IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 3 Ver. I (May- Jun. 2016), PP 71-75
www.iosrjournals.org

Lap Splices in Tension Between Headed Reinforcing Bars And Hooked Reinforcing Bars of Reinforced Concrete Beam

Seunghun Kim[1]
[1](Professor, Department Of Architectural Engineering, Hanbat National University, Republic Of Korea)

Abstract : *For application of headed deformed bars to the various connection details, it needs to use the design of lap splices between headed bar and hooked deformed bar. The experimental works were conducted to evaluate the lap splice of headed deformed bar and hooked deformed bars. Seven specimens were tested. Main parameters of experiments were the diameter of headed bar and hooked bar, the confinement details, and the lap lengths. As a results, specimens with lap failure had two different patterns which were the bond splitting failure caused by tension in the lap bars and the prying failure caused by the curvature of the specimen and bending moments in the lap bars. The lap length and the confinement detail in the lap zone did not affect the initial stiffness and the cracking load of specimens, and influenced the second stiffness and the maximum load. It need to increase the lap length by ACI 318-08 method between headed and hooked bars to have the sufficient performance of lap splice over the nominal strength.*
Keywords : *Headed bar, Hooked bar, Lap splice, Reinforced concrete, Lap zone*

I. Introduction

The advantages of designing with headed reinforcement are acknowledged by engineers all over the world. An increasing number of contractors are choosing headed reinforcement because of the benefits of their use, especially the increased speed of installation. For reinforcing bars in tension, headed deformed bars are designed to develop the tensile strength of the rebar without crushing normal strength concrete beneath the head.[1-3] That makes the full capacity of the rebar available from its end. So, headed deformed bars can be developed in a shorter length than required for standards hooks. Because short lap splices of headed bars are great for closure pours and other locations not permitting the length of conventional lap splices, lap splices of headed reinforcements have been attempted to the joints of precast concrete members and to the connections between old and new concrete members. For application of headed deformed bars to the various connection details, it needs to use the design of lap splices between headed bar and hooked deformed bar.

The aim of the present research was to evaluate the lap splice of headed reinforcing bars and hooked reinforcing bars throughout experimental works. The main parameters of experiments were the diameter of headed bar and hooked bar, the confinement details, and the lap lengths. Structural performance of lap splice specimens was evaluated on the basis of failure mode, the load-deflection curves, and the strengths.

II. Development And Lap Splice Design By ACI318

Development length for headed deformed bars in tension, l_{dt}, shall be determined from equation (1) by ACI318[4], where the value of the specified compressive strength of concrete, f'_c, used to calculate l_{dt} shall not exceed 40 MPa, and factor Ψ_e shall be taken as 1.2 for epoxy-coated reinforcement and 1.0 for other cases. f_y is the yield strength of reinforcement and d_b is the reinforcing bar diameter.

$$l_{dt} = (0.19\ \Psi_e\ f_y/(f'c)^{1/2})d_b \qquad (1)$$

Use of heads to develop deformed bars in tension shall be limited to conditions satisfying (a) through (f): (a) Bar f_y shall not exceed 420 MPa, (b) Bar size shall not exceed No. 36, (c) Concrete shall be normal weight, (d) Net bearing area of head A_{brg} shall not be less than four times bar area A_b, (e) Clear cover for bar shall not be less than $2d_b$, and (f) Clear spacing between bars shall not be less than $4d_b$.

Development length for deformed bars in tension terminating in a standard hook for normal concrete, l_{dh}, shall be determined from Eq. (2), but l_{dh} shall not be less than the larger of $8d_b$ and 150 mm.

$$l_{dh} = (0.24\ \Psi_e\ f_y/(f'c)^{1/2})d_b \qquad (2)$$

Where 180-degree hooks of No. 36 and smaller bars are enclosed within ties or stirrups perpendicular to the bar being developed, spaced not greater than $3d_b$ along l_{dh}, length l_{dh} in equation (2) shall be permitted to be multiplied by 0.8. Where reinforcement provided is in excess of that required by analysis, except where development of the yield strength of reinforcement, f_y, is specifically required, a factor of $(A_{s\_required})/(A_{s\_provided})$ may be applied to the expression for l_{dt} and l_{dh}. Length l_{dt} and l_{dh} shall not be less than the larger of $8d_b$ and 150 mm.

In ACI318, the lap lengths of headed or hooked deformed bars don't be yet clearly indicated. For tension lap splices of total straight deformed bars, ACI318 uses the minimum length of lap shall be as required for 1.3 times development length, but not less than 300 mm. M. K. Thompson et al (2006)[1] proposed a strut and tie model to be drawn for the lap splice of headed bars such as shown in Fig. 1. Struts at angles of 55° from the bar axis propagating from opposing bar heads should be used to define the available anchorage length, L_a. For the present, structural engineers calculate the lap length Ls of headed deformed bars as equation (3) considering the development length $L_a(=l_{dt})$ of ACI 318's and struts at angles of 55°. The lap length of hooked deformed is assumed as $1.3l_{dh}$ calculated by the same method of straight deformed bars.

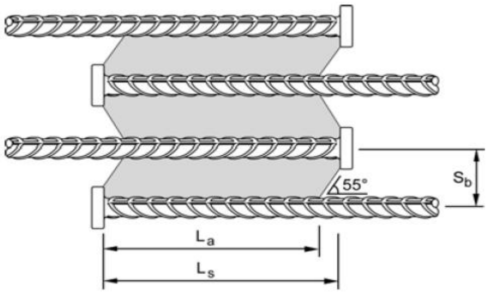


Fig. 1 Lap splice of headed bars[1]

III. Experimental Program

An experimental program was carried out to evaluate the structural performance of lap splice method of headed deformed bar and 180° hooked deformed bars. Total seven specimens of full scale were tested. The main parameters of experiments were the diameter of headed bar and hooked bar, the confinement details, and the lap lengths as shown in the Table 1.

Table 1 List of specimens

Specimen	Headed bar Number-Diameter	Hooked bar Number-Diameter	Confinement details,	B [mm]	S_b [mm]	L_s [mm]
H19-D13-B0	2-D19	3-D13	-	380	60	384
H19-D16-B0	2-D19	3-D16	-	380	60	408
H19-D16-A0	2-D19	3-D16	-	380	60	314
H19-D16-A1	2-D19	3-D16	D10@50	380	60	314
H25-D19-B0	2-D25	3-D19	-	460	80	505
H25-D19-A0	2-D25	3-D19	-	460	80	388
H25-D19-A1	2-D25	3-D19	D10@50	460	80	388

To induce lap failure by headed bars, lap lengths of headed bars were assumed as $1.3l_{dt}$ and $1.0l_{dt}$ out of consideration of the effect of $S_b\tan35°$, and the number and diameter of hooked bars were designed to have less lap length than headed bars.

Fig. 2 shows the basic reinforcement layout for a confined and unconfined specimen. All specimens consisted of 300mm thick, 3800mm long slabs. No transverse reinforcement was placed for 1000mm at a middle portion. The tensile reinforcements were spliced at the mid-span of these specimens.

Two headed bars were lapped with three hooked bars in the top layer of reinforcement of the specimen. Three D16 continuous bars were placed in the bottom of the beam. D10 closed hoop stirrups were tied around the two layers of longitudinal bars starting at a distance 500mm from the center of the span. Clear spacing $2S_b$ between bars was either 120mm or 160mm over six times headed bar diameter. The width of the specimen was altered to accommodate the bar spacing: 380mm for 60mm S_b and 460mm for 80mm S_b. Minimum 57.5mm clear cover was provided over the lapped bars so that the effective depth of the top reinforcement was about 230mm. For specimen H19-D16-A1 and specimen H25-D19-A1, D10 closed hoop stirrups with 50mm spacing were placed over the lapped bars in the lap zone.

The compressive concrete strength by material tests was 21.69 MPa. Low compressive concrete strength is advantageous to increase the likelihood of splice failure rather than bar yielding. All the reinforcing steel bars used in the specimens conformed to KS SD400. Mechanical properties of the reinforcing bars are listed in Table 2.

Fig. 2 Reinforcement details of specimens

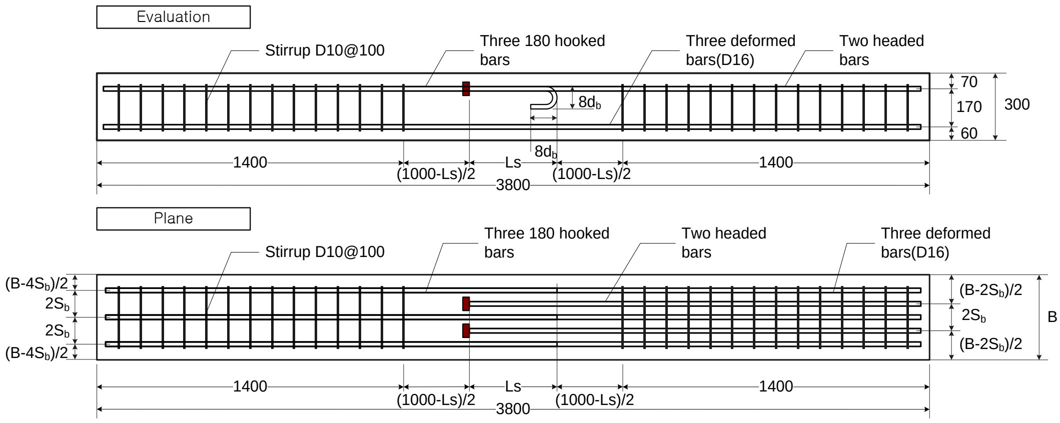


Table 2 Mechanical properties of reinforcing bars

Type of reinforcing bars	**Cross-sectional area, A_s [mm^2]**	**Elastic modulus, E_s [GPa]**	**Yield strength, f_{sy} [MPa]**	**Tensile strength, f_{su} [MPa]**
D10 (Stirrup)	71.3	169.8	478.0	591.9
D13 (hook bar)	126.7	161.7	412.6	515.3
D16 (hook bar)	198.6	195.2	496.1	630.3
D19 (hook bar)	286.5	189.3	479.0	593.9
D19 (headed bar)	286.5	180.3	433.9	550.3
D25 (headed bar)	506.7	183.4	440.9	550.0

Loading of the specimens was designed to place this middle portion under constant moment creating tension on the top surface so that cracks could be observed and recorded. Four point loads by UTM were applied until the splice failed or the lapped bars yielded. Specimens were controlled by values of LVDT, which was located on the center of specimens.

IV. Test Results

Fig. 3 shows the failure patterns of specimens. For all specimens, cracking initiated outside of the lap zone at the location of the loading points which were 500mm from the center of the span. Then, cracking occurred along the line of heads and hooks at each end of the lap at a slightly higher load. As additional load was applied, the different patterns of crack and failure were observed. Specimen H19-D13-B0 failed as shown as Fig. 3(a). It had the flexural failure with the increased width of transverse cracks frequently cut across the width of the specimen along the line of heads.

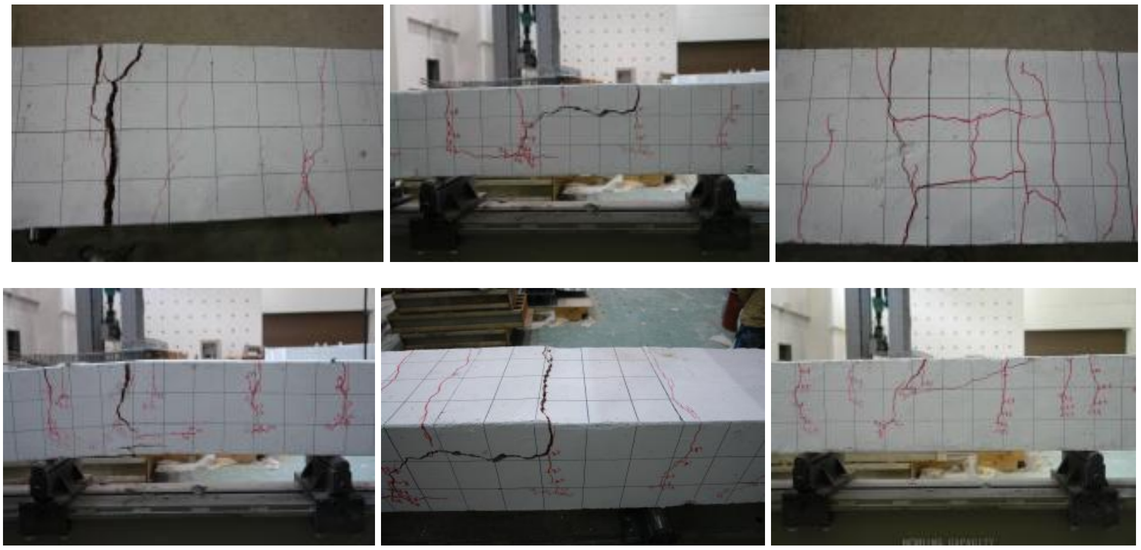
The other specimens showed two lap failure patterns which were the bond splitting failure caused by tension in the lap bars and the prying failure caused by the curvature of the specimen and bending moments in the lap bars. Specimen H19-D16-B0, specimen H19-D16-A0, and H25-D19-B0 had the prying failure as shown as Fig. 3(b). Specimen H19-D16-A1, specimen H25-D19-A0, and H25-D19-A1 had the bond splitting failure with longitudinal splitting cracks and diagonal cracks along the lap splice struts as shown as Fig. 3(c).

Fig. 4 shows the load-deflection curves at the center span for all specimens. Table 3 shows the test results about the maximum loads P_{max} and deflections of specimens. P_{max} was compared to the calculated nominal load P_n based on the experimentally material properties and the nominal flexural strength M_n by section analysis. M_n has the minimum value between M_{n1} for headed bar section and M_{n2} for hooked bar section.

P_{max} of specimen H19-D13-B0 was 75.6kN over the nominal load, P_n, 57.2kN at the hooked bar section. Specimen H19-D13-B0 had ductile behavior after yielding as shown as Fig. 4(a). These results showed that specimen H19-D13-B0 had a sufficient lap capacity. In the comparison of P_{max} / P_n for all specimens except specimen H19-D13-B0, P_{max} / P_n measured 0.56～0.94. This result show that it need to increase the lap length by ACI 318-08 method between headed and hooked bars to have the sufficient performance of lap splice over P_{max} / P_n =1.

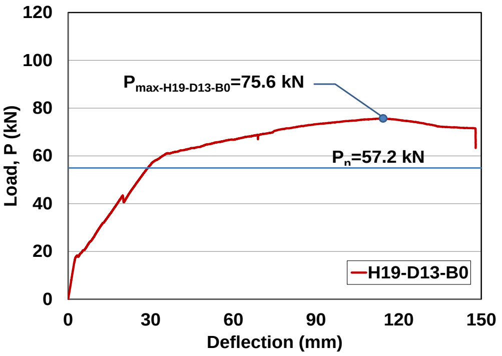
The lap length and the confinement detail in the lap zone did not affect the initial stiffness and the cracking load of specimens, and influenced the second stiffness and the maximum load. From the comparison of the load-deflection curves for confined and unconfined specimens which are presented in Fig. 4(b) and Fig. 4(c), unconfined specimens, such as specimen H19-D16-A0 and specimen H25-D19-A0, were less stiff after cracking load and had less maximum load than the confined specimens, such as specimen H19-D16-A1 and specimen

H25-D19-A1. For unconfined specimens, specimens with short lap length also had less capacity than specimens with long lap length.

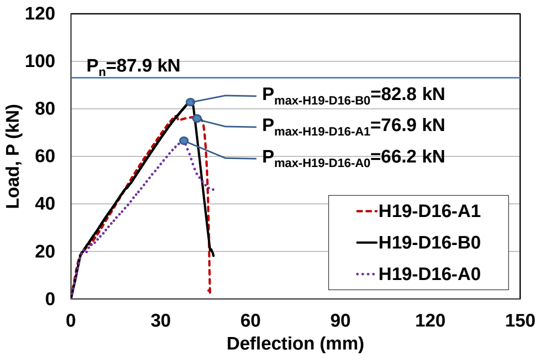


(a) Flexural failure (specimen H19-D13-B0) (b) Prying failure (specimen H19-D16-A1) (c) Bond splitting failure (specimen H25-D19-A0)

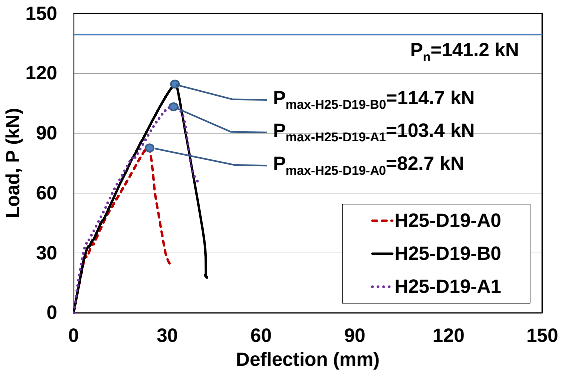
Fig. 3 Failure patterns



(a) H19-D13



(b) H19-D16



(c) H25-D19

Fig. 4 Load-deflection curves

Table 3 Test results

Specimen	**P_{max} [kN]**	**Deflection at P_{max} [mm]**	**M_{n1} [kNm]**	**M_{n2} [kNm]**	**M_n [kNm]**	**P_n [kN]**	**P_{max} /P_n**	**Failure patterns***
H19-D13-B0	75.6	114.8	52.8	34.3	34.3	57.2	1.32	FF

H19-D16-B0	82.8	43.1	52.8	61.8	52.8	87.9	0.94	PF
H19-D16-A0	66.2	38.1	52.8	61.8	52.8	87.9	0.75	PF
H19-D16-A1	76.9	39.9	52.8	61.8	52.8	87.9	0.87	BSF
H25-D19-B0	114.7	35.0	91.0	84.7	84.7	141.2	0.81	PF
H25-D19-A0	82.7	25.4	91.0	84.7	84.7	141.2	0.59	BSF
H25-D19-A1	103.4	35.0	91.0	84.7	84.7	141.2	0.73	BSF

FF: flexural failure, PF: prying failure, BSF: bond splitting failure

V. Conclusion

In this research, the experimental works were conducted to evaluate the lap splice of headed deformed bar and hooked deformed bars with parameters of the diameter of headed bar and hooked bar, the confinement details, and the lap lengths. Based on the obtained results, the following conclusions are drawn;

1) Specimens with lap failure had two different patterns which were the bond splitting failure caused by tension in the lap bars and the prying failure caused by the curvature of the specimen and bending moments in the lap bars. 2) The lap length and the confinement detail in the lap zone did not affect the initial stiffness and the cracking load of specimens, and influenced the second stiffness and the maximum load. 3) For unconfined specimens, specimens with short lap length also had less capacity than specimens with long lap length. 4) It need to increase the lap length by ACI 318-08 method between headed and hooked bars to have the sufficient performance of lap splice over the nominal strength.

VI. Acknowledgements

This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF-2013R1A1A2013485).

References

[1]. M. K. Thompson, A. Ledesma, J. O. Jirsa, and J. E. Breen, Lap Splices Anchored by Headed Bars, ACI Structural Journal, 103(2), 2006, 271-279.

[2]. Y. T. Lee, S. H. Kim, S. H. Chea, and B. Y. Bahn, An Experimental Study on the Lap Strength of Headed Steel Reinforcements with Lap-spliced, Journal of Aik, 24(3), 2008, 87-94.

[3]. S. H. Kim, Y. T. Lee, T. S. Kim, and S. H. Chea, An Experimental Study on Noncontact Lap Splices of Headed Reinforcements with Different Effective Depths, Journal of Aik, 26(5), 2010, 3-10.

[4]. ACI Committee 318, Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary (ACI 318R-11), 2011.