ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY **ENGINEERING NOTE** **Mechanical Engineering Department**			**BaBar Detector**
WBS#: 1.3.1.1	LBNL Serial #: M7621	DIRC Note #: 74	Page 1 of 21
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First Line: BaBar Detector
Second Line: DIRC PID
Title: Support Structure Bolting and Pinning

MAG

INTRODUCTION

This note summarizes the calculations that were performed to size bolts and pins in the DIRC Support Structure. The assembly is important to the structural integrity of the larger BaBar Detector because it supports the Backward End Plug, the DIRC Standoff Box, and the Drift Chamber. The design of bolted and pinned connections between components in this structure was judged to be of critical importance due to the magnitude of magnetic and seismic loads which it must withstand.

LOAD DESCRIPTION

The analysis utilized loads calculated using an ANSYS, Rev 5.3, finite element model of the DIRC subsystem, "Finite Element Stress Analysis of the DIRC Structure," MCR Associates, Inc. 10/15/96. An analysis was performed to obtain loads on the joints for the static operating condition as well as worst case loads during seismic events. Using nodal force summations over interfaces between components, net axial and shear forces were extracted. In order to guarantee the conservatism of load data, all axial loads were assumed to act in tension on the bolts. Forces were averaged per bolt over each interface zone.

JOINT ANALYSIS

The connections were designed to achieve a total safety factor on static loading of at least three and a total safety factor on seismic loading of at least one, as shown in Table #1. Shear force was resisted by bolts and shear pins in those locations in which an increase in magnetic loading could cause catastrophic failure in slippage between the members. In locations where magnetic loading could not cause catastrophic slip failure, shear forces were resisted by bolts with no shear pins. All joints are designed as slip-critical, rather than bearing-type connections. In other words the joints resist shear through friction between the members rather than by loading the bolts in shear.

The analysis followed the technique prescribed by the *American Institute of Steel Construction (AISC) Manual of Steel Construction*, 9th edition, Part 5, Specification for Structural Steel Buildings - Allowable Stress Design and Plastic Design, and

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Specification for Structural Joints Using ASTM A325 or A490 Bolts. The code could not be adhered to strictly because metric bolts were used in the design. Metric property class 8.8 socket head cap screws and standard hex head screws were used instead of A325 or A490 heavy hex head bolts. The analysis assumes a Class B coating on both faces comprising each bolted interface. According to Appendix A of the AISC Specification for Structural Joints Using ASTM A325 or A490 Bolts, this coating guarantees a slip coefficient of greater than or equal to 0.5. In locations in which clearance holes were made oversized in order to allow for adjustment, the allowable slip load was decreased in accordance with the code.

JOINT SPECIFICATIONS

LBNL Specification number M871 (DIRC Note number 73) describes the requirements for fasteners, joint preparation, and bolt tightening in the DIRC Support Structure. The attached drawings, load data, and calculations show how the size and number of fasteners were determined for each joint. The structure was divided into nineteen zones, shown in Figure #1 and Figure #2, for which separate loads and solutions were determined. In some zones safety factors on static loading were higher or slightly lower than three. In these cases, geometric and mechanical constraints affected the selection of fasteners.

The table below summarizes the results of the bolt and shear pin sizing calculations for each zone.

Table #1: Summary of Bolting and Pinning

Zone	Pin Diam. (mm)	Number of pins	Bolt Diam. (mm)	Number of Bolts	Total Safety Factor for Slippage Under Seismic Loading	Total Safety Factor for Slippage Under Static Loading
1	12	10	12	11	2.90	3.23
2	-	-	-	-	-	-
3	30	7	30	7	6.56	7.12
4	30	7	30	7	2.53	3.04
5			36	11	2.84	3.13
6			36	14	2.54	3.10
7			30	8	1.44	8.74
8			25.4	13	2.35	2.58
9			38.1	18	3.31	5.33
10			38.1	6	10.42	29.29
11	30	4	30	6	3.53	3.54
12			38.1	10	2.95	2.95
13	30	7	30	8	6.98	7.51
14	30	7	30	8	2.85	3.22
A			24	24	22.57	35.58
B			24	60	33.69	33.79
C			24	60	20.90	22.43
D			20	12	1.79	12.20
E			4	6	6.54	6.54

COMMENTS

A major challenge in determining the size and number of fasteners proved to be designing to an American structural engineering code while using metric fasteners. The bolts specified, metric property class 8.8 bolts, have an equivalent or higher yield strength than do ASTM A325 bolts. The minimum yield strength of property class 8.8 bolts is 92,800 psi. The yield strength of ASTM A325 bolts ranges from 81,000 psi to 92,000 psi, depending on the size of the fastener. As a result of the slightly higher yield strength of the metric bolts, the safety factors calculated for the bolts are assumed to be conservative because they are based on a bolt yield strength of 81,000 psi. Metric A325 bolts exist but are extremely difficult to find compared to the readily available property class 8.8 metric bolts.

$$SF_{BOLTS} = \frac{28000psi\left(1 - \frac{0lb}{0.7 \times 7 \times 81000psi \times 1.0956in^2}\right)1.0956in^2 \times 7}{208846lb} = 1.03$$

Solve for the safety factor for bolt yield under the combination of pre-tension and applied axial load using Equation #4:

EQUATION #4 $$SF_{by} = \frac{S_y}{0.7S_y + \frac{F_A}{N_b A_b}}$$

Solve for the safety factor on bolt yield under seismic loading using Equation #4:

$$SF_{by} = \frac{81000psi}{0.7 \times 81000psi + \frac{3848lb}{7 \times 1.0956in^2}} = 1.42$$

Solve for the safety factor on bolt yield under static loading using Equation #4:

$$SF_{by} = \frac{81000psi}{0.7 \times 81000psi + \frac{0lb}{7 \times 1.0956in^2}} = 1.43$$

Pin Sizing

Solve for the minimum number of shear pins required, N_{MIN} to obtain a safety factor of one on seismic loading (i.e.: stressing the pins to their shear strength) using Equation #5:

EQUATION #5: $$N_{MIN} = \frac{F_{SHEAR}}{S_{sy} A_b}$$ (rounded up to nearest integer)

$$N_{MIN} = \frac{250747lb}{54815psi \times 1.0956in^2} = 4.1753 \rightarrow 5 \text{ shear pins}$$

The number of shear pins selected for this joint, N, is 7. Solve for a safety factor for failure through shear of the pins according to Equation #6:

EQUATION #6: $$SF_{PINS} = \frac{S_{sy} N A_b}{F_{SHEAR}}$$

Solve for the safety factor for seismic loading according to Equation #6:

$$SF_{PINS} = \frac{54815psi \times 7 \times 1.0956in^2}{250747lb} = 1.68$$

Solve for the safety factor for static loading according to Equation #6:

$$SF_{PINS} = \frac{54815psi \times 7 \times 1.0956in^2}{208846lb} = 2.01$$

Total Safety Factor for Joint Slippage:
The total safety factor for the joint is calculated by adding the safety factors for bolts and shear pins for each case. This direct addition is valid because the safety factors for the bolts and shear pins were calculated independently.

Total Seismic Safety Factor for Slippage $= SF_{BOLTS} + SF_{PINS} = 0.85 + 1.68 = 2.53$

Total Static Safety Factor for Slippage $= SF_{BOLTS} + SF_{PINS} = 1.03 + 2.01 = 3.04$

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FIGURE #1: BOLTING AND PINNING ZONES

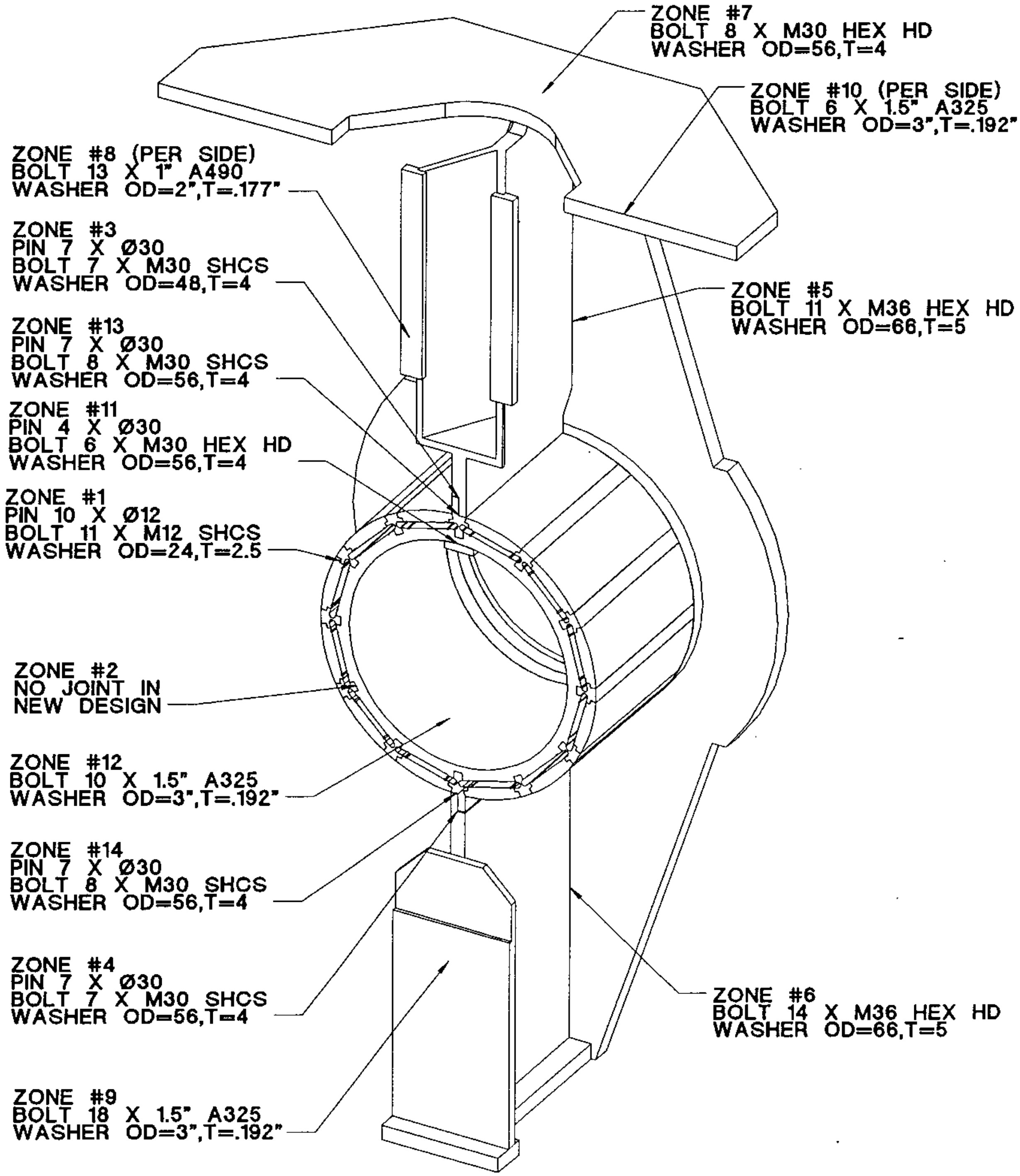


FIGURE #2: INTERNAL BOLTING ZONES

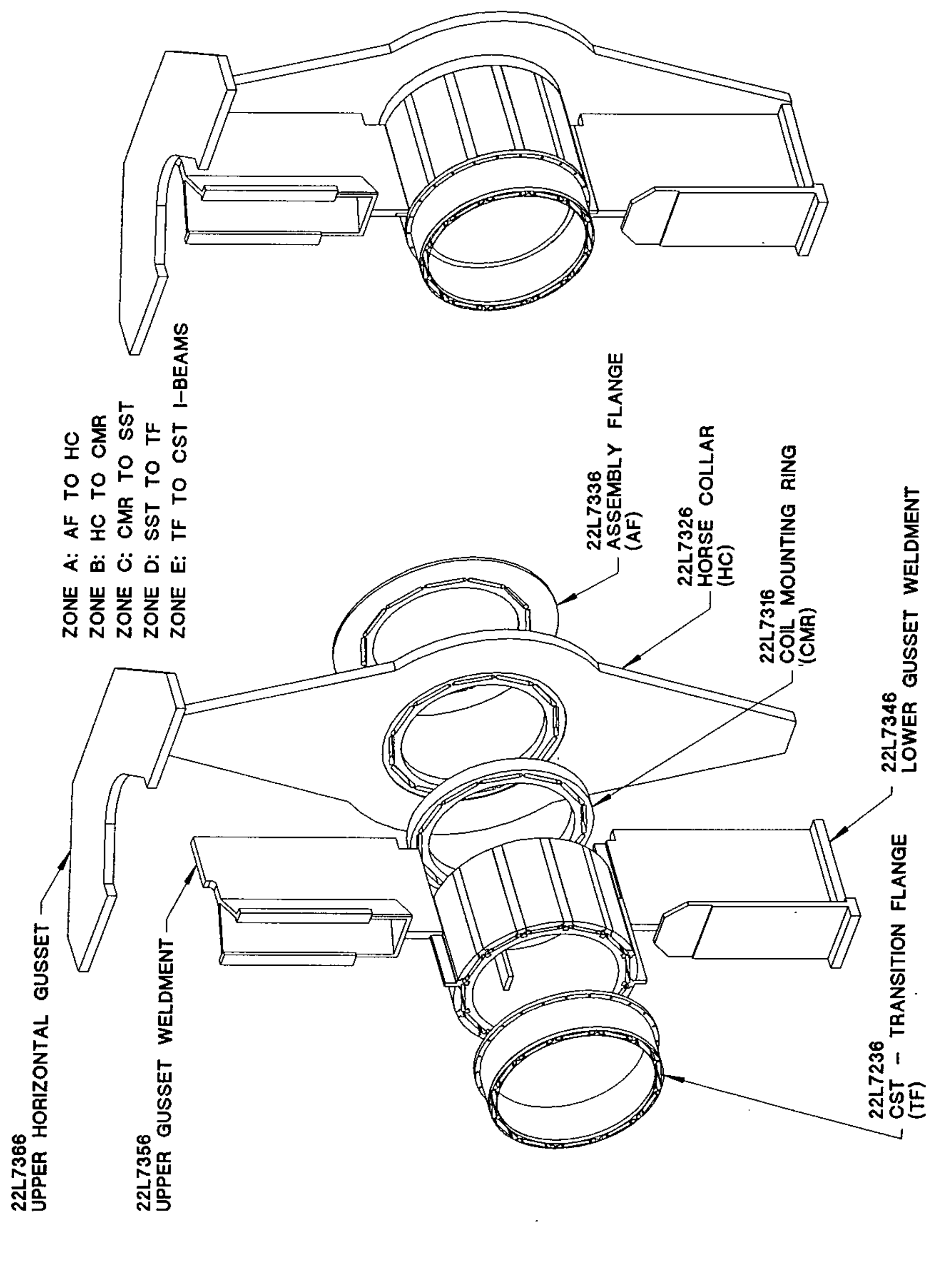


Table #2: Bolt Sizing

Bolt Properties: Assume **A325 Bolts**
Source: *AISC Manual of Steel Construction, Ninth Edition*
Yield Strength Fy = 81000 psi

Bolt Properties: Zone 8: **A490 Bolts**
Source: AISC Manual of Steel Construction
Yield Strength Fy = 131000 psi

Assume Class B Contact Surfaces

		A325	A490
Slip Coefficient	u_s =	0.5	
Allowable Slip Load per Unit of Bolt Area =	F_v =	28000 psi	34000 psi
For Oversized Holes =	F_v =	24000 psi	29000 psi
Tighten bolts to:	**70%**	of Yield Strength	

Bolts sized to resist shear force with friction

Zone	Seismic Shear Force (lb)	Seismic Axial Force (lb)	Static Shear Force (lb)	Static Axial Force (lb)	Total Stress Area Req. (in^2)	Bolt Diam. (mm)	Area of Bolt (in^2)	Minimum Number of Bolts Req.	Chosen Number of Bolts	Safety Factor Seismic (slippage)	Safety Factor Static (slippage)	Safety Factor Seismic (bolt yield)	Safety Factor Static (bolt yield)
Variable	F_{SHEAR}	F_A	F_{SHEAR}	F_A	A_T	d	A_B	N_{MIN}	N	SF_{BOLTS}	SF_{BOLTS}	SF_{by}	SF_{by}
Equation					Equation #1			Equation #2		Equation #3	Equation #3	Equation #4	Equation #4
1	50837	5237	46153	1739	1.8856	12	0.1753	11	11	1.01	1.15	1.36	1.41
2	109984	55380	69830	25810	4.85622575	-	-	-	-	-	-	-	-
3	96575	2452	89213	0	3.4498	30	1.0956	4	7	2.21	2.41	1.42	1.43
4	250747	3848	208846	0	8.9126	30	1.0956	9	7	0.85	1.03	1.42	1.43
5	165865	30862	151338	24840	6.3949	36	1.5777	5	11	2.84	3.13	1.39	1.39
6	236890	34606	194772	28368	8.9662	36	1.5777	6	14	2.54	3.10	1.39	1.40
7	167596	7916	27810	4972	6.0513	30	1.0956	6	8	1.44	8.74	1.41	1.41
8	116658	43853	106775	39305	3.0226	25.4	0.7854	4	13	2.35	2.58	2.15	2.16
9	197070	263500	139267	48665	11.5986	38.1	1.7671	7	18	3.31	5.33	1.25	1.39
10	28319	3592	10117	1105	1.0623	38.1	1.7671	1	6	10.42	29.29	1.42	1.43
11	120000	343	120000	0	4.2389	30	1.0956	4	6	1.53	1.53	1.43	1.43
12	152000	94400	152000	94400	7.0265	38.1	1.7671	4	10	2.95	2.95	1.31	1.31
13	93783	23184	87498	17408	3.7169	30	1.0956	4	8	2.49	2.71	1.36	1.38
14	211263	129328	195894	72402	9.7329	30	1.0956	9	8	0.86	1.07	1.13	1.25

NOTES:
Seismic Stresses: "Allowable stresses may be increased 1/3 above the values otherwise provided when produced by wind or seismic loading . . ." AISC MSC (Chap. A Sect. A5)
In Zone 8, where the Upper Gusset Weldment bolts to the Flux Return center gap plate, A490 bolts were used because Kawasaki drilled and tapped 26 x 1" diameter holes in the gap plate because of confusion between SLAC and Kawasaki.

Table #3: Pin Sizing

Pin Properties Assume 4140 Normalized steel

Yield Strength:	S_y =	95000 psi
Shear Strength:	S_{sy} =	54815 psi
Ultimate Strength:	S_u =	148000 psi

Pins

Zone	Seismic Shear Force (lb)	Static Shear Force (lb)	Pin Diam (mm)	Minimum Number of Pins Req..	Chosen Number of Pins	Seismic Safety Factor	Static Safety Factor
Variable	F_{SHEAR}	F_A	d	N_{MIN}	N	SF_{PINS}	SF_{PINS}
Equation				Equation #5		Equation #6	Equation #6
1	50837	46153	12	6	10	1.89	2.08
2	109984	69830	-	-	-	-	-
3	96575	89213	30	2	7	4.35	4.71
4	250747	208846	30	5	7	1.68	2.01
5	165865	151338	-	-	-	-	-
6	236890	194772	-	-	-	-	-
7	167596	27810	-	-	-	-	-
8	116658	106775	-	-	-	-	-
9	197070	139267	-	-	-	-	-
10	28319	10117	-	-	-	-	-
11	120000	120000	30	2	4	2.00	2.00
12	152000	152000	-	-	-	-	-
13	93783	87498	30	2	7	4.48	4.80
14	211263	195894	30	4	7	1.99	2.15

Table #4: Bolt and Pin Sizing Data

ZONE #1		T-bar to Outer Ring Segments				
	Face	**Direction**	**Combination 1**	**Combination 2**	**Combination 3**	**Combination 4**
			Force (lb)	**Force (lb)**	**Force (lb)**	**Force (lb)**
	1	Shear	**41247**	38097	40926	38704
	1	Axial	1114	906	**3005**	1287
	2	Shear	45704	42892	**48751**	43510
	2	Axial	1106	791	**3122**	1465
	3	Shear	**33343**	30827	31255	29947
	3	Axial	1612	1491	**3034**	1588
	4	Shear	36646	34212	**36777**	33758
	4	Axial	**371**	121	189	339
	5	Shear	**50837**	48890	46515	46377
	5	Axial	1869	2389	**5237**	1739
	6	Shear	**50167**	47707	46791	46153
	6	Axial	1476	1744	**4472**	1472
MAX SHEAR FORCE =			**50837**	**lb**		
MAX AXIAL FORCE =			**5237**	**lb**		
STATIC SHEAR FORCE =			46153	lb		
STATIC AXIAL FORCE =			1739	lb		
ZONE #2		T-bar to Inner Ring				
	Face	**Direction**	**Combination 1**	**Combination 2**	**Combination 3**	**Combination 4**
			Force (lb)	**Force (lb)**	**Force (lb)**	**Force (lb)**
	1	Shear	**58528**	56660	46556	56466
	1	Axial	5346	7266	**25836**	6874
	2	Shear	13490	12961	**24890**	14899
	2	Axial	2037	2024	**4908**	2169
	3	Shear	6923	8212	**18464**	6648
	3	Axial	6156	6304	**14242**	6223
	4	Shear	71056	67536	**109984**	69830
	4	Axial	21180	14180	**55380**	25810
MAX SHEAR FORCE =			**109984**	**lb**		
MAX AXIAL FORCE =			**55380**	**lb**		
STATIC SHEAR FORCE =			69830	lb		
STATIC AXIAL FORCE =			25810	lb		
ZONE #3		Upper T-bar to Upper Gusset				
		Direction	**Combination 1**	**Combination 2**	**Combination 3**	**Combination 4**
			Force (lb)	**Force (lb)**	**Force (lb)**	**Force (lb)**
		x-direction	980	**2452**		
		y-direction	22988	-19640	**23184**	-17408
		z-direction	**93751**	-89999	-78816	-87498
MAX SHEAR FORCE =			**96575**	**lb**		
MAX AXIAL FORCE =			**2452**	**lb**		
STATIC SHEAR FORCE =			89213	lb		
STATIC AXIAL FORCE =			0	lb		
ZONE #4		Lower T-bar to Lower Gusset				
		Direction	**Combination 1**	**Combination 2**	**Combination 3**	**Combination 4**
			Force (lb)	**Force (lb)**	**Force (lb)**	**Force (lb)**
		x-direction	1540	**3848**		
		y-direction	74074	73072	**129328**	72402
		z-direction	211228	-2022208	**-214822**	-195894
MAX SHEAR FORCE =			**250747**	**lb**		

MAX AXIAL FORCE =			**3848**	**lb**		
STATIC SHEAR FORCE =			208846	lb		
STATIC AXIAL FORCE =			0	lb		
ZONE #5		Upper Gusset to Horse Collar				
TOP		**Direction**	**Combination 1**	**Combination 2**	**Combination 3**	**Combination 4**
			Force (lb)	**Force (lb)**	**Force (lb)**	**Force (lb)**
		x-direction	540	**1350**		
		y-direction	**165860**	-15714	-115304	-151338
		z-direction	**30862**	-27248	-17910	-24840
MAX SHEAR FORCE =			**165865**	**lb**		
MAX AXIAL FORCE =			**30862**	**lb**		
STATIC SHEAR FORCE =			151338	lb		
STATIC AXIAL FORCE =			24840	lb		
ZONE #6		Bottom Gusset to Horse Collar				
BOTOM		**Direction**	**Combination 1**	**Combination 2**	**Combination 3**	**Combination 4**
			Force (lb)	**Force (lb)**	**Force (lb)**	**Force (lb)**
		x-direction	936	**2340**		
		y-direction	213010	202066	**236878**	194772
		z-direction	**34606**	-30862	-3410	-28368
MAX SHEAR FORCE =			**236890**	**lb**		
MAX AXIAL FORCE =			**34606**	**lb**		
STATIC SHEAR FORCE =			194772	lb		
STATIC AXIAL FORCE =			28368	lb		
ZONE #7		Top Brace to Upper Gusset				
		Direction	**Combination 1**	**Combination 2**	**Combination 3**	**Combination 4**
			Force (lb)	**Force (lb)**	**Force (lb)**	**Force (lb)**
		x-direction	18424	24846	**28446**	16414
		y-direction	3592	-6572	**-7916**	-4972
		z-direction	78964	**165164**	37334	22450
MAX SHEAR FORCE =			**167596**	**lb**		
MAX AXIAL FORCE =			**-7916**	**lb**		
STATIC SHEAR FORCE =			27810	lb		
STATIC AXIAL FORCE =			4972	lb		
ZONE #8		Chimney Flange to IFR Barrel				
		Direction	**Combination 1**	**Combination 2**	**Combination 3**	**Combination 4**
			Force (lb)	**Force (lb)**	**Force (lb)**	**Force (lb)**
		x-direction	**78850**	72958	69850	73056
		y-direction	**85976**	77279	31625	77870
		z-direction	**43853**	39874	25702	39305
MAX SHEAR FORCE =			**116658**	**lb**		
MAX AXIAL FORCE =			**43853**	**lb**		
STATIC SHEAR FORCE =			106775	lb		
STATIC AXIAL FORCE =			39305	lb		
ZONE #9		Lower Gusset Flange to IFR Barrel				
		Direction	**Combination 1**	**Combination 2**	**Combination 3**	**Combination 4**
			Force (lb)	**Force (lb)**	**Force (lb)**	**Force (lb)**
		x-direction	17593	9310	**29238**	21092
		y-direction	-146002	-137594	**-194889**	-137661
		z-direction	26977	-16972	**71234**	48665
					Max Axial	
MAX SHEAR FORCE =			**197070**	**lb**	**Force From**	
MAX AXIAL FORCE =			71234	lb	**Hand Calc =**	**263500**
STATIC SHEAR FORCE =			139267	lb		
STATIC AXIAL FORCE =			48665	lb		
ZONE #10		Top Brace to IFR Barrel				

		Direction	Combination 1	Combination 2	Combination 3	Combination 4
			Force (lb)	Force (lb)	Force (lb)	Force (lb)
		x-direction	-13654	-19195	-16319	-10117
		y-direction	-1126	-1221	-3592	-1105
		z-direction	-15117	-20496	-20821	-13023
MAX SHEAR FORCE =			28319	lb		
MAX AXIAL FORCE =			3592	lb		
STATIC SHEAR FORCE =			10117	lb		
STATIC AXIAL FORCE =			1105	lb		
ZONE #11		Upper Plug Stop to Inner Ring				
		Direction	Force (lb)			
		x-direction	0			
		y-direction	343			
		z-direction	120000			
MAX SHEAR FORCE =			120000	lb		
MAX AXIAL FORCE =			343	lb		
STATIC SHEAR FORCE =			120000	lb		
STATIC AXIAL FORCE =			0	lb		
ZONE #12		Lower Stationary Plug to Inner Ring				
		Direction	Force (lb)			
		x-direction	0			
		y-direction	94400			
		z-direction	152000			
MAX SHEAR FORCE =			152000	lb		
MAX AXIAL FORCE =			94400	lb		
STATIC SHEAR FORCE =			152000	lb		
STATIC AXIAL FORCE =			94400	lb		
ZONE #13		Upper T-bar to Gusset Bracket				
		Direction	Combination 1	Combination 2	Combination 3	Combination 4
			Force (lb)	Force (lb)	Force (lb)	Force (lb)
		x-direction	980	2452		
		y-direction	22988	-19640	23184	-17408
		z-direction	93751	-89999	-78816	-87498
MAX SHEAR FORCE =			93783	lb		
MAX AXIAL FORCE =			23184	lb		
STATIC SHEAR FORCE =			87498	lb		
STATIC AXIAL FORCE =			17408	lb		
ZONE #14		Lower T-bar to Gusset Bracket				
		Direction	Combination 1	Combination 2	Combination 3	Combination 4
			Force (lb)	Force (lb)	Force (lb)	Force (lb)
		x-direction	1540	3848		
		y-direction	74074	73072	129328	72402
		z-direction	211228	-2022208	-214822	-195894
MAX SHEAR FORCE =			211263	lb		
MAX AXIAL FORCE =			129328	lb		
STATIC SHEAR FORCE =			195894	lb		
STATIC AXIAL FORCE =			72402	lb		

Table #5: Internal Bolt Sizing

Bolt Properties: Assume **A325 Bolts**
Source: *AISC Manual of Steel Construction, Ninth Edition*

Yield Strength F_y = 81000 psi

Assume Class B Contact Surfaces

Slip Coefficient u_s = 0.5

Allowable Slip Load per Unit of Bolt Area = F_v = 28000 psi

For Oversized Holes = F_v = 24000 psi

Tighten bolts to: **70%** of Yield Strength

Bolts sized to resist shear force with friction

Zone	Seismic Shear Force (lb)	Seismic Axial Force (lb)	Static Shear Force (lb)	Static Axial Force (lb)	Total Stress Area Req.. (in^2)	Bolt Diam. (mm)	Area of Bolt (in^2)	Minimum Number of Bolts Req..	Chosen Number of Bolts	Safety Factor Seismic (slippage)	Safety Factor Static (slippage)	Safety Factor Seismic (bolt yield)	Safety Factor Static (bolt yield)
Variable	F_{SHEAR}	F_A	F_{SHEAR}	F_A	A_T	d	A_B	N_{MIN}	N	SF_{BOLTS}	SF_{BOLTS}	SF_{by}	SF_{by}
Equation					Equation #1			Equation #2		Equation #3	Equation #3	Equation #4	Equation #4
A	20139	33756	12864	27447	1.3057	24	0.7012	2	24	22.57	35.58	1.38	1.39
B	34233	49989	34233	43197	2.0891	24	0.7012	3	60	33.69	33.79	1.40	1.40
C	54797	66496	51211	59791	3.1057	24	0.7012	5	60	20.90	22.43	1.39	1.39
D	73663	63990	11038	58626	3.7269	20	0.4869	8	12	1.79	12.20	1.20	1.21
E	500	0	500	0	0.0176	4	0.0195	1	6	6.54	6.54	1.43	1.43

ZONE DESCRIPTIONS

- A *AF to HC*
- B *HC to CMR*
- C *CMR to SST*
- D *SST to TF*
- E *TF to CST I-beams*

NOTES:

Seismic Stresses: "Allowable stresses may be increased 1/3 above the values otherwise provided when produced by wind or seismic loading . . ."
AISC MSC (Chap. A Sect. A5)

Table #6: Internal Bolt Data

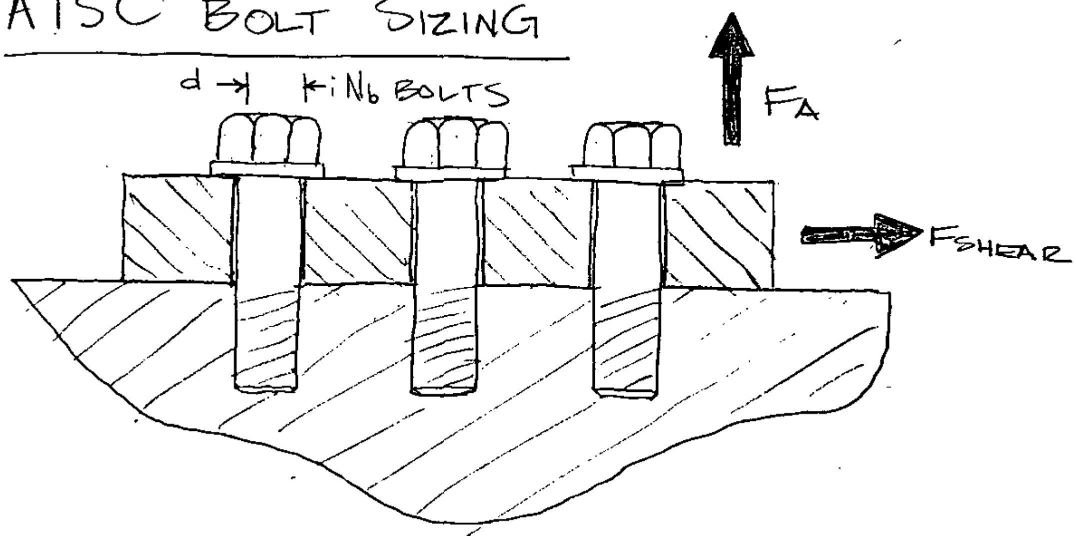
ZONE DESCRIPTIONS

- A *AF to HC*
- B *HC to CMR*
- C *CMR to SST*
- D *SST to TF*
- E *TF to CST I-beams*

DATA

ZONE	LOAD COMBINATION #1		LOAD COMBINATION #2		LOAD COMBINATION #3		LOAD COMBINATION #4		MAXIMUM VALUES	
	Shear Force (lb)	Axial Force (lb)	Shear Force (lb)	Axial Force (lb)	Shear Force (lb)	Axial Force (lb)	Shear Force (lb)	Axial Force (lb)	Shear Force (lb)	Axial Force (lb)
A	16273	27347	**20139**	**33756**	15619	26266	12864	27447	**20139**	**33756**
x-direction	-16259		-20074		-15180		-12588			
y-direction	674		1613		3675		2648			
B	**35678**	44347	29192	**49989**	31477	41465	34233	43197	**35678**	**49989**
x-direction	35640		29071		30823		34037			
y-direction	1649		2655		6385		3657			
C	**54797**	61942	47198	**66496**	47644	57377	51211	59791	**54797**	**66496**
x-direction	54741		47073		47255		51023			
y-direction	2482		3432		6078		4387			
D	10610	**63990**	10361	62106	**30463**	58405	11038	58626	**73663**	**63990**
x-direction	2213		-768		5102		3714			
y-direction	-10377		-10332		-30033		-10394			
E	*11832*	*64913*	*12420*	*62848*	*32119*	*59828*	*11737*	*59828*	**500**	**0**
x-direction	*-1188*		*-4031*		*639*		*636*			
y-direction	*-11772*		*-11748*		*-32113*		*-11720*			

AISC BOLT SIZING



AISC

F_u = ULTIMATE STRENGTH = S_{ut}
F_y = YIELD STRENGTH = S_y

- IN ORDER TO PREVENT SLIPPAGE ASSUME BOLTS MUST RESIST F_{SHEAR} WITH FRICTION BETWEEN THE MEMBERS

$$F_{SHEAR} \leq \mu_s (F_i - F_A)$$

WHERE: $F_i = (0.70) S_y A_b N_b$ {ASTM MSC 5-274 TABLE 4}

$$F_i = \frac{F_{SHEAR}}{\mu_s} + F_A$$

$$(0.70) S_y \underbrace{A_b N_b} = \frac{F_{SHEAR}}{\mu_s} + F_A$$

$A_b N_b = A_T$ = TOTAL STRESS AREA

(AISC BOLT SIZING CONT.)

- SOLVING FOR TOTAL REQUIRED STRESS AREA, A_T:

$$A_T = \frac{\left(\frac{F_{SHEAR}}{\mu_S}\right) + F_A}{(0.70)S_y}$$

EQUATION #1
TOTAL STRESS AREA REQD. PER BOLTING ZONE

- USE A_T AND THE SELECTED SCREW DIAMETER, d, TO CALCULATE THE REQUIRED NUMBER OF BOLTS, N_b.

$$N_{MIN} = \frac{A_T}{\pi \frac{d^2}{4}}$$

EQUATION #2
NUMBER OF BOLTS REQUIRED

- SAFETY FACTOR FOR BOLT SLIPPAGE:

THE FORCE ON A SLIP-CRITICAL JOINT SHALL NOT EXCEED THE ALLOWABLE RESISTANCE, P_S, OF THE CONNECTION:

$$P_S = F_S A_b N_b N_S$$ {AISC MSC 5-270 5(b)}

F_S = ALLOWABLE SLIP LOAD PER UNIT OF BOLT AREA
A_b = NOMINAL BODY AREA OF BOLT
N_b = NUMBER OF BOLTS IN JOINT
N_S = NUMBER OF SLIP PLANES

NOTE: FOR A325 BOLTS, ALLOWABLE SHEAR, F_V:

STANDARD SIZE HOLES

CLASS A (SLIP COEFFICIENT 0.33), F_V = 17000 psi

CLASS B (SLIP COEFFICIENT 0.50), F_V = 28000 psi

CLASS B OVERSIZED HOLES F_V = 24000 psi {AISC MSC 5-271 TABLE 3}

(AISC BOLT SIZING CONT.)

- COMBINED TENSION AND SHEAR IN SLIP-CRITICAL JOINTS:

REDUCTION FACTOR FOR F_V

$$F_S = F_V\left(1 - \frac{f_t A_b}{T_b}\right) \quad \{\text{AISC MSC 5-74}\}$$

f_t = AVE TENSILE STRESS IN BOLT DUE TO DIRECTLY APPLIED AXIAL LOAD TO BOLTS

T_b = PRETENSION LOAD OF THE BOLT

$$\left.\begin{aligned} T_b &= 0.70\, S_y A_b \\ f_t &= \frac{F_A}{A_b N_b} \end{aligned}\right\} \Rightarrow F_S = F_V\left[1 - \frac{F_A}{N_b (0.70) S_y A_b}\right]$$

- SAFETY FACTOR FOR JOINT SLIPPAGE:

$$SF_{BOLTS} = \frac{F_S A_b N_b}{F_{SHEAR}}$$

$$S.F. = \frac{F_V\left[1 - \frac{F_A}{N_b (0.70) S_y A_b}\right] A_b N_b}{F_{SHEAR}}$$

EQUATION #3 ← SAFETY FACTOR (SLIPPAGE)

22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS AMPAD

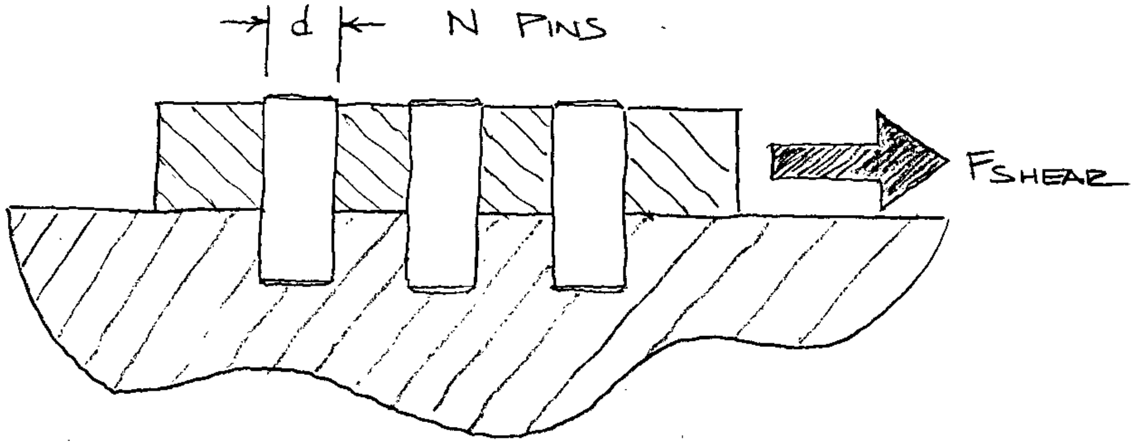
(AISC BOLT SIZING CONT.)

- SAFETY FACTOR FOR BOLT YIELDING IN TENSION:

$$SF_{by} = \frac{S_y}{(0.70)S_y + \frac{F_A}{N_b A_b}}$$

EQUATION #4 SAFETY FACTOR (BOLT YIELD)

PIN SIZING



SHEAR STRENGTH OF THE PINS BASED ON YIELD STRENGTH, S_y:

SHEAR STRENGTH = $S_{sy} = 0.577\, S_y$
(BY DISTORTION ENERGY THEORY)

$$N_{MIN} = \frac{F_{SHEAR}}{S_{sy}\left(\frac{\pi d^2}{4}\right)}$$

EQUATION #5
NUMBER OF PINS REQUIRED

SAFETY FACTOR FOR SLIPPAGE:

$$SF_{PINS} = \frac{S_{sy} N \left(\frac{\pi d^2}{4}\right)}{F_{SHEAR}}$$

EQUATION #6
SAFETY FACTOR (SLIPPAGE)