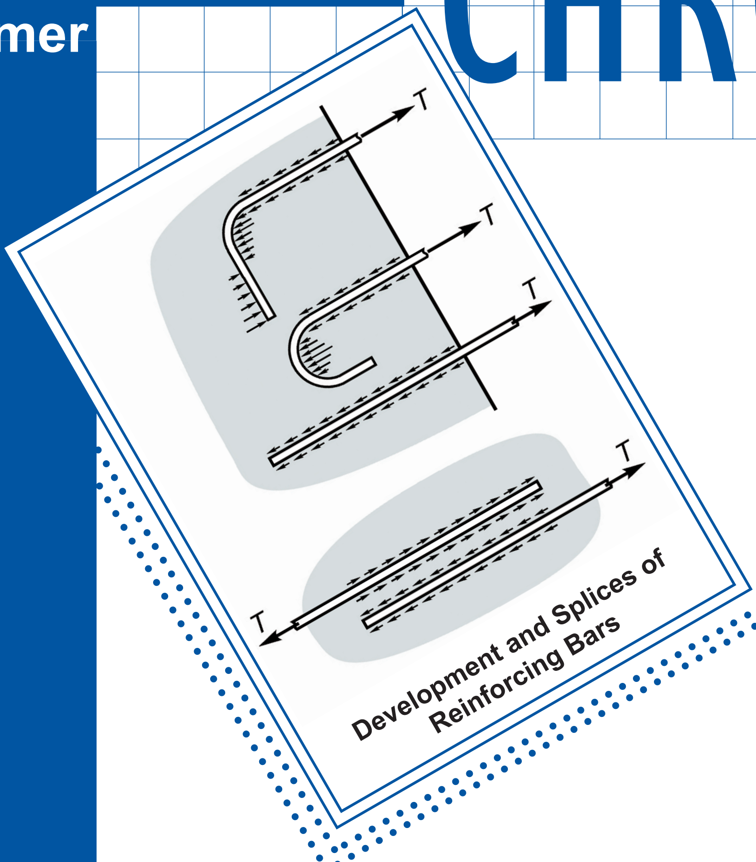
Engineering Notes For Design With Concrete Block Masonry

MASONRY CHRONICLES

Summer 2008



Reinforcement Development and Lap Splices in Reinforced Concrete Masonry

Introduction

Reinforced concrete masonry is designed to behave as a composite material made up of concrete masonry units, grout and steel reinforcement. For this to occur, the bond between the reinforcement and grout must be capable of transferring stresses between the two materials. Figure 1 shows the stresses in a straight reinforcing bar embedded in masonry. In Figure 1 it can be assumed that the bond stress between the grout and reinforcement is uniform along its length. Therefore, the force that can be developed is proportional to the depth of embedment or development length of the reinforcing bar. In hooked bars, the development length also determines the force that can be transferred. However, the presence of a hook means that more force can be transferred over a shorter length since bearing stresses also contribute to the resistance of load, as shown in Figure 2. If the development length is not sufficient to transfer the applied forces, reinforcing bars will pull out of the masonry, and this could result in failure of the structure. To prevent this from occurring, an adequate development length, which is the distance over which the steel stresses are transferred to the masonry, must be provided.

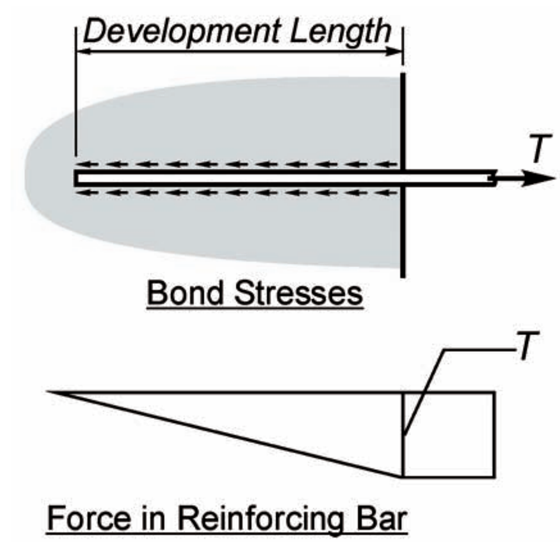


Figure 1: Bond Stresses and Development Length in Straight Bars

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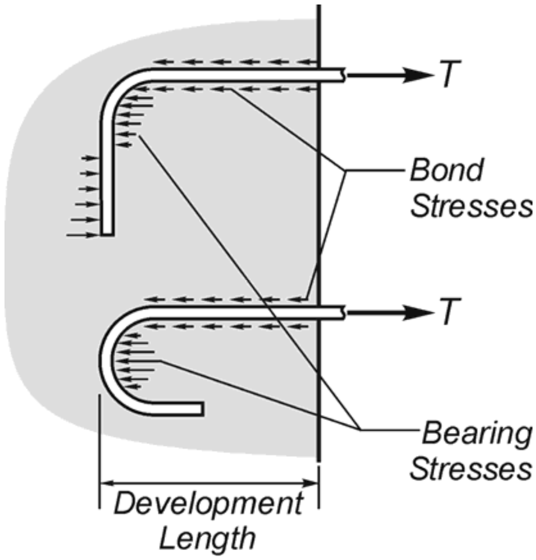

Figure 2: Development of Hooked bars

The limits on the length of a reinforcing steel bar that can be stored, transported, or constructed efficiently means that reinforcement is rarely placed in structures without splicing. For example, the vertical reinforcement in concrete masonry walls typically does not extend continuously from the foundation to the roof and needs to be spliced at some point along the wall height. Splicing is typically achieved by lapping the reinforcing bars as shown in Figure 3. While welded or mechanical splices may also be used, construction constraints make lap splices the most common form of splice used in concrete masonry. In a lap splice, the force is transferred from one bar to the grout and then from the grout to the other bar utilizing a mechanism similar to that shown in Figure 1. To ensure that a concrete masonry structure performs as designed, adequate lap splice lengths over which steel forces can be transferred from one reinforcing bar to the next must be provided.

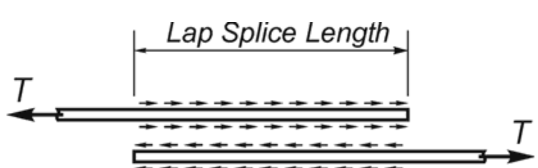

Figure 3: Reinforcement Lap Splice

The 2006 International Building Code (2006 IBC) [1] requirements for development and lap splice lengths in masonry structures are different depending on whether allowable stress design on strength design procedures are used. This can be confusing since ACI 530-05, *Building Code Requirements for Masonry Structures*, which is also referred to as the 2005 Masonry Standards Joint Committee (2005 MSJC) Code [2] and is referenced by the 2006 IBC, contains similar requirements for both design procedures

Nomenclature

The nomenclature in this article is as follows:

d_b	=	bar diameter
f'_m	=	specified masonry compressive strength
f_s	=	computed stress in reinforcement
F_s	=	Allowable stress in reinforcement
f_y	=	specified steel yield strength
l_d	=	required development length
l_e	=	equivalent development length
l_{de}	=	unfactored development length
K	=	least of cover or clear spacing between adjacent bars
ϕ	=	strength reduction factor
γ	=	reinforcement size factor

2005 MSJC Requirements

The MSJC code contains identical requirements for the minimum development length of reinforcing bars when using allowable stress design or strength design procedures. MSJC Sections 2.1.10.3 and 3.3.3.3 provide the requirements for allowable stress and strength design, respectively. All straight reinforcing bars must extend from the point of maximum moment in either direction for a distance no less than the development length, l_d, which is given by the following equation:

$$l_d = \frac{0.13 d_b^2 f_y \gamma}{K\sqrt{f'_m}} \geq 12 \text{ in}$$

Note that there is no upper limit on the required development length. Bar development failures usually occur due to cracks on the surface of the masonry between or adjacent to reinforcement. Thus, the factor K is introduced to account for the fact that development length is dependent on the spacing between bars or the masonry cover. The value of K shall not exceed the smaller of the masonry cover, the clear spacing between bars, or 5 bar diameters.

The reinforcement factor, γ takes into consideration the fact that larger bars require relatively longer development lengths. They are outlined in the code as follows:

γ = 1.0 for #3 through #5 bars

γ = 1.3 for #6 through #7 bars

γ = 1.5 for No. #8 through #11 bars

For epoxy coated bars, development lengths shall be increased by 50 percent.

The MSJC also requires that the reinforcement shall extend beyond the point at which it is no longer required a distance equal to the effective depth of the member or $12d_b$, whichever is greater. However, this requirement does not apply at the supports of simple spans and at the free end of cantilevers.

The dimensions for standard 180-degree and 90-degree hooks are shown in Figure 4. Standard stirrup and tie anchorage hooks require a 90-degree or 135-degree bend plus an extension of at least 6 bar diameters. For standard hooks in tension, different values are provided for allowable stress and strength design. Under allowable stress design, a standard hook is equivalent to an embedment length, l_e, of 11.25 bar diameters (Section 2.1.10.5). This means that the required development can be reduced by the above amount if there is a hook at the end of a bar.

For strength design, an embedment length of 13 bar diameters, measured from the start of the hook, can be assumed to develop a bar in tension (Section 3.3.3.2). The effect of hooks must be neglected for bars in compression.

Single leg or U-stirrups, which are used to resist shear, must be adequately anchored. As shown in Figure 5, single leg and U-stirrups must be anchored by a standard hook plus a minimum embedment length of $0.5l_d$. The embedment length is measured from the start of the hook to the mid-depth of the member. For #5 bars and smaller, anchorage may be provided by a 135-degree hook around longitudinal reinforcement plus an embedment length of $0.33l_d$.

At the end of shear walls, horizontal reinforcement used to resist shear must be bent around vertical reinforcement with a 180-degree hook. At wall intersections, horizontal shear reinforcement must be bent around the edge vertical reinforcing with a 90-degree standard hook and extend horizontally into the intersecting wall a for a length equal to or greater than the development length l_d. Figure 6 illustrates the required anchorage of horizontal reinforcement at wall ends and intersections.

#3	4.5 in
#4	6.0 in
#5	7.5 in
#6	9.0 in
#7	10.5 in
#8	12.0 in

	Grade 40	Grade 60
#3	2.0 in	$2\frac{1}{4}$ in
#4	2.5 in	3.0 in
#5	$3\frac{1}{8}$ in	$3\frac{3}{4}$ in
#6	$3\frac{3}{4}$ in	4.5 in
#7	$4\frac{3}{8}$ in	$5\frac{1}{4}$ in
#8	5.0 in	6.0 in

#3	2.5 in
#4	2.5 in
#5	2.5 in
#6	3.0 in
#7	3.5 in
#8	4.0 in

Figure 4: Standard Hooks in Masonry Construction

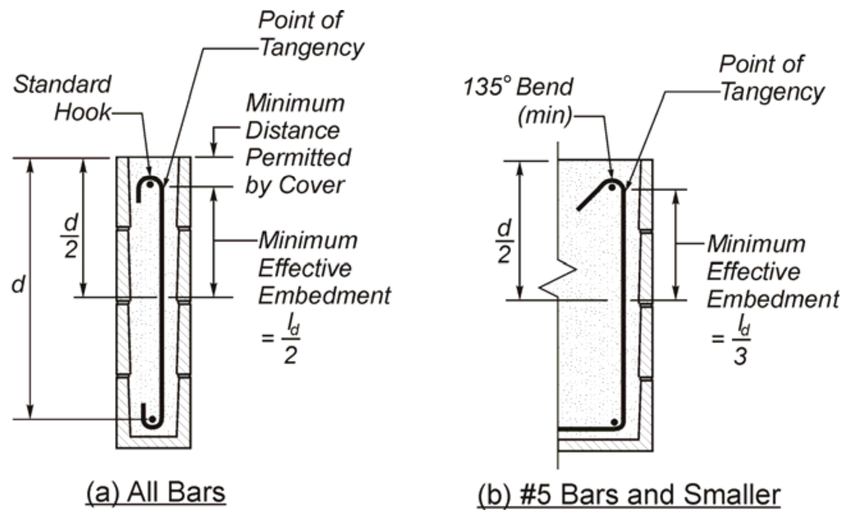

Figure 5: Anchorage of Standard Hooks in Masonry Construction

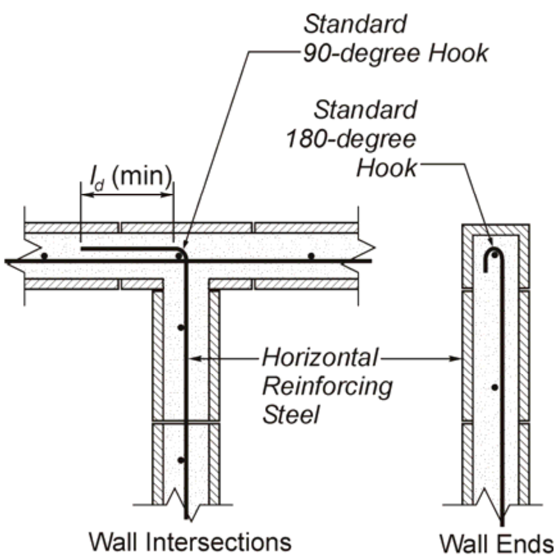

Figure 6: Anchorage of Shear Reinforcement at Wall Ends and Intersections

Lap splice lengths for allowable stress and strength design are calculated using the same equation used for reinforcing bar development (Section 2.1.10.7.1 and Section 3.3.3.4, for allowable stress design and strength design, respectively). The development and lap splice length shall not be less than 12 inches. Section 3.3.3.4 of the MSJC code also stipulates that welded and mechanical splices must be capable of developing 125 percent of the yield strength, f_y of the reinforcing bar in tension or compression.

Non-contact lap splices should not be spliced further apart that one-fifth the required lap length or 8 inches. This means that in a typical concrete masonry wall, bars may be placed in adjacent cells.

2006 International Building Code Requirements

The 2006 IBC makes some adjustments to the lap splice lengths prescribed in the 2005 MSJC for allowable stress design and strength design. Different requirements are given for allowable stress design and strength design. In Section 2107.5 of the IBC, the equation for the minimum lap splice length using allowable stress design is:

$$l_d = 0.002 d_b f_s \leq 12 \ inches$$

The length of a lap splice should also not be less than 40 bar diameters. The above equation is identical to the equation used in the 1997 Uniform Building Code (1997 UBC) [3] for allowable stress design. When design tensile stresses are greater than 80 percent of the allowable steel stresses, the lap splice is to be increased by a minimum of 50 percent. It should be noted that while the 2006 IBC modifications only refer to lap splices, it is logical to assume that they also apply to the development length of reinforcing bars.

For strength design, the 2006 IBC modifies 2005 MSJC Equation (3-15):

$$l_d = \frac{0.13 d_b^2 f_y \gamma}{K\sqrt{f'_m}} \leq 72 d_b$$

The minimum development length of 12 inches still applies. However, the development length need not exceed 72 bar diameters, a limit that is not contained in the 2005 MSJC. The 72 bar diameter limit can also be applied to lap splices.

Conclusions

Table 1 shows the calculated lap splice lengths for reinforcing bars with cover greater that 5 bar diameters for typical concrete masonry material strengths. The splice lengths required for allowable strength design using the 2006 IBC are calculated assuming the steel stress is equal to the allowable stress of 24,000 psi, an approach commonly used to simplify the calculations. Note that if a one third increase in allowable stresses is permitted, the required splice lengths would increase. In addition, if the calculated stress in the bar exceeds 80 percent of the allowable stress, the required splice lengths will need to be increased by 50 percent. For bars with sufficient cover, the IBC strength design requirements are identical to the MSJC requirements, since the required lap splice lengths are less than 72 bar diameters

Table 1: Lap Splice Lengths for Reinforcing Bars with Cover > 5d_b (f'_m =1500 psi, f_y = 60 ksi)

Bar Size	2005 MSJC (ASD and Strength Design)	2006 IBC (Allowable Stress Design)
#3	16” (40d_b)	18” (48d_b)
#4	21” (40d_b)	24” (48d_b)
#5	26” (40d_b)	30” (48d_b)
#6	40” (52d_b)	36” (48d_b)
#7	46” (52d_b)	42” (48d_b)
#8	61” (60d_b)	48” (48d_b)
#9	69” (60d_b)	55” (48d_b)

Table 1 shows that for smaller bars, the 2005 MSJC requirements (and 2006 IBC strength design requirements) result in smaller minimum splice lengths. However, the 2006 IBC requires smaller splice lengths when larger bars are used with allowable stress design. This is because the 2006 IBC allowable stress design procedures do not account for the fact that larger reinforcing bars require relatively longer splice lengths.

The differences in the various codes and procedures become more apparent when the cover to reinforcement is reduced. Figure 7 illustrates the required lap for reinforcing bars placed in the middle of an 8-inch thick concrete masonry wall. For #3 through #7 bars, lap splice lengths are longest using allowable stress design when the calculated stresses are greater than 0.8F_s. For #8 and #9 bars, the absence of an upper limit in the 2005 MSJC leads to larger lengths.

Figure 8 shows the lap splice lengths required when the cover to the reinforcing bars is equal to 2.5 inches. This condition could occur in a retaining wall, or a 12-inch wall with two layers of reinforcement. Figure 7 shows a dramatic increase in the lap lengths required by the MSJC due to the absence of an upper limit. For larger bars, the lengths cannot be easily constructed and are too long to be practical for most structures. The upper limit of 72 bar diameters provided in the 2006 IBC for strength design helps to alleviate this problem. However, the allowable stress design procedures in the 2006 IBC ignore the effect of cover and bar size on lap splice and development lengths.

It could be argued that the strength design procedures of the 2006 IBC are most reasonable since they consider the effect of bar size and cover, while providing practical lap and development lengths for all bar sizes. In addition, it is clear that engineers should endeavor to design with the smallest size of reinforcing bar possible, since lap splice development lengths can become quite long when larger reinforcing bars are used.

References

[1] International Code Council (ICC), 2006 International Building Code, International Code Council, Inc., Falls Church, Virginia, 2006.

[2] Masonry Standards Joint Committee (MSJC), Building Code Requirements for Masonry Structures (ACI 530.1-05/ASCE 6-05/TMS 602-05), Masonry Standards Joint Committee, Boulder, Colorado, 2005.

[3] International Conference of Building Officials (ICBO), 1997 Uniform Building Code, International Conference of Building Officials, Whittier, California, 1997.

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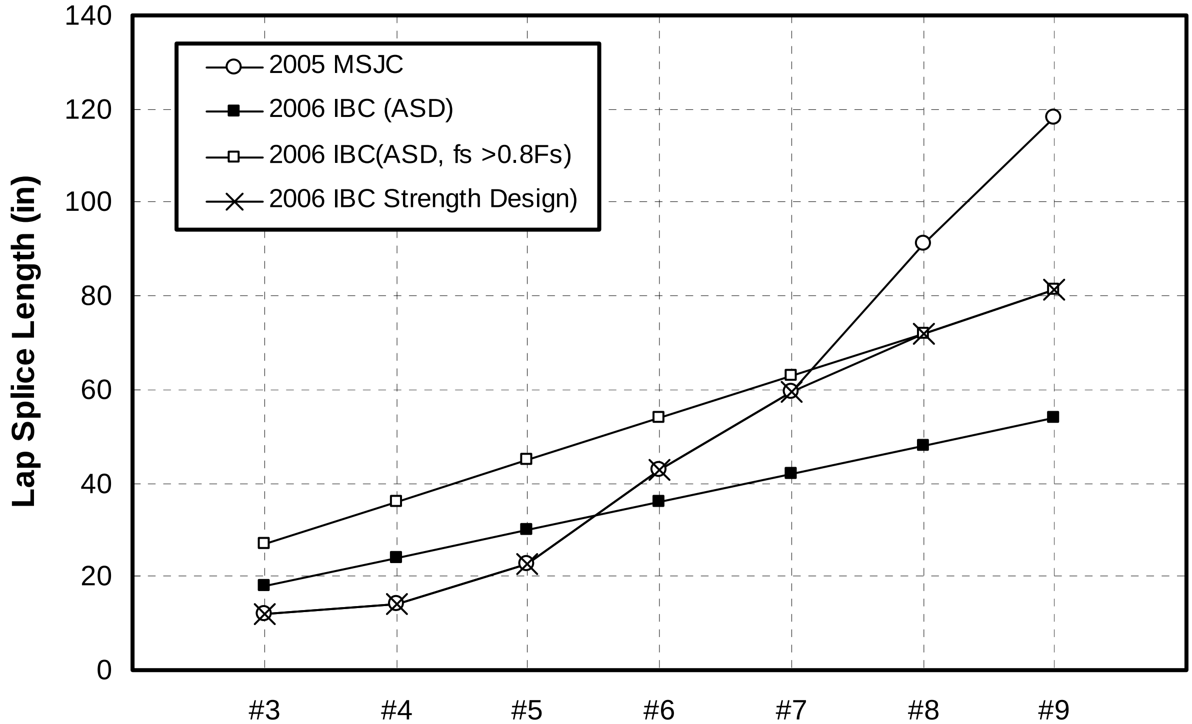

Figure 7: Lap Splice Length for Bars in the Middle of an 8" CMU Wall (Cover ~3.5 Inches)

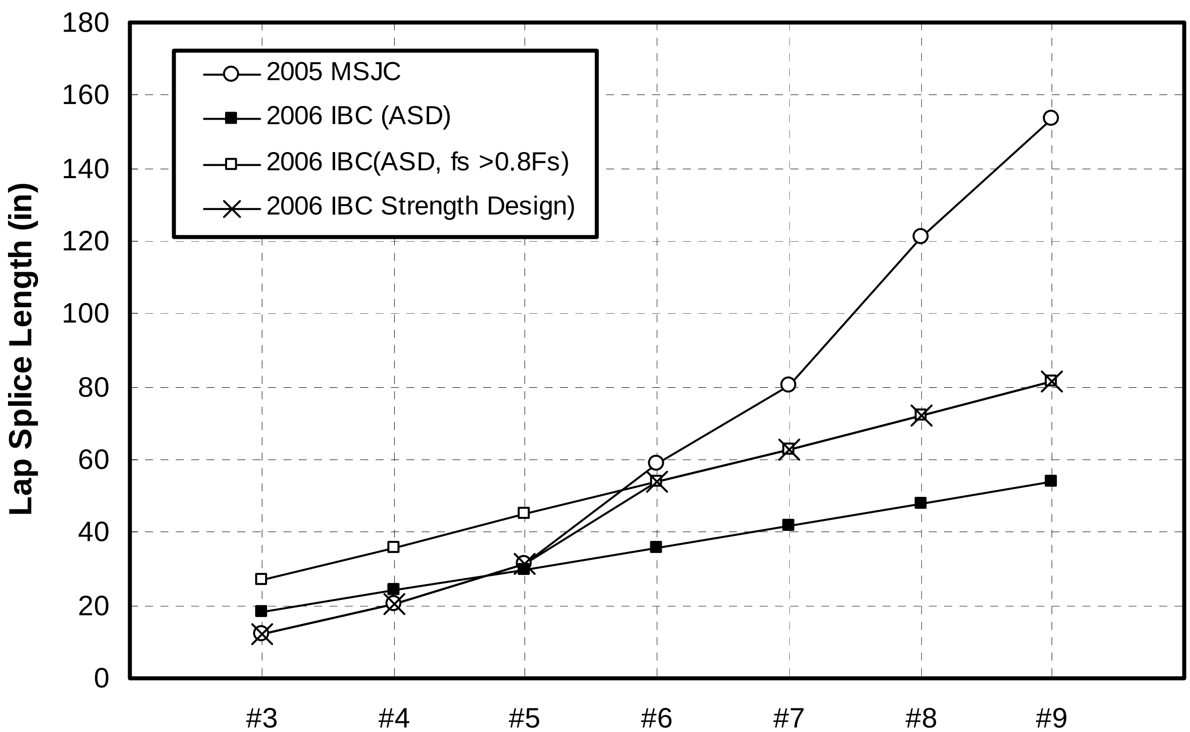

Figure 8: Lap Splice Lengths for Bars with a Cover of 2.5 Inches

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