CAP POCKET PIPE THICKNESS—
DERIVATION AND INFLUENCE OF DESIGN PARAMETERS

Cap Pocket Pipe Thickness–Derivation and Influence of Design Parameters

The following provides the derivations of the thickness of the steel pipe, t_{pipe}, for cap pocket connections. All variables are defined under Notation in the Final Report.

I. Derivation of t_{pipe} equations
   A. Derivation of general equation for t_{pipe}
   B. Derivation of simplified equation for t_{pipe} when the principal tension stress, p_t, in the joint is less than $0.11\sqrt{f_c'}$
   C. Derivation of simplified equation for t_{pipe} when the principal tension stress, p_t, in the joint is greater than or equal to $0.11\sqrt{f_c'}$

II. Influence of Design Parameters

I. Derivation of t_{pipe} equations

A. Derivation of General Equation for t_{pipe}

Setting the nominal confining hoop force in the cap pocket joint region, $F_{H_{CP}}$, greater than or equal to the nominal hoop force for a cast-in-place joint, F_H, solve for t_{pipe}:

$$F_{H_{CP}} = t_{pipe} H_p f_{yp} cos\theta$$

$$t_{pipe} H_p f_{yp} cos\theta \geq F_H$$

$$t_{pipe} \geq \frac{F_H}{H_p f_{yp} cos\theta} \qquad \text{Eq. A-1 (8.15.3.2.2-1)}$$

Per Equation A-1, t_{pipe} is also required to be 0.060 in. (16 gauge) or greater. This provides a reasonable minimum thickness that also matches the size used in test specimens.

B. Derivation of Simplified Equation for t_{pipe} (principal tension stress, p_t, in the joint less than $0.11\sqrt{f_c'}$)

From Eq. A-1:

$$t_{pipe} \geq \frac{F_H}{H_p f_{yp} cos\theta}$$

In which:

$$F_H = n_h A_{sp} f_{yh} \qquad \text{Eq. A-2 (8.15.3.2.2-2)}$$

Also:

$$n_h = \frac{H_p}{s} + 1$$

But n_h can be taken as:

$$n_h = \frac{H_p}{s} k \qquad \text{Eq. A-3}$$

Where:

$$k = equivalence\ factor$$

As shown in Figures A-1 through A-6, k can be conservatively taken as 1.40 as assumed. Note that $k = 1.40$ for Eqs. C8.15.3.2.2-1 and C8.15.3.2.2-2, based on a range of hoop sizes (#3 to #8), column diameters (24 in to 60 in), and area of column longitudinal reinforcement, relative to column area, A_{st}/A_{col} (0.01 to 0.02). This k value is more conservative as the diameter of the column increases. The average increase in required pipe thickness over the general equation is approximately 14% but varies from 5% to 33%.

Substituting Eq. A-2 and Eq. A-3 into Eq. A-1 gives:

$$t_{pipe} \geq \frac{F_H}{H_p f_{yp} cos\theta} = \frac{n_h A_{sp} f_{yh}}{H_p f_{yp} cos\theta} = \frac{\frac{H_p}{s} k A_{sp} f_{yh}}{H_p f_{yp} cos\theta}$$

$$t_{pipe} \geq \frac{\frac{A_{sp}}{s} k f_{yh}}{f_{yp} cos\theta} \qquad \text{Eq. A-4}$$

By definition:

$$\rho_s = \frac{4A_{sp}}{D's} \qquad \text{Eq. A-5}$$

For $p_t < 0.11\sqrt{f_c'}$:

$$\rho_s \geq \frac{0.11\sqrt{f_c'}}{f_{yh}} \qquad \text{Eq. A-6 (8.15.3.1-1)}$$

Solving Eq. A-5 and A-6 for $\frac{A_{sp}}{s}$, gives

$$\frac{A_{sp}}{s} = \frac{0.11\sqrt{f_c{}'}D'}{4f_{yh}} \qquad \text{Eq. A-7}$$

Substituting $\frac{A_{sp}}{s}$ from Eq. A-7 into Eq. A-4 and using $k = 1.40$ gives:

$$t_{pipe} \geq \frac{\frac{A_{sp}}{s}kf_{yh}}{f_{yp}cos\theta} = \frac{\frac{0.11\sqrt{f_c{}'}D'}{4f_{yh}}kf_{yh}}{f_{yp}cos\theta} = \frac{\frac{0.0385\sqrt{f_c{}'}D'}{f_{yh}}f_{yh}}{f_{yp}cos\theta}$$

$$t_{pipe} \geq \frac{0.04\sqrt{f_c{}'}D'}{f_{yp}cos\theta} \qquad \text{Eq. A-8}$$

(C8.15.3.2.2-1)

C. Derivation of Simplified Equation for t_{pipe} (principal tension stress, p_t, in the joint greater than or equal to $0.11\sqrt{f'_c}$)

From Eq. A-4:

$$t_{pipe} \geq \frac{\frac{A_{sp}}{s}kf_{yh}}{f_{yp}cos\theta}$$

For $p_t \geq 0.11\sqrt{f'_c}$:

$$\rho_s \geq \frac{0.40A_{st}}{l_{ac}{}^2} \qquad \text{Eq. A-9}$$

(8.15.3.1-2)

Solving Eq. A-5 and A-9 for $\frac{A_{sp}}{s}$:

$$\frac{A_{sp}}{s} = \frac{0.40A_{st}D'}{4l_{ac}{}^2} \qquad \text{Eq. A-10}$$

Plugging in Eq. A-10 and $k = 1.40$ into Eq. A-4 gives:

$$t_{pipe} \geq \frac{\frac{A_{sp}}{s}kf_{yh}}{f_{yp}cos\theta} = \frac{0.1A_{st}D'kf_{yh}}{l_{ac}{}^2f_{yp}cos\theta}$$

$$t_{pipe} \geq \frac{0.14A_{st}D'f_{yh}}{l_{ac}{}^2f_{yp}cos\theta} \qquad \text{Eq. A-11}$$

(C8.15.3.2.2-2)

Note: In practice, the larger pipe thickness based on Eq. A-8 and Eq. A-11 is used.

II. Influence of Design Parameters

Figures A-1, A-3, and A5 compare the pipe thickness required by Eq. 8.15.3.2.2-1, Eq. C8.15.3.2.2-1, and Eq. C8.15.3.2.2-2. Column diameters range from 24 in to 60 in, equivalent hoop sizes vary according to the column diameter, and the column is assumed to have a longitudinal steel ratio, A_{st}/A_{col}, or 0.015. These figures reveal: 1) using the general (more accurate) equation always results in the thinnest required pipe; 2) using the approximate equations (larger of the two) usually results in a pipe thickness one gage size larger than that required by the general equation, assuming gage sizes given in Table 3-2 of the Final Report; 3) a reasonable pipe thickness results in all cases; and 4) Eq. C8.15.3.2.2-1 governs over Eq. C8.15.3.2.2-2 for all but the largest column diameter (60 in).

Figures A-2, A-4, and A6 compare the pipe thickness for varying column longitudinal steel ratios, A_{st}/A_{col}, of 0.010, 0.015, and 0.020. The figures show the significant impact of A_{st}/A_{col} on required pipe thickness. It also shows that Eq. C8.15.3.2.2-2 results in thick gage pipes for larger columns, indicating that the designer may prefer to use the general equation in such conditions to minimize the required pipe size.

Figures A-2, A-4 and A-6 also show the change in pipe thickness for f_c' of 4000 psi, 6000 psi, and 8000 psi. The required pipe thickness increases approximately 10%-30% with f_c' based on Eqs. C8.15.3.2.2-1 and C8.15.3.2.2-2. For example, for a 36-in diameter column with #6 hoops (A_{st}/A_{col} =0.015), the pipe thickness increases 18% as f_c' increased from 4000 psi to 8000 psi. Eq. C8.15.3.2.2-1 results in a larger increase of 41% (proportional to $\sqrt{f_c'}$). Eq. C8.15.3.2.2-2 is not dependent on f_c'.

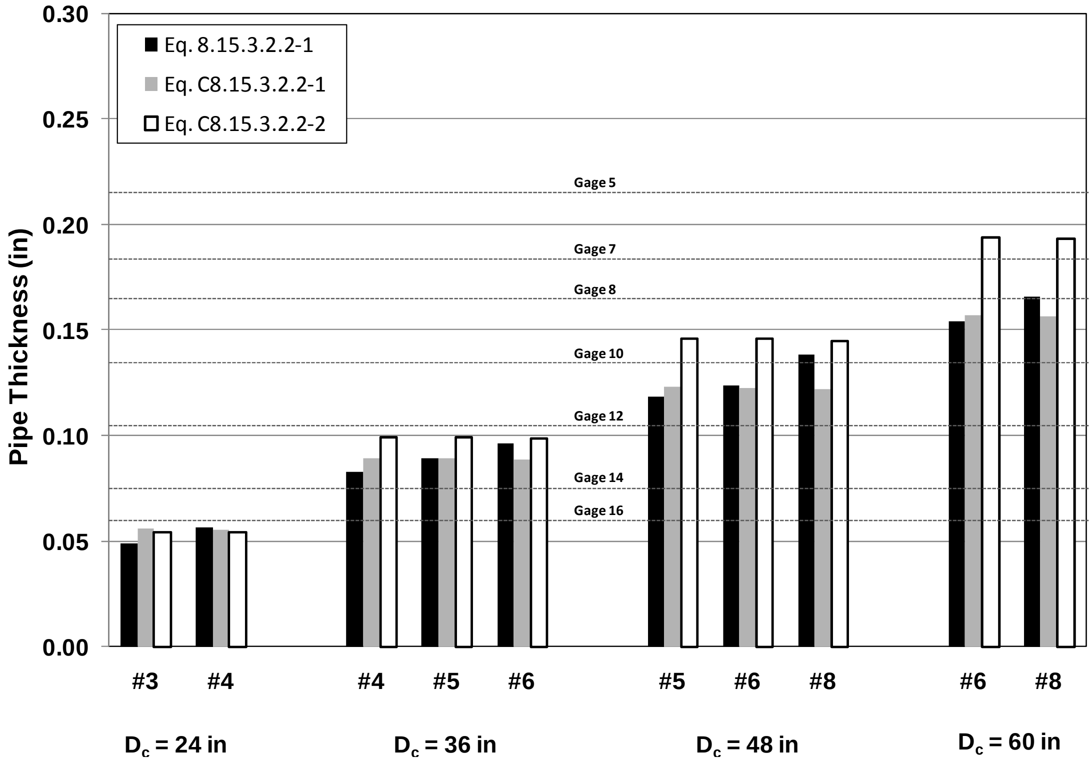

Figure A-1. Pipe Thickness vs. Column Diameters and Equivalent CIP Hoop Size (A_{st}/A_{col} = 0.015, f'_c = 4000 psi for bent cap)

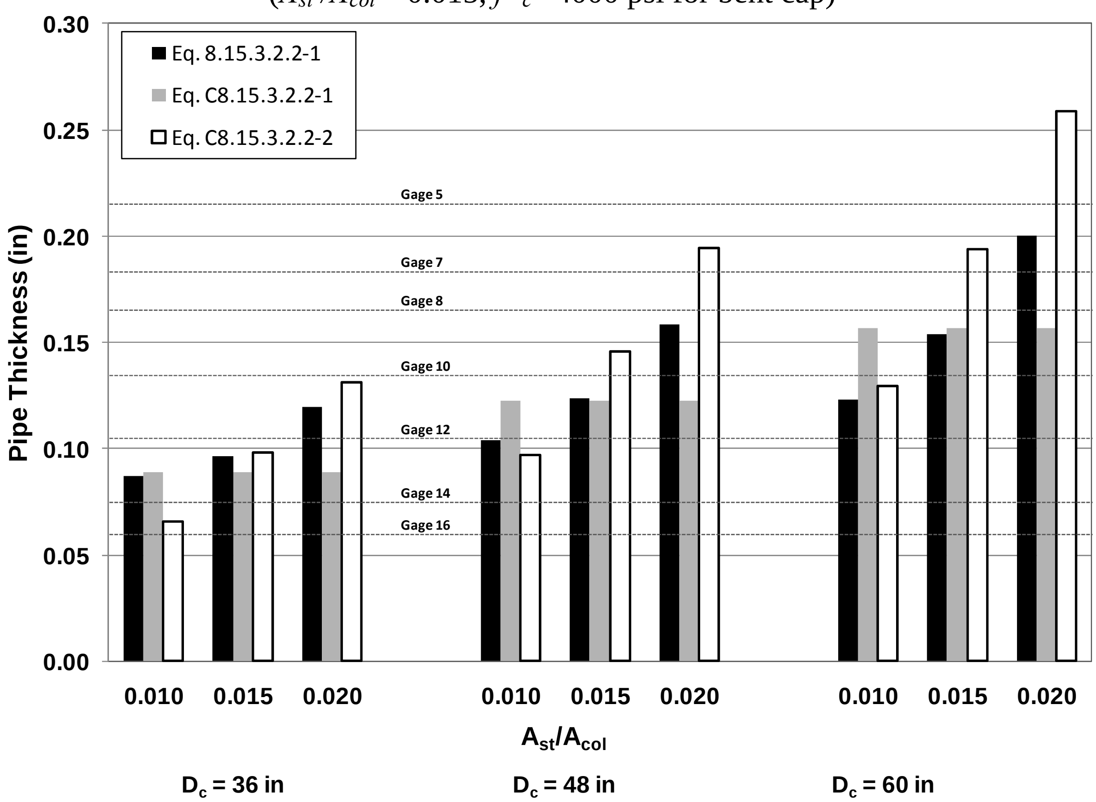

Figure A-2. Pipe Thickness vs. Column Diameter and Column Flexural Reinforcement Ratio (#6 Hoop, f'_c = 4000 psi for bent cap)

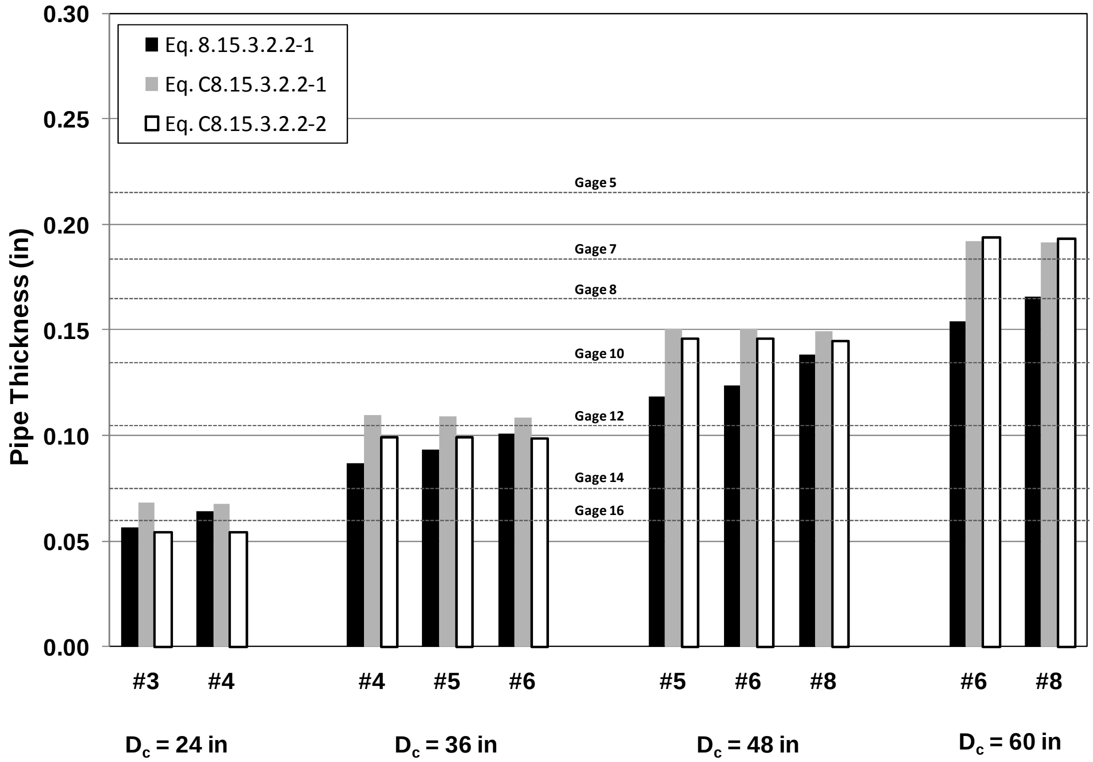

Figure A-3. Pipe Thickness vs. Column Diameters and Equivalent CIP Hoop Size (A_{st} / A_{col} = 0.015, f'_c = 6000 psi for bent cap)

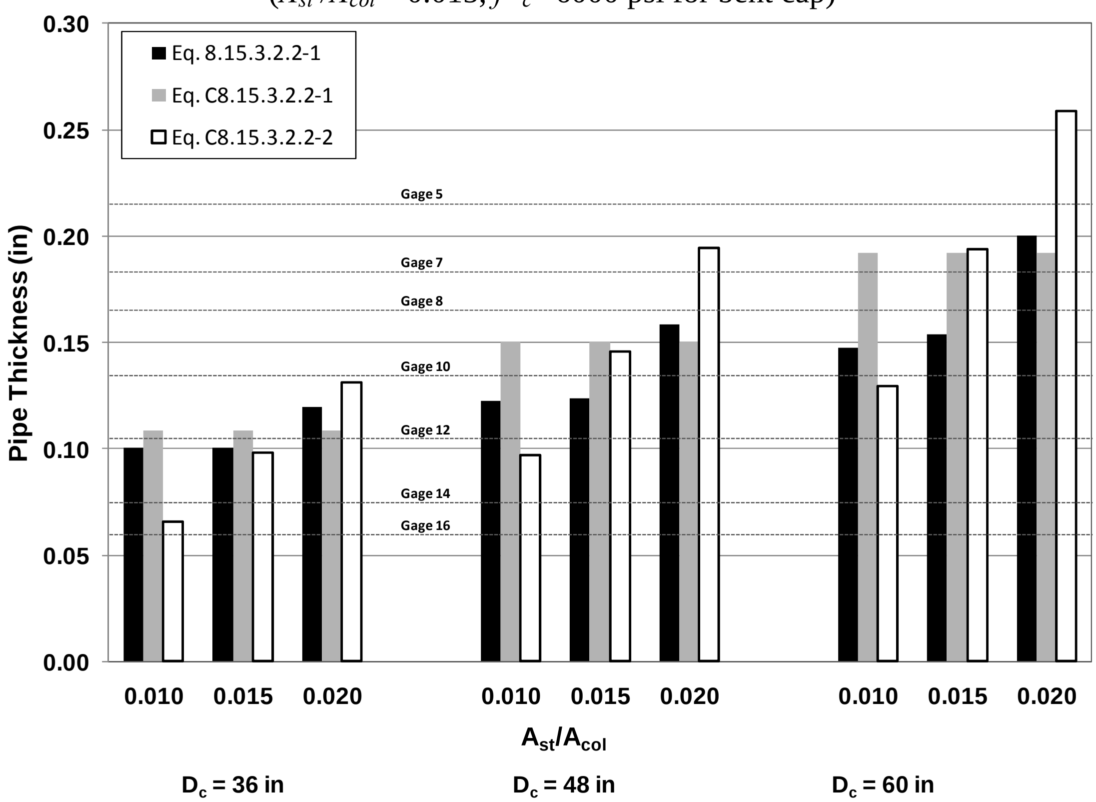

Figure A-4. Pipe Thickness vs. Column Diameter and Column Flexural Reinforcement Ratio (#6 Hoop, f'_c = 6000 psi for bent cap)

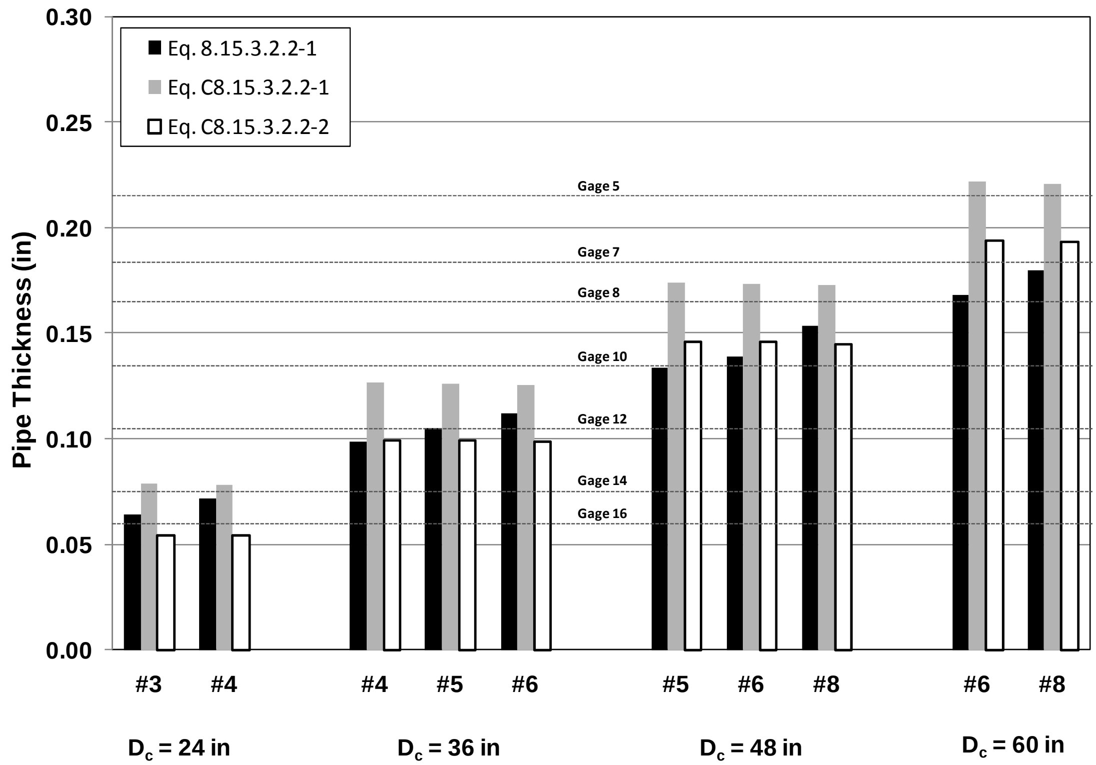

Figure A-5. Pipe Thickness vs. Column Diameters and Equivalent CIP Hoop Size
(A_{st} /A_{col} = 0.015, f'_c= 8000 psi for bent cap)

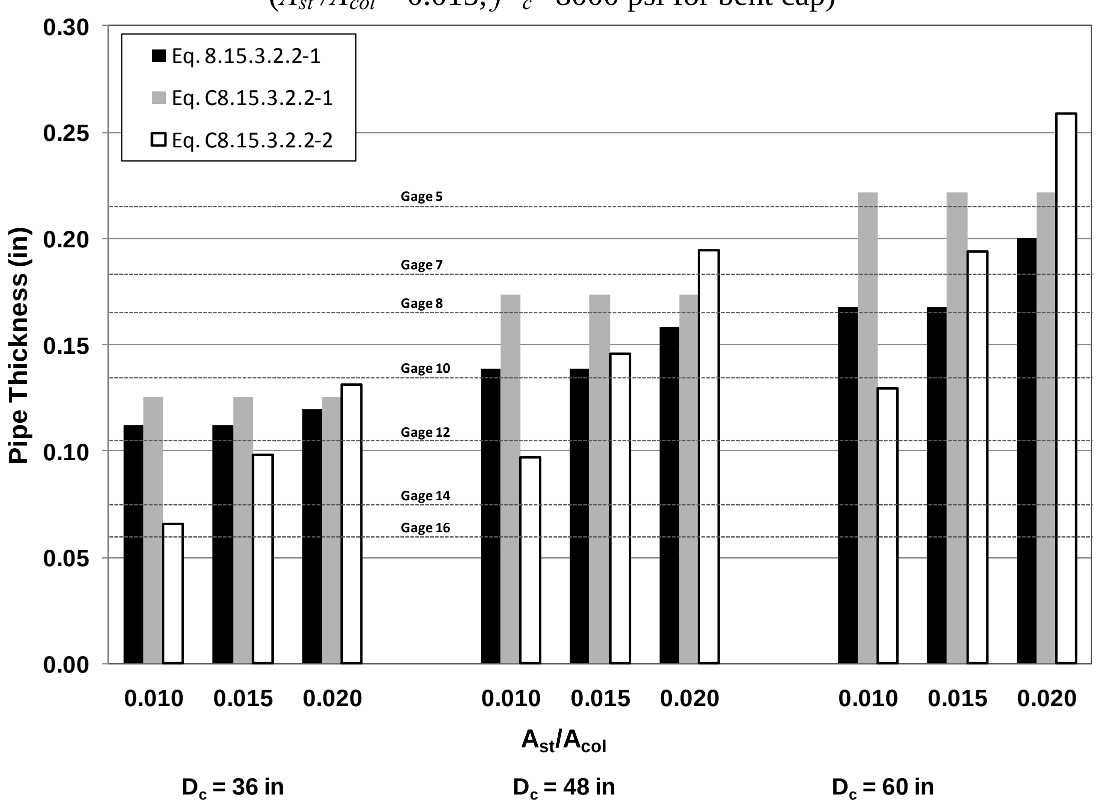

Figure A-6. Pipe Thickness vs. Column Diameter and Column Flexural Reinforcement Ratio
(#6 Hoop, f'_c= 8000 psi for bent cap)