Concrete Breakout Strength in Tension for Vertical Vessel Anchorage in Octagon Pedestals

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ABSTRACT

Vertical vessel anchorages present unique design considerations for engineers because of the nature of loading, the geometry of the anchorage, and the constraints of typical construction techniques. The nature of the loading is primarily tension due to transient lateral loads such as wind or earthquake. Vertical vessels that are set directly on a foundation are typically set on an octagon pedestal, which requires a different design procedure for calculating concrete breakout strength in tension for anchors than that of a square pedestal.

The updated ASCE "Design of Anchorage in Petrochemical Facilities" includes recommendations for calculating concrete breakout strength in tension of anchors in an octagon pedestal. Methods for calculating concrete breakout strength in tension should be practical, quick to perform, and follow the methods of current codes and standards. Several methods for determining the breakout capacity in tension of anchors within an octagon pedestal are presented, compared, and example problems are provided.

INTRODUCTION

A common foundation type in the petrochemical industry is an octagon pedestal used to support a vertical vessel, tower, or process column. These foundations typically have cast-in-place anchor bolts in a circular pattern. The updated ASCE Report *Design of Anchorage in Petrochemical Facilities* (ASCE 2010, proposed) provides guidelines for calculating concrete breakout strength in tension for anchorage in an octagon pedestal foundation.

The design of anchorage in a circular pattern should be approached differently than anchorage in a rectangular pattern, and complicating the matter is that the method for determining the concrete breakout strength of an anchor provided in ACI 318, Appendix D (ACI 2008) is derived from a rectangular pattern of anchors. In order to adapt this method for a circular pattern certain interpretations, modifications and adjustments should be made.

The following sections examine methods for calculating concrete breakout strength in tension for vertical vessel anchorage to octagon pedestals. Example problems of each method are presented and the results are compared.

Challenges of Calculating Concrete Breakout Strength in Tension for an Octagon Pedestal

Concrete breakout strength of an anchorage is significantly impacted by embedment depth, the edge distances and the center to center spacing of anchors. Industry practice for the determination of concrete breakout strength for new anchorage is generally based on ACI 318, Appendix D. The method of calculating concrete breakout strength for a group of anchors outlined in ACI 318, Appendix D was specifically derived for a rectangular pattern of anchors. Vertical vessel anchorage, however; is typically arranged in a circular pattern. Direct application of the ACI 318, Appendix D method to anchors in a circular pattern embedded in an octagon pedestal presents several challenges, such as the concept of perpendicular edge distances, and eccentric loading.

The concept of perpendicular edge distances cannot directly be applied to a circular anchor bolt pattern in an octagon pedestal, which is the method used within ACI 318, Appendix D to determine limits for the failure surface. Complicating matters is the ACI limit on the effective embedment, which states that if the perpendicular edge distance on three sides of the anchor group is less than the minimum (i.e., 1.5 h_{ef}, where h_{ef} is the effective embedment depth), then the embedment length is reduced by the largest edge distance divided by 1.5. If anchors are arranged in a circular pattern then rectangular failure planes do not directly apply.

Eccentricity of load presents another challenge; when vertical vessels are resisting lateral loads due to wind or earthquake there is varying tension in anchors that is balanced with compression on vessel base ring. Eccentricity on the tension anchor group should be calculated in order to apply the ACI 318, Appendix D method to determine concrete breakout strength.

Prior to the ACI 318, Appendix D Method vertical vessel anchorage was typically designed based on evaluating the anchor with the highest tension. The concrete breakout of a single anchor was considered by taking into account the area of the projected pullout cone that was not overlapped by adjacent anchors or edges. Neither the effect of eccentricity nor the effect of anchor group was considered.

A method is required that is aligned with ACI 318, Appendix D and adequately reflects the characteristics of anchors arranged in a circular pattern with varying tension on the bolts. In order to apply this method the tension force on all anchors in tension needs to be determined even though it is not needed for any other part of the foundation design. The method of calculation of concrete breakout strength should be simple and easy to apply due to the frequent nature of this calculation. An onerous and tedious method would bog down the practicing engineer and introduce more chances of errors.

Several methods were examined for calculating concrete breakout strength for a vertical vessel anchorage in an octagon pedestal foundation. Appendix 1 presents a comparison of all investigated methods in the form of graphs of unity check against different parameters. An Example Problem Statement common to all methods is given in Appendix 2. Examples of Methods 1, 2 and 3 are presented in Appendices 3, 4 and 5, respectively. The following sections outline each method that was evaluated.

METHOD 1: GROUP METHOD WITH SHIFTED NEUTRAL AXIS

This Method more closely follows the procedures presented in ACI 318, Appendix D because it looks at the capacity of the group reduced by the eccentricity. It then modifies the capacity of the group by A_{NC}/A_{NCO}. It is more tedious than the other methods because of the requirements to calculate the loads on all anchors in tension and calculate the eccentricity of the anchor group.

Unlike checking the steel capacity of an anchor N_{sa}, the factored tension load on each bolt should be calculated in order to use the Group Method to calculate the concrete breakout strength in tension. This adds significantly more work that might not otherwise be required. The tension on the bolts should be balanced out with the compression from the base ring of the vessel. The tension on each anchor can be found by considering compatibility of strain and the summation of forces about the neutral axis. The example problem in the Appendix provides a calculation of the anchor tensions by using the shifted neutral axis method as described by Brownell and Young in *Process Equipment Design*, Chapter 10 "Design of Supports for Vertical Vessels" (Brownell 1959). This method determines the location of the neutral axis within the octagon by an iterative process assuming a triangular distribution of compression from the base ring on the concrete.

The embedment depth, h_{ef}, is used in determining the concrete breakout strength in tension for this method. The effective embedment depth, h'_{ef}, is not used because the proximity to an edge on three sides is not part of the geometry. The geometry of the failure surface for a group of anchors in a circular pattern is in the shape of a partial doughnut. This area is determined by limiting inner circle with a diameter of the bolt circle minus 3 times h_{ef}, where 3 times h_{ef} cannot be larger than the bolt circle. The eccentricity of the equivalent tension force, e'_N, is determined as follows:

$e'_N = \Sigma M_{BLT} / \Sigma Tu$ **, where** ΣTu **= sum of the total tension force on anchors and**
$\Sigma M_{BLT} =$ **eccentric moment in anchor group**

The modification factor for eccentricity of load, on the anchor group, $\Psi_{ec,N}$, is determined using equation D-9 which requires the calculation of e'_N.

METHOD 2: SAW CUT METHOD WITH h'_{ef} with Neutral Axis at Center

This method follows the common industry practice of evaluating the breakout strength of a single anchor subjected to the highest tension and applies the ACI 318, Appendix D method as if there were saw cuts midway between anchors. It simplifies the design so that only the most heavily loaded anchor is being considered for the breakout strength. This is done by treating the lines midway between adjacent anchors as free edges and applying ACI 318, Appendix D for a single anchor. This method considers the effective embedment depth, h'_{ef} , in accordance with ACI 318, Appendix D, Section D.5.2.3, as if there were three sides with edge distances less than 1.5 h_{ef}. In this section of ACI 318 the effective embedment depth is limited to the greater of $C_{a,max}/1.5$.

The assumptions of the "Saw Cut" method allow the individual anchors to be treated as independent single anchors and significantly simplify the calculation because the focus of the calculation is on one anchor. Tension on the other anchors and Eccentricity of the anchor group do not have to be calculated.

The effective concrete failure area, $A_{NC,}$ is calculated for the most severely loaded anchor. The distance from the center of the anchor to the outside edge forms the edge distance, C_{a1}. C_{a2} and C_{a4} are formed by edge distances perpendicular to C_{a1} and bounded by the adjacent saw cut edges. The edge of the failure area from the centerline of the bolt towards the center of the octagon is limited by 1.5 h'_{ef} and is labeled C_{a3}. The modification factor for eccentricity of load on the anchor group, $\Psi_{\mathbf{ec,N}}$,is not required for a single anchor in the Saw Cut Method. In this method the neutral axis is assumed to be at the center.

METHOD 3: SAW CUT METHOD WITH h'_{ef} and Shifted Neutral Axis

This method is very similar to Method 2 with the exception that the location of the neutral axis is calculated as in Method 1. Method 3 does not make the simplifying assumption that the neutral axis is located in the center of the octagon.

METHOD 4: SAW CUT METHOD WITHOUT h'_{ef} and Neutral Axis at Center

This method for determining concrete breakout strength is very comparable to Method 2 with the exception of using the full embedment length, h_{ef} , which not only results in a larger embedment length but also changes the ratio of A_{nc}/A_{nco}. Method 4 does not reduce the embedment length to the effective embedment depth, h'_{ef}. In a similar manner to Method 2, this method provides a simplified design so that only one anchor is being considered in the breakout strength. This method assumes the neutral axis is located at the center of the octagon.

COMPARISON OF METHODS

Appendix 1 provides graphs of parameter studies using the three methods presented herein. Although Method 1: “Group Method” is the most similar to the ACI 318, Appendix D method, it is very laborious to implement and is not conducive to be a commonplace calculation method. Method 4: “Saw cut method without h'_{ef} with the Neutral Axis at Center ” is simpler than the “Group Method”, however; the results are too conservative to justify using in practice. The Method 2: “Saw Cut Method with h'_{ef} with Neutral Axis at Center” is also simpler than the “Group Method” and yields results that are very close or slightly more conservative than the “Group Method” in practical ranges of the parameters.

Figure 1 shows a graph of number of anchors verse unity check. The small upward bump in this graph for the saw cut methods at 28 anchors is due to the $\Psi_{ed,N}$ term which is effected by the transition from $C_{a,min}$ being governed by the outside edge, $C_{a1,}$ to half of the spacing between the anchor, C_{a2} and C_{a4}. In the Saw Cut with h'_{ef} the distance half way between the anchors is assumed to be an edge. It should be noted that vertical vessel anchors are always in multiples of four. This graph show that the results of Methods 1 and 3 are very similar and the results of Method 2 and 4 are more conservative.

Figure 2 shows a graph of embedment depth verse unity check where results of Method 3 are slightly above those of Method 1 in the lower range of embedment depths and Methods 2 and 4 have significantly higher unity ratios. The reason why the Group Method yields higher unity checks at embedment larger than 37 inches is because the ratio of A_{nc}/A_{nco} decreases at a rate faster than N_b increases with increasing embedment.

Figure 3 (Bolt Circle Diameter verse Unity Check) and Figure 4 (Edge Distance verse Unity Check) are parameter study graphs that yield similar results. It should be noted that the Saw Cut Method with h'_{ef} and neutral axis at the center has been shown to yield results with higher unity checks than the Group Method for the examples and parameters studied in this paper. The ultimate strengths and failure mechanisms of an anchorage in an octagon pedestal are not currently supported by experimental test data or numerical simulation.

SUMMARY

When assessing vertical vessel anchorage into an octagon pedestal, today's engineer has to adapt ACI 318, Appendix D methods to a geometry that stretches the limits of the method. Guidelines and methods for evaluating concrete breakout strength in tension for octagon pedestals are presented in this paper. From the comparison of Concrete breakout methods presented in Appendix 1, it is concluded that Method 2: "Saw Cut Method with h'_{ef} with neutral axis at the center" is the most efficient and safe method for calculating concrete breakout strength in tension for an octagon pedestal within the parameters studied in this paper. It is recommended that experimental testing and numerical simulation of octagon pedestal behavior be done to support the predicted ultimate strengths and failure mechanisms.

ACKNOWLEGEMENT

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Brownell, L., and Young, E., (1959) "Chapter 10: Design of Supports for Vertical Vessels." *Process Equipment Design*, John Wiley & Sons, pp 183-197

APPENDIX 1 : COMPARISON OF METHODS

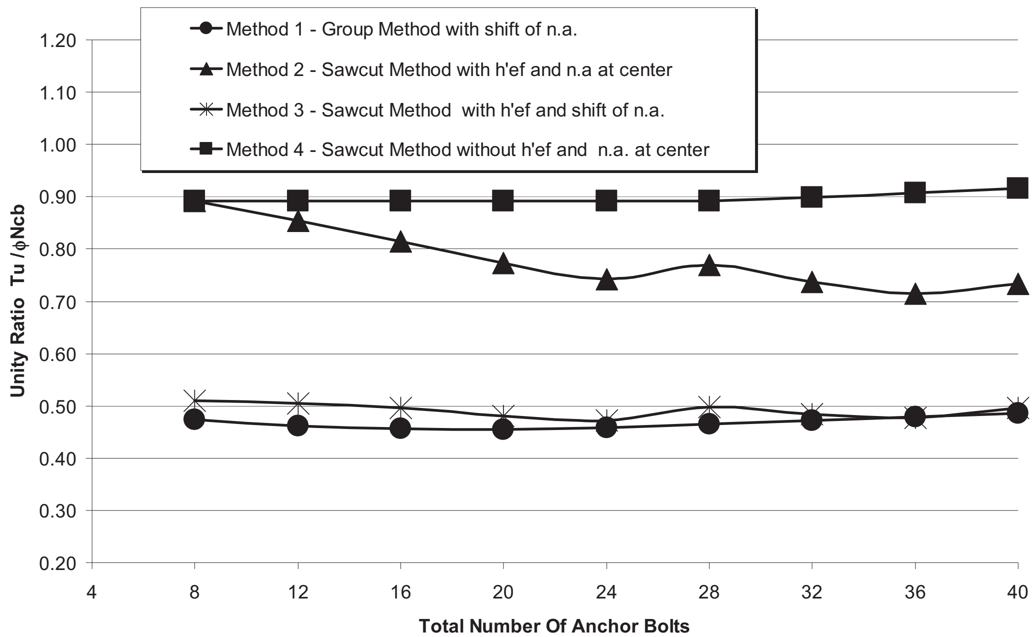


FIGURE 1 – Number Of Anchor Bolts vs Unity Ratio

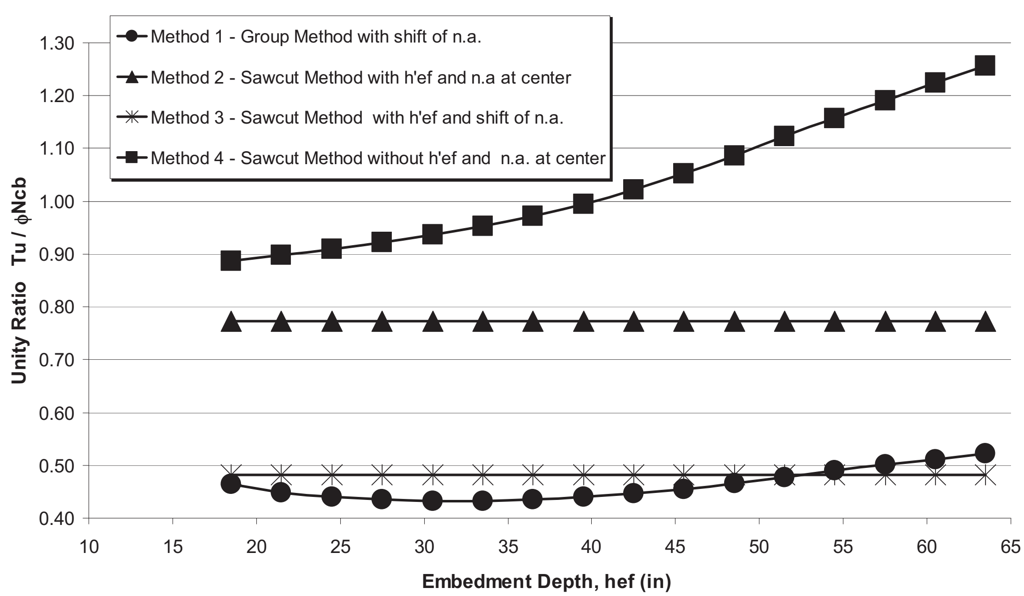


FIGURE 2 – Embedment Depth, hef vs Unity Ratio

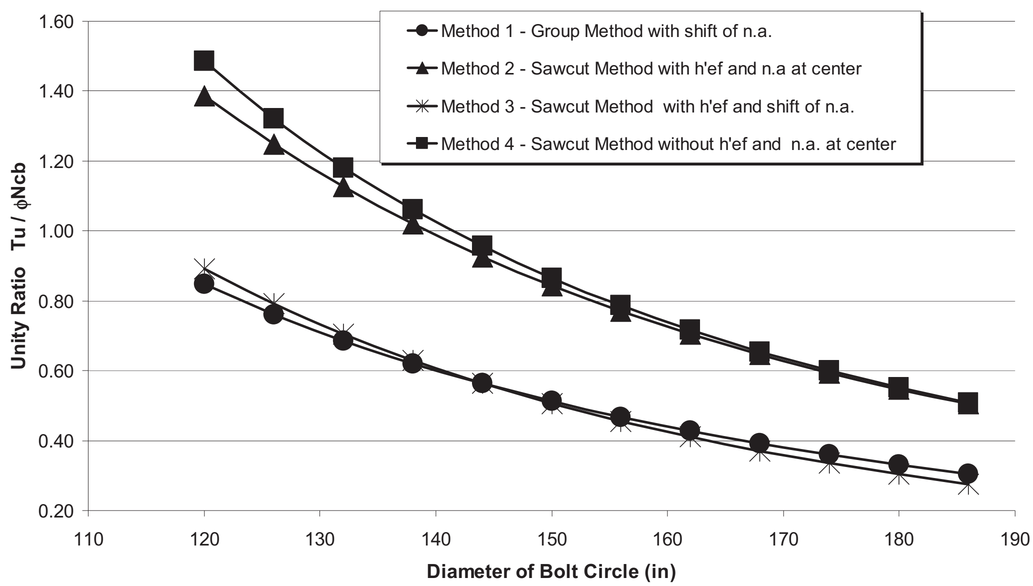


FIGURE 3 – Diameter of Bolt Circle vs Unity Ratio

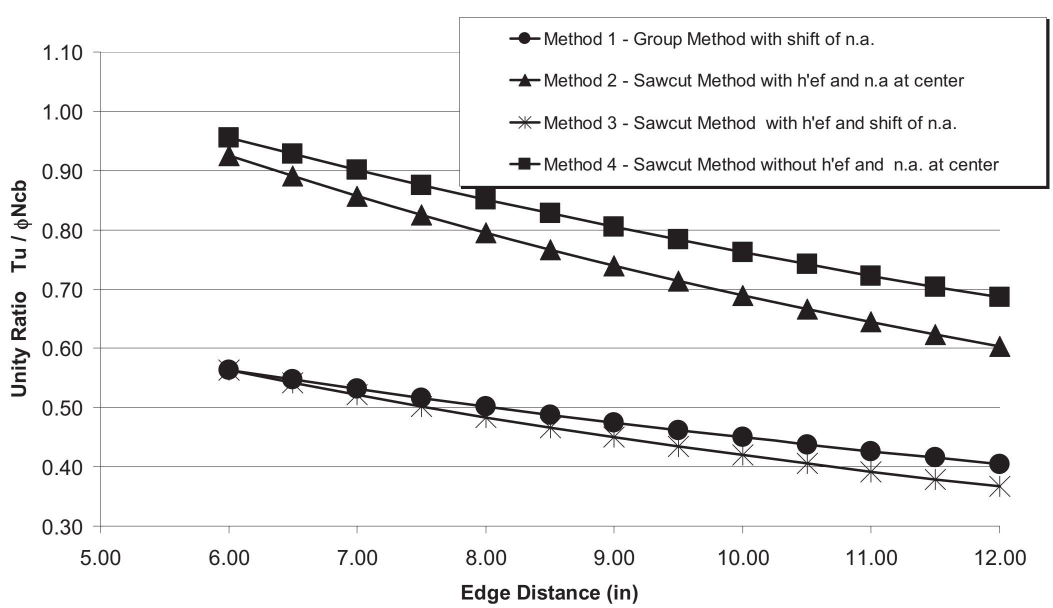
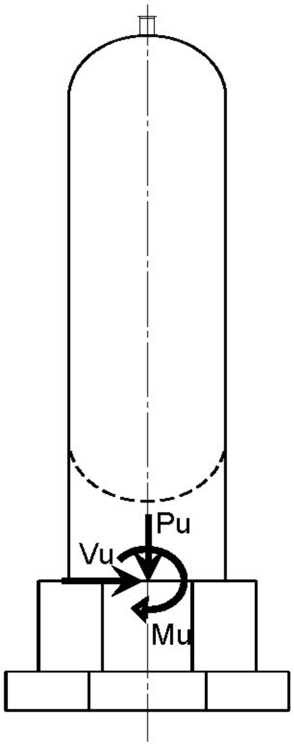


FIGURE 4 – Edge Distance vs Unity Ratio

APPENDIX 2 : Example Problem Statement



GIVEN:

Bolt Circle Dia. (D_{bc}): **144** inch

Bolts: 12 Qty 1 1/2" Dia.

Material: ASTM F1554 Grade 36

Face to Face of Pedestal (Dp): **13.28** ft

For Anchor Bolt information refer following page.

WIND LOADS

Mu: **1328** k-ft

Vu: **44** kips

EARTHQUAKE LOADS (OPERATING)

(Does not control)

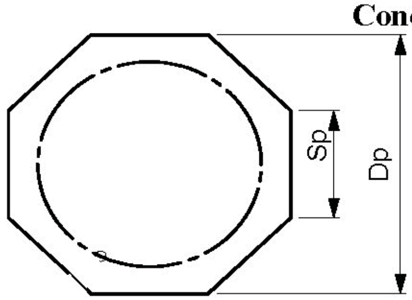
VESSEL WEIGHTS (UNFACTORED)

EMPTY We: **98** kips

OPER Wo: **240** kips

REQUIRED:

Concrete Breakout Strength of Anchorage



Anchor Bolt General Information

Bolt Length, L = **3.10** ft

Grout = **1** in

Grip = **10** in

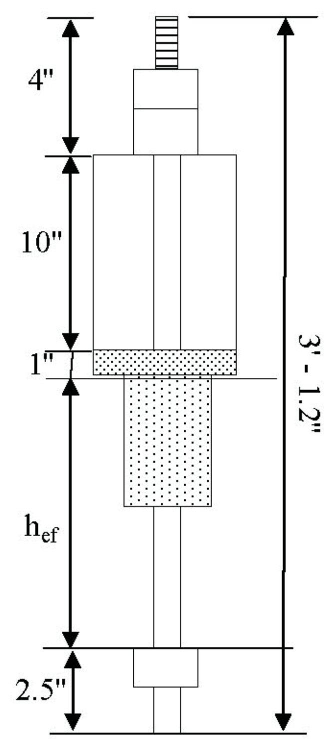
Thread Length at Bottom = **2.5** in

Nut Allowance (2 nuts) = **4** in

Actual Embedment Length, h_{ef} = **19.70** in

Anchor Bolt Circle Dia., D_{bc} = 144.00 in

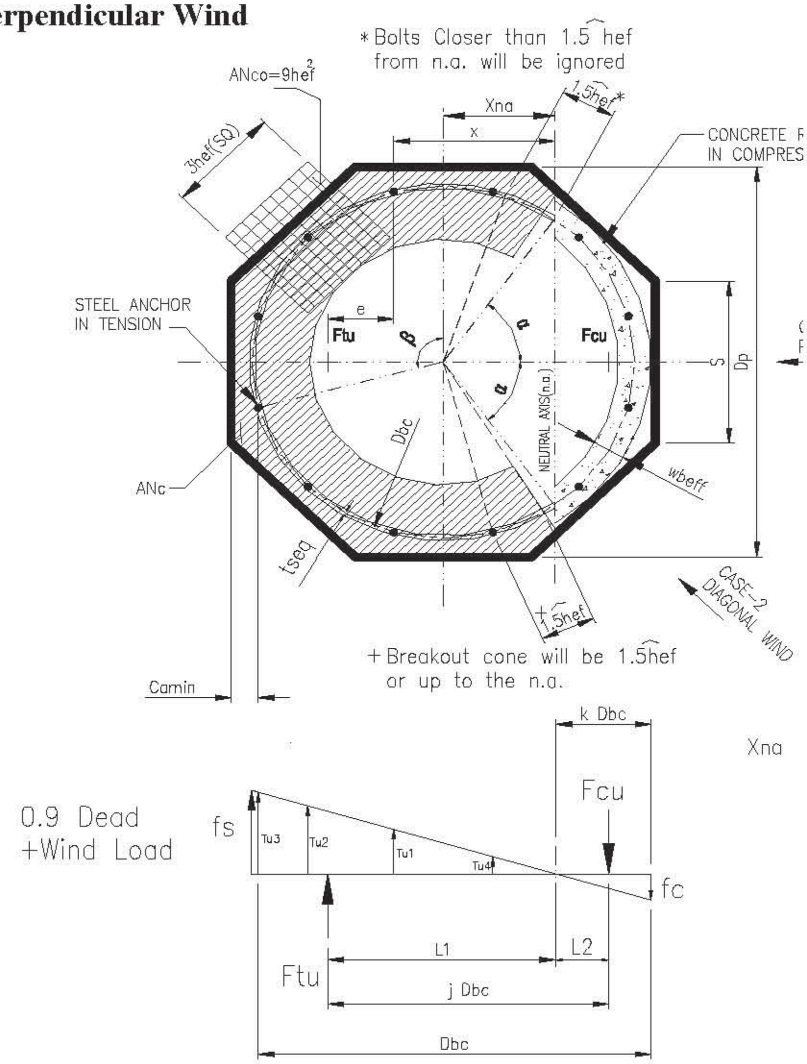
Number of Anchor Bolts, N_{ab} = **12** Nos.



APPENDIX 3 : Method 1 - Group Method with shift of n.a.

Concrete Breakout Strength of a Group Of Anchors in Tension (Ncbg)
Using ACI 318-08 notations and Symbols, we have

Perpendicular Wind



Factored Loads On Top of Pedestal For Critical Condition:

Empty Weight, 0.9We = 88 kips

Factored Applied Wind Moment, Mu = 1328 kip-in

Bolt Diameter d_b (in) : 1.500 Bearing Plate Width w_b (in): 6.000

Compr Strength Of Concrete f'_c (psi) : 4000 Bolts Spacing s_{ab} (in) = 37.699

Modulus of Elasticity Steel E_s (ksi) : 29000

Modulus of Elasticity Conc. E_c (ksi) : = $57\ f'_c{}^{0.5}$ = 3605

Ratio $n = E_s/E_c$: = 29000 / 3605 = 8.04

Using the Shift of neutral axis procedure

Ref. : Process Equipment Design by Brownell and Young, Page 183-188

Calculating Constants :

Make an Initial Guess for k to determine constants:

Initial k_0 : 0.181

Angle α (rad): $\alpha = \cos^{-1}(1-2k)$ = ACOS (1 - 2 x 0.181) = 0.9

$$C_t = \frac{2}{1+\cos\alpha}((\Pi-\alpha)\cos\alpha + \sin\alpha)$$

Ct = 2 x ((3.14 - 0.9) x COS (0.9) + SIN (0.9)) / (1 + COS (0.9)) = 2.70

$$C_c = \frac{2(\sin\alpha - \alpha.\cos\alpha)}{1-\cos\alpha}$$

Cc = 2 x (SIN (0.9) - 0.9 x COS (0.9)) / (1 - COS (0.9)) = 1.16

$$j = \frac{1}{2}\left[\frac{(\Pi-\alpha)\cos^2\alpha + \frac{1}{2}(\Pi-\alpha) + \frac{3}{2}\sin\alpha\cos\alpha}{(\Pi-\alpha)\cos\alpha + \sin\alpha}\right] + \frac{1}{2}\left[\frac{\frac{1}{2}\alpha - \frac{3}{2}\sin\alpha\cos\alpha + \alpha\cos^2\alpha}{\sin\alpha - \alpha\cos\alpha}\right]$$

j = 0.5 x ((3.14 - 0.9) x COS (0.9) ^ 2 + 0.5 x (3.14 - 0.9) + 3 / 2 x (SIN (0.9) x COS (0.9))) / ((3.14 - 0.9) x COS (0.9) + SIN (0.9))

\+ 0.5 x (0.5 x 0.9 - 3 / 2 x SIN (0.9) x COS (0.9) + 0.9 x COS (0.9) ^ 2) / (SIN (0.9) - 0.9 x COS (0.9))

Thus,

j= 0.63 + 0.14 = 0.77

$$z = \frac{1}{2}\left[\cos\alpha + \left(\frac{\frac{1}{2}\alpha - \frac{3}{2}\sin\alpha\cos\alpha + \alpha\cos^2\alpha}{\sin\alpha - \alpha\cos\alpha}\right)\right]$$

z = 0.5 x (COS (0.9) + 0.14 / 0.5) = 0.46

Note: The Second term is same as that for calculating j except it does not have to multiplied by 0.5

Calculating Stress in Steel

Total Tension in All Anchor Bolts F_{tu} = (Mu - P_u z D_{bc}) / j.D_{bc}

F_{tu} = (1328 - 88 x 0.46 x 144.0 / 12) / (0.77 x 144.0 / 12) =

F_{tu} = 90.2 kips

Acting at L1 = j1 Dbc = 0.63 x 144.0 = 90.678 in

For the given bolt dia. , the Effective C/S Area A_{se}: 1.41 in^2

Total Anchor Bolt Area A_t =n Ase= = 1.41 x 12 = 17 in^2

Equivalent Shell Thickness t_{seq} = A_t / πD_{bc}

t_{seq} = 17 / (3.14 x 144.0 / 12 x 12) = 0.04 in

Induced Tensile Stress f_s = F_t / (C_t t_{seq} D_{bc}/2)

f_s = 90.2 / (2.70 x 0.04 x 144.0 / 12 x 12 / 2) =

f_s 12.40 ksi

Calculating Compressive Force

F_{cu} = F_{tu} + P_u = = 90.2 + 88 = 178 kips

Acting at L2 = 0.14 x 144.0 = 20.786 in

Calculating Bearing Stress in Concrete

Resistance Factor Φ_b: 0.65

Width Of Bearing w_b = 6.00 in

Eff. Width Of Bearing $w_{b\,Eff}$ = w_b - t_{seq}

$w_{b\,Eff}$ = 6.00 - 0.04 = 5.96 in

(Excluding the Anchor Bolt Area's Eqv. Shell Thk.)

Max. Compr. Stress @ Blt Line Dia. f_c (ksi): $= \dfrac{F_c}{(w_{beff} + n\ t_{seq})\dfrac{D_{bc}}{2}C_c}$

f_c = 178 / ((5.96 + 8.04 x 0.04) x (144.0 / 12 x 12) / 2 x 1.16) = 0.34 ksi

Max. Compr. Stress in Conc. f_{cMAX} (ksi): $= f_c \dfrac{2kD_{bc} + w_b}{2kD_{bc}}$

f_{cMAX} = 0.34 x (2 x 0.181 x 144.0 / 12 x 12 + 6.00) / (2 x 0.181 x 144.0 / 12 x 12)

f_{cMAX} = 0.38 ksi

Bearing Strength = Φ_b 0.85 f'_c / 1000 =

= .65 x 0.85 x 4000 / 1000 = 2.21 ksi

Unity Ratio: = 0.38 / 2.21 = 0.17

Calculating k based on calculated values of f_s and f_c

$$k = \frac{1}{1 + \dfrac{f_s}{n\ f_c}}$$

k = 1 / (1 + (12.40 / (8.04 x 0.34))) = 0.18

Compare Neutral Axis Location Between Assumed and Calculated Values

X_{NA} (in): = 0.5 D_{bc} - k D_{bc}

$X_{NA\text{-}Act}$ = (0.5 x 144.0 / 12 - 0.181 x 144.0 / 12) x 12 = 45.87 in

$X_{NA\text{-}Calc}$ = (0.5 x 144.0 / 12 - 0.18 x 144.0 / 12) x 12 = 45.87 in

Deviation (%): = 1- ($X_{NA\text{-}Act}$ / $X_{NA\text{-}Calc}$)

Deviation (%): = ABS (1 - 45.87 / 45.87) = 0.00%

Thus, assumption is correct

Calculating Resultant Tensile Load on the base of the vessel.

Max. Tensile Force Ftu_{MAX} = f_s A_{se} = 17.485 kips

Empty Weight, 0.9We = -88 kips

Factored Applied Wind Moment, Mu = 15936 kip-in

Dbc = 144 in β = 15 deg.

Nab = 12 nos

Pedestal Side, Sp = D_p / 2.414 = = 13.28 / 2.414 = 5.50 ft

Pedestal Area, Ap = (0.8284 x (13.28 x 12) ^ 2) = 21038 in^2

Calculating β , x and r based on the geometry

The first row is calculated as follows:

For anchor bolts on the tension side except the ones closer than 1.5 hef from n.a.

For, β = 345 deg. Xna= 45.87 in

Subtended Angle α = 50.424 deg as calculated above

x = - D_{bc} /2*SIN(α)) + Xna

x = - (144 / 2 x SIN ((345))) + 45.87 = 64.51 in

Now, Calculate X_{max} = 115.42 in and x' = 75.99 in

r = x^2 / X_{max} = = 64.51 ^ 2 / 115.42 = 36.05 in

Note: - Ignore the anchor bolts closer than 1.5hef or bolt spac. from the n.a.

- β is measured clockwise from the vertical for each bolt

	β	Abs(x)	r =x^2/x_{max}	Tu	e = x - x'	M_{BLT} = Tu e
	(deg)	(in)	(in)	(kip)	(in)	(kip-in)
1)	**345**	64.51	36.05	9.57	-11.48	-110
2)	315	96.78	81.16	14.36	20.80	299
3)	285	115.42	115.42	17.12	39.43	675
4)	255	115.42	115.42	17.12	39.43	675
5)	225	96.78	81.16	14.36	20.80	299
6)	195	64.51	36.05	9.57	-11.48	-110
7)	165	27.24	6.43	4.04	-48.75	-197
8)	15	27.24	6.43	4.04	-48.75	-197
	Sigma	607.9	478.1	**90.2**		**1333.8**

X_{max}= 115.42 in No. of Anchors in Tension n = 8 nos

Ca_{MIN} = 0.5 D_p - X_{max} = 0.5 x (13.28 x 12) - 115.42 + 45 10.13 in

X' = = Σ x / n = = 607.9 / 8 = 75.99 in

From the table above we have,

Σ T_u= 90.17 kips ΣM$_{BLT}$= 1334 kip-in

Using Similar triangle to get the force on the farthest bolts we have

Max. Tensile Force Ftu_{MAX} = 17.485

Tu = 17.485 x 115.42 / (144 / 2 + 45.87)

Thus, Tu = 17.12 kips

Similarly calculating forces on all other bolts as shown in sketch previously:

Tu = 64.51 / 115.42 x 17.12 = 9.569 kips

Projected Concrete Failure Area, A_{Nco}

$$A_{nco} = 9 h_{ef}^2 = $$ = 9 x 19.70 ^ 2 = 3493 in^2

ACI 318 - Eq. D-6

Effective Concrete Failure Area, A_{NC} *ACI 318 - D.5.2*

Perimeter @ bolt circle, $P_{bc} = \Pi\ D_{bc}$ = 3.14 x 144 = 452.39 in

Len. Of Arc used for Anc, $La = \min\left[(n-1)s_{ab} + 3h_{ef}, P_{bc}\dfrac{(360-2\alpha)}{360}\right]$

La = (8 - 1) x 37.699 + 3 x 19.70 , 452.39 x (360 - 50.424 x 2) / 360

La = = Min(323 , 326) = 323

Thus,

$$A_{nc} = \left[A_p - \frac{\pi}{4}\left[D_{bc} - Min(3h_{ef}, D_{bc}\right]^2\right]\cdot\frac{L_a}{P_{bc}}$$

Anc = (21038 - 3.14 / 4 x (144.00 - MIN (3 x 19.70 , 144.00)) ^ 2) x 323 / 452.39

Anc = 10978 in^2

Now, n Anco = 8 x 3493 = 27942 in2

Also, Anc = Min (Calculated Anc and n Anco) *ACI 318 - D.5.2b*

Anc = MIN (10978 , 27942.48)

Thus, Anc = 10978 in^2

Anc/Anco = 10978 / 3493 = 3.14

Basic Concrete Breakout Strength, N_b

$$N_b = k_c \lambda \sqrt{f'_c}\, h_{ef}^{1.5}$$ *ACI 318 - Eq. D-7*

k_c = 24 (cast-in anchors)

λ = 1.00 (reduction factor for light weight concrete)

f'_c = 4000

N_b = 24 x 1 x SQRT (4000) x (19.70) ^ 1.5 / 1000 = 132.72 kips

• Modification Factors, ψ

$$\psi_{ec,N} = \frac{1}{\left(1 + \dfrac{2e'_N}{3h_{ef}}\right)}$$ *ACI 318 - Eq. D-9*

$e'_N = \Sigma M_{BLT} / \Sigma T_u$ = 1334 / 90.17 = 14.8 in

$\psi_{ec,N}$ = = 1 / (1 + (2 x 14.8) / (3 x 19.70)) = 0.67

$$\psi_{ed,N} = 0.7 + 0.3\frac{C_{a,\min}}{1.5h_{ef}}$$ ($C_{a,\min} < 1.5h_{ef}$) *ACI 318 - Eq. D-11*

$\psi_{ed,N}$ = = 0.7 + (0.3 x (10.13 / (1.5 x 19.70))) = 0.803

$\psi_{c,N}$ = 1.25 (cast-in anchor) *ACI 318 - D.5.2.6*

$\psi_{cp,N}$ = 1.00

Concrete Breakout Strength of Anchor in Tension

$$N_{cb} = \frac{A_{Nc}}{A_{Nco}}\psi_{ec,N}\psi_{ed,N}\psi_{c,N}\psi_{cp,N}N_b$$ *ACI 318 - Eq. D-5*

N_{cb} = (10978 / 3493) x 0.67 x 0.803 x 1.25 x 1.00 x 132.72 =

N_{cb} = 279.0 kips

using Φ = 0.7

$\Phi\ N_{cb}$ = .7 x 279.0 = 195.3 kips > $\Sigma\ T_u$= 90.2 kips

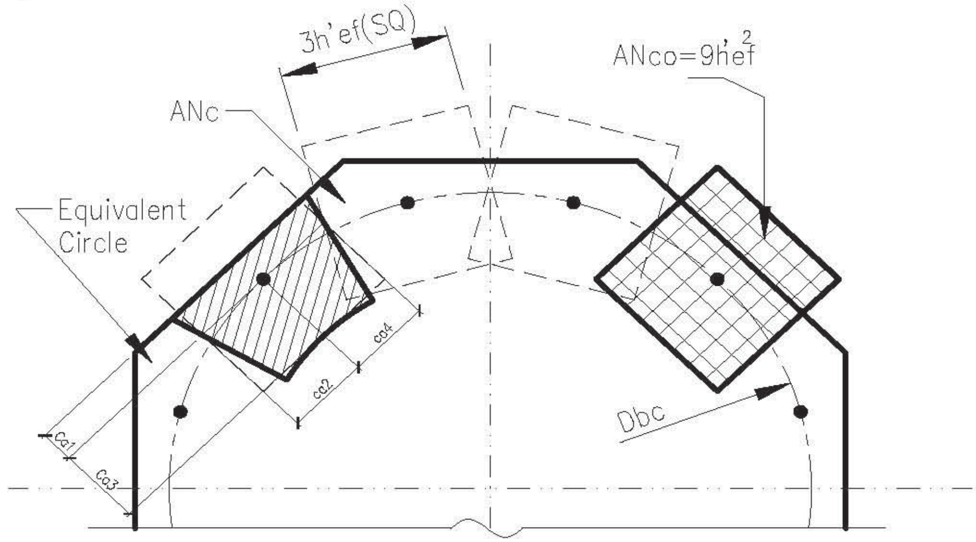
Unity Ratio = 90.2 / 195.3 = 0.46

Thus, OK. Concrete Breakout does not controll

APPENDIX 4 : Method 2 - Sawcut with h'ef and n.a. at center

Concrete Breakout Strength of a Single Anchor in Tension (Ncb)

Using ACI 318-08 notations and Symbols, we have



Pedestal Side, Sp = D_p / 2.414 = = 13.28 / 2.414 = 5.50 ft

Pedestal Area, Ap = (0.8284 x (13.28 x 12) ^ 2) = 21038 in^2

Embedment Length, h_{ef}

Edge Distances:

C_{a1} = (12*D_p - D_{bc})/2 = 12 x 13.28 / 2 - 144.00 / 2 = 7.68 in

$$C_{a2} = \frac{D_{bc}}{2} \tan\left(\frac{360}{2N_{ab}}\right)$$

C_{a2} = = 144.00 / 2 x TAN ((360 / (2 x 12))) = 19.29 in

C_{a4}= C_{a2} = 19.29 in

Effective Embedment Length, h'_{ef}

All three edge distances are less than 1.5h_{ef}, therefore;

C_{aMAX} = MAX (7.68 , 19.29 , 19.29) = 19.29 in

$h'_{ef} = c_{a,max}/1.5$ = = MIN (14.50 , 19.29 / 1.5) = 12.86 in

ACI 318 - D.5.2.3

C_{a3} = Min(1.5 h'_{ef},0.5Dbc). = MIN (1.5 x 12.86 , 0.5 x 144.00)

C_{a3} = 19.29 in

C_{aMIN} = MIN (7.68 , 19.29 , 19.29 , 19.29) = 7.68 in

Projected Concrete Failure Area, A_{Nco}

$A_{nco} = 9h'^2_{ef}$ = 9 x 12.86 ^ 2 = 1489 in^2

ACI 318 - Eq. D-6

Effective Concrete Failure Area, A_{Nc}

$$A_{NC} = \frac{Ap - \frac{\pi}{4}\left[\left(D_{bc} - Min\,(3h'_{ef}\ , D_{bc})\right)^2\right]}{N_{ab}}$$

Anc = (21038 - 3.14 / 4 x (144.00 - MIN (3 x 12.86 , 144.00)) ^ 2) / 12

Calculated Anc = 1026 in^2

For a single anchor Anc > Anco thus,

Anc= Min(Calculated Anc and n Anco) *ACI 318 - D.5.2b*

Anc= MIN (1026 , 1489)

Thus, Anc= 1026 in^2

Anc/Anco = 1026 / 1489 = 0.69

Basic Concrete Breakout Strength, N_b

$$N_b = k_c \lambda \sqrt{f_c^{'}}\, h'^{1.5}_{ef}$$ *ACI 318 - Eq. D-7*

k_c = **24** (cast-in anchors) f'_c = **4000** psi

λ = **1.00** (reduction factor for light weight concrete)

N_b = 24 x 1 x SQRT (4000) x (12.86) ^ 1.5 / 1000 = 70.01 kips

- Modification Factors, ψ

$$\psi_{ed,N} = 0.7 + 0.3\frac{C_{a,\min}}{1.5h'_{ef}}$$ ($C_{a,min} < 1.5h'_{ef}$) *ACI 318 - Eq. D-11*

$\psi_{ed,N}$ = = 0.7 + (0.3 x (7.68 / (1.5 x 12.86))) = 0.819

$\psi_{c,N}$ = **1.25** (cast-in anchor) $\psi_{cp,N}$ = **1.00** *ACI 318 - D.5.2.6*

- Concrete Breakout Strength of Anchor in Tension

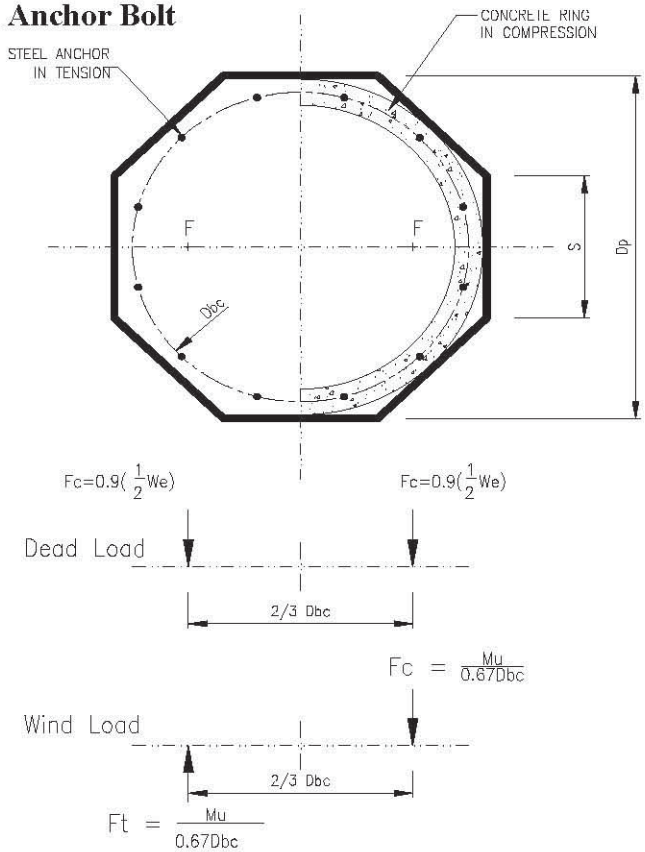
$$N_{cb} = \frac{A_{Nc}}{A_{Nco}}\psi_{ed,N}\psi_{c,N}\psi_{cp,N}N_b$$ *ACI 318 - D-4*

N_{cb} = (1026 / 1489) x 0.819 x 1.25 x 1.00 x 70.01 =

N_{cb} = 49.41 kips Φ = 0.7

Φ N_{cb} = = 49.41 x 0.7 = 34.59 kips

Loading on Anchor Bolt



Vessel Loading: Empty Weight, We = 98 kips

Factored Applied Wind Moment, Mu = 1328 k-ft - Strength Level

Applied Tensile Load on Anchor Bolts

$$T_u = \frac{4M_u}{N_{ab}D_{bc}} - \frac{0.9W_e}{N_{ab}}$$

T_u = 4 x 1328 x 12 / (12 x 144.00) - 0.9 x 98 / 12 = 29.54 kips

T_u = 29.54 < ΦN_{cb} = 34.59

Unity Ratio = 29.54 / 34.59 = 0.85

Thus, OK. Concrete Breakout does not controll

APPENDIX 5 : Method 3 - Sawcut with h'ef with shifted n.a.

If the shift of neutral axis method is used to calculate the neutral axis then as shown in Method 1

Maximum Tension of the Bolt T_u : 17.12 kips

As shown in the Appendix 3 the ΦN_{cb} = 34.59 kips

T_u = 17.12 < ΦN_{cb} = 34.59

Unity Ratio = 17.12 / 34.59 = 0.49

Thus, OK. Concrete Breakout does not controll