PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1- 160 PAGE 1 OF 22
REV.	DEO #	DATE	BY:	CHECK	TITLE: **Washington Site Redesign of Equipment Anchorage for Extended Grout Pads**	
0	0556	10/6/97	RDC	DMoore		
					BY: R. D. Ciatto	DEPT.: 744
PROJECT: LIGO Vacuum Equipment					PROJECT NO: V59049	

PURPOSE: The as-built floor elevations at the corner station and the left end station of the Washington site are more than 1 inch lower than planned. This calculation evaluates the effects of extending the equipment grout pads to accommodate the low floors on the anchorage design.

METHOD: Hand calculations are performed to determine the maximum anchor bolt tensile and shear forces. These are compared to allowable forces published by Hilti for the HVA concrete anchor system.

ASSUMPTIONS: See calculation.

INPUTS: See calculation for unbalanced forces and anchor loads derived in other calculations.

REFERENCES:
1. Hilti Product Technical Guide, 1995.
2. Amer. Concrete Inst., ACI 318-89, Building Code Rq'mts for Reinforced Concrete.
3. Rogers Surveying, Survey Data for LIGO – Hanford, Job No. 15597, transmitted with TIM 70.

CALCULATIONS: (SEE ATTACHED)

NOV 14 1997

CONCLUSIONS: Required modifications to the vacuum equipment concrete anchorage are summarized on sheets 4 and 5 of this calculation.

NOTES: Modifications resulting from this evaluation are implemented in RFCs V049 - 072 to – 076.

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REVISION HISTORY

Rev. 0 Original Issue - Oct. 1997

Required Changes

1. All rod length must increase at corner station and end station for the left arm.

2. Shear bars must be added to underside of base plates for WBSC-7 & 8, WB-6,7,2A,2B,3A, & 5A, and WB-9A & 9B.

3. Change anchor rod from HAS standard to HAS super for mode cleaner tubes:

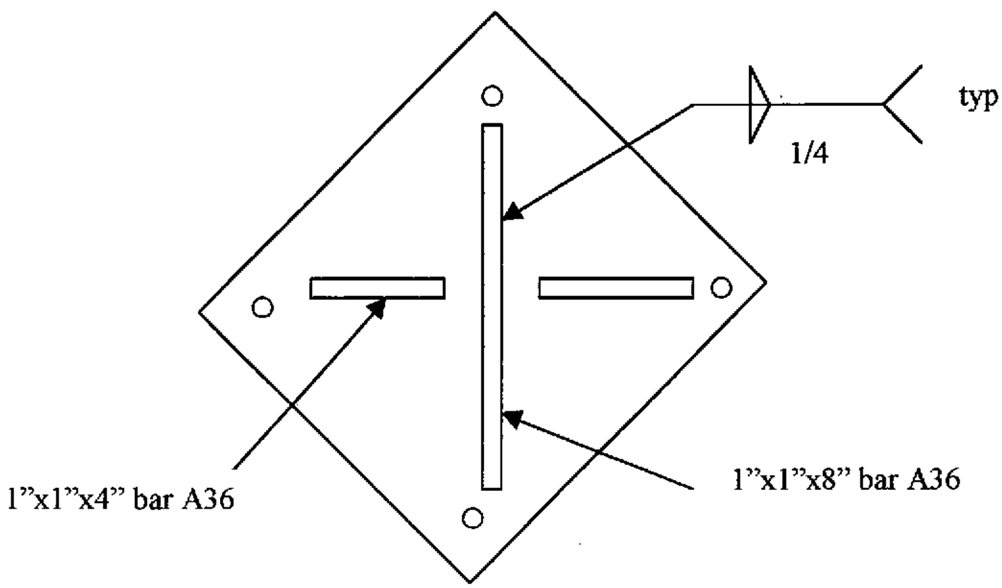
   WB-2A
   WB-2B
   WB-3A
   WB-5A

   This change is required only at base plates connected to diagonal members.

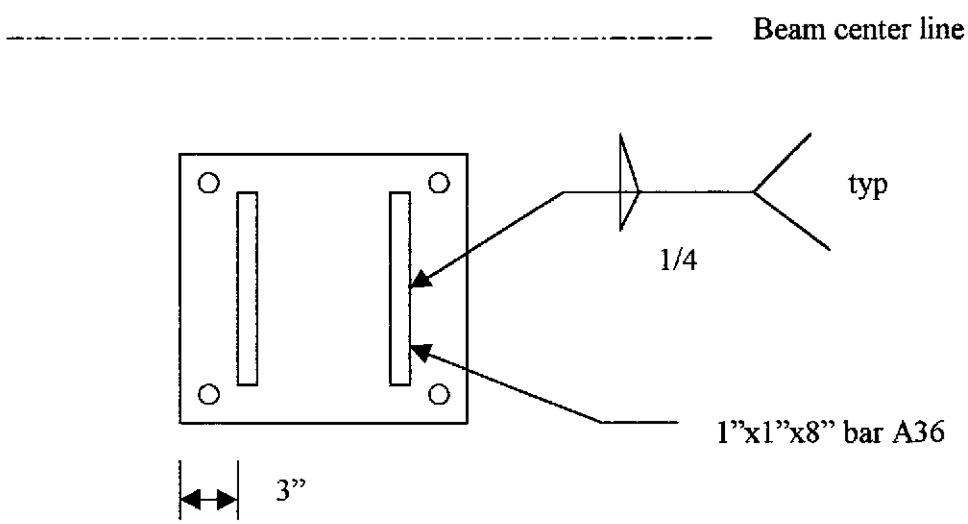
4. Roughen concrete floor with 1/4 inch indentations.

5. Increase preload torque on super rods to 400 ft-lb and decrease torque on standard rods to 250 ft-lb.

Shear bars are to be added to WBSC-7 and WBSC-8 on undersides of base plates.



Other base plates listed in item 2 of the previous sheet (plates connected to diagonal members) shall be modified to add shear bars as follows.



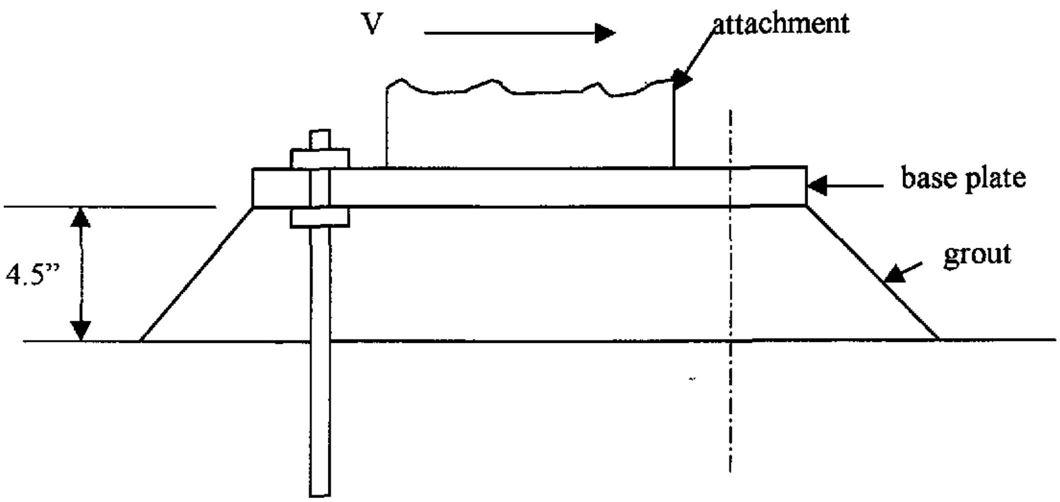
Bars must be perpendicular to beam centerline.

SUMMARY OF RESULTS

Component	Unbal. Force Kips	Ref. Calc. V049-1-	Anchor Type	Embed-ment in.	Max Bolt Tension Kips	Max Bolt Shear, K	S/T Interaction	Status
WHAMs	45.5	032 P. 8	HAS Std.	8 1/4		1.9		ok
WCPs (long)	27.6	083 P. 8	HAS Super	12 3/8	5.5	8.6	<.76	
WCPs (short)	27.6	083 P. 8	HAS Super	12 3/8	10	8.6	.76	ok
Adapters WB-6, WB-7	32.2	095 P. 8	HAS Super	12 3/8	11.6	10.2	1.00	ok – Shear Lugs added
Mode Cleaner Tubes	32.6	087 P.1	HAS Super	8 1/4	2.7 at diagonal	9.8	.46	ok – Shear Lugs added
WB-1A, WB-1B	18.6	088 P. 8	HAS Std.	8 1/4	0	5.4	<1.0	ok
WB-9A, WB-9B	38.1	089 P. 10	HAS Super	8 1/4	0	11	<1.0	ok – Shear Lugs added
WBSC1, WBSC3	16	032 P. 5	HAS Std	8 1/4	2.1	4	.71	ok
WBSC2	~ 0	032 P. 5					N/A	
WBSC4	16	032 P. 7	HAS Std	8 1/4	4.2	4	.90	ok
WBSC5 WBSC6	~ 0	032 P. 12					N/A	
WBSC9 WBSC10	25.4	032 P.13	HAS Super	12 3/8	3.33	6.4	.58	ok
WBSC7 WBSC8	45.5	024 P. 5	HAS Super	12 3/8	1.1	18.4	> 1.0	ok – Shear Lugs added

Detailed Calculations

The floor height is 1"+/- lower than the design height. The 3"+/- grout pads will become 4"+/-. Assume that the maximum grout pad height is 4.5". (This upper limit was confirmed by the Rogers survey data, Ref. 3.)



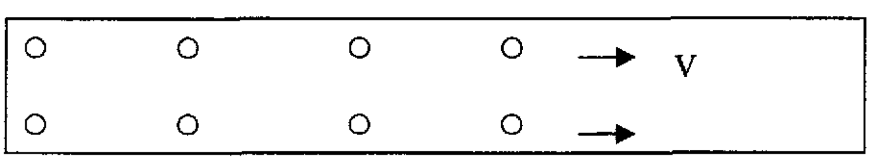
The shear, V, on the attachment will cause excessive bending of bolts. Therefore, the grout must resist the load and transfer force to the scarified floor. In the above sketch, the left anchor has sufficient edge distance to the right to resist V, which is also to the right. The right bolt, however, has low shear capacity for that load since the edge distance to the right is so small.

HAMS

High unbalanced loads exist at HAMS at ends of arms. At the Washington site these are WHAMs 1,6,7, and 12. The unbalanced force is 45.5k. For these components the average shear load is

$$F = 45.5/24 \text{ bolts} = 1.9 \text{ k per bolt}$$

$V = 1.9 << V_{all} = 8$ k for Hilti HAS standard rod ok



Cryopumps

The unbalanced force is 27.6 k (Ref. V049-1-083, p. 8). Both the long and short pumps have the same shear force in base plates at the diagonal members. But, the short pump has higher tensile loads since legs are closer together.

Long pumps – force at each bolt

$T = 5.5$ k and $V = 4.3$ k (Ref. V049-1-083, p. 80)

Shear tension interaction

$S/T = .70$ for the standard rod.

Short pump – force at each bolt

$T = 10$ k and $V = 4.3$ k (Ref. V049-1-083, p. 38)

$S/T = .61$ for super rod.

The anchor embedment for both components is 12 3/8 ". At the base plates connected to the diagonal members, 2 anchors have enough edge distance to resist the force through the grout as discussed on the previous sheet. Then, doubling the shear force gives

$V = 2 \times 4.3 = 8.6$ k

$V_{all} = 16.7$ k for the super bolts ok

Shear tension interaction is

$$S/T = (T/T_{all})^{5/3} + (V/V_{all})^{5/3} = (10/16.5)^{5/3} + (8.6/16.7)^{5/3}$$
$$= .43 + .33 = .76 \quad \text{ok}$$

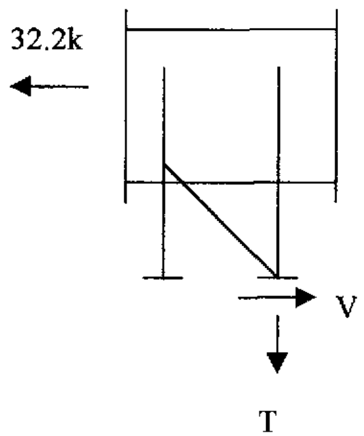
∴ Cryopumps base plates that are anchored with super Hilti HAS rods using a minimum embedment of 12 3/8 " are acceptable.

Adapters WB-6 and WB-7

These are similar to the short cryopumps. The unbalanced force is 32.2 k (Ref. V049-1-095, p. 8).

T = 11.6 k per bolt (Ref. V049-1-095, p. 42)
V = 5.1 k per bolt " " "
S/T = .75 for the super rod with an embedment of 12 3/8 "

Double the shear force as was done for the cryopump at the base plate connected to the diagonal member.



V = 10.2

$S/T = T/T_{all} + V/V_{all}$
$= 11.6/16.5 + 10.2/16.7$
$= .70 + .61 = 1.28$

Using the alternate 5/3 interaction formula

$S/T = (T/T_{all})^{5/3} + (V/V_{all})^{5/3}$
$= .56 + .44 = 1.00$ ok

Mode Cleaner Tubes

WB-2A
WB-2B
WB-3A
WB-5A

The unbalanced force is 32.6 k (Ref. V049-1-087, p. 1)

T = 2.7 at base plate connected to diagonal members
V = 4.9 k
S/T = .89 for standard rod with 8 1/4" embedment (Ref. V049-1-087, p. 46)

Double the shear force as was done for the cryopumps and WB-6 and WB-7.

$V = 9.8$ k

Allowable shear force = 7.7k, ultimate shear capacity = 21.8 k. If the bolts are changed to Super,

Vall = 16.7 k

gives $V < V_{all}$ ok

∴ Use super rod for the base plates connected to the diagonal members. Check interaction.

$S/T = (2.7/16.5)^{5/3} + (9.8/16.7)^{5/3} = .05 + .41 = .46$ ok

Beam tube manifold WB-1A and WB-1B

The unbalanced force = 18.6 k (Ref. V049-1-088, p. 8)

T = 0 (Ref. V049-1-088, p. 43)
V = 2.7 k per bolt
S/T = .63

Again, double the bolt shear at the base plate connected to the diagonal member.

V = 5.4 k < Vall for HAS standard rod with 8 1/4" embedment ok

Beam tube manifold WB-9A and WB-9B

The unbalanced force is 38.1 k (Ref. V049-1-089, p. 10)

T = 0 (Ref. V049-1-089, p. 36)
V = 5.5 k at base plate connected to the diagonal member
S/T = .98 for HAS standard rod with 8 1/4 " embedment

Double the shear at the base plate connected to the diagonal member.

V = 11.0 k
Vall = 8 for standard rod

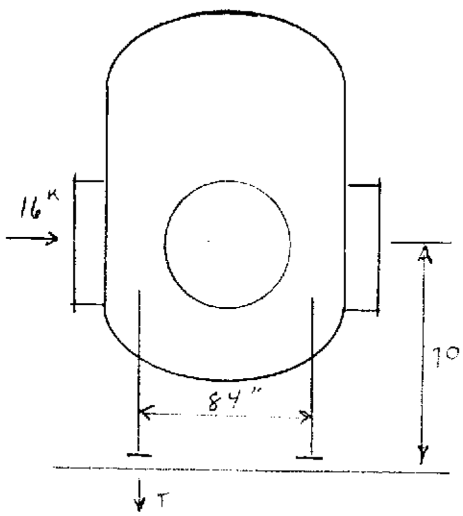
But, HAS super rod will be used at the base plate connected to the diagonal member.

Vall = 16.7 > 11.0 k ok

Beam Splitters

WBSC1 and WBSC3

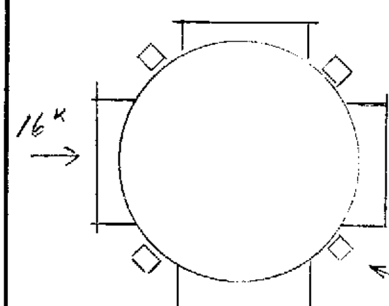
The unbalanced force = 16 k (Ref. V049-1-032, p. 5)



2Tx84 = 16 x 70
T = 6.67 k per column
T = 6.67/4 = 1.7 k per anchor
V = 16/16 = 1 k average per bolt

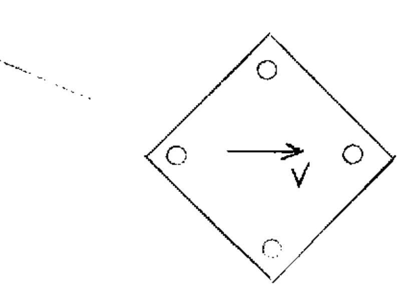
Increase T by 25% for prying
T = 1.25 x1.7 = 2.1

See sketch to left and below. Most shear is resisted by 1 bolt because edge distance is small for other 3 anchors.
$\therefore$ Multiply V by 4
V = 4 k per anchor.



$T/T_{all} + V/V_{all} = 2.1/11 + 4/7.7 = .71 < 1$

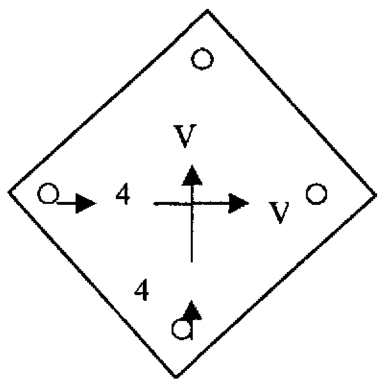
HAS standard rod embeded 8 1/4 " is acceptable.



WBSC2 – This component has negligible unbalanced load. (Ref. V049-1-032, p. 6) ok

WBSC4 – The unbalanced force for this component is 16 k in 2 directions.
(Ref. V049-1-032, p. 7)

The analysis is similar to that performed for WBSC1 and 3. The tensile force is doubled at one plate.



T = 2 x 2.1 = 4.2 k per bolt

Shear V = 4 k (same as WBSC1 & 3)

$T/T_{all} + V/V_{all} = 4.2/11 + 4/7.7$
$= .38 + .52 = .90$ ok

∴ HAS standard rod with an 8 1/4" embedment is acceptable for BSC4.

WBSC5 & WBSC6 – No unbalanced load. ok
Ref. V049-1-032, p. 12

WBSC9 & WBSC10 – End Station
Unbalanced force = 25.4 k (Ref. V049-1-032, p. 13). From the previous sheet for WBSC1 & 3,

T = 2.1 x 25.4/16 = 3.33k

V = 4 x 25.4/16 = 6.35

$T/T_{all} + V/V_{all} = 3.33/11 + 6.35/7.7 = .30 + .82 = 1.12 > 1.0$
for standard rod with 8 1/4" embedment. For super rod with 12 3/8" embedment that is used at the end of the beam tube arm,

$T/T_{all} + V/V_{all} = 3.33/16.5 + 6.35/16.7 = .20 + .38 = .58$ ok

Note: All rods for WBSC9 & 10 are HAS super. Rod for base plates at ends of arms have 12 3/8" embed. Rods for other plates have 8 1/4" embedment.

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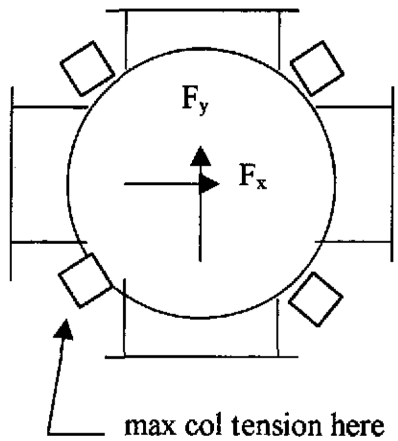
WBSC7 & WBSC8

Unbalanced forces

$F_x = 45.5$ k
$F_z = 29.5$ k



Ref. V049-1-024, p. 5.

Tensile force in column due to Fx

$2T \times 84 = F_x \times 70 = 45.5 \times 70$
$T = 19.0$ k

Tensile force in column due to Fz

$T = 19.0 \times 29.5/45.5 = 12.3$ k

Total column tensile force.

$T = 19.0 + 12.3 = 31.3$k

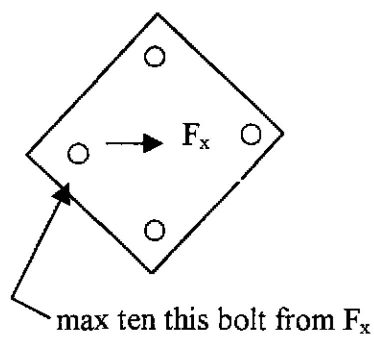
Force per bolt with 25 % prying factor,

$T = (31.3/4) \times 1.25 = 9.8$ k

Maximum shear applied by Fx

$V = 45.5/4 = 11.4$ k

Plate with max tension



Interaction:

$$S/T = (T/T_{all})^{5/3} + (V/V_{all})^{5/3} = (9.8/16.5)^{5/3} + (11.4/16.7)^{5/3}$$

$$= (.59)^{5/3} + (.68)^{5/3} = .95 \qquad \text{ok}$$

$\therefore$ Use HAS super rod with 12 3/8 embedment.

Check WBSC7 & WBSC8 using forces computed on p. 28 of V049-1-024.

Node 1 — $T = 1.1$ k per bolt
$V = 18.4$ k due to Fx (max value)

$T/T_{all} + V/V_{all} = 1.1/16.5 + 18.4/16.7 = 1.17$*

This is 10% greater than allowable on shear alone.

Node 4 — $T = 0$
$V = 5.8$ due to Fx (max value)
$V/V_{all} = 5.8/17.7 = .35$ ok

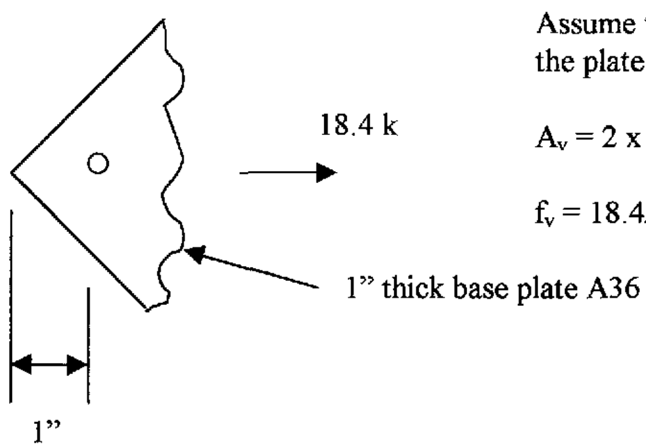
Node 7 — $T = 0$
$V = 15.6$
$V/V_{all} = 15.6/16.7 = .95$ ok

Node 10 — $T = 8.75$
$V = 6.5$
$T/T_{all} + V/V_{all} = 8.75/16.5 + 6.5/16.7 = .53 + .39 = .92$ ok

*See the following sheets. Shear will be resisted by shear bars on the bottom of plates.

Check base plate tear out for WBSC7 & 8 which have maximum shear.

$V = 18.4$ k



Assume that the minimum distance from the hole to the plate edge is 1.0 in. This is very conservative.

$A_v = 2 \times 1 \times 1 = 2$ in^2

$f_v = 18.4/2 = 9.2$ ksi ok

Check bolt torque for the slip critical connection. Bolt torque for the major components is

$T = 375$ ft-lb $= 4.5$ in-k

Get bolt tension, Ft

$T = .20\ D\ F_t$ (Ref. Shigley Eq. 7-16)

$D = 1$ in

$F_t = 4.5/(.20 \times 1) = 22.5$ k

Bolt tensile stress, $A_b = .785$ in2

$f_t = Ft/A_b = 22.5/.785 = 28.7 \cong .50$ Fu
$f_t << .50\ F_u$ for A193 B7, $F_u = 125$ ksi

Get max slip load, Ps (shear), that can be resisted by a single rod.

$P_s = mnF_tks$ (Ref. NF-3000, p. 79, ASME III).
m = no. of shear planes = 2 (NF 3324.6)
n = no. of bolts = 1
k_s = slip coefficient (Table NF 3324.6(a)
= .45 for zinc silicate paint.
$P_s = 2 \times 1 \times 22.5 \times .45 = 20.3$ k

$\therefore$ A maximum shear force of 20.3 k can be resisted before the bolt slips and the gap closes.

The slip resistance is an upper bound since Shigley's equation may account for some thread lubrication. Also, the precise slip coefficient, ks, is not known but is probably not less than .30. To get a lower bound slip resistance, use .30 for both thread friction and k_s.

$T = .30\ D\ F_t$
$F_t = 4.5/(.30 \times 1) = 15$ k
$f_t = F_t/A_b = 15/.785 = 19.1$ ksi
$P_s = 2 \times 1 \times 15 \times .30 = 9$ k

For HAS super rods increase torque to 400 ft-lb.

$P_s = 9 \times 400/375 = 9.6$ k min value

Hence, shear add bars to base plates connected to diagonal members at:

WBSC7 & 8
WB-6 & 7,
mode cleaner tubes WB-2A, 2B, 3 A & 5A
WB-9A & 9B

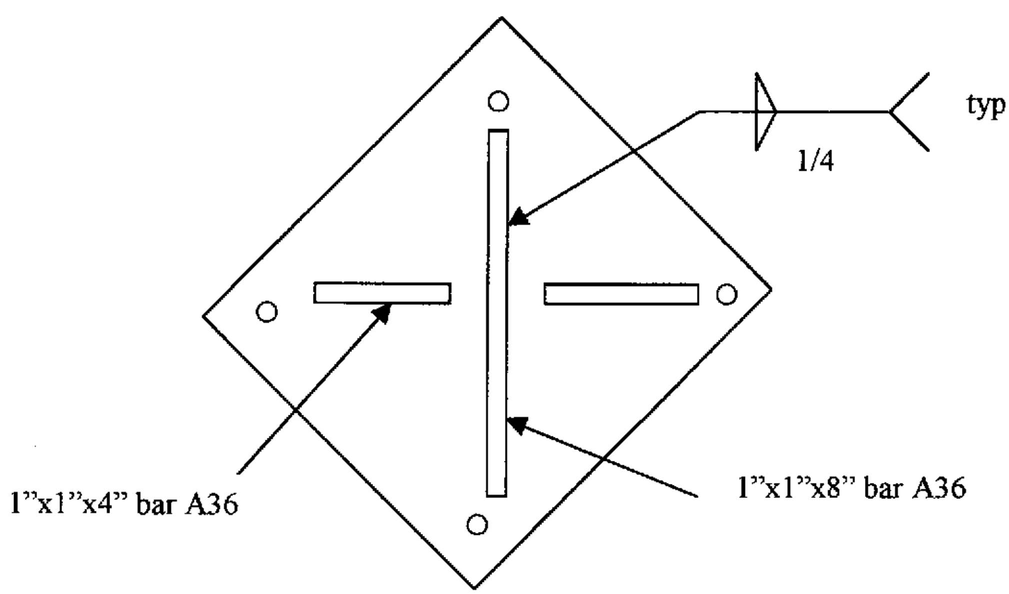
Also, chip concrete to expose aggregate at these plates.

Since 400 ft-lb may be too high a torque for HAS standard rods, use 250 ft–lb for these anchors.

$P_s = 9 \times (250/375) = 6$ k min value > 5.4 at WB-1A & 1B. ok

The shear force for WBSC7 & 8 is only slightly lower than P_s ; therefore it is necessary to ADD shear bars to the bottom of the base plates of these units to transfer the shear force to the scarified floor.

Try adding 8"x1" bars to the bottom of each base plate.



Bearing stress on grout

$f = F_x/(8 \times 1) = 18.4/8 = 2.3$ ksi << 7 ksi ok

Try 1/4" fillet weld

$f_v = 18.4/(2 \times 8 \times .707 \times (1/4))$
$= 6.5$ ksi < 21 ksi ok

Check maximum shear friction between grout and concrete floor

Base plate area $A = 14 \times 14 = 196$ in2 (min – doesn't account for beveled edge of grout pad)

$V_{max} = 24$ k (Ref. V049-1-024, p. 38)

$f_V = 24/196 = .122$ ksi = 122 psi

Check allowable shear friction from the ACI code.

$V_n = A_{vf} \times f_y \times \mu$ (Ref. ACI 11.7.4)
A_{vf} = area of Hilti's = $4 \times .785 = 3.14$ in^2
$f_y = 60$ ksi max < F_y for A193 B7 (Super rods)
$\mu = 1.0\ \lambda$
$\lambda = 1.0$
$V_n = 3.14 \times 60 \times 1 = 188$k >> 24 k

But the concrete must be roughened per ACI 11.7.9 to amplitude of 1/4 in.

The maximum shear friction resistance is

$V_{n\,max} = .2f'_c\ A_c < 800\ A_c$ lb (Ref. ACI 11.7.5)
$f'c = 4000$ psi for floor
$A_c = 12 \times 12 = 144$ for small base plate
$V_{n\,max} = .2 \times 4000 \times 144 = 800 \times 144 = 115200$ lb
$= 115$ k >> 24 k ok