T/C

Virginia Electric and Power Company

Richmond, Virginia 23261

December 17, 1980

Mr. James P. O'Reilly, Director
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Region II
101 Marietta Street, Suite 3100
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Dear Mr. O'Reilly:

REQUEST FOR ADDITIONAL INFORMATION
NRC I.E. BULLETIN 79-02
NORTH ANNA UNIT NO. 1

This letter is written in response to your request for additional information concerning our reply to NRC I.E. Bulletin 79-02, "Pipe Support Baseplate Designs Using Concrete Expansion Anchor Bolts" for North Anna Unit No. 1. You requested that we provide a more complete description of the finite element modeling techniques used in the evaluation at North Anna along with sample calculations for typical baseplates. We forwarded the description of the finite element methods in our letter Serial No. 910 dated November 17, 1980.

The purpose of this letter is to provide sample calculations for typical baseplates based on the finite element methods used. Attached are sample calculations for a four bolt square plate and a six bolt rectangular plate. Also attached is the Stone and Webster procedure for reviewing baseplates, NA-EM.1.

If you have any questions or require any additional information, please contact us.

Very truly yours,

B. R. Sylvia
Manager - Nuclear
Operations and Maintenance

cc: Mr. Victor Stello, Director
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Washington, D.C. 20555

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BASEPLATE REVIEWS

Sample 1.	Four bolt square plate
Sample 2.	Six bolt rectangular plate
NA-EM.1	Procedure for Reviewing Baseplates.

J.O.Nos. 11715/12050

June 24, 1977

PROCEDURE

FOR

REVIEWING BASEPLATES

– NA - EM.1 –

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1.0 SCOPE

This procedure is only applicable to square or rectangular pipe support baseplates attached to concrete building structure with four or more Hilti Kwik bolts and only if the following assumptions are applicable:

1. Baseplates and anchor bolts were originally analyzed assuming equal bolt loads for applied tension and bolt loads for applied moment were calculated assuming the rigid baseplate pivoted about an edge.

2. Maximum tension and maximum moments were applied simultaneously.

3. Bolts, as originally analyzed, were within the tension and shear allowables presented in EMTG-22 and that tension-shear interaction was considered.

4. Support member and member to baseplate attachment stresses are within allowable limits for the applicable design loads.

If assumptions 1, 2, and 3, above, are not applicable to a particular baseplate, this procedure can still be applied provided the $L_1/t \leqq 5$ screening step is omitted and the baseplate is subjected to the analysis described in this procedure.

2.0 DEFINITIONS AND TERMS

L_2 — Distance from compression side of member to farthest row of bolts on the opposite side, in. For rectangular plates, use the L_2 for the long dimension.

t — Plate thickness, in.

P_s — The maximum tension loaded bolt load calculated by the Simplified Method, lb.

P_{max} — The maximum tension loaded bolt load calculated by multiplying P_s by a load factor.

N — Total number of bolts.

P_{AL} — Allowable tension load on anchor bolts, considering shear interaction, lb.

S — Applied shear load per bolt, lb.

S_A — Allowable shear load per bolt per EMTG-22, lb (reference: Table 1).

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T_A Allowable tension load per bolt, when no shear is present (reference: Table 1), lb.

L_1 Distance from side of member to farthest row of bolts on the same side of the member, in. For rectangular plates, use L_1 for the long dimension, in.

$T_{req'd}$ The required plate thickness for a given applied moment, in.

ℓ_n The distance from the compression side of a member to the nth row of tension loaded bolts, in.

N_n The number of bolts in the nth row.

M_x The moment applied by a member to a baseplate about the X-axis at the member to plate interface, in.-lb.

M The vector sum of the two moments applied by a member at the member-to-plate interface, in.-lb.

P_T The tension load in a bolt due to a member applying a tension normal force to a baseplate, lb.

P_{M_x} The maximum tension bolt load due to M_x, in.-lb.

3.0 GENERAL PROCEDURE FOR REVIEWING BASEPLATES (SEE FIGURE 1)

1. Check L_1/t. If $L_1/t \leq 5$, accept as is.

2. If $L_1/t > 5$, calculate:

P_s	(See Section 4.0)
P_{AL}	(See Section 5.0)
$T_{req'd}$	(See Section 6.0)
L_2/t	(See Section 7.0)
P_{max}	(See Section 8.0)

3. Check P_s bolt load against allowable P_{AL}.

4. If $P_s > P_{AL}$, check P_s against $1.5 \times P_{AL}$. If $P_s < P_{AL}$ go to Step 7.

5. If $P_s > 1.5\ P_{AL}$, reject baseplate.

6. If $P_s < 1.5\ P_{AL}$, gusset baseplate per G_1 procedure (Section 9.0).

7. Check plate stiffness ratio L_2/t. If stiffness ratio is okay, check plate t. If not, go to Step 9.

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8. If plate t is okay, accept as is. If not okay, gusset baseplate per G_2 procedure (Section 10.0).

9. Check stiffness ratio against upper limit.

10. If not okay, gusset per G_3 procedure (Section 11.0).

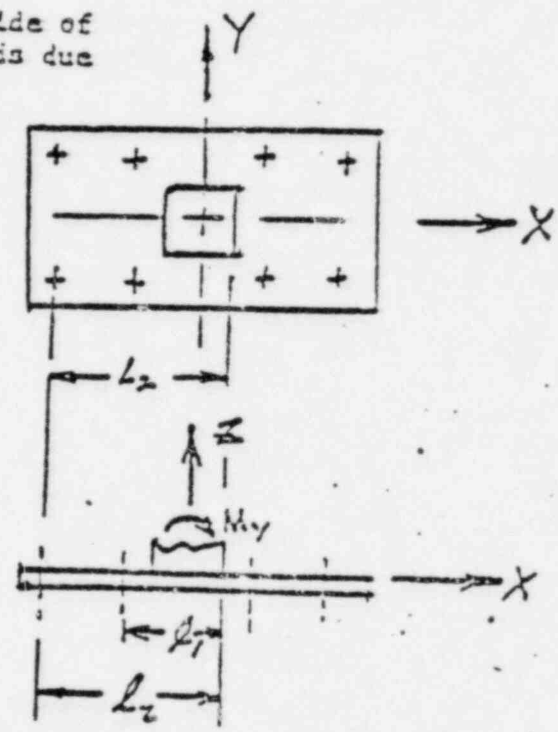
11. If okay, check maximum bolt load against P_{AL}.

12. If P_{max} exceeds P_{AL}, gusset plate per procedure G_3.

13. If P_{max} is less than P_{AL}, check plate t and repeat Step 8.

4.0 SIMPLIFIED METHOD OF BASEPLATE ANALYSIS

Assume pivot at compression side of member and solve for bolt loads due to an applied moment:



a. Determine distance from compression side of member to each row of bolts on tension side of member, ℓ_1 and ℓ_2.

b. Determine the number of bolts in each tension row, N_1 and N_2.

c. Calculate the maximum bolt tension due to M_y by:

$$P_{M_y} = \frac{\ell_2 M_y}{N_1 \ell_1^2 + N_2 \ell_2^2}$$

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d. Similarly, calculate the maximum bolt tension due to M_x.

e. Calculate the bolt tension due to pull-out (+Z) load by:

$$P_T = \frac{F_z}{N}$$, where N is the total number of bolts

f. Calculate the maximum bolt tension load, P_s, by:

$$P_s = P_T + P_{M_x} + P_{M_y}$$

5.0 DETERMINATION OF TENSION ALLOWABLE

a. Calculate the $\frac{S}{S_A}$ ratio.

b. Determine P_{AL} by:

$$P_{AL} = T_A \left[1 - \left(\frac{S}{S_A}\right)^{5/3} \right]^{3/5}$$

6.0 DETERMINATION OF REQUIRED THICKNESS

a. Determine the vector sum of the moments applied to the surface of the plate, M, by:

$$M = \sqrt{M_x^2 + M_y^2}$$

b. Calculate the required baseplate thickness, $T_{req'd}$, by:

$$T_{req'd} = \frac{\sqrt{M}}{418}$$

7.0 DETERMINATION OF STIFFNESS RATIO

From the geometry of the baseplate, determine the distance from the compression side of the member to the farthest row of bolts on the opposite side of the member. This distance, L_2, is illustrated

in Section 4.0. For rectangular plates, or if the attachment member is offset, always use the longest distance to determine L_2.

Calculate the stiffness ratio by dividing L_2 by the baseplate thickness, in.

8.0 DETERMINATION OF MAXIMUM TENSION LOAD

To determine the maximum tension bolt load, enter Figure 2 with the value of L_2/t for the baseplate and find the corresponding load factor, P_{max}/P_s.

Calculate P_{max} by:

$$P_{max} = P_s \left(\frac{P_{max}}{P_s}\right)$$

9.0 GUSSETING PROCEDURE G_1

a. Calculate the ratio $\frac{P_{AL}}{P_s}$.

b. Enter Figure 2 with a load factor equal to P_{AL}/P_s and find the corresponding value of L_2/t.

c. Size gussets to obtain a section moment of inertia equivalent to a plate with the L_2/t determined in Step (b) above. Use 7.5 t as the effective width of plate in bending when calculating the section moment of inertia.

d. Extend gussets to within two times bolt diameter of each bolt center line.

e. Orient gussets to be most effective in providing load path from the member to the bolts.

f. Use the load factor of Step (a) above to determine the maximum bolt load, P_{max}.

g. Check plate, gusset, and weld stresses by applying P_{max} to each bolt in tension assumed to act simultaneously.

10.0 GUSSETING PROCEDURE G_2

If G_2 is invoked (because $t \ngeq T_{req'd}$), then the only problem is plate stress, not bolt loading:

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a. Apply the Simplified Method bolt loads and recheck the plate stress.

b. Add gussets, as required, to bring the plate stress within allowable.

11.0 GUSSETING PROCEDURE G_3

If G_3 is invoked (because L_2/t exceeded the upper limit), both bolt load and stress in the plate are in doubt:

a. Add gussets sized to provide an L_2/t of 16.5 or less if $N = 4$ or L_2/t of 9 or less if $N > 4$. Limit effective width of plate in bending to 7.5 t.

b. Extend gusset at least two-thirds of distance from member to edge of plate, weld gusset to plate and member, orient gusset to be effective in providing load path from member to bolt.

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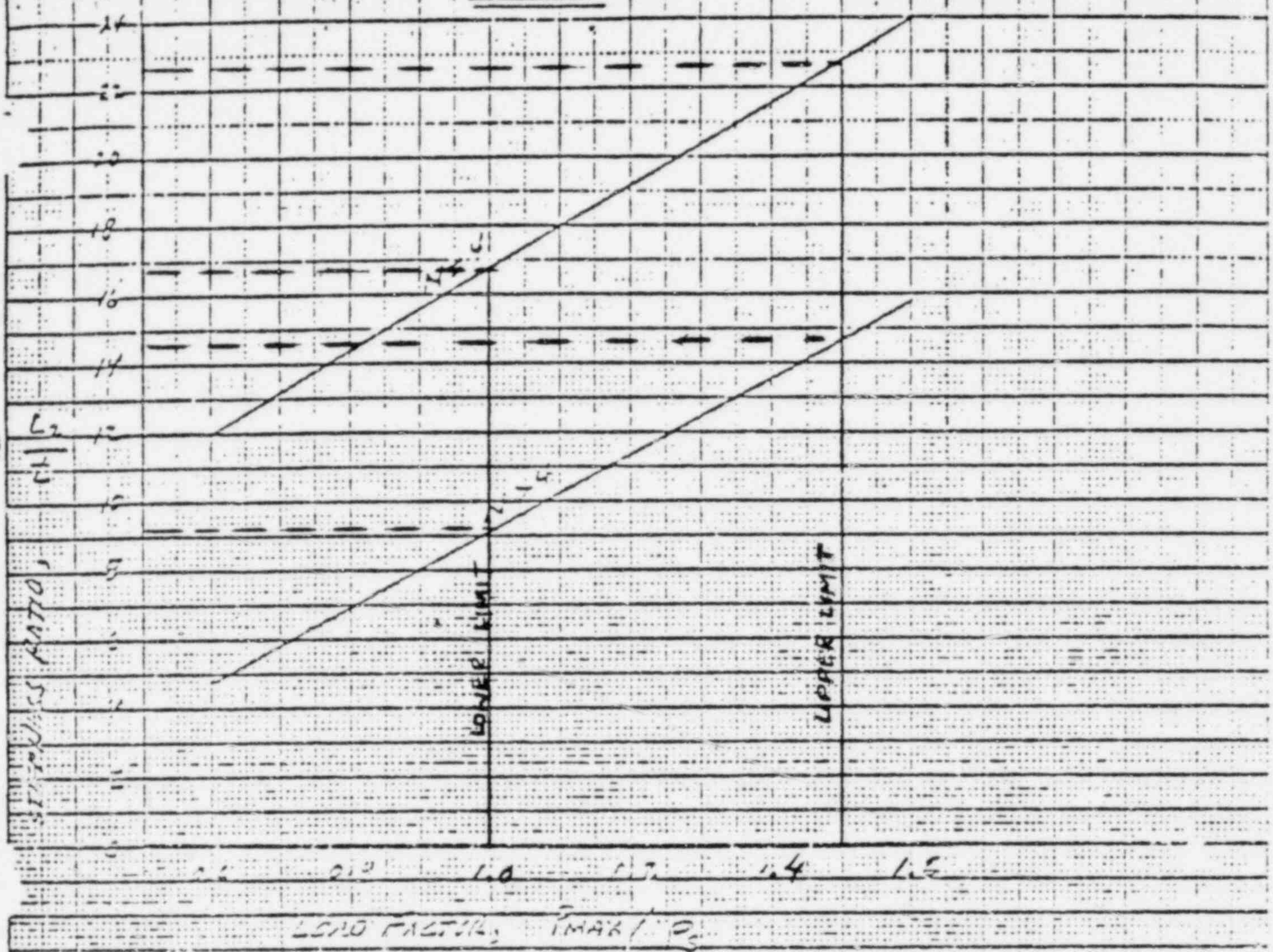
TABLE 1

ANCHOR BOLT ALLOWABLE LOADS FOR f'_c = 3,000 PSI CONCRETE

Size (d)	STD-MS-13-3-1 Allowable Load in Lb Tension (T_A)	Shear (S_A)	Hilti Kwik Bolt Allowable Load in Lb Tension (T_A)	Minimum Embedment, In.
3/8"	700.	700.	950.	3
1/2"	1000.	1000.	2185.	4
5/8"	1500.	1500.	2145.	4
3/4"	2200.	1800.	3525.	5
7/8"	3000.	2200.		6
1"	3500.	2500.	5710.	7
1 1/4"			7730.	9

FIG. 2

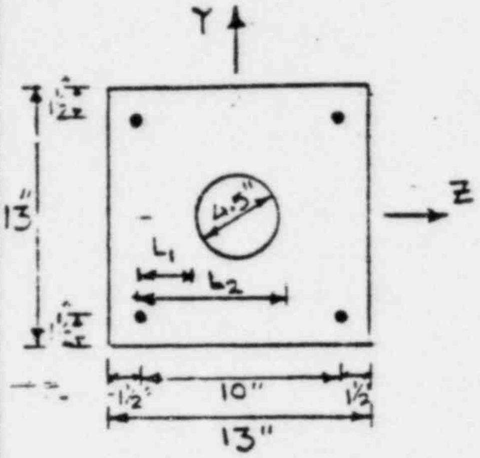


BASEPLATE ANCHOR BOLT LOAD RATIO VS STIFFNESS RATIO

NA-EM.1 'PROCEDURE FOR REVIEWING BASEPLATES'

REVIEW PROCEDURE EXAMPLE 1

PL 1/2" × 13" × 13" WITH 4 - 3/4" HILTI KWIK BOLTS



LOADS ON BASE PLATE FROM THE MEMBER

$F_x = 656$ lb

$F_Y = 654$ lb

$F_Z = \pm 215$ lb

$M_x = \pm 3300$ in-lb

$M_Y = \pm 5,273$ in-lb

$M_Z = \pm 15,141$ in-lb

FROM GEOMETRY

$$L_1 = \frac{13}{2} - 1.5 - \frac{4.5}{2} = 2.75''$$

$$L_2 = \frac{13}{2} - 1.5 + \frac{4.5}{2} = 7.25''$$

STEP 1. CHECK L_1/t

$$\frac{L_1}{t} = \frac{2.75}{0.5} = 5.5 > 5$$

STEP 2. IF $L_1/t > 5$ CALCULATE P_S, P_{AL}, $T_{req'd.}$, L_2/t, P_{max}

2a. CALCULATE P_S ASSUMING PLATE PIVOTS AT COMPRESSION SIDE OF THE MEMBER AS EXPLAINED IN SECTION 4.0

DETERMINE DISTANCE FROM COMPRESSION SIDE OF THE MEMBER TO EACH ROW OF BOLTS ON TENSION SIDE

SINCE IN THIS EXAMPLE ONLY ONE ROW OF BOLTS IS PRESENT ON THE TENSION SIDE ONLY ℓ_1 NEEDS TO BE CALCULATED

$$\ell_1 = 13/2 - 1.5 + 4.5/2 = 7.25''$$

REVIEW PROCEDURE EXAMPLE 1 CONT

NO. OF BOLTS IN THIS ROW = 2

MAXIMUM BOLT TENSION DUE TO M_Y AND M_Z

$$P_{M_Y} = \frac{l_1 M_Y}{N_1 l_1^2} = \frac{M_Y}{N_1 l_1}$$

$$= \frac{5273}{2 \times 7.25}$$

$$= 364 \text{ lb.}$$

SIMILARLY $P_{M_Z} = \frac{l_1 M_Z}{N_1 l_1^2} = \frac{M_Z}{N_1 l_1}$ (SINCE PLATE IS SQUARE WITH A CIRCULAR MEMBER l_1 DOES NOT CHANGE)

$$= \frac{15,141}{2 \times 7.25}$$

$$= 1,044 \text{ lb.}$$

CALCULATE BOLT TENSION DUE TO LOAD PULLING THE PLATE

$$P_T = \frac{F_x}{N} = \frac{656}{4}$$

$$= 164$$

∴ MAXIMUM BOLT TENSION $P_S = P_T + P_{M_Y} + P_{M_Z}$

$$P_S = 164 + 364 + 1044$$

$$= 1,572 \text{ lb}$$

2b. CALCULATE P_{AL}

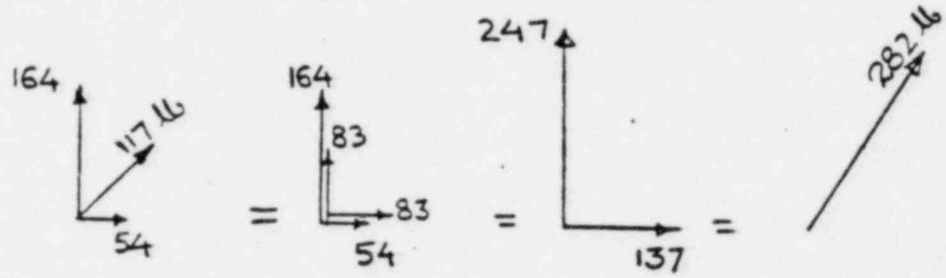
DETERMINE APPLIED SHEAR IN BOLT

DUE TO F_Y $\frac{654}{4} = 164$ lb ALONG Y AXIS

DUE TO F_Z $\frac{215}{4} = 54$ lb ALONG Z AXIS

REVIEW PROCEDURE EXAMPLE 1 (CONT.)

DUE TO M_x $\frac{3300}{4\sqrt{5^2+5^2}} = 117$ lb AT 45° WITH Z AXIS



$\therefore S = 282$ lb

FROM TABLE 1 OF NA - EM.1

$S_A = 1800$ lb AND $T_A = 3525$ lb

$\frac{S}{S_A} = \frac{282}{1800} = 0.157$

$$\therefore P_{AL} = T_A \left[1 - \left(\frac{S}{S_A}\right)^{5/3}\right]^{3/5}$$

$$= 3525\left[1 - (0.157)^{5/3}\right]^{3/5}$$

$$= 3428 \text{ lb}$$

2C. DETERMINE $T_{reqd.}$

$$M = \sqrt{M_Y^2 + M_Z^2}$$

$$= \sqrt{5273^2 + 15141^2}$$

$$= 16033 \text{ in-lb.}$$

$$T_{reqd} = \frac{\sqrt{M}}{418} = \frac{\sqrt{16033}}{418}$$

$$= 0.303''$$

REVIEW PROCEDURE EXAMPLE 1 (CONT.)

2d. CALCULATE $\frac{L_2}{t}$

$$\frac{L_2}{t} = \frac{7.25}{0.5} = 14.5$$

2e. DETERMINE P_{max}

FROM FIG. 2 OF NA-EM.1

$$\frac{P_{max}}{P_s} = 0.81$$ USE MINIMUM OF 1

$$\therefore P_{max} = P_s \left(\frac{P_{max}}{P_s} \right) = 1{,}572 \times 1 = 1{,}572 \text{ lb}$$

STEP 3. CHECK P_s BOLT LOAD AGAINST ALLOWABLE P_{AL}

$P_s = 1{,}572$ lb (FROM PAGE 2)

$P_{AL} = 3{,}428$ lb (FROM PAGE 3)

$\therefore P_s = 1{,}572 < 3{,}428 = P_{AL}$ O.K.

SKIP STEP 4, 5, AND 6 SINCE $P_s < P_{AL}$

STEP 7. CHECK PLATE STIFFNESS RATIO L_2/t

$L_2/t = 14.5 < 16.5$ (SEE FIG. 2 OF NA-EM.1)

$t = 0.5'' > 0.303'' = T_{reqd.}$

REVIEW PROCEDURE EXAMPLE 1 (CONT.)

STEP 8

SINCE $t > T_{reqd.}$

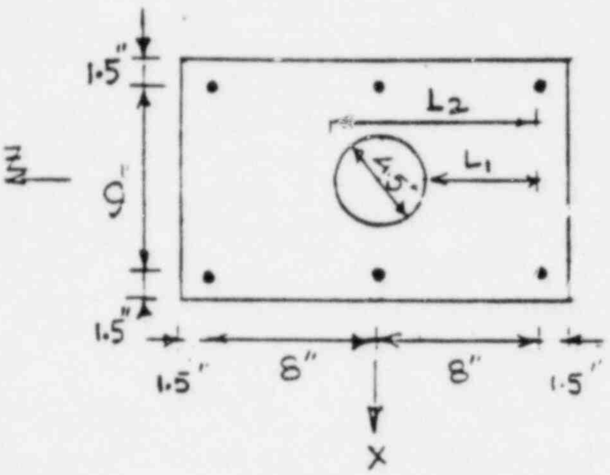
∴ BASEPLATE IS O.K.

STEP 9, 10, 11, 12 AND 13 NOT REQUIRED FOR THIS BASEPLATE

CONCLUSION :- ANCHOR BOLTS AND BASEPLATE ARE ACCEPTABLE

NA-EM.1 'PROCEDURE FOR REVIEWING BASEPLATES'

EXAMPLE 2: 6 BOLTS $1" \times 12" \times 19"$ PLATE
3/4" HILTI KWIK BOLTS



FORCES ON BASEPLATE

$F_Y = 627$ LB

$F_Z = 284$

$F_X = 916$

$M_X = 25165$ IN-LB

$M_Y = \pm 18768$

$M_Z = 15428$

$L_2 = 8 + \frac{4.5}{2} = 10.25$

$L_1 = 8 - \frac{4.5}{2} = 5.75$

$t = 1"$

STEP 1 CHECK L_1/t

$$\frac{L_1}{t} = \frac{5.75}{1} = 5.75 > 5$$

STEP 2 SINCE $L_1/t > 5$, CALCULATE P_S, P_{AL}, $T_{req'd}$, L_2/t, P_{max}

2a. CALCULATE F_S ASSUMING PLATE PIVOTS AT COMPRESSION SIDE OF MEMBER

DETERMINE DISTANCE FROM COMPRESSION SIDE OF THE MEMBER TO EACH ROW OF BOLTS ON TENSION SIDE.

$\ell_1 = 2.25"$ NUMBER OF BOLTS IN ROW 1 $N_1 = 2$

$\ell_2 = 10.25"$ NUMBER OF BOLTS IN ROW 2 $N_2 = 2$.

EXAMPLE 2 (CONT.)

$$P_{M_x} = \frac{l_2 M_x}{N_1 l_1^2 + N_2 l_2^2}$$ (MAXIMUM BOLT TENSION DUE M_x)

$$= \frac{10.25 \times 28166}{2 \times 2.25^2 + 2 \times 10.25^2}$$

$$= 1311$$

FOR M_z MOMENT $l_1 = \frac{9}{2} + \frac{4.5}{2}$

$= 6.75$

$N_1 = 3$

$$\therefore P_{M_z} = \frac{l_1 M_z}{N_1 l_1^2}$$

$$= \frac{6.75 \times 18428}{3 \times 6.75^2}$$

$$= 910 \text{ lb}$$

$$P_T = \frac{F_V}{N}$$

$$= \frac{627}{6}$$

$$= 105 \text{ lb.}$$

$$P_S = P_T + P_{M_x} + P_{M_z}$$

$$= 105 + 1311 + 910$$

$$= 2326 \text{ lb}$$

2b. CALCULATE P_{AL}

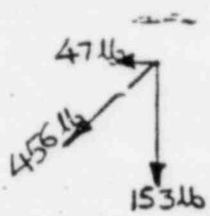
DETERMINE APPLIED SHEAR IN BOLT

DUE TO F_x $= \frac{916}{6} = 153$ lb ALONG X AXIS

DUE TO F_z $= \frac{284}{6} = 47$ lb ALONG Z AXIS

DUE TO M_y $= \frac{18768\sqrt{(8^2+4.5^2)}}{4\times8^2+6\times4.5^2}$

$= 456$ lb/BOLT



$$S = \sqrt{\left(47+456\cdot\frac{4.5}{9.18}\right)^2+\left(153+456\cdot\frac{8}{9.18}\right)^2}$$

$= 613$ lb

FROM TABLE 1 OF NA-EM1

$S_A = 1800$ lb $\qquad T_A = 3525$ lb

$$P_{AL} = 3525\left[1-\left(\frac{613}{1800}\right)^{5/3}\right]^{3/5}$$

$\therefore P_{AL} = 3160$ lb.

2c. DETERMINE $T_{req'd}$

$$M = \sqrt{M_x^2+M_z^2}$$

$$= \sqrt{28168^2+18428^2}$$

$= 33660$ lb

$$T_{req'd} = \frac{\sqrt{M}}{418}$$

$$= \frac{\sqrt{33660}}{418}$$

$$= 0.44''$$

2d. CALCULATE L_2/t

$$\frac{L_2}{t} = \frac{10.25}{1} = 10.25$$

2e DETERMINE P_{max}

$$P_{MAX} = P_S \left(\frac{P_{MAX}}{P_S} \right)$$

FOR $\frac{L_2}{t} = 10.25$ $\frac{P_{MAX}}{P_S} = 1.09$

$$\therefore P_{MAX} = 2326 \times 1.09$$

$$= 2535 \text{ lb}$$

STEP 3. CHECK P_S BOLT LOAD AGAINST ALLOWABLE P_{AL}

$P_S = 2,326$ (FROM PAGE 2)

$P_{AL} = 3,160$ (FROM PAGE 3)

$\therefore P_S = 2,326 < 3,160 = P_{AL}$ O.K.

SINCE $P_S < P_{AL}$ SKIP STEP 4, 5, AND 6

EXAMPLE 2 (CONT.)

STEP 7. CHECK PLATE STIFFNESS RATIO L_2/t

$$\frac{L_2}{t} = 10.25$$

SINCE $\frac{L_2}{t}$ IS GREATER THAN 9.2 (SEE FIG. 2)

SKIP STEP 8 AND GO TO STEP 9

STEP 9. CHECK PLATE STIFFNESS RATIO L_2/t AGAINST UPPER LIMIT.

SINCE $\frac{L_2}{t} = 10.25 < 15$ (WHICH IS THE UPPER LIMIT OF STIFFNESS RATIO TO ASSURE $\frac{P_{max}}{P_S} \leq 1.5$. SEE FIG. 2)

∴ SKIP STEP 10 AND GO TO STEP 11

STEP 11 CHECK MAXIMUM BOLT LOAD AGAINST P_{AL}

P_{max} = 2,535 lb. (FROM PAGE 4)

P_{AL} = 3,160 lb (FROM PAGE 3)

∴ $P_{max} \leq P_{AL}$ SKIP STEP 12

STEP 13 CHECK PLATE THICKNESS

$t = 1''$

$T_{reqd.} = 0.44''$

∴ $t > T_{reqd.}$

CONCLUSION: ANCHOR BOLTS AND BASEPLATE ARE ACCEPTABLE