress, σ_{max} : Maximum strength
ϵ_u : Maximum elongation



(a) Envelopes of Beam Tip Load VS. Deflection Curves

(b) Relationships between Maximum Strength and Applied Axial Load

Fig. 5 Influence of Column Axial Load

However, in the case of a specimen with short lead embedment length, the flexural strength of the beam was not developed and the anchorage strength deteriorated rapidly after the attainment of the maximum anchorage capacity.

TEST SERIES II

Considering test results in test series I, further research was carried out to improve the performance on the strength and behavior of 90° bent-down anchorages of top and bottom beam bars with short lead embedment lengths.

The mechanisms of anchorage resistance of top and bottom beam bars in exterior joints are shown in Fig. 6. The mechanism of anchorage resisitance of the beam bar is closely connected with the mechanism of shear resistance of the beam-column joint. In this mechanism, Diagonal concrete struts transmitting the compressive forces C_1,C_2 are developed in the columns and joint. On the other hand, beam acts for maintaining a equlibrium of compression transmitted by diagonal concrete strut.

When the lead embedment length is enough long, equlibrium will be maintained by compressive forces C_1,C_2 and beam bars in tension T at point O. But, if the lead embedment length is not enough long, equlibrium will not be maintained, because tension force can not be balanced. Therefore, it is considered that per-

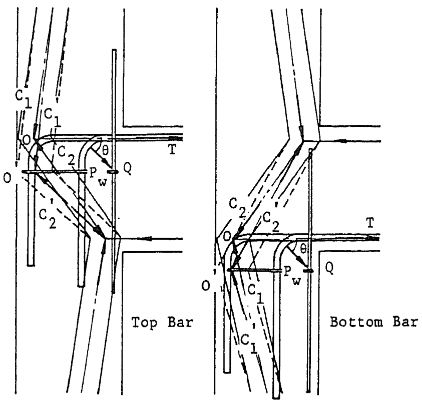


Fig. 6 Anchorage Resistance Mechanism

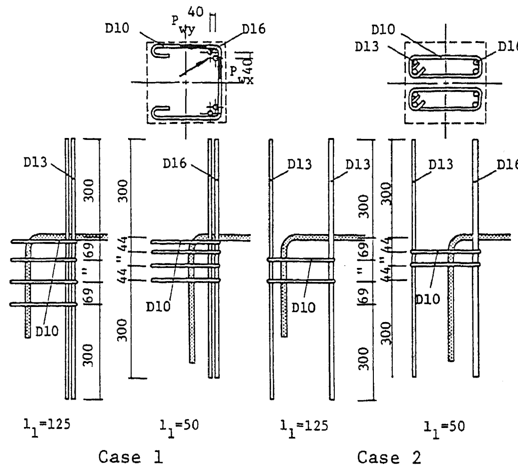


Fig. 7 Suggested Details

formance of 90° bent-down anchorages of top and bottom beam bars with short lead embedment lengths in exterior joints is extremely inferior.

The tension force, T, developed in the top or bottom bars of the beam is introduced to the point Q by the concrete compression force P_W at the bed. Provided the transverse reinforcing bars are arranged between point O' and Q, the horizontal component $P_W\cos\Theta$ of the concrete compression P_W is transmitted to point O' through point Q. Equlibrium will be maintained by compressive forces C_1', C_2' and transverse reinforcing bars in tension $P_W\cos\Theta$ at point O'. On the other hand, provided the vertical reinforcing bars are arranged at point Q, the vertical component $P_W\sin\Theta$ of the concrete compression P_W is introduced to the vertical reinforcing bars. Vertical forces will be balanced with bond forces from the vertical reinforcing bars. Therefore, it is expected that the performance of 90° bent-down anchorages of top or bottom beam bars with short lead embedment lengths will be improved.

Based on the above mentioned consideration, the two reinforcing bar details as shown in Fig. 7 were proposed. In case 2 , tension force, T, is transmitted to the outer face of the column passing through the joint core directly. On the other hand, in case 1 , tension force, T, is transferred from the longitudinal inside bars of the column to the outer face of the column through the side faces of the column. In case 1 , ease of construction was considered.

To clarify the effectiveness of these reinforcing bar details, a total of

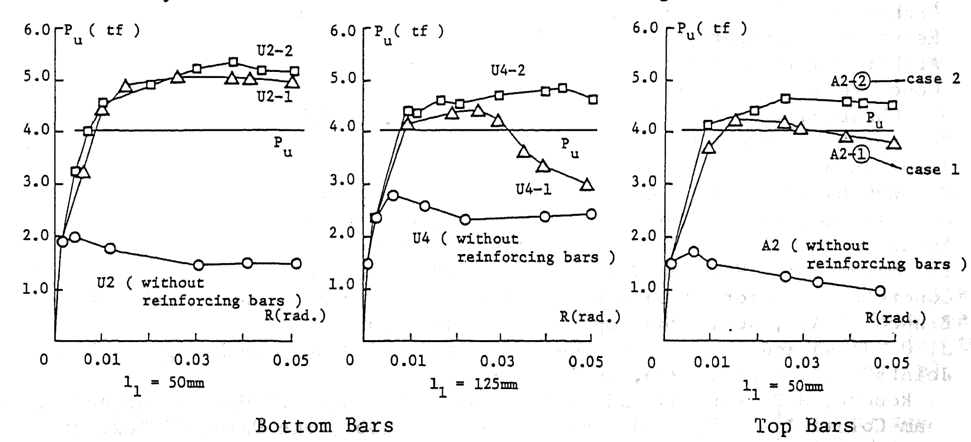


Fig. 8 Improvement of Performance of 90° Bent-down Anchorages

six specimens were tested. Both case1 and case 2 , the strength of the transverse and vertical reinforcement respectively was designed to comply with the yield strength of the beam bars. In A series, the lead embedment length was 50 mm. in U series, the lead embedment lengths were 50 mm and 125 mm. The overall dimensions of the specimens, the reinforcement details of the column and the beam and method of testing were identical with those used in test series I. Mechanical properties of materials were listed in Table 1.

Fig. 8 shows the envelop curves for hysteresis loop for all the specimens. The ordinate represents the applied load at the end of the beam. The absissa gives the deflection of the beam relative to the column at the point of the load. P_u denotes the calculated ultimate strength of the beam. Strength of the specimen with proposed reinforcing bars drastically increased and the flexural strength of the beam was developed for all the specimen. Proposed details were effective to improve the performance of 90 deg bent-down anchorage of top and bottom beam bars with short lead embedment lengths.

CONCLUDING REMARKS

Based on the test results, the following conclusions can be drawn :

1) The anchorage strength of bent bars is dependent on the lead embedment length and can not be estimated only by bond length. The anchorage strength of the bottom bars is smaller than that of the top bars for the same lead embedment length. The anchorage strength of the top bars can be estimated by the Pinc., Watkins and Jirsa equation. The anchorage strength of the bottom bars is approximately 70% of the values calculated by the Pinc., Watkins and Jirsa equation.

2) The transverse reinforcing bars placed at the bent portion are effective in increasing the anchorage strength of the hook. On the other hand, the transverse reinforcing bars placed at the tail extension portion act in preventing the anchorage strength from deteriorating after attainment of the maximum strength.

3) The anchorage strength increases with the applied axial compression. However, in the case of specimens with short lead embedment length, flexural strength of the beam is not developed and the anchorage strength deteriorates rapidly after the attainment of maximum strength.

4) The proposed reinforcing bar details are effective in improving the performance of the 90° bent-down anchorages of top and bottom beam bars with short lead embedment lengths.

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