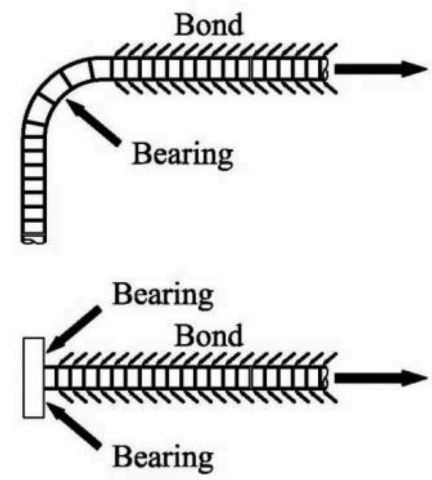

Figure 1. Development Mechanisms

SPECIMENS

A total of 24 beam-end specimens were tested. The dimensions of the specimens, applied load, and reactions are shown in Figure 2. All specimens used #25 reinforcing bars (#8) with a diameter, d_b, of 25 mm (1 in.) and cross-sectional area, A_b, of 500 mm^2 (0.79 in^2). Six specimens had straight bars, six had hooked bars, and twelve had headed bars. The ends of the reinforcing bars were placed 600 mm (24 in.) from the front or loaded face of the specimen. A PVC tube around the bar was used to control bonded length. For straight and hooked bars the bonded length, l_b, was either 200 mm (8 in.), 300 mm (12 in.) or 400 mm (16 in.) with four specimens having a 200 mm (8 in.) bonded length, four specimens having a 300 mm (12 in.) bonded length, and four with 400 mm (16 in.) bonded length. For headed bars the bonded length, l_b, was either 200 mm (8 in.) or 400 mm (16 in.) with each bonded length used in six specimens. Clear cover, C_c, was either 25 mm (1 in.) or 50 mm (2 in.) with twelve specimens having 25 mm (1 in.) clear cover and twelve with 50 mm (2 in.).

The specimens were cast with the reinforcing bar placed on the bottom of the form and inverted for testing.

For the headed bars three head sizes were used. Four specimens used 100 mm x 50 mm (4.00 in. x 2.00 in.) heads providing a bearing area to bar area ratio, A_{brg}/A_b, of 9. Four specimens used 68 mm x 50 mm (2.75 in. x 2.00 in.) heads providing a bearing area to bar area ratio, A_{brg}/A_b, of 6. Four specimens used 44 mm x 50 mm (1.75 in. x 2.00 in.) heads providing a bearing area to bar area ratio, A_{brg}/A_b, of 3.5. Hooked bars terminated in standard ACI hooks. There was no transverse reinforcement present along the bonded length.

Strain gauges were placed on the bars at the head and the beginning of the hook.

The reinforcing bars had a yield strength, f_y, of 420 MPa (60 ksi) and a yield capacity of 200 kN (45 kips). The concrete had a compression capacity, f'_c, of 34 MPa (4900 psi).

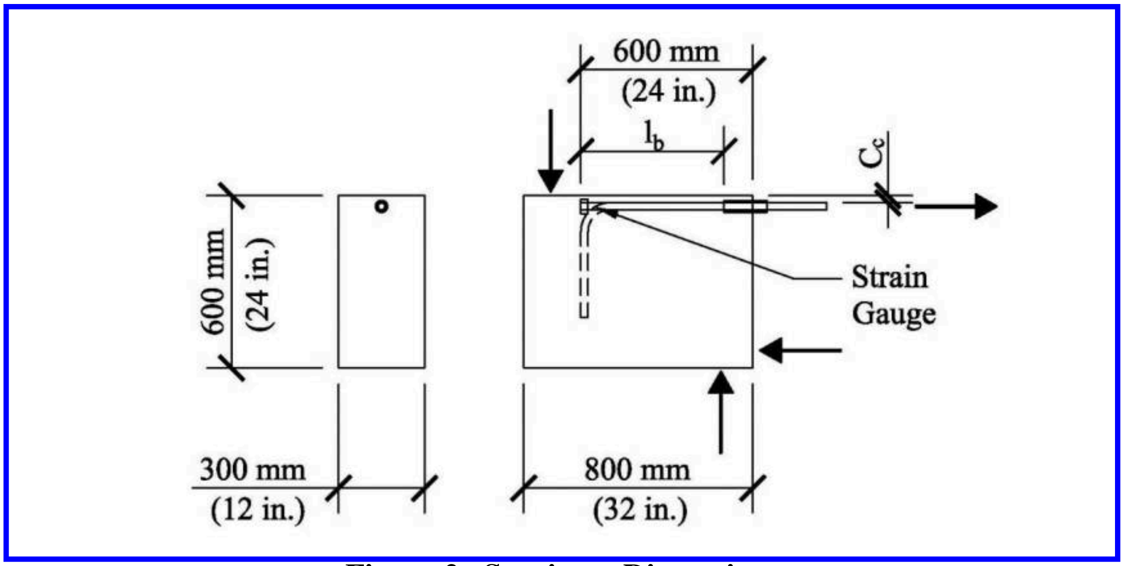

Figure 2. Specimen Dimensions

RESULTS

The variable dimensions and failure load, F_u, for each specimen are listed in Table 1 (Blau, 2010; Bolda, 2011). Tension force was applied to the reinforcing bars until a concrete failure – splitting for straight and hooked bars, blowout for headed bars – occurred. If a concrete failure did not take place, the test was ended when the applied force was about 230 kN (52 kips), approximately 115% of the yield capacity of the reinforcing bars.

Straight Bar Results

The variable dimensions and results solely for the straight bars are shown in Table 2 (Bolda, 2011). Included in Table 2 are two predictions for capacity. The first, F_o, is calculated using the equation for average bond stress along a bonded length proposed by Orangun (Orangun, 1977). The bond stress, μ, is given by $\mu = \left(1.2 + {}^{3C}/_{d_b} + {}^{50d_b}/_{l_b}\right)\sqrt{f'_c}$ where C is the clear cover, C_c, plus one-half bar diameter, d_b, $(C_c + {}^{d_b}/_2)$. The Orangun equation is written in US units with compressive strength, f'_c, and the bond stress, μ, in psi. The predicted capacity, F_o, is the average bond stress, μ, multiplied by the surface area of the bonded length, l_b: $F_o = \mu(\pi d_b)(l_b)$.

Table 1. Dimensions and Results

Specimen	Bar Type	d_b, mm (in.)	A_b, mm^2 (in^2)	l_b, mm (in.)	C_c, mm (in.)	A_{brg}/A_b	F_u, kN (k)	Failure Type
1	Straight	25 (1.00)	500 (0.79)	200 (8.0)	25 (1.0)	-	166 (37.4)	Splitting
2	Straight	25 (1.00)	500 (0.79)	300 (12.0)	25 (1.0)	-	196 (44.0)	Splitting
3	Straight	25 (1.00)	500 (0.79)	400 (16.0)	25 (1.0)	-	247 (55.5)	Yield
4	Straight	25 (1.00)	500 (0.79)	200 (8.0)	50 (2.0)	-	196 (44.0)	Splitting
5	Straight	25 (1.00)	500 (0.79)	300 (12.0)	50 (2.0)	-	212 (47.7)	Yield
6	Straight	25 (1.00)	500 (0.79)	400 (16.0)	50 (2.0)	-	206 (46.2)	Yield
7	Hooked	25 (1.00)	500 (0.79)	200 (8.0)	25 (1.0)	-	245 (55.1)	Yield
8	Hooked	25 (1.00)	500 (0.79)	300 (12.0)	25 (1.0)	-	246 (55.2)	Yield
9	Hooked	25 (1.00)	500 (0.79)	400 (16.0)	25 (1.0)	-	246 (55.4)	Yield
10	Hooked	25 (1.00)	500 (0.79)	200 (8.0)	50 (2.0)	-	246 (55.2)	Yield
11	Hooked	25 (1.00)	500 (0.79)	300 (12.0)	50 (2.0)	-	242 (54.5)	Yield
12	Hooked	25 (1.00)	500 (0.79)	400 (16.0)	50 (2.0)	-	206 (46.4)	Yield
13	Headed	25 (1.00)	500 (0.79)	200 (8.0)	25 (1.0)	3.5	203 (45.6)	Blowout
14	Headed	25 (1.00)	500 (0.79)	400 (16.0)	25 (1.0)	3.5	238 (53.4)	Yield
15	Headed	25 (1.00)	500 (0.79)	200 (8.0)	50 (2.0)	3.5	242 (54.5)	Yield
16	Headed	25 (1.00)	500 (0.79)	400 (16.0)	50 (2.0)	3.5	203 (45.6)	Yield
17	Headed	25 (1.00)	500 (0.79)	200 (8.0)	25 (1.0)	6.0	229 (51.4)	Blowout
18	Headed	25 (1.00)	500 (0.79)	400 (16.0)	25 (1.0)	6.0	234 (52.6)	Blowout
19	Headed	25 (1.00)	500 (0.79)	200 (8.0)	50 (2.0)	6.0	205 (46.0)	Yield
20	Headed	25 (1.00)	500 (0.79)	400 (16.0)	50 (2.0)	6.0	203 (45.7)	Yield
21	Headed	25 (1.00)	500 (0.79)	200 (8.0)	25 (1.0)	9.0	215 (48.3)	Blowout
22	Headed	25 (1.00)	500 (0.79)	400 (16.0)	25 (1.0)	9.0	234 (52.7)	Yield
23	Headed	25 (1.00)	500 (0.79)	200 (8.0)	50 (2.0)	9.0	251 (56.4)	Yield
24	Headed	25 (1.00)	500 (0.79)	400 (16.0)	50 (2.0)	9.0	209 (47.0)	Yield

The second predicted capacity, F_s, is based on Equation 12-1 in ACI 318-11 – the equation for straight bar development length. Equation 12-1 provides the required straight bar development length for a bar to reach yield. Equation 12-1 (with transverse reinforcement factor and inapplicable modification factors removed) is: $l_d = \frac{3}{40}\frac{f_y}{\sqrt{f'_c}}\frac{d_b}{c_b}d_b$ where c_b is the clear cover, C_c, plus one-half bar diameter, d_b, $(C_c + {}^{d_b}/_2)$. Equation 12-1 is written in US units of pounds and inches. The predicted capacity, F_s, is taken as the yield force of the bar, F_y = 200 kN (45 kips), multiplied by the ratio of bonded length to development length: $F_s = \left({}^{l_b}/_{l_d}\right)F_y$. For all six specimens F_o and F_s underestimate the measured capacity.

Table 2. Straight Bar Dimensions and Results

Specimen	Bar Type	l_b, mm (in.)	C_c, mm (in.)	F_u, kN (k)	Failure Type	F_o, kN (k)	F_u/F_o	F_s, kN (k)	F_u/F_s
1	Straight	200 (8.0)	25 (1.0)	166 (37.4)	Splitting	93 (21.0)	1.78	37 (8.4)	4.46
2	Straight	300 (12.0)	25 (1.0)	196 (44.0)	Splitting	115 (26.0)	1.70	56 (12.6)	3.51
3	Straight	400 (16.0)	25 (1.0)	247 (55.5)	Yield	138 (31.0)	1.79	75 (16.7)	3.32
4	Straight	200 (8.0)	50 (2.0)	196 (44.0)	Splitting	117 (26.2)	1.68	62 (14.0)	3.16
5	Straight	300 (12.0)	50 (2.0)	212 (47.7)	Yield	151 (33.9)	1.41	93 (20.9)	2.28
6	Straight	400 (16.0)	50 (2.0)	206 (46.2)	Yield	185 (41.5)	1.12	124 (27.9)	1.66

Hooked Bar Results

The variable dimensions and results solely for the hooked bars are shown in Table 3 (Bolda, 2011). According to Section 12.5 of ACI 318-11, the hook development length required to yield the reinforcing bar is 300 mm (12.0 in.) Based on the recommendations by Marques and Jirsa (Marques et al., 1975), the bearing force at the hook provides 80% of the yield force of the reinforcing bar. To reach yield, an additional 275 mm (11.0 in.) of bonded length is required. Assuming a linear relationship between bonded length and capacity suggests that hooked bars with 200 mm (8 in.) of bonded length should have a capacity of 189 kN (43 k) and hooked bars with 300 mm (12 in.) or 400 mm (16 in.) of bonded length should have a capacity greater than or equal to the yield capacity. All hooked bar specimens had capacities equal to or greater than the yield force of the reinforcing bar.

Table 3. Hooked Bar Dimensions and Results

Specimen	Bar Type	l_b, mm (in.)	C_c, mm (in.)	A_{brg}/A_b	F_u, kN (k)	Failure Type
7	Hooked	200 (8.0)	25 (1.0)	-	245 (55.1)	Yield
8	Hooked	300 (12.0)	25 (1.0)	-	246 (55.2)	Yield
9	Hooked	400 (16.0)	25 (1.0)	-	246 (55.4)	Yield
10	Hooked	200 (8.0)	50 (2.0)	-	246 (55.2)	Yield
11	Hooked	300 (12.0)	50 (2.0)	-	242 (54.5)	Yield
12	Hooked	400 (16.0)	50 (2.0)	-	206 (46.4)	Yield

Headed Bar Results

The variable dimensions and results solely for the headed bars are shown in Table 4 (Blau, 2011). Included in Table 4 are two predictions for capacity. The first, F_{bo}, is calculated using the equation for blowout capacity from DeVries (DeVries, 1996). The blowout capacity predicted by the equation: $F_{bo} = 0.017C_1\sqrt{A_n f'_c}$ where C_1 is the clear cover, C_c, plus one-half bar diameter, d_b, $(C_c + {}^{d_b}/_2)$ and A_n is the net bearing area of the head.

The second predicted capacity, F_{hd}, is based on Equation D-16 in ACI 318-11 – the equation for blowout capacity of a headed anchor. Equation D-16 is: $F_{hd} = 160C_1\sqrt{A_{brg} f'_c}$ where C_1 is the clear cover, C_c, plus one-half bar diameter, d_b, $(C_c + {}^{d_b}/_2)$ and A_{brg} is the net bearing area of the head. Equation D-16 is written in US units of pounds and inches. Both equations for F_{bo} and F_{hd} represent capacity due to only bearing against the head and do not include any additional capacity from bonded length. Both equations for F_{bo} and F_{hd} predicted the reinforcing bar would reach the yield capacity except when the clear cover, C_c, was 25 mm (1.0 in.). Both equations for F_{bo} and F_{hd} underestimated the capacity for a large majority of the tests.

Table 4. Headed Bar Dimensions and Results

Specimen	Bar Type	l_b, mm (in.)	C_c, mm (in.)	A_{brg}/A_b	F_u, kN (k)	Failure Type	F_{bo}, kN (k)	F_u/F_{bo}	F_{hd}, kN (k)	F_u/F_{hd}
13	Headed	200 (8.0)	25 (1.0)	3.5	203 (45.6)	Blowout	155 (34.8)	1.31	124 (27.8)	1.64
14	Headed	400 (16.0)	25 (1.0)	3.5	238 (53.4)	Yield	155 (34.8)	-	124 (27.8)	-
15	Headed	200 (8.0)	50 (2.0)	3.5	242 (54.5)	Yield	258 (57.9)	-	206 (46.4)	-
16	Headed	400 (16.0)	50 (2.0)	3.5	203 (45.6)	Yield	258 (57.9)	-	206 (46.4)	-
17	Headed	200 (8.0)	25 (1.0)	6.0	229 (51.4)	Blowout	202 (45.5)	1.13	162 (36.5)	1.41
18	Headed	400 (16.0)	25 (1.0)	6.0	234 (52.6)	Blowout	202 (45.5)	1.16	162 (36.5)	1.44
19	Headed	200 (8.0)	50 (2.0)	6.0	205 (46.0)	Yield	337 (75.8)	-	270 (60.8)	-
20	Headed	400 (16.0)	50 (2.0)	6.0	203 (45.7)	Yield	337 (75.8)	-	270 (60.8)	-
21	Headed	200 (8.0)	25 (1.0)	9.0	215 (48.3)	Blowout	248 (55.7)	0.87	199 (44.7)	1.08
22	Headed	400 (16.0)	25 (1.0)	9.0	234 (52.7)	Yield	248 (55.7)	-	199 (44.7)	-
23	Headed	200 (8.0)	50 (2.0)	9.0	251 (56.4)	Yield	413 (92.9)	-	331 (74.4)	-
24	Headed	400 (16.0)	50 (2.0)	9.0	209 (47.0)	Yield	413 (92.9)	-	331 (74.4)	-

Distribution of Load

By placing a strain gauge on the bars at the head or start of the hook, the strain in the bar at the end was measured and the stress and force in the bar at that location was calculated. Cutting a free body diagram at the strain gauge shows the force in the bar at this location is the bearing force at the head or hook. Subtracting the bearing force from the applied load results in the force being carried by bond. The distribution of load between bearing and bond for typical tests is shown in Figures 3 through 7.

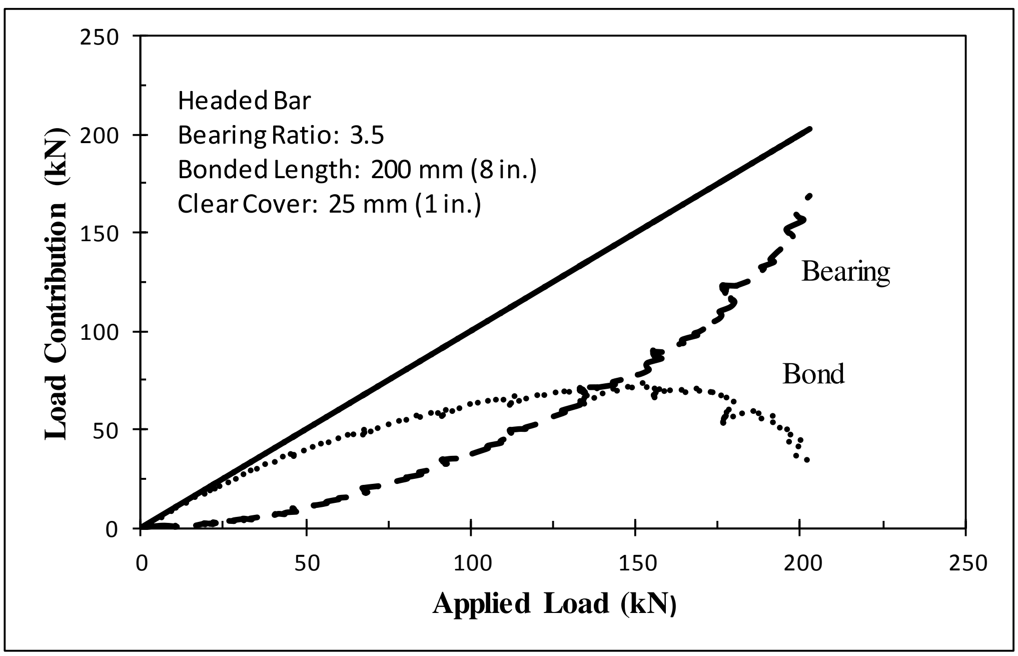

Figure 3. Load Distribution

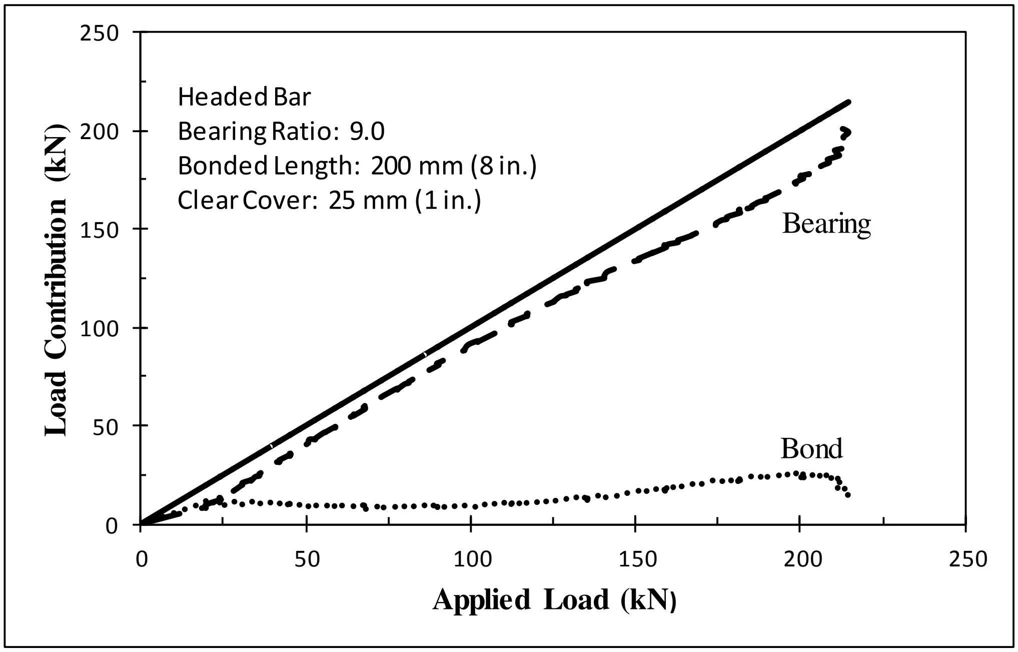

Figure 4. Load Distribution

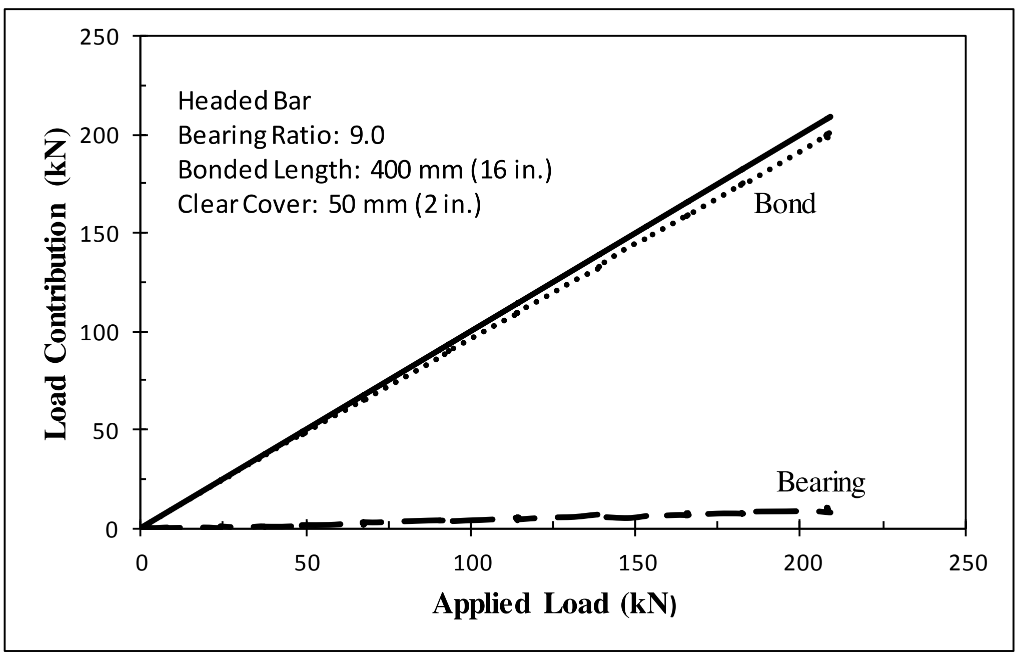

Figure 5. Load Distribution

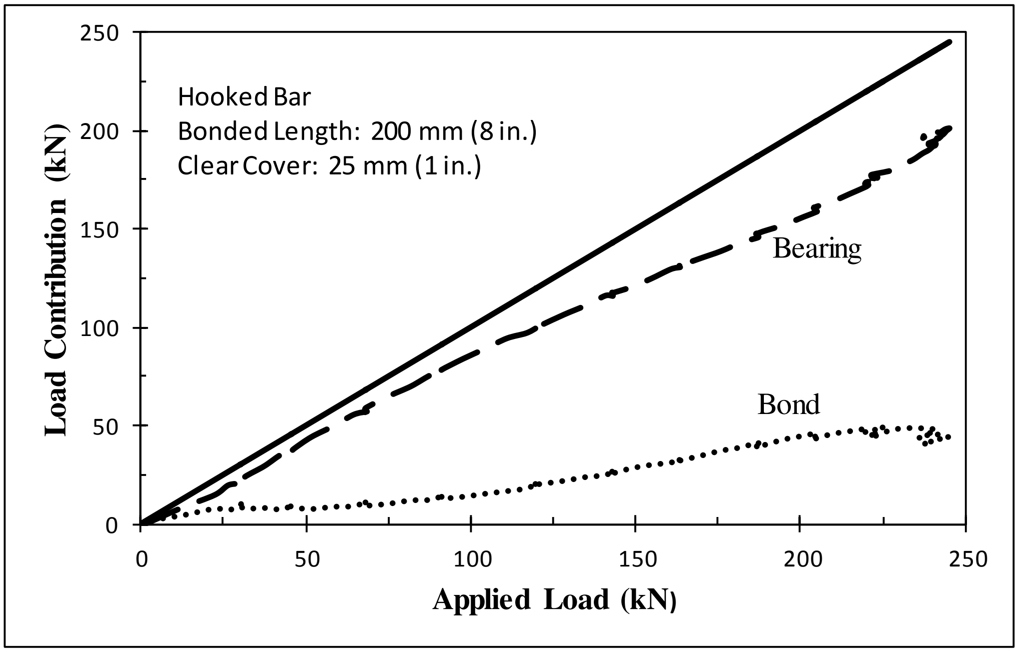

Figure 6. Load Distribution

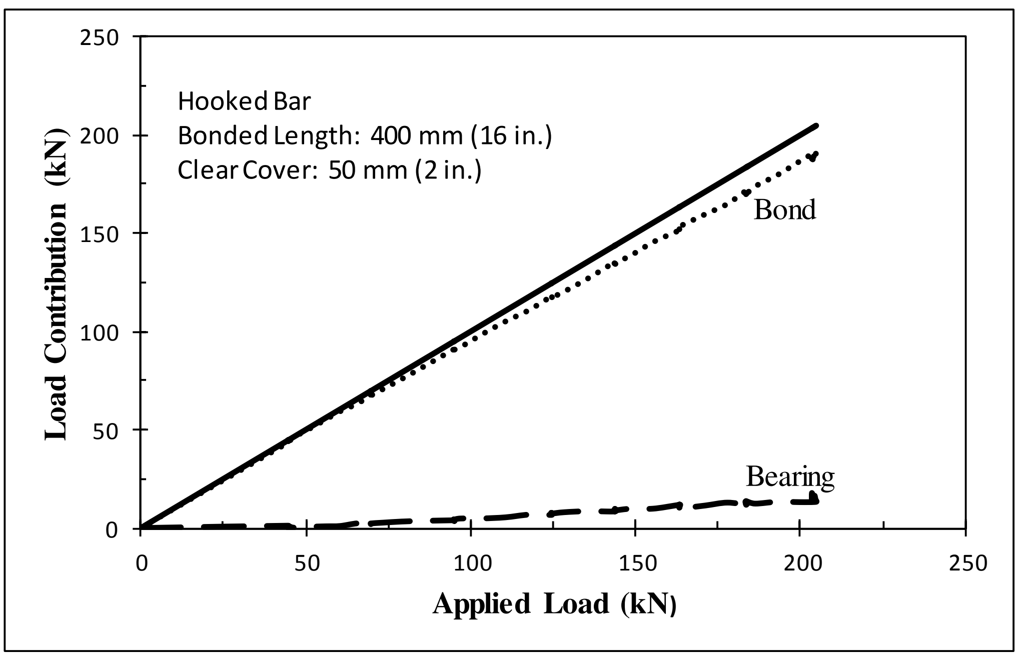

Figure 7. Load Distribution

The distribution of force between bond and bearing followed the same pattern for all tests. At low loads, bond would carry the majority of the load. As the load increased bond would continue to carry the majority of load if the bonded length was 400 mm (16 in.). For bonded lengths of 200 mm (8 in.), bearing would take over carrying the majority of the load as the load increased.

The percentages of load carried by bearing and bond when the applied load was 190 kN (43 kips), approximately 95% of the yield force of the bar, are listed in Table 5 for all 18 tests. Again, the basic pattern of bond carrying the majority of the load when the bonded length is 400 mm (16 in.) and bearing carrying the majority when the bonded length is 200 mm (8 in.) is followed for all tests.

Table 5. Percentage of Load at 190 kN (43 kips)

Specimen	Bar Type	l_b, mm (in.)	C_c, mm (in.)	A_{brg}/A_b	% Bearing	% Bond
7	Hooked	200 (8.0)	25 (1.0)	-	79%	21%
8	Hooked	300 (12.0)	25 (1.0)	-	42%	58%
9	Hooked	400 (16.0)	25 (1.0)	-	21%	79%
10	Hooked	200 (8.0)	50 (2.0)	-	62%	38%
11	Hooked	300 (12.0)	50 (2.0)	-	37%	63%
12	Hooked	400 (16.0)	50 (2.0)	-	7%	93%
13	Headed	200 (8.0)	25 (1.0)	3.5	61%	39%
14	Headed	400 (16.0)	25 (1.0)	3.5	8%	92%
15	Headed	200 (8.0)	50 (2.0)	3.5	62%	38%
16	Headed	400 (16.0)	50 (2.0)	3.5	4%	96%
17	Headed	200 (8.0)	25 (1.0)	6.0	72%	28%
18	Headed	400 (16.0)	25 (1.0)	6.0	17%	83%
19	Headed	200 (8.0)	50 (2.0)	6.0	63%	37%
20	Headed	400 (16.0)	50 (2.0)	6.0	3%	97%
21	Headed	200 (8.0)	25 (1.0)	9.0	79%	21%
22	Headed	400 (16.0)	25 (1.0)	9.0	7%	93%
23	Headed	200 (8.0)	50 (2.0)	9.0	57%	43%
24	Headed	400 (16.0)	50 (2.0)	9.0	4%	96%

CONCLUSION

Based on testing results, the assumption that force in reinforcing bars is resisted by a constant ratio between bond and bearing is incorrect. Instead, at low loads bond carries the majority of load and the portion carried by bearing increases as the load increases. The amount of increase in portion carried by bearing is dependent on the bond capacity. If the bonded length (straight bar development length) capacity is approximately the yield capacity of the bar then little to no load will be carried by bearing. If the bonded length capacity is lower then bearing will carry the majority of the load. In general the portion of load carried by bearing for hooked bars is lower than for headed bars. Given the difficulty of determining when the bonded length capacity is sufficient to carry the majority of load, it is recommend for design of anchorages using headed bars to ignore any additional capacity from bonded length and design and detail the head to carry the entire bar force.

REFERENCES

American Concrete Institute (ACI). 2011. Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary. ACI 318-11. Farmington Hills, Michigan: American Concrete Institute.

Blau, Andrew M. June 2010. "Head and Bond Contributions to Anchorage of a Headed Reinforcing Bar." Master's thesis, Milwaukee School of Engineering.

Bolda, Jacob. 2010. Untitled Capstone Report in Progress about Straight and Hooked Reinforcing Bars. Master’s thesis, Milwaukee School of Engineering.

DeVries, Richard A. December 1996. “Anchorage of Headed Reinforcement in Concrete.” Ph.D., University of Texas at Austin.

Marques, Jose L.G., and J.O. Jirsa. May 1975. "A Study of Hooked Bar Anchorages in Beam-Column Joints." ACI Journal Vol. 72(5), pp. 198-209.

Orangun, C.O., J.O. Jirsa, and J.E. Breen. March 1977. "A Reevaluation of Test Data on Development Length and Splices." ACI Journal Vol. 74(3), pp. 114-122.

Analysis of a Fixed Passive Louver Shading Device

S. W. Baur, Ph.D.[1]; and C. J. Brennan[2]

[1]Department of Civil, Architectural, and Environmental Engineering, Missouri University of Science and Technology, 1401 Pine Street, Rolla, MO 65409. E-mail: baur@mst.edu

[2]Department of Civil, Architectural, and Environmental Engineering, Missouri University of Science and Technology, 1401 Pine Street, Rolla, MO 65409. E-mail: cjbdm3@mst.edu

Abstract

This research has implemented simulation modeling software, Energy Plus, to predict the effect of passive louver shades across a standard year on a home within the Midwest. This energy model of the building has been validated against actual experimental data, over the course of six months. This research optimized a passive louver shading array, unique to this latitude, by generating converging simulations to track energy demands of the heating and cooling systems of the home. The optimized array characteristics are derived from the minimization of the overall energy performance of these systems. Based on a proposed louver configuration a reduction of 17% in overall energy consumption was predicted when compared to a similar house model without a louver array. A Louver Configuration Input Program was developed to allow a user to input continuous values within the range of variable and be output an estimate of energy loading.

INTRODUCTION

Passive solar shading techniques are not a new concept, and in many ways are reemerging across many architecture styles. Passive architecture and the concept of solar shading have been in existence since the earliest days of recorded architecture. Elements of passive architecture and light and heat control techniques can be seen in most historical designs (Lechner, 1991), throughout many regions of the world including: Ancient Greece, utilizing shading colonnades, as well as indigenous American as seen in Fig. 1, mainly of the Southwest region. Many of these societies used passive architecture did so to remedy the extensive heat load of the building, before any kind of cooling systems had been developed.

A louver shading system affects many of the interior environmental systems of a building including heating, cooling, and lighting systems. A louver array, or a patterned series of louvers, can be built into a structure's façade, acting on the main purpose to reduce solar energy entering the space. In many cases, louvers are placed in front of fenestration or glazed surfaces to maximize its affect.