FINAL REPORT

on

DESIGN REVIEW OF THE D-ZERO CENTRAL
CALORIMETER MODULE ASSEMBLY
CALCULATIONS APPENDIX

to

FERMI NATIONAL ACCELERATOR LABORATORY

November, 1987

by

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CALCULATIONS

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CC-MOD-01

Review and Verification of the Finite Element Analyses

REVIEW AND VERIFICATION OF THE FINITE ELEMENT ANALYSES

A. REVIEW

Fermilek personnel performed 2-D and 3-D finite element analyses of the module assembly. The loadings considered were deadweight and differential thermal expansion. Their results were provided in the attachments ^(2,3,4) to this calc. These results were reviewed for appropriateness of modelling technique and reasonableness of assumptions and results.

Model Geometry

Both the 2-D and 3-D models considered one-quarter of the structure, taking advantage of the vertical lines of symmetry of the structure and loadings. This is a useful and appropriate technique. Based on the proportions of the main structural features shown in the figures, such as the support beams and straps and the ring assemblies, the model geometry appears correct.

Modelling Assumptions

As indicated, the model takes advantage of symmetry to consider one-quarter of the structure. Each ring was modelled by two elements through the thickness (in the radial direction). The rings were treated as uniform and continuous circumferentially, with 32 elements subtending 5.625° of arc circumferentially. Friction plane lift-off (gap) elements were used to represent the interface between the rings.

Analyses were initially performed assuming conditions of zero friction on the bearing surfaces between the rings. However, the bearing surfaces are bare stainless steel-on-stainless steel, which may have a stick-slip coefficient of friction between 0.5 and 1.0. At Battelle's suggestion an analysis was performed considering a "sticking" condition between rings at the locations of maximum constrained radial expansion, which would correspond to the highest normal and tangential forces.

These conditions occurred at angular locations corresponding to the supports, $\pm 56.25^\circ$ from BDC.

The supports were alternately treated as rolling (horizontally unrestrained) and horizontally fixed, in Femilab analyses.

A thermal gradient was also considered to occur during the cool-down cycle. The gradient is as shown in Figure 5 of the Attachment 2. Battelle cannot comment on the validity of the assumed distribution, except that it appears to be plausible. The thermal gradient was applied to the 3-D model only.

Results

The attached summaries^{2,3&4, provided by Femilab} indicate the results. The 2-D and 3-D analyses returned very similar results for the deadweight loading for almost all load components throughout the structure. A negligible effect was seen^{in the results} between the assumption of rolling or laterally fixed beam supports. This is due to the fact that the tension strap

analyzed for deadweight only.

The actual condition in the physical structure will probably be intermediate between the zero friction and full-friction case, assuming conditions such as surface treatments, impact or vibration do not occur. Some degree of stick-slip can be expected during the construction process and also during the cool-down process.

Unless specific actions are taken to guarantee that ^{a controllable degree of} friction does or does not occur, the actual degree of sticking will be unknown. Therefore, in analyzing the structure, the zero-friction loads will be used where they are greater than the loads calculated considering friction. If the loads calculated considering friction are significantly greater than the zero-friction loads, recommendations to alleviate the condition will be made. This approach guarantees (within the limits of uncertainty inherent in the analyses) that the structure will be adequate for the actual loads.

For additional conservatism, and to account for unknown aspects inherent to the thermal expansion analysis, a load factor of 1.25 ($LF = 1.25$) will be used in applying results from the finite element analyses, unless other conservatisms are inherent.

B. VERIFICATION

Finite Element Check Model

The Ferunlab analyses evidently have been performed using appropriate methods. The results appear credible and consistent. However, as a reasonableness check, a highly simplified finite element analysis was performed on the CH ring under load. This was done instead of using hand calculations because of the complexity of the loading and constraints.

The CH ring was modelled ^{using program SAVFEM} as a ring with a mean radius of 7.7.712 inches, using 32 general beam elements over a 180° arc. The model was 2-D. The beam cross-sectional properties were based on the CH module endplates projected in a vertical plane. The weight of the CH ring was accounted for in an effective material density and cross-sectional area, with a vertical body force factor of 1.0g. The combined weight of the FH and EM rings was applied as a radial load distribution over the lower 180° , varying as $w(\theta) = w_r \cos \theta$. This was considered

a reasonable working assumption. Other distributions are plausible, such as a linear variation, $w(\theta) = w_r(1 - \frac{2\theta}{\pi})$, or a uniform radial load.

A saddle support condition was considered between $\theta = \pm 56.25^\circ$, which approximates the support of the CH ring, except for the restrained radial displacement.

ASSUMED LOADINGS =

ASSUMED BOUNDARY CONDITIONS =

Note that radial loads within $0^\circ \leq \theta \leq 56.25^\circ$ were omitted from the analysis, as they are reacted directly by the assumed saddle constraint.

Results

The results of the simple model analysis are compared with the Fermilab 3-D analysis (weight only, no friction), in the following graphs of hoop force and bending moment. Due to erroneous input, the simple model support conditions were terminated at $\theta = 45^\circ$ instead of 56.25° of arc. There is a factor difference of perhaps 2 to 3 on the magnitude of loads. However, the order of magnitude of the loads between the analyses is consistent and the general trends are in good agreement. It is apparent that the interaction between the rings, and between the CH ring and the supports, is too complex to be adequately represented by this simple analysis. However, this model does give good indications that the results of the Fermilab models are credible. The computer output is found in Attachment 1.

(Shear forces were not available.)

CC-MOD-01 WYR 10/1/87 10/10

FERMILAB D-ZERO MODULE ASSEMBLY -- CH RING LOADING CHECK, DEADWEIGHT ONLY, NO FRICTION

MATERIAL PROPERTIES

MATERIAL 1 -- ELASTIC - ISOTROPIC

E = 3.0000E+07
NU = 3.0000E-01
G = 1.1540E+07
WEIGHT = 7.1550E+00
MASS = 0.0000E+00
ALPHA = 0.0000E+00

GRID POINT	MATRIX FX	ORDERING FY	MZ	GRID COORDINATES X	Y
1	0	0	0	0.0000E+00	-7.7712E+01
2	0	1	2	7.8170E+00	-7.7338E+01
3	0	3	4	1.5161E+01	-7.6219E+01
4	0	5	6	2.2559E+01	-7.4368E+01
5	0	7	8	2.9739E+01	-7.1797E+01
6	0	9	10	3.6833E+01	-6.8536E+01
7	0	11	12	4.3174E+01	-6.4615E+01
8	0	13	14	4.9300E+01	-6.0072E+01
9	0	15	16	5.4951E+01	-5.4951E+01
10	17	18	19	6.0072E+01	-4.9300E+01
11	20	21	22	6.4615E+01	-4.3174E+01
12	23	24	25	6.8536E+01	-3.6833E+01
13	26	27	28	7.1797E+01	-2.9739E+01
14	29	30	31	7.4368E+01	-2.2559E+01
15	32	33	34	7.6219E+01	-1.5161E+01
16	35	36	37	7.7338E+01	-7.8170E+00
17	38	39	40	7.7712E+01	0.0000E+00
18	41	42	43	7.7338E+01	7.8170E+00
19	44	45	46	7.6219E+01	1.5161E+01
20	47	48	49	7.4368E+01	2.2559E+01
21	50	51	52	7.1797E+01	2.9739E+01
22	53	54	55	6.8536E+01	3.6833E+01
23	56	57	58	6.4615E+01	4.3174E+01
24	59	60	61	6.0072E+01	4.9300E+01
25	62	63	64	5.4951E+01	5.4951E+01
26	65	66	67	4.9300E+01	6.0072E+01
27	68	69	70	4.3174E+01	6.4615E+01
28	71	72	73	3.6833E+01	6.8536E+01
29	74	75	76	2.9739E+01	7.1797E+01
30	77	78	79	2.2559E+01	7.4368E+01
31	80	81	82	1.5161E+01	7.6219E+01
32	83	84	85	7.8170E+00	7.7338E+01
33	86	0	0	0.0000E+00	7.7712E+01

45°
56.25°

90°

180°

RING WT = 254400# → use 255K

$$R_{mean} = \frac{1}{2}(88.199 + 67.225) = 77.712"$$

$$WT/INCH = \frac{255000}{(2\pi)(77.712)} = 522.24 \#/IN$$

END PLATES

$$d = 88.199 - 67.225 = 20.974"$$

$$t = 1.74"$$

$$A = (2)(1.74)(20.974) = 72.990 in^2$$

for 2 plates

$$Effective I = 2\left(\frac{1}{12}\right)(1.74)(20.974)^3 = 26757 in^4$$

$$Effective \rho_w = \frac{522.24 \#/in}{73.0 in^2} = 7.155 \#/in^3$$

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GRID POINT ROTATIONS

GRID POINT ROTATIONAL MATRIX 1 FOR GRID POINTS

1

ROW 1	0.0000E+00	-1.0000E+00	
ROW 2	1.0000E+00	0.0000E+00	
GRID POINT ROTATIONAL MATRIX 2 FOR GRID POINTS			
ROW 1	9.8000E-02	-9.9520E-01	2
ROW 2	9.9520E-01	9.8000E-02	
GRID POINT ROTATIONAL MATRIX 3 FOR GRID POINTS			
ROW 1	1.9510E-01	-9.8080E-01	3
ROW 2	9.8080E-01	1.9510E-01	
GRID POINT ROTATIONAL MATRIX 4 FOR GRID POINTS			
ROW 1	2.9030E-01	-9.5690E-01	4
ROW 2	9.5690E-01	2.9030E-01	
GRID POINT ROTATIONAL MATRIX 5 FOR GRID POINTS			
ROW 1	3.8270E-01	-9.2390E-01	5
ROW 2	9.2390E-01	3.8270E-01	
GRID POINT ROTATIONAL MATRIX 6 FOR GRID POINTS			
ROW 1	4.7140E-01	-8.8190E-01	6
ROW 2	8.8190E-01	4.7140E-01	
GRID POINT ROTATIONAL MATRIX 7 FOR GRID POINTS			
ROW 1	5.5580E-01	-8.3150E-01	7
ROW 2	8.3150E-01	5.5580E-01	
GRID POINT ROTATIONAL MATRIX 8 FOR GRID POINTS			
ROW 1	6.3440E-01	-7.7300E-01	8
ROW 2	7.7300E-01	6.3440E-01	
GRID POINT ROTATIONAL MATRIX 9 FOR GRID POINTS			
ROW 1	7.0710E-01	-7.0710E-01	9
ROW 2	7.0710E-01	7.0710E-01	
GRID POINT ROTATIONAL MATRIX 10 FOR GRID POINTS			
ROW 1	7.7300E-01	-6.3440E-01	10
ROW 2	6.3440E-01	7.7300E-01	
GRID POINT ROTATIONAL MATRIX 11 FOR GRID POINTS			
ROW 1	8.3150E-01	-5.5580E-01	11
ROW 2	5.5580E-01	8.3150E-01	
GRID POINT ROTATIONAL MATRIX 12 FOR GRID POINTS			
ROW 1	8.8190E-01	-4.7140E-01	12
ROW 2	4.7140E-01	8.8190E-01	
GRID POINT ROTATIONAL MATRIX 13 FOR GRID POINTS			
ROW 1	9.2390E-01	-3.8270E-01	13
ROW 2	3.8270E-01	9.2390E-01	
GRID POINT ROTATIONAL MATRIX 14 FOR GRID POINTS			
ROW 1	9.5690E-01	-2.9030E-01	14
ROW 2	2.9030E-01	9.5690E-01	
GRID POINT ROTATIONAL MATRIX 15 FOR GRID POINTS			
ROW 1	9.8080E-01	-1.9510E-01	15
ROW 2	1.9510E-01	9.8080E-01	
GRID POINT ROTATIONAL MATRIX 16 FOR GRID POINTS			
ROW 1	9.9520E-01	-9.8000E-02	16
ROW 2	9.8000E-02	9.9520E-01	

COORDINATE ROTATIONAL MATRIX

$$\begin{Bmatrix} x' \\ y' \end{Bmatrix} = \begin{bmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{bmatrix} \begin{Bmatrix} X \\ Y \end{Bmatrix}$$

$$x' = X \sin \theta - Y \cos \theta$$

$$y' = X \cos \theta + Y \sin \theta$$

$$\therefore R_{11} = R_{22} = \sin \theta$$

$$-R_{12} = +R_{21} = \cos \theta$$

GRID POINT ROTATIONAL MATRIX 17 FOR GRID POINTS			17
ROW 1	1.0000E+00	0.0000E+00	
ROW 2	0.0000E+00	1.0000E+00	
GRID POINT ROTATIONAL MATRIX 18 FOR GRID POINTS			18
ROW 1	9.9520E-01	9.8000E-02	
ROW 2	-9.8000E-02	9.9520E-01	
GRID POINT ROTATIONAL MATRIX 19 FOR GRID POINTS			19
ROW 1	9.8080E-01	1.9510E-01	
ROW 2	-1.9510E-01	9.8080E-01	
GRID POINT ROTATIONAL MATRIX 20 FOR GRID POINTS			20
ROW 1	9.5890E-01	2.9030E-01	
ROW 2	-2.9030E-01	9.5890E-01	
GRID POINT ROTATIONAL MATRIX 21 FOR GRID POINTS			21
ROW 1	9.2390E-01	3.8270E-01	
ROW 2	-3.8270E-01	9.2390E-01	
GRID POINT ROTATIONAL MATRIX 22 FOR GRID POINTS			22
ROW 1	8.8190E-01	4.7140E-01	
ROW 2	-4.7140E-01	8.8190E-01	
GRID POINT ROTATIONAL MATRIX 23 FOR GRID POINTS			23
ROW 1	8.3150E-01	5.5580E-01	
ROW 2	-5.5580E-01	8.3150E-01	
GRID POINT ROTATIONAL MATRIX 24 FOR GRID POINTS			24
ROW 1	7.7300E-01	6.3440E-01	
ROW 2	-6.3440E-01	7.7300E-01	
GRID POINT ROTATIONAL MATRIX 25 FOR GRID POINTS			25
ROW 1	7.0710E-01	7.0710E-01	
ROW 2	-7.0710E-01	7.0710E-01	
GRID POINT ROTATIONAL MATRIX 26 FOR GRID POINTS			26
ROW 1	6.3440E-01	7.7300E-01	
ROW 2	-7.7300E-01	6.3440E-01	
GRID POINT ROTATIONAL MATRIX 27 FOR GRID POINTS			27
ROW 1	5.5580E-01	8.3150E-01	
ROW 2	-8.3150E-01	5.5580E-01	
GRID POINT ROTATIONAL MATRIX 28 FOR GRID POINTS			28
ROW 1	4.7140E-01	8.8190E-01	
ROW 2	-8.8190E-01	4.7140E-01	
GRID POINT ROTATIONAL MATRIX 29 FOR GRID POINTS			29
ROW 1	3.8270E-01	9.2390E-01	
ROW 2	-9.2390E-01	3.8270E-01	
GRID POINT ROTATIONAL MATRIX 30 FOR GRID POINTS			30
ROW 1	2.9030E-01	9.5890E-01	
ROW 2	-9.5890E-01	2.9030E-01	
GRID POINT ROTATIONAL MATRIX 31 FOR GRID POINTS			31
ROW 1	1.9510E-01	9.8080E-01	
ROW 2	-9.8080E-01	1.9510E-01	
GRID POINT ROTATIONAL MATRIX 32 FOR GRID POINTS			32

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ROW 1 9.8000E-02 9.9520E-01
 ROW 2 -9.9520E-01 9.8000E-02

GRID POINT ROTATIONAL MATRIX 33 FOR GRID POINTS 33
 ROW 1 0.0000E+00 1.0000E+00
 ROW 2 -1.0000E+00 0.0000E+00

SMALL DISPLACEMENT LINEAR ANALYSIS OPTION SELECTED

NO MASS MATRIX OPTION SELECTED

NO DAMPING MATRIX OPTION SELECTED

NO CREEP/RELAXATION SOLUTION OPTION SELECTED

REFERENCE MEAN TEMPERATURE = 0.0000E+00
 TEMPERATURE GRADIENT = 0.0000E+00

GENERAL BEAM ELEMENT PROPERTIES

CROSS SECTION NUMBER	SUB SECTION NUMBER	A OR THICKNESS C-33	S-1 OR X-2 S-33	J-11 OR X-3	C-11 OR X-2	S-11 OR X-3	I-22	C-22	S-22	I-33
1	0	7.2990E+01 1.0487E+01	1.0000E+00 1.5000E+00	2.6385E+02	3.4800E+00	1.0000E+00	7.3881E+01	1.7400E+00	1.5000E+00	2.8757E+03

ELEMENT NUMBER	GRID POINT 1	GRID POINT 2	MATERIAL NUMBER	PRINT OPTION	NUMBER -INTEG. PTS. X-1	CROSS - SECTION- NUMBER X-2/3	DIRECTION COSINES L-3 M-3 N-3	LENGTH
1	1	2	1	0	0	1	0.00000 0.00000 1.00000	7.6282E+00
2	2	3	1	0	0	1	0.00000 0.00000 1.00000	7.6285E+00
3	3	4	1	0	0	1	0.00000 0.00000 1.00000	7.6285E+00
4	4	5	1	0	0	1	0.00000 0.00000 1.00000	7.6258E+00
5	5	6	1	0	0	1	0.00000 0.00000 1.00000	7.6284E+00
6	6	7	1	0	0	1	0.00000 0.00000 1.00000	7.6282E+00
7	7	8	1	0	0	1	0.00000 0.00000 1.00000	7.6287E+00
8	8	9	1	0	0	1	0.00000 0.00000 1.00000	7.6282E+00
9	9	10	1	0	0	1	0.00000 0.00000 1.00000	7.6282E+00
10	10	11	1	0	0	1	0.00000 0.00000 1.00000	7.6287E+00
11	11	12	1	0	0	1	0.00000 0.00000 1.00000	7.6282E+00
12	12	13	1	0	0	1	0.00000 0.00000 1.00000	7.6284E+00
13	13	14	1	0	0	1	0.00000 0.00000 1.00000	7.6258E+00
14	14	15	1	0	0	1	0.00000 0.00000 1.00000	7.6285E+00
15	15	16	1	0	0	1	0.00000 0.00000 1.00000	7.6285E+00
16	16	17	1	0	0	1	0.00000 0.00000 1.00000	7.6282E+00
17	17	18	1	0	0	1	0.00000 0.00000 1.00000	7.6262E+00
18	18	19	1	0	0	1	0.00000 0.00000 1.00000	7.6285E+00
19	19	20	1	0	0	1	0.00000 0.00000 1.00000	7.6285E+00
20	20	21	1	0	0	1	0.00000 0.00000 1.00000	7.6258E+00
21	21	22	1	0	0	1	0.00000 0.00000 1.00000	7.6284E+00
22	22	23	1	0	0	1	0.00000 0.00000 1.00000	7.6282E+00
23	23	24	1	0	0	1	0.00000 0.00000 1.00000	7.6287E+00
24	24	25	1	0	0	1	0.00000 0.00000 1.00000	7.6282E+00
25	25	26	1	0	0	1	0.00000 0.00000 1.00000	7.6282E+00

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26	26	27	1	0	0	0	1	0.00000	0.00000	1.00000	7.8267E+00
27	27	28	1	0	0	0	1	0.00000	0.00000	1.00000	7.8262E+00
28	28	29	1	0	0	0	1	0.00000	0.00000	1.00000	7.8264E+00
29	29	30	1	0	0	0	1	0.00000	0.00000	1.00000	7.8258E+00
30	30	31	1	0	0	0	1	0.00000	0.00000	1.00000	7.8265E+00
31	31	32	1	0	0	0	1	0.00000	0.00000	1.00000	7.8265E+00
32	32	33	1	0	0	0	1	0.00000	0.00000	1.00000	7.8262E+00

TOTAL NUMBER OF ELEMENTS IN K11-UPPER = 312

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LOAD CASE 1 - STATIC LOAD

APPLIED NON-ZERO LOAD CASE FORCE/DISPLACEMENT VECTOR

GRID POINT	FX	FY	NZ	
12	9.9080E+03	0.0000E+00	0.0000E+00	ROTATED COORDINATE SYSTEM
13	8.0430E+03	0.0000E+00	0.0000E+00	ROTATED COORDINATE SYSTEM
14	6.1020E+03	0.0000E+00	0.0000E+00	ROTATED COORDINATE SYSTEM
15	4.0870E+03	0.0000E+00	0.0000E+00	ROTATED COORDINATE SYSTEM
16	2.0590E+03	0.0000E+00	0.0000E+00	ROTATED COORDINATE SYSTEM

LOAD CASE DIRECTIONAL MATERIAL WEIGHT MULTIPLIERS

GLOBAL X-AXIS DIRECTION = 0.0000E+00
GLOBAL Y-AXIS DIRECTION = -1.0000E+00

Net radial force @ Node n
 $F_n = \frac{1}{2} w r (\sin \phi_{n+1} - \sin \phi_{n-1})$

Radial load distribution

$$w(\alpha) = w \cos \alpha, \text{ #/in}$$

Net vertical component

$$W = \int_0^{\pi/2} (w \cos \alpha) \cos \alpha r d\alpha$$

$$= \int_0^{\pi/2} w r \cos^2 \alpha d\alpha$$

$$= w r \left(\frac{\alpha}{2} + \frac{\sin 2\alpha}{4} \right) \bigg|_0^{\pi/2}$$

$$= \frac{\pi}{4} w r$$

$$\therefore w = \frac{4W}{\pi r} = \frac{(4)(\frac{1}{2})(293000 + 44000)}{(\pi)(77.712)} = 2760.7 \text{ #/in}$$

* It is assumed that 50% of the load goes directly through the CH ring to the support beams, and that the other 50% is distributed over the CH ring between the support beams.

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INCREMENTAL LOAD STEP 1 - LOAD FACTOR = 1.0000E+00 - TIME = 0.0000E+00

DIRECTIONAL MATERIAL WEIGHT MULTIPLIERS

GLOBAL X-AXIS DIRECTION = 0.0000E+00
GLOBAL Y-AXIS DIRECTION = -1.0000E+00

DISPLACEMENT VECTOR

GRID POINT	X	Y	THETA-Z	
1	0.0000E+00	0.0000E+00	0.0000E+00	ROTATED COORDINATE SYSTEM
2	0.0000E+00	-3.2060E-04	-4.1191E-06	ROTATED COORDINATE SYSTEM
3	0.0000E+00	-8.3984E-04	-8.2545E-06	ROTATED COORDINATE SYSTEM
4	0.0000E+00	-9.5649E-04	-1.2224E-05	ROTATED COORDINATE SYSTEM
5	0.0000E+00	-1.2688E-03	-1.6616E-05	ROTATED COORDINATE SYSTEM
6	0.0000E+00	-1.5768E-03	-1.9179E-05	ROTATED COORDINATE SYSTEM
7	0.0000E+00	-1.8749E-03	-2.8204E-05	ROTATED COORDINATE SYSTEM
8	0.0000E+00	-2.1772E-03	-1.2837E-05	ROTATED COORDINATE SYSTEM
9	0.0000E+00	-2.4280E-03	-8.7546E-05	ROTATED COORDINATE SYSTEM
10	1.0888E-03	-2.8798E-03	-2.5222E-04	ROTATED COORDINATE SYSTEM
11	3.1542E-03	-3.1058E-03	-3.5310E-04	ROTATED COORDINATE SYSTEM
12	5.7122E-03	-3.7751E-03	-3.9833E-04	ROTATED COORDINATE SYSTEM
13	8.3289E-03	-4.7088E-03	-3.9173E-04	ROTATED COORDINATE SYSTEM
14	1.0868E-02	-5.8898E-03	-3.5199E-04	ROTATED COORDINATE SYSTEM
15	1.2477E-02	-7.2723E-03	-2.8823E-04	ROTATED COORDINATE SYSTEM
16	1.3595E-02	-8.7925E-03	-2.0986E-04	ROTATED COORDINATE SYSTEM
17	1.3933E-02	-1.0373E-02	-1.2439E-04	ROTATED COORDINATE SYSTEM
18	1.3454E-02	-1.1934E-02	-3.7360E-05	ROTATED COORDINATE SYSTEM
19	1.2170E-02	-1.3393E-02	4.6990E-05	ROTATED COORDINATE SYSTEM
20	1.0129E-02	-1.4673E-02	1.2500E-04	ROTATED COORDINATE SYSTEM
21	7.4139E-03	-1.5700E-02	1.9362E-04	ROTATED COORDINATE SYSTEM
22	4.1329E-03	-1.8415E-02	2.5044E-04	ROTATED COORDINATE SYSTEM
23	4.1829E-04	-1.8787E-02	2.9370E-04	ROTATED COORDINATE SYSTEM
24	-3.5902E-03	-1.8722E-02	3.2224E-04	ROTATED COORDINATE SYSTEM
25	-7.7313E-03	-1.8258E-02	3.3554E-04	ROTATED COORDINATE SYSTEM
26	-1.1849E-02	-1.5371E-02	3.3363E-04	ROTATED COORDINATE SYSTEM
27	-1.5788E-02	-1.4073E-02	3.1712E-04	ROTATED COORDINATE SYSTEM
28	-1.9404E-02	-1.2390E-02	2.8709E-04	ROTATED COORDINATE SYSTEM
29	-2.2580E-02	-1.0361E-02	2.4508E-04	ROTATED COORDINATE SYSTEM
30	-2.5144E-02	-8.0419E-03	1.9304E-04	ROTATED COORDINATE SYSTEM
31	-2.7057E-02	-5.4921E-03	1.3316E-04	ROTATED COORDINATE SYSTEM
32	-2.8234E-02	-2.7855E-03	8.7938E-05	ROTATED COORDINATE SYSTEM
33	-2.8832E-02	0.0000E+00	0.0000E+00	ROTATED COORDINATE SYSTEM

* DUE TO INPUT ERROR
 $\theta = 45^\circ$ INSTEAD OF 56.25° .

GENERAL BEAM ELEMENT FORCES, STRESSES, AND CURVATURES

POINT ID	AXIAL FORCE	AXIAL STRESS	TORSIONAL TORQUE	TORSIONAL STRESS	BENDING-2 MOMENT	BENDING-2 STRESS	CURVATURE	MOMENT	BENDING-3 STRESS	CURVATURE
1E										
1G	-9.1942E+04	-1.2597E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	4.3581E+04	1.7081E+02	5.4292E-07
2G	-9.1942E+04	-1.2597E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	4.3132E+04	1.6905E+02	5.3732E-07
2E										
2G	-9.1549E+04	-1.2543E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	4.3158E+04	1.6914E+02	5.3762E-07
3G	-9.1549E+04	-1.2543E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	4.3898E+04	1.7205E+02	5.4687E-07

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3E												
3G	-9.0794E+04	-1.2439E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	4.3947E+04	1.7224E+02	5.4748E-07	
4G	-9.0794E+04	-1.2439E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.9817E+04	1.5527E+02	4.9353E-07	
4E												
4G	-8.9580E+04	-1.2273E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.9889E+04	1.5555E+02	4.9443E-07	
5G	-8.9580E+04	-1.2273E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	5.2777E+04	2.0885E+02	6.5747E-07	
5E												
5G	-8.8304E+04	-1.2098E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	5.2871E+04	2.0722E+02	6.5885E-07	
6G	-8.8304E+04	-1.2098E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0758E+03	4.2158E+00	1.3400E-08	
6E												
6G	-8.5548E+04	-1.1721E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.1928E+03	4.6751E+00	1.4860E-08	
7G	-8.5548E+04	-1.1721E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.8879E+05	7.3994E+02	2.3519E-08	
7E												
7G	-8.6639E+04	-1.1870E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.8893E+05	7.4048E+02	2.3538E-08	
8G	-8.6639E+04	-1.1870E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-5.1240E+05	-2.0082E+03	-8.3833E-08	
8E												
8G	-7.1929E+04	-9.8547E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-5.1224E+05	-2.0078E+03	-8.3813E-08	
9G	-7.1929E+04	-9.8547E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.0850E+08	8.1717E+03	2.5974E-05	
9E												
9G	-5.8893E+04	-7.7947E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.0851E+08	8.1723E+03	2.5976E-05	
10G	-5.8893E+04	-7.7947E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.3815E+08	5.4145E+03	1.7210E-05	
10E												
10G	-6.2461E+04	-8.5575E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.3817E+08	5.4152E+03	1.7213E-05	
11G	-6.2461E+04	-8.5575E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	7.4197E+05	2.9080E+03	9.2432E-06	
11E												
11G	-6.8958E+04	-9.1737E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	7.4218E+05	2.9088E+03	9.2458E-06	
12G	-6.8958E+04	-9.1737E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.6784E+05	6.5782E+02	2.0909E-06	
12E												
12G	-6.8932E+04	-9.5811E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.6808E+05	6.5868E+02	2.0938E-06	
13G	-6.8932E+04	-9.5811E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-2.8499E+05	-1.0386E+03	-3.3012E-06	
13E												
13G	-7.1019E+04	-9.7300E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-2.8476E+05	-1.0377E+03	-3.2983E-06	
14G	-7.1019E+04	-9.7300E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-5.7191E+05	-2.2415E+03	-7.1247E-08	
14E												
14G	-7.0462E+04	-9.6537E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-5.7167E+05	-2.2408E+03	-7.1217E-08	
15G	-7.0462E+04	-9.6537E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-7.7041E+05	-3.0195E+03	-9.5976E-06	
15E												
15G	-6.8536E+04	-9.3899E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-7.7017E+05	-3.0185E+03	-9.5945E-06	
16G	-6.8536E+04	-9.3899E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-8.7982E+05	-3.4475E+03	-1.0958E-05	
16E												
16G	-6.5534E+04	-8.9785E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-8.7938E+05	-3.4465E+03	-1.0955E-05	
17G	-6.5534E+04	-8.9785E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-9.1988E+05	-3.6053E+03	-1.1480E-05	
17E												
17G	-6.1761E+04	-8.4616E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-9.1983E+05	-3.6043E+03	-1.1458E-05	
18G	-6.1761E+04	-8.4616E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-9.1247E+05	-3.5763E+03	-1.1387E-05	
18E												
18G	-5.7432E+04	-7.8885E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-9.1223E+05	-3.5753E+03	-1.1384E-05	
19G	-5.7432E+04	-7.8885E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-8.8338E+05	-3.3839E+03	-1.0758E-05	
19E												
19G	-5.2664E+04	-7.2153E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-8.8314E+05	-3.3829E+03	-1.0753E-05	
20G	-5.2664E+04	-7.2153E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-7.7898E+05	-3.0530E+03	-9.7042E-06	
20E												
20G	-4.7579E+04	-6.5188E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-7.7874E+05	-3.0521E+03	-9.7013E-06	
21G	-4.7579E+04	-6.5188E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-8.8588E+05	-2.8097E+03	-8.2950E-06	
21E												
21G	-4.2298E+04	-5.7950E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-8.8583E+05	-2.8088E+03	-8.2922E-06	
22G	-4.2298E+04	-5.7950E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-5.3068E+05	-2.0799E+03	-6.6111E-06	
22E												
22G	-3.8943E+04	-5.0615E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-5.3046E+05	-2.0791E+03	-6.6084E-06	
23G	-3.8943E+04	-5.0615E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-3.8017E+05	-1.4900E+03	-4.7380E-06	
23E												
23G	-3.1637E+04	-4.3344E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-3.7898E+05	-1.4882E+03	-4.7338E-06	

$\theta = 70.25^\circ$
@ NODE 11

$\theta = 90^\circ$
@ NODE 17

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24G	-3.1837E+04	-4.3344E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-2.2088E+05	-8.8571E+02	-2.7517E-08
24E											
24G	-2.8490E+04	-3.8292E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-2.2089E+05	-8.8498E+02	-2.7493E-08
25G	-2.8490E+04	-3.8292E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-5.9148E+04	-2.3181E+02	-7.3682E-07
25E											
25G	-2.1808E+04	-2.9804E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-5.8970E+04	-2.3112E+02	-7.3483E-07
28G	-2.1808E+04	-2.9804E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	9.9121E+04	3.8848E+02	1.2348E-08
28E											
28G	-1.7100E+04	-2.3428E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	9.9278E+04	3.8910E+02	1.2388E-08
27G	-1.7100E+04	-2.3428E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.4837E+05	9.7343E+02	3.0941E-08
27E											
27G	-1.3058E+04	-1.7888E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.4851E+05	9.7397E+02	3.0958E-08
28G	-1.3058E+04	-1.7888E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.8359E+05	1.5034E+03	4.7788E-08
28E											
28G	-9.5539E+03	-1.3089E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.8370E+05	1.5039E+03	4.7801E-08
29G	-9.5539E+03	-1.3089E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	5.0044E+05	1.9814E+03	6.2343E-08
29E											
29G	-8.8850E+03	-9.1314E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	5.0054E+05	1.9818E+03	6.2355E-08
30G	-8.8850E+03	-9.1314E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	5.9525E+05	2.3330E+03	7.4154E-08
30E											
30G	-4.4477E+03	-8.0937E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	5.9532E+05	2.3333E+03	7.4183E-08
31G	-4.4477E+03	-8.0937E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	6.8511E+05	2.6088E+03	8.2857E-08
31E											
31G	-2.9451E+03	-4.0349E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	6.8518E+05	2.6070E+03	8.2863E-08
32G	-2.9451E+03	-4.0349E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	7.0789E+05	2.7744E+03	8.8186E-08
32E											
32G	-2.1863E+03	-2.9954E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	7.0791E+05	2.7745E+03	8.8189E-08
33G	-2.1863E+03	-2.9954E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	7.2230E+05	2.8309E+03	8.9982E-08

TOP OF
Ridg

UNBALANCED EQUILIBRATED GRID POINT FORCE VECTOR

GRID POINT	FX	FY	MZ	
1	-9.1829E+04	-8.5593E+03	4.6109E+04	ROTATED COORDINATE SYSTEM
2	-1.2557E+03	1.2751E+04	2.7285E-12	ROTATED COORDINATE SYSTEM
3	-2.8373E+03	1.3258E+04	-1.0004E-11	ROTATED COORDINATE SYSTEM
4	-3.0138E+03	9.9334E+03	6.4574E-11	ROTATED COORDINATE SYSTEM
5	-8.0024E+03	1.9319E+04	2.0009E-11	ROTATED COORDINATE SYSTEM
6	9.1024E+03	-1.7029E+04	1.0681E-10	ROTATED COORDINATE SYSTEM
7	-7.1213E+04	1.0658E+05	2.2919E-10	ROTATED COORDINATE SYSTEM
8	2.8717E+05	-3.2554E+05	1.8007E-10	ROTATED COORDINATE SYSTEM
9	-3.1215E+05	3.1215E+05	-4.8568E-10	ROTATED COORDINATE SYSTEM
10	-1.5511E-10	-9.1998E-11	3.7835E-10	ROTATED COORDINATE SYSTEM
11	5.3882E-10	4.8384E-10	-8.4401E-10	ROTATED COORDINATE SYSTEM
12	1.1703E+03	-4.8711E+03	-3.0288E-09	ROTATED COORDINATE SYSTEM
13	6.1207E+02	-3.0781E+03	-3.7107E-09	ROTATED COORDINATE SYSTEM
14	2.8300E+02	-1.7714E+03	-3.1432E-09	ROTATED COORDINATE SYSTEM
15	7.8662E+01	-7.9932E+02	-4.8566E-09	ROTATED COORDINATE SYSTEM
16	9.8832E+00	-2.0178E+02	-2.4593E-09	ROTATED COORDINATE SYSTEM
17	-2.4187E-10	-3.8380E-12	-2.7212E-09	ROTATED COORDINATE SYSTEM
18	-5.2381E-10	1.0642E-10	-3.9436E-09	ROTATED COORDINATE SYSTEM
19	-1.2460E-09	3.2204E-10	2.1973E-09	ROTATED COORDINATE SYSTEM
20	1.1858E-09	-8.7434E-10	2.1828E-09	ROTATED COORDINATE SYSTEM
21	-1.1057E-09	5.1708E-10	1.4552E-09	ROTATED COORDINATE SYSTEM
22	4.0883E-10	1.9088E-10	-2.0373E-10	ROTATED COORDINATE SYSTEM
23	-4.9729E-10	4.0010E-10	5.0204E-10	ROTATED COORDINATE SYSTEM
24	2.4428E-10	-1.1912E-09	1.1751E-09	ROTATED COORDINATE SYSTEM
25	4.3795E-10	-7.8652E-10	-8.4574E-11	ROTATED COORDINATE SYSTEM
26	-8.9840E-10	3.4030E-10	1.8226E-09	ROTATED COORDINATE SYSTEM

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27	-1.2486E-09	1.0733E-09	-4.0018E-10	ROTATED COORDINATE SYSTEM
28	1.3837E-09	-6.0100E-10	-8.6366E-09	ROTATED COORDINATE SYSTEM
29	1.0267E-10	3.3294E-10	-1.5862E-09	ROTATED COORDINATE SYSTEM
30	-7.6727E-10	1.5178E-09	3.1869E-09	ROTATED COORDINATE SYSTEM
31	3.0962E-10	2.7499E-10	3.1869E-09	ROTATED COORDINATE SYSTEM
32	3.7077E-10	-2.6150E-09	-2.3283E-10	ROTATED COORDINATE SYSTEM
33	2.0912E+03	-1.0958E-09	-7.1977E+05	ROTATED COORDINATE SYSTEM

TOTAL UNBALANCED EQUILIBRIATED GRID POINT FORCE VECTOR
 -2.0960E+05 1.1434E+05 -6.7368E+05

A1-11/11

Fermilab

ATTACHMENT 2
TO CC-MOD-01

A2-1/31

D0 Office FAX : 312-879-0048

Mail Station : 357

Confirmation No. : 312-840-4591

Mike
Here's copy of latest
and probably final FEA
produced loads for D0
Module Array.
(nomenclature OH=CH)
Regards.
Pete.

D0 Telefax Message from Fermilab

Telefax Cover Sheet

To : Peter Kroon

BNL

From : Bob Wands

Fermilab

Number of pages : 33
(Incl. cover sheet)

Time & Date sent : 8/18/87

1p

A2-2/31

(support points are not fixed,
can move out laterally.)

Peter,

Enclosed is the second draft of D. Rudland's report on the CC connecting forces. The report now includes information at 5.625 deg. intervals as requested. In addition, I am enclosing a copy of three graphs which show that the "rolling support" assumption makes little difference in the forces and moments in the CH arch, and therefore must make little difference in the FH and EM arches.

We were unable to run an "infinite friction" case due to the amount of work involved changing the input. The support system between modules that you are proposing must be very poor at sustaining forces tangent to the support surface in the diametral plane of the detector, which would imply that the frictionless case is the more accurate. In addition to this, it is true that the stresses and deflections of a statically indeterminate body-force loaded structure which is built incrementally can only be approximated by an analysis of this type, which is essentially equivalent to assembly in an unstressed state followed by a "switching on" of gravity to provide forces. Due to this approximation, and since time and manpower don't provide for an incremental analysis, a safety factor should be applied to the numbers presented in this report.

It is my opinion that the connector assemblies used in the CC should be designed to withstand forces equal to 1.25 times those presented in this report in order to account for uncertainties in the analysis. This safety factor should be in addition to the AISC or other safety factor applied to the working stress in the design calculation.

arbitrary

If I can provide any more information or aid in the interpretation of the results, just let me know.

Bob Wanda

MOMENTS = IN - #
FORCES = #

A2-3/31

A2-4/31

Tangential force

OH Normal Roll Versus NoRoll

A2-5/31

A2-6/31

Central Calorimeter
Thermal Gradient
Module Connection Analysis

Bob,

Draft #2

D-Zero Engineering Note 3740.212-EN-102

DL Rudland
8/7/87

Approved _____

CC Thermal Gradient Connection Analysis

A2-7/31

Table 1 2-D Versus 3-D FEM Model

2-D	3-D
STIF 63 plate STIF 45 beam	STIF 63 plate STIF 45 beam
Just end plates	end plates, side, top, bottom skins
Solid ring of plate elements	Separate modules, coupled nodes
180 degrees arch support	90 degrees arch support <i>spacers only on lower half</i>
0 degree slope on OH arch	20 degree slope on OH arch
3-D Beam-Strap Support	Exact Beam-Strap per BNL
Support point on beam	<u>Support off beam</u> , exact location <i>to account for stanchion bus</i>
OH-Beam Connection- 61.875°	OH-Beam Connection- <u>56.25°</u>
Weight totally on end plates	Weight totally on end plates

Loads**Weight**

All of the module weight is essentially transferred through the end plates of the modules in the actual structure; therefore, the weight of the module in the FEM model was placed on the end plates only. This was done by assigning appropriate densities to the endplates and applying a global acceleration. Approximately the same weight was placed on both the 2-D and 3-D arches (The time between the model generation of the two brought slight changes in the CC weight). Graphs 1-9 show a force and moment comparison between the 2-D and 3-D static load case. Figure 4 shows a generic end plate force diagram to be used in reference with the graphs.

A2-8/31

Figure 4 Force Diagram

The graphs clearly show a very similar trend in the forces for the three arches. Any differences are a direct result from the model contrasts stated in Table 1.

Thermal Gradient

To study the effects of cool down on the CC modules, a temperature gradient had to be added to the 3-D FEM model. Using the coordinate system given in Figure 2, the temperature profile in the Y (Vertical) direction is given in Figure 5.

Note: Inside of modules, i.e. ϕ from side view is at 300°K

Figure 5 Vertical Temperature Gradient Distribution
 on front/back Faces of Modules

Linear variation assumed from front/back to center at 300°K.

Figure 1

2-D ENDPLATES, 3-D BEAM/STRAP

ANSYS J2B
JUL 28 1987
8:38:28
FLOT NO. 1
POST1 ELEMENTS

ORIG SCALING
N=1
DIST=98.6
XF=44.1
YF=-1.38
ZF=-22.3
HIDDEN

AUG 18 1987
348 FERMILAB D-8 P.01

A2-9/31

ANSYS 4.2B
JUN 24 1 1987
15:13:15
PLOT NO. 1
PREP7 ELEMENTS

ORIG SCALING
XV=1
YV=.5
ZV=1
DIST=98.6
XF=32.4
YF=2.8
ZF=-36.5
HIDDEN

CENTRAL CALORIMETER ARC STRUCTURE

A2-10/31

A2-11/31

2-D Versus 3-D OH Shear

Graph 1

A2-12/31

2-D Versus 3-D OH Normal Graph 2

A2-13/31

2-D VS 3-D OH Moment **Graph 3**

A2-14/31

Graph 4

2-D VERSUS 3-D FH SHEAR

A 2-15/31

Graph 5

A 2-16/31

Graph 6 2-D Versus 3-D FH Moment

Graph 7

AL-17/31

AZ-10/31

Graph 8

2-D Versus 3-D EM Normal

A2-19/31

Graph 9

AZ-20/31

Thu, Aug 6, 1987 10:57 AM

Graph Data

OH Data KSV POST

Table 2

angle	OH SHEAR	OH Normal	OH Moment	OH Therm Norm	OH Therm SURF &	OH Therm MOMENT
0	1367.617	-50705.03	13334	-48317.87	1317.87	2942.377
5.625	-6.729237	-46187.93	37181.04	-47594.03	385.8536	-4548.760
11.25	6148.409	-50144.97	-26058.15	-48718.93	7346.57	-33677.3
16.875	3789.570	-45513.78	-7452.67	-47592.63	4723.974	-5866.974
22.5	-5728.644	-48724.74	-7647.82	-46611.76	-3012.589	2074.533
28.125	-8172.757	-47116.45	-72202.51	-45468.43	-5433.797	-41492.6
33.75	-1092.859	-45253.26	-156422	-44596.4	2877.177	-105124.1
39.375	-13781.23	-42623.91	-187548.5	-41787.603	-9667.603	-105811.7
45	-19533.66	-39536.09	-318461	-38316.22	-16830.62	-206466.7
50.625	-17129.46	-36003.33	-482210.8	-35468.39	-17752.02	-331918.4
56.25	45909.91	-33242.89	-625693.6	-33582.34	45734.82	-497930.9
61.875	31368.47	-34421.34	-288906	-33670.17	31414.78	-160542.1
67.5	20632.44	-35865.65	-73440.07	-34989.05	19821.62	54705.03
73.125	16370.94	-36324.71	64093.28	-35357.18	15624.34	185384.5
78.75	12238.49	-35932.9	172369.1	-36103.85	11379.08	287382.9
84.375	8443.224	-34773.5	250158.7	-33998.87	7303.209	338724.1
90	4993.65	-33345.08	300547.7	-32521.4	4119.241	401162.2
95.625	1905.226	-31605.36	327279.3	-30747.35	1100.777	422160.1
101.25	-812.6415	-29679.38	332685.1	-29508.63	-1672.053	421446.8
106.875	-3118.084	-27377.68	317431.2	-26413.21	-4015.757	399530.1
112.5	-4986.899	-25016.95	286957.7	-23957.61	-5796.421	362305
118.125	-6430.078	-22576.33	244638.4	-21462.89	-7144.046	314527.4
123.75	-7462.836	-20156.42	193177.2	-19669.61	-8191.431	257685.1
129.375	-8078.77	-17673.65	134603.9	-16472.19	-8810.5	193452
135	-8295.251	-15341.06	73101	-14050.61	-8914.768	126629
140.625	-8142.801	-13119.04	11729.63	-11794.87	-8644.114	61409.97
146.25	-7655.362	-11120.39	-47764.34	-10391.81	-8142.181	-1819.712
151.875	-6863.172	-9322.604	-101861.4	-7919.959	-7328.722	-59424.78
157.5	-5814.93	-7841.81	-149508.3	-6387.121	-6150.27	-110366.0
163.125	-4534.231	-6397.324	-188239.6	-5129.264	-4736.167	-130839.2
168.75	-3126.66	-5712.925	-217873.4	-4853.312	-3297.608	-181974.8
174.375	-1587.745	-5178.687	-234710	-3677.847	-1726.029	-199884.2

A2-21/31

Graph 10

OH Normal Warm Versus Thermal

A2-22/31

Graph 11

OH Shear Warm Versus Thermal

A2-23/31

Graph 12

OH Moment Warm Versus Thermal

-2-24/37

not Graph Data

FHMAT6

Table 3

Thu, Aug 6, 1987 11:00 AM

Angle	3-D FH Normal	3-D FH Shear	3-D FH Moment	FH Normal Ther	FH Shear Ther	FH Moment Thermal
0	-34519.16	3578.691	58549.86	-54011.44	-00046175	520293.8
5.625	-34436	1637.119	56428.5	-54937.22	-517.4983	514340.4
11.25	-34001.2	-5971.42	48234.2	-55722.82	-6234.742	491566.1
16.875	-49260.57	-3359.162	-90501.64	-55638.55	-9746.97	429033.4
22.5	-50894.78	-2247.729	-61223.94	-55298.14	-5836.406	361013.5
28.125	-47429.01	-10096.7	-125046.4	-53153.4	-8151.75	310926.6
33.75	-44747.32	-5920.015	-193852.8	-50846.46	-15238.16	250224.8
39.375	-41456.20	23400.49	-193333.3	-47701.7	-9268.768	152576.4
45	-42590.43	9427.624	-229526.9	-45073.82	2287.506	89900.12
50.625	-41640.51	17944.71	-83390.7	-42601.89	19047.49	91082.76
56.25	-41161.01	20773.12	-1398.415	-42304.77	13500.98	178056.8
61.875	-40570.81	16669.36	197853.7	-41585.22	17861.23	234216.6
67.5	-40947.63	21461.97	96134.01	-41552.94	20000.62	314993.9
73.125	-39756.1	12162.9	275179.9	-40707.76	15125.77	408334.7
78.75	-39468.74	7981.61	329804.7	-39728.2	10612.91	477820.5
84.375	-34544.66	-901.3032	369245.9	-38359.2	6437.228	523968.8
90	-36835.05	2501.471	363823.5	-36835.05	-939.7966	550270.2
95.625	-32037.92	-3834.116	338417.5	-33927.61	-4333.791	357102.7
101.25	-29311.89	-6288.026	333508.5	-31057.44	-7209.123	308474.7
106.875	-23466.71	-9733.372	251146.9	-28035.49	-9333.172	466030.8
112.5	-26480.63	-8261.065	297274.8	-25163.72	-11440.38	413203.3
118.125	-20491.84	-10709.95	198844.3	-21580.89	-12795.96	330247.7
123.75	-17570.18	-11206.83	142657.6	-18299.19	-13571.08	282330.9
129.375	-12130.86	-10872.29	27900.33	-15142.79	-13941.91	211499.4
135	-14791.96	-11254.33	84999.78	-12358.62	-13687.69	141145.7
140.625	-9734.301	-10095.18	-26234.16	-9249.565	-13073.57	71731.96
146.25	-7616.715	-8970.673	-75443.17	-6670.368	-12005.16	6961.276
151.875	-4380.022	-5883.864	-132349.5	-4415.388	-10573.68	-51682.69
157.5	-5833.099	-7530.516	-118243.8	-2655.782	-8867.432	-102043.2
163.125	-4380.022	-5883.864	-132349.5	-219.4897	-6993.695	-144373.9
168.75	-3323.463	-4026.625	-177326	1842.790	-4679.953	-173806.7
174.375	-2663.057	-2040.992	-192157	3680.929	-2130.302	-188477.4

A2-25/31

Graph 13

FH Normal Warm VS Thermal

A2-26/31

Graph 14

FH Shear Warm Versus Thermal

A2-27/31

Graph 15

FH Moment Warm Versus Thermal

3-D EM Normal

3-D EM Shear

Table 4

TUE, Aug 4, 1987 11:44 AM

3-D EM Moment

Angle EM Ther Norm EM Ther Shear EM Ther Moment

A2-28/31

1	-8723.899	0	10642.47	0	-8740.320	0	4790.547
2	-8663.84	308.3270	8490.916	5.625	-8730.494	992.2937	2636.782
3	-8570.937	-872.3780	7459.268	11.25	-8653.178	-198.2199	4060.566
4	-8352.228	-2031.633	2192.209	16.875	-8561.031	-1373.812	1228.587
5	-7977.659	562.642	-7214.149	22.5	-8188.251	100.3726	-5847.717
6	-7852.185	323.844	-7143.254	28.125	-8067.937	125.2028	-7479.858
7	-7644.59	-727.134	-7854.297	33.75	-7786.528	-945.9307	-8935.44499
8	-7337.683	-1083.665	-12334.4	39.375	-7510.537	-1600.002	-14258.51
9	-6943.673	1927.036	-17966.13	45	-7009.246	3933.499	-21805.92
10	-6853.615	2021.778	-12622.03	50.625	-7171.107	3457.713	-9193.642
11	-6727.005	1153.502	-6824.855	56.25	-7126.479	2550.628	1718.432
12	-6523.021	2247.118	-4130.241	61.875	-7114.530	1673.117	9439.137
13	-6389.533	2126.933	2653.803	67.5	-6860.468	839.6414	14006.49
14	-6256.826	1391.513	9048.159	73.125	-6660.841	59.65497	15678.4
15	-6021.878	706.0264	12858.8	78.75	-6241.132	-658.9616	14571.67
16	-5738.541	78.18606	14316.15	84.375	-5874.96	-1360.9	11043.75
17	-5371.844	1172.219	13574.14	90	-5286.588	1640.571	5270.621
18	-5136.393	671.9427	16959.73	95.625	-5182.238	1137.413	10335.54
19	-4838.894	230.8832	18590.47	101.25	-4896.113	689.8684	13636.6
20	-4524.985	-147.7334	18781.62	106.875	-4660.758	299.8494	15483.3
21	-4170.552	-461.8583	17663.2	112.5	-4302.06	-29.69941	15956.84
22	-3815.884	-710.5324	15369.85	118.125	-4036.367	-298.0377	15408.32
23	-3441.998	-894.3339	12648.11	123.75	-3653.363	-505.3907	13929.16
24	-3083.884	-1014.519	9207.206	129.375	-3380.605	-652.9645	11866.91
25	-2726.673	-1074.158	5414.638	135	-3011.22	-743.309	9314.773
26	-2399.903	-1076.601	1521.577	140.625	-2761.458	-779.8805	6580.543
27	-2091.814	-1027.063	-2289.305	146.25	-2434.854	-767.1794	3760.175
28	-1826.612	-930.7791	-5845.13	151.875	-2239.107	-710.2961	1098.925
29	-1594.447	-794.6413	-8961.315	157.5	-1980.942	-615.6307	-1314.718
30	-1414.632	-623.4450	-11351.83	163.125	-1862.215	-489.6722	-3309.309
31	-1277.928	-431.2152	-13448.59	168.75	-1691.183	-339.9564	-4818.498
32	-1199.489	-219.8748	-14650.48	174.375	-1664.96	-174.03	-5746.002
33							

Graph 16

A2-29/31

EM Normal Warm Versus Thermal

Graph 17

A 2-30/31

EM Moment Warm Versus Thermal

ATTACHMENT 3

A3-1/7

TO CC-MOD-01

Peter,

Enclosed are plots of the radial displacements of the outer circumference of the Three CC module assemblies for both the weight only (warm) case, and the weight + thermal gradient case. Mike Rosenfeld requested these in a phone conversation with me two weeks ago. Could you please forward copies to him?

The displacement is labeled UX on the plot, but really corresponds to the radial displacement. The x-axis is labeled "DIST", and is the distance along the arc beginning at the bottom of a module assembly. To clarify,

Thanks,
Bob Wendt

ANSYS .2B

SEP 8 1987

9:49:51

PLOT NO. 3

POST1

DSYS=1

STEP=1

ITER=15

PATH PLOT

NOD1=1

NOD2=321

UX

CSYS=1

ORIG SCALING

ZV=1

DIST=1.43

weight only

A3-2/7

1 CH RADIAL DISPLACEMENTS

FH
H RADIAL DISPLACEMENTS

ANSYS 4.2B
SEP 8 1987
9:51:06
PLOT NO. 4
POST1
DSYS=1
STEP=1
ITER=15
PATH PLOT
NOD1=1026
NOD2=1307
UX
CSYS=1

ORIG SCALING
ZV=1
DIST=1.43

Weight only

A3-3/7

EM RADIAL DISPLACEMENTS

ANSYS 4.2B
SEP 8 1987
9:52:19
PLOT NO. 5
POST1
DSYS=1
STEP=1
ITER=15
PATH PLOT
NOD1=2001
NOD2=2481
UX
CSYS=1

ORIG SCALING
ZV=1
DIST=1.43

Weight only

A3-4/7

SEP 09 '87 08:26 048 FERMILAB D-0 P.05

Weight+Therm

A3-5/7

UX

FH RADIAL DISPLACEMENTS

ANSYS 11.2B
SEP 4 1987
15:18:19
PLOT NO. 2
POST1
DSYS=1
STEP=1
ITER=1
PATH PLOT
NOD1=1026
NOD2=1307
UX
CSYS=1

ORIG SCALING
ZV=1
DIST=1.43

Weight + Therm

A3-6/7

EM

EM RADIAL DISPLACEMENTS

ANSYS)2B
SEP 4 1987
15:20:21
PLOT NO. 3
POST1
DSYS=1
STEP=1
ITER=1
PATH PLOT
NOD1=2001
NOD2=2481
UX
CSYS=1

ORIG SCALING
ZV=1
DIST=1.43

Weight+Therm

A3-7/7

Peter,

ATTACHMENT 4
TO CC-MOD-01

A4-1/16

Here are the results of the "infinite friction" case for the CC assembly. Caroline Kuritz produced these and in the process discovered a minor post-processing error in the previous FH results. They now plot w/o the "saw-tooth" action to a great extent.

[Recall that the "infinite friction" was achieved by locking one arch to the other at the point which produced the highest contact force in the original analysis]

Caroline is getting started on making plots of the beam stresses. These should be available in a few days.

Please forward this information to Mike Rosenfeld

Thanks

Bob Wands

	angle	OH Shear	OH Normal	OH Moment	OH Therm Norm	OH Therm SHEAR	OH Therm MOMENT	OH Shear Fix	OH Normal Fix
1	0	1367.617	-50705.03	13334	-48317.87	1317.87	2942.377	-348.84	18546.5
2	5.625	-6.729237	-46187.93	37181.04	-47594.03	385.8556	-4548.760	-552.3972	16708.09
3	11.25	6148.409	-50144.97	-26068.15	-48718.93	7346.57	-33677.5	1934.773	18959.98
4	16.875	3789.570	-49513.78	-7452.67	-47592.63	4723.974	-5866.974	1211.481	19340.69
5	22.5	-5728.644	-48724.74	-7647.82	-46611.76	-3012.589	2074.535	-331.1028	19989.33
6	28.125	-8172.757	-47116.45	-72202.51	-45468.43	-5433.797	-41492.6	1351.121	20768.67
7	33.75	-1092.859	-45255.26	-156422	-44596.4	2877.177	-105124.1	4497.305	21725.58
8	39.375	-13781.25	-42623.91	-187548.5	-41787.603	-9667.603	-105811.7	-105.7987	22629.02
9	45	-19535.66	-39556.09	-318461	-38816.22	-16830.62	-206466.7	-6958.752	56857.18
10	50.625	-17129.46	-36003.35	-482210.8	-35468.39	-17752.02	-351918.4	-16013.36	58816.12
11	56.25	45909.91	-33242.89	-625898.6	-33582.54	45754.82	-497930.9	64648.55	-28865.00
12	61.875	31388.47	-34421.54	-288906	-33670.17	31414.78	-160542.1	44242.15	-32771.02
13	67.5	20632.44	-35865.65	-73440.07	-34989.05	19821.62	54705.03	23635.68	-34889.53
14	73.125	16370.94	-36324.71	64093.28	-35557.18	15624.54	185384.5	19474.7	-35384.07
15	78.75	12238.49	-35932.9	172369.1	-36103.85	11379.08	287382.9	15440.99	-35295.88
16	84.375	8443.224	-34773.5	250158.7	-33998.87	7503.209	358724.1	11693.42	-34437.94
17	90	4993.65	-33345.08	300547.7	-32521.4	4119.241	401162.2	8259.118	-33352.50
18	95.625	1905.226	-31605.56	327279.3	-30747.35	1100.777	422160.1	5153.861	-31924.83
19	101.25	-812.6415	-29679.58	332685.1	-29508.63	-1672.055	421446.8	2389.855	-30316.60
20	106.875	-3118.084	-27377.68	317431.2	-26413.21	-4015.757	399530.1	6.729882	-28318.75
21	112.5	-4986.899	-25016.95	288957.7	-23957.61	-5796.421	362306	-1970.887	-26266.72
22	118.125	-6430.078	-22576.33	244638.4	-21462.89	-7144.046	314527.4	-3550.341	-24109.98
23	123.75	-7462.856	-20156.42	193177.2	-19669.61	-8191.431	257685.1	-4747.910	-21970.45
24	129.375	-8078.77	-17673.65	134603.9	-16472.19	-8810.5	193452	-5555.261	-19737.02
25	135	-8295.251	-15341.06	73101	-14050.61	-8914.768	126629	-5986.290	-17642.89
26	140.625	-8142.801	-13119.04	11729.65	-11794.87	-8644.114	61409.97	-6070.634	-15635.88
27	146.25	-7655.362	-11120.39	-47764.54	-10391.81	-8142.181	-1819.712	-5841.294	-13835.33
28	151.875	-6863.172	-9322.604	-101861.4	-7919.959	-7328.722	-59424.78	-5325.034	-12193.22
29	157.5	-5814.93	-7841.81	-149508.3	-6387.121	-6150.27	-110366.0	-4565.329	-10846.32
30	163.125	-4554.251	-6597.324	-188239.6	-5129.264	-4756.167	-150839.2	-3605.228	-9713.369
31	168.75	-3126.66	-5712.925	-217873.4	-4853.512	-3297.608	-181974.8	-2489.644	-8915.442
32	174.375	-1587.745	-5178.687	-234710	-3677.847	-1726.029	-199884.2	-1268.997	-8418.966
33									
34									

Deadweight
No Friction

Deadweight + Thermal
No Friction

A4-2/16

OH ment Fix

1	90518.28
2	68769.41
3	82056.25
4	94513.17
5	103900.1
6	102210.0
7	114800.2
8	150311.2
9	-157790.8
10	-200003.2
11	-1131510
12	-663160.8
13	-345452.1
14	-178137.5
15	-46003.20
16	57066.26
17	131760.1
18	182887.5
19	212138.1
20	221067.1
21	213631.4
22	193522.4
23	163009.0
24	124250.3
25	80872.44
26	36002.51
27	-8759.804
28	-50354.78
29	-87553.79
30	-117992.1
31	-141432.5
32	-154898.9
33	
34	

Deadweight only
with friction

FAX to: Mike Rosenfeld

Battelle Columbus Lab.

FAX Tel # 614-424-5263

Verification 614-424-5059

A4-3/16

Data from "OH Data NEW POST"

A4-4/16

Data from "OH Data NEW POSI"

A4-5/16

Data from 'OH Data NEW POST'

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Angle	FH Normal	3-D FH Shear	3-D FH Moment	FH Normal Ther	Shear Ther	FH Moment	FH Shear fix	FH Normal f
0	-54519.16	3573.691	58548.86	-54011.44	-00046175	520293.8	1502.646	-20613.76
5.625	-54456	1637.119	56428.6	-54937.22	-517.4983	514340.4	-1398.801	-20447.00
11.25	-54001.2	-5971.42	48234.2	-55722.82	-8234.742	491566.1	-5654.655	-19773.31
16.875	-49260.57	-3369.162	-40501.64	-55638.55	-9746.97	429035.4	-6355.250	-18475.71
22.5	-50894.78	-2247.729	-61223.94	-55298.14	-5836.406	361013.5	-6588.198	-16950.73
28.125	-47429.01	-10096.7	-125046.4	-53155.4	-8151.75	310926.6	-10647.13	-15187.61
33.75	-44747.32	-3920.015	-193862.8	-50846.46	-15238.16	250224.8	-14003.09	-12891.07
39.375	-41456.20	23400.49	-193353.3	-47701.7	-9268.768	152576.4	-11172.36	-10040.49
45	-42590.43	9427.624	-229526.9	-45073.82	2287.506	89900.12	757.7530	-43217.61
50.625	-41640.51	17944.71	-83390.7	-42601.89	19047.49	91082.76	14736.55	-41408.76
56.25	-41161.01	20773.12	-1398.415	-42304.77	13500.98	178056.8	9328.768	-40715.44
61.875	-40570.81	16669.36	197855.7	-41585.22	17861.23	234216.6	17078.17	-39315.77
67.5	-40947.63	21461.97	98134.01	-41552.94	20000.62	314993.9	26933.13	-38681.40
73.125	-39756.1	12162.9	275179.9	-40707.76	15125.77	408334.7	22335.85	-38846.84
78.75	-38468.74	7981.61	329804.7	-39728.2	10612.91	477820.5	17970.81	-38957.02
84.375	-34544.66	-901.3032	369245.9	-38359.2	6437.228	523968.8	13875.10	-37881.79
90	-36835.05	2501.471	363823.5	-36835.05	-939.7966	550270.2	8933.534	-36835.05
95.625	-32037.92	-3834.116	358417.5	-33927.61	-4353.791	537102.7	5499.301	-35169.04
101.25	-29311.89	-6288.026	333508.5	-31057.44	-7209.123	508474.7	2474.291	-33287.35
106.875	-23466.71	-9735.372	251146.9	-28035.49	-9553.172	466030.8	-132.4978	-31171.96
112.5	-26480.63	-8261.065	297274.8	-25163.72	-11440.38	413203.3	-2318.614	-28942.08
118.125	-20491.84	-10709.95	198844.5	-21580.89	-12795.96	350247.7	-4063.587	-26490.93
123.75	-17570.18	-11206.83	142657.6	-18299.19	-13571.08	282330.9	-5361.967	-24057.33
129.375	-12130.86	-10872.29	27900.33	-15142.79	-13841.91	211499.4	-6234.072	-21641.76
135	-14791.96	-11254.35	84999.78	-12358.62	-13687.69	141145.7	-6706.195	-19340.12
140.625	-9734.301	-10095.18	-26234.16	-9249.565	-13073.57	71731.96	-6792.759	-17093.70
146.25	-7616.715	-8970.673	-75443.17	-6670.368	-12005.16	6961.276	-6521.721	-15072.61
151.875	-4380.022	-5883.864	-152349.5	-4415.388	-10573.68	-51682.69	-5937.639	-13279.00
157.5	-5835.099	-7550.516	-118243.8	-2655.782	-8867.432	-102043.2	-5089.072	-11777.55
163.125	-4380.022	-5883.864	-152349.5	-219.4897	-6993.695	-144375.9	-4018.733	-10515.86
168.75	-3323.463	-4026.625	-177326	1842.790	-4679.953	-173806.7	-2771.547	-9607.040
174.375	-2665.057	-2040.992	-192157	3680.929	-2130.302	-188477.4	-1407.754	-9040.307

Deadweight only
No Friction

Deadweight + Thermal
No Friction

Deadweight only,
With Friction

A4-7/16

FM Moment (lx)	FM Shear	FM Normal	FM Moment	Angle
299145.4	3573.691	-54519.16	58348.86	0
296305.9	1637.119	-54456.00	56428.60	5.625
279115.0	-5971.420	-54001.20	45120.86	11.25
239885.2	-7086.415	-53560.95	-5418.892	16.875
197450.0	-2247.729	-50894.78	-61223.94	22.5
153015.3	-3369.162	-49260.57	-90501.64	28.125
880025.7	-10096.70	-47492.01	-125046.4	33.75
7050.215	-3920.015	-44747.32	-193862.8	39.375
-413347.8	9427.624	-42590.43	-229526.9	45
-424561.3	23400.49	-41456.20	-193353.3	50.625
-359556.2	17944.71	-41640.51	-83390.70	56.25
-321541.7	20773.12	-41161.01	-1398.415	61.875
-242623.4	21461.97	-40947.63	96134.01	67.5
-110975.3	16669.36	-40570.81	197855.7	73.125
-3508.750	12162.90	-39756.10	275179.9	78.75
81777.67	7891.610	-38468.74	329804.7	84.375
146418.2	2501.471	-36835.05	363823.5	90
185882.7	-901.3032	-34544.66	369245.9	95.625
208444.3	-3834.116	-32037.92	358417.5	101.25
216278.0	-6288.026	-29311.89	333508.5	106.875
211674.9	-8261.065	-26480.63	297274.8	112.5
196194.4	-9735.372	-23466.71	251146.9	118.125
172834.9	-10709.95	-20491.84	198844.5	123.75
143762.0	-11206.83	-17570.18	142657.6	129.375
111139.0	-11254.35	-14791.96	84999.78	135
76693.20	-10872.29	-12130.86	27900.33	140.625
42677.08	-10095.18	-9374.301	-26234.16	146.25
10835.85	-8970.673	-7616.715	-75443.17	151.875
-17442.84	-7550.516	-5835.099	-118243.8	157.5
-40600.67	-5883.864	-4380.022	-152349.5	163.125
-57789.96	-4026.625	-3323.463	-177326.0	168.75
-68131.67	-2040.992	-2665.057	-192157.0	174.375

Deadweight only,
with friction

A4-8/16

Data from "FH DATA"

A4-9/16

A4-11/16

3-D EM Normal

3-D EM Shear

3-D EM Moment

Angle

EM Ther Nor

EM Ther Shear

EM Ther Moment

EM Local Max

EM No.

-8723.899	0	10642.47	0	-8740.320	0	4790.547	0	-12510.47
-8663.84	308.3270	8490.916	5.625	-8730.494	992.2937	2636.782	1214.727	-12437.82
-8570.937	-872.3780	7459.268	11.25	-8653.178	-198.2199	4060.566	-340.2792	-12409.66
-8362.223	-2031.633	2192.209	16.875	-8561.031	-1373.812	1228.587	-1069.496	-12240.52
-7977.659	562.642	-7214.149	22.5	-8188.251	100.3726	-5847.717	-1666.337	-11927.08
-7852.185	323.844	-7143.254	28.125	-8067.937	125.2028	-7479.858	-715.0314	-11568.59
-7644.59	-727.134	-7854.297	33.75	-7786.538	-945.9307	-8965.4499	-2124.159	-11231.97
-7337.683	-1083.665	-12334.4	39.375	-7510.537	-1600.002	-14258.51	-3157.513	-10780.01
-6943.675	1927.036	-17966.13	45	-7009.246	3933.499	-21805.92	-1925.614	-7328.011
-6853.615	2021.778	-12622.03	50.625	-7171.107	3457.713	-9193.642	333.8216	-6828.252
-6727.005	1153.502	-6824.855	56.25	-7126.479	2550.628	1718.432	-525.2026	-6534.373
-6523.021	2247.118	-4130.241	61.875	-7114.550	1675.117	9439.137	2050.713	-6168.841
-6389.533	2126.933	2653.803	67.5	-6860.468	839.6414	14006.49	3024.251	-6018.371
-6256.826	1391.513	9048.159	73.125	-6660.841	59.65497	15678.4	2321.053	-5974.854
-6021.878	706.0264	12858.8	78.75	-6241.132	-658.9616	14571.67	1658.788	-5832.036
-5738.541	78.18606	14316.15	84.375	-5874.96	-1360.9	11043.75	1044.875	-5643.330
-5371.844	1172.219	13574.14	90	-5286.588	1640.571	5270.621	1633.546	-5371.711
-5136.393	671.9427	16959.73	95.625	-5182.238	1137.413	10335.54	1130.968	-5181.603
-4838.894	230.8832	18590.47	101.25	-4886.115	689.8684	13636.6	683.3315	-4928.533
-4524.985	-147.7334	18781.62	106.875	-4660.758	299.8494	15485.3	293.6517	-4658.878
-4170.552	-461.8543	17663.2	112.5	-4302.06	-29.69941	15956.84	-35.67175	-4346.648
-3815.884	-710.5324	15569.85	118.125	-4036.367	-298.0377	15408.32	-303.7496	-4033.314
-3441.998	-894.3359	12648.11	123.75	-3655.363	-505.3907	13929.16	-510.7789	-3697.791
-3083.884	-1014.519	9207.206	129.375	-3380.605	-652.9645	11866.91	-657.9709	-3376.496
-2726.673	-1074.158	5414.638	135	-3011.22	-743.309	9314.773	-747.9700	-3052.321
-2399.903	-1076.601	1521.577	140.625	-2761.458	-779.8805	6580.543	-783.9892	-2756.451
-2091.814	-1027.063	-2289.305	146.25	-2434.854	-767.1794	3760.175	-770.7780	-2474.790
-1826.612	-930.7791	-5845.13	151.875	-2239.107	-710.2961	1098.925	-713.3491	-2233.395
-1594.447	-794.6413	-8961.315	157.5	-1980.942	-615.6307	-1314.718	-618.1095	-2020.022
-1414.632	-625.4450	-11551.83	163.125	-1862.215	-489.6722	-3309.309	-491.5523	-1856.018
-1277.928	-431.2152	-13448.59	168.75	-1691.183	-339.9564	-4818.498	-341.2201	-1729.736
-1199.489	-219.8748	-14650.48	174.375	-1664.96	-174.03	-5746.002	-174.6648	-1658.514

Deadweight only
No Friction

Deadweight + Thermal
No Friction

Deadweight only,
With Friction

44-12/16

25207.06
22399.15
23960.03
19960.68
13324.38
4634.409
-502.1210
-10699.50
-13610.77
-22192.34
-22475.61
-25868.74
-19718.5
-10018.23
-2762.861
2161.079
4954.678
10001.06
13269.27
15104.74
15566.52
14984.36
13498.18
11403.88
8847.554
6084.291
3263.297
576.5697
-1833.644
-3849.644
-5351.000
-6295.503

Deadweight only
with Friction

A4-13/16

Data from "EM Data"

A4-14/16

3-D EM Normal

Data from "EM Data"

A4-16/16

3-D EM Shear

Angle

CC-MOD-02

Main Support Beam and Strap

MAIN SUPPORT BEAM & STRAP

The objective is to calculate stresses in the main beam and strap members.

MAIN BEAM:

$$30 - 19 \sin 30 \\ \approx 20 \text{ " approximately}$$

$$At \quad \bar{I}_1 = \frac{1}{2}(5.5)(30)^3 = 12375 \text{ in}^4 \\ \bar{Z}_1 = 825 \text{ in}^3$$

$$\bar{I}_2 = \frac{1}{2}(30)(5.5)^3 = 416 \text{ in}^4 \\ \bar{Z}_2 = 151.3 \text{ in}^3$$

$$A_{max} \approx (5.5)(30) = 165.0 \text{ in}^2$$

$$A_{ends} \approx (2)(20) = 41.0 \text{ in}^2$$

dimensions,

$$a = 12.25 \sin 56.25 = 10.19 \text{ "}$$

$$b = 12.25 \cos 56.25 = 6.81 \text{ "}$$

Included angles, $\alpha_1 = \frac{180}{\pi} \cdot \frac{15}{88.2} = 9.75^\circ$

$$\alpha_2 = \frac{180}{\pi} \cdot \frac{20}{88.2} = 13.0^\circ$$

$$\alpha_3 = \frac{180}{\pi} \cdot \frac{30}{88.2} = 19.5^\circ$$

A free-body diagram of the beam will be developed that relies on the following assumptions:

- a) no friction exists between the module assembly and the tension strap, or between the module assembly and the mating beam surfaces;
- b) external reactions to the beam are vertical (the beam is on rollers);
- c) the strap is flexible enough to conform to the shape of the module assembly without transmitting shear and bending loads (it is loaded only in tension);
- d) there is a normal (radial) force between the module assembly and mating surfaces of the beam.
- e) The strap tension resists the tendency for the beam to be pushed outward horizontally.
- f) There is a radial load between the strap and module assembly. However, strap tension may be obtained from an analysis of the beam.

$$R_i = 88.2"$$

$$\theta = 56.25^\circ$$

$$\alpha_1 = 9.75^\circ$$

$$\alpha_2 = 13.0^\circ$$

$$d = 2.0"$$

$$WEIGHT = 600000 \#$$

$$\beta = \theta - \alpha_1 = 46.5^\circ$$

$$\sin \beta = .7254$$

$$\cos \beta = .6884$$

$$R = \frac{W}{4} = 150000 \#$$

$$= 150K$$

$$\text{Dimension } A = R(\sin \theta - \sin \beta) - \frac{d}{2} \sin \beta$$

$$= (88.2)(.106) - (1.0)(.725) = 8.632"$$

$$C = R(\cos \beta - \cos \theta) + \frac{d}{2} \cos \beta - 12.25$$

$$= (88.2)(.133) + (1.0)(.688) - 12.25 = .150"$$

$$B = R(\sin \theta - \sin \phi)$$

$$= 73.336 - 88.2 \sin \phi$$

$$D = 12.25 - R(\cos \phi - \cos \theta)$$

$$= 61.251 - 88.2 \cos \phi$$

B, D, ϕ
unknown.

Strap force T is unknown but occurs at a known location and orientation. Normal force N is unknown, and occurs at a location and

an angle as yet unknown such that the beam is in static equilibrium. But it is assumed that N remains oriented radially in any case. Reaction R is known from the assembly weight.

Summing forces in all directions:

$$1) \quad \Sigma F_H = -T \cos \beta + N \sin \varphi = 0$$

$$\therefore N \sin \varphi = T \cos \beta, \quad \sin \varphi = \frac{T}{N} \cos \beta$$

$$2) \quad \Sigma F_V = -T \sin \beta - N \cos \varphi + R = 0$$

$$\therefore T \sin \beta + N \cos \varphi = R, \quad \cos \varphi = \frac{1}{N} (R - T \sin \beta)$$

$$3) \quad \Sigma M_O = -T \cos \beta \cdot C + T \sin \beta \cdot A + N \cos \varphi \cdot B - N \sin \varphi \cdot D = 0$$

$$= -T \cos \beta \cdot C + T \sin \beta \cdot A + N \cos \varphi (73.336 - 88.2 \sin \varphi)$$

$$- N \sin \varphi (61.25 - 88.2 \cos \varphi)$$

$$= -T \cos \beta \cdot C + T \sin \beta \cdot A + N \cdot \frac{1}{N} (R - T \sin \beta) (73.336 - 88.2 \sin \varphi)$$

$$- N \left(\frac{T}{N} \cos \beta \right) (61.25 - 88.2 \cdot \frac{1}{N} (R - T \sin \beta))$$

$$= -T (6884)(150) + T (7254)(8632) + (150 - 7254 T) (73.336 - (88.2)(6884) \frac{T}{N})$$

$$- (6884 T) (61.25 - 88.2 (\frac{150}{N} - .7254 \frac{T}{N}))$$

$$= -.1033 T + 6.262 T + 11000.0 - 9107.5 \frac{T}{N}$$

$$- 53.198 T + 44.044 \frac{T^2}{N} - 42.165 T$$

$$+ 9107.5 \frac{T}{N} - 44.044 \frac{T^2}{N} = 0$$

$$\text{So, } 11000.0 - 89.204 \cdot T = 0$$

$$\therefore T = \frac{11000}{89.204} = \underline{\underline{123.312 \text{ kips}}}$$

Note also that $\sin^2 \varphi + \cos^2 \varphi = 1.0$,

$$\text{so, } \left(\frac{T}{N} \cos \beta \right)^2 + \left(\frac{R}{N} - \frac{T}{N} \sin \beta \right)^2 = 1.0$$

$$\left(\frac{1}{N} (123,312)(.6884) \right)^2 + \left[\frac{1}{N} (150 - (123,312)(.7254)) \right]^2 = 1.0$$

$$\frac{7206.0}{N^2} + \frac{3666.2}{N^2} = \frac{10872.2}{N^2} = 1.0$$

$$\therefore N = \sqrt{10872.2} = \underline{\underline{104.270}} \text{ Kips}$$

$$\begin{aligned} \text{Then, angle } \varphi &= \sin^{-1} \left(\frac{T}{N} \cos \beta \right) \\ &= \sin^{-1} \left(\frac{123,312}{104,270} (.6884) \right) \\ &= \sin^{-1} (.8141) = \underline{\underline{54.50^\circ}} \end{aligned}$$

$$\frac{1}{2} \text{ dimensions } B = 73.376 - 88.2 \sin 54.5 = 1.530''$$

$$D = 61.25 - 88.2 \cos 54.5 = 10.032''$$

TENSION STRAP

Tension in the strap is $T = 123312^\#$,

$$\text{so } \sigma_t = \frac{123312}{(2)(5)} = \underline{\underline{12331}} \text{ psi} < .60 F_y \text{ per AISC 1.5.1.1}$$

This stress poses no problem for the butt weld assuming full penetration, good weld quality, selection of weld metal with strength equal or greater than the base material, thorough inspection, and no fatigue loading. PWHT may not be necessary for Type 304.

SUPPORT BEAM

Conservatively take the bending moment arm to be the full $19\frac{1}{8}"$ distance from the support bosses out to the beam ends,

$$\sigma_{b_1} = \frac{(123312)(19.125)}{825} = 2860 \text{ psi}$$

$$\sigma_{b_2} = \frac{(104270)(19.125)}{151.3} = 13180 \text{ psi}$$

Maximum bending occurs along the uppermost corner edge, $\sigma_b = 2860 + 13180 = 16040 \text{ psi} < 605 \text{ ksi}$
per AISC 1.5.1.4

These moments were conservatively calculated by using the $19.125"$ moment arm.

There is a torsional moment applied as a result of the angular location of N :

$$S \approx R(\phi - \beta - \frac{\alpha_2}{2})$$

$$= (88.2)(54.5 - 46.5 - \frac{13.0}{2})(\frac{\pi}{180}) = 2.31"$$

$$M_T \approx N \cdot S = (104270)(2.31) = 240864 \text{ in-lb}$$

Torsional stress is a maximum at the surface at the midpoint of the long dimension,

$$\max \tau_T = M_T \frac{3W + 1.8t}{W^2 t^2}$$

$$= (240864) \frac{(3)(20) + (1.8)(2)}{(20)^2 (2)^2} = 9574 \text{ psi}$$

Transverse shears, $\tau = V/A$

$$\tau_1 = \frac{123312}{(20)(2)} = 3083 \text{ psi}$$

$$\tau_2 = \frac{104270}{(20)(2)} = 2607 \text{ psi}$$

Resultant gross shear

$$\tau_R = \sqrt{3083^2 + 2607^2} = 4037 \text{ psi} < 1.40 F_y = 12 \text{ ksi}$$

per AISC
1.5.1.2.1

Maximum local shear,

$$\tau_{max} = \tau_T + \tau_1 = 9574 + 3083 = 12657 \text{ psi}$$

This is acceptable because actual shear resistance is greater at all cross sections inboard from the ends.

CC-MOD-03

Connection Pin Loads

CONNECTION PIN LOADS

This calculation summarizes the loadings on the pins connecting the module end plate and end plate brackets. Results from finite element analyses ^{of the module assembly}, performed by Fermilab personnel were used as input.

Finite element analyses were performed using both 2-D and 3-D models. Loadings considered were deadweight and a prescribed distribution of differential temperature.

LOAD COMBINATIONS

The positive load convention from the finite element analyses is shown below. These loads were then resolved onto the endplate bracket at the connection pin locations as shown:

For pins 1-4,

$$F_1 = \frac{1}{2}F_N - \frac{M}{A} - \frac{1}{2}F_S \frac{B}{A} \quad (1)$$

$$F_2 = \frac{1}{2}F_N + \frac{M}{A} + \frac{1}{2}F_S \frac{B}{A}$$

$$F_3 = \frac{1}{2}F_N + \frac{M}{A} - \frac{1}{2}F_S \frac{B}{A}$$

$$F_4 = \frac{1}{2}F_N - \frac{M}{A} + \frac{1}{2}F_S \frac{B}{A}$$

The resultant shear on the pin (1-4)

is then
$$V_{R1-4} = \sqrt{(F_{1-4})^2 + (\frac{1}{2}F_3)^2} \quad (2)$$

The pins are installed with some net clearance. For the 2" $\varnothing$ pins in the CH and FH modules, the minimum and maximum clearances are :

$$C = (2.0040^{+.0018}_{-.0000}) - (2.0000^{+.0005}_{-.0005})$$

$$C = .0063" \text{ max}$$

$$C = .0035" \text{ min}$$

This is a relatively small clearance for a 2" connector, and for such a large and massive structure. Nevertheless, it is possible to imagine a condition whereby due to relative rotations between modules and due to clearances, 100% of load F_N , F_3 and/or $F_3 \frac{B}{A}$ may occur on one pin instead of 50% going to each of two pins. The maximum possible load would then be

$$V_R = \left[(|F_N| + \left| \frac{M}{A} \right| + \left| F_3 \frac{B}{A} \right|)^2 + (F_3)^2 \right]^{1/2} \quad (3)$$

This could be considerably greater (by 50% approximately) than the ^{maximum} resultant pin load as calculated previously (per top of sheet).

However, in the unlikely event that this load is developed at a particular pin, the bearing loads would probably cause local yielding in the plate resulting in a redistribution of the load to the other pins. This would be the case as long as the shear strength of the pin is not exceeded. It is noted that in both aircraft and construction design, it is standard practice to disregard fastener/hole clearance within bearing connections in calculating the working stresses, as long as clearances and edge distances are specified in accordance with applicable criteria or standard good practice.

Loads were calculated for all four pins, using the reported hoop, shear and moment loadings at angular intervals of 5.625° around each ^{module} ring assembly. Depending on the sense of the applied loads and the pin location, some pin holes will be loaded in a

Refer to computer
printout.

bearing-only mode, while others will be loaded in a shear tear-out mode:

BEARING ONLY

SHEAR TEAR-OUT

The worst combination of loadings for shear tear-out for pins 1-4 are

PIN 1	$+F_1 / -F_5$
PIN 2	$+F_2 / +F_5$
PIN 3	$+F_3 / -F_5$
PIN 4	$+F_4 / +F_5$

based on the load combinations on pg. 2.

The ^{worst} shear tear-out load may or may not be the largest load on the bracket at a given angular position in the ring.

Maximum bearing and tear-out loads as calculated by equation (2) and the maximum possible load, as calculated by equation (3) are listed on the following page.

Review of these loads indicate the tear-out loads are always less than the compressive loads. Also, the maximum possible load, which would be compressive, as calculated by equation (3), is about 50% greater than the maximum probable load per equation (2).

CH MODULE ENDPLATE BRACKET PIN LOADS -- DWT + THERMAL, NO FRICTION

I.D.	ANGLE	HOOP	SHEAR	MOMENT	F1	VR1	F2	VR2	F3	VR3	F4	VR4	MAX F	MAX VR
1	0.000	-48318	1318	2942	-24530	24539	-23788	23797	-24167	24176	-24151	24160	48878	48896
2	5.625	-47594	386	-4549	-23572	23573	-24022	24022	-24133	24133	-23461	23462	47985	47987
3	11.250	-48719	7347	-33678	-23342	23630	-25377	25641	-27490	27735	-21229	21544	52907	53414
4	16.875	-47592	4724	-5867	-24114	24230	-23478	23596	-24837	24949	-22755	22877	49312	49538
5	22.500	-46112	-3013	2075	-22750	22800	-23362	23410	-22495	22545	-23617	23665	47107	47203
6	28.125	-45468	-5434	-41493	-19397	19587	-26071	26212	-24507	24658	-20961	21136	49587	49883
7	33.750	-44596	2877	-105124	-16238	16302	-28358	28394	-29185	29221	-15411	15478	51897	51977
8	39.375	-41788	-9667	-105812	-12987	13858	-28801	29203	-26019	26464	-15769	16493	51085	51992
9	45.000	-38816	-16831	-206467	-4273	9438	-34543	35554	-29701	30870	-9115	12406	56373	58832
10	50.625	-35468	-17752	-351918	6491	10996	-41959	42887	-36852	37905	1384	8983	62246	64728
11	56.250	-33583	45755	-497931	7289	24011	-40872	46839	-54036	58679	20453	30687	77409	89921
12	61.875	-33670	31415	-160542	-11468	19448	-22202	27197	-31240	34967	-2430	15894	52594	61262
13	67.500	-34989	19822	54705	-23715	25702	-11274	15011	-16977	19658	-18012	20559	44061	48314
14	73.125	-35557	15625	185385	-31442	32398	-4115	8830	-8610	11626	-26947	28057	51468	53788
15	78.750	-36104	11379	287383	-37386	37816	1282	5832	-1992	6028	-34112	34583	57075	58198
16	84.375	-33999	7503	358724	-40169	40344	6170	7221	4011	5492	-38010	38195	58248	58729
17	90.000	-32521	4119	401162	-41557	41608	9036	9267	7851	8116	-40372	40424	58410	58555
18	95.625	-30747	1101	422160	-41529	41532	10782	10796	10465	10479	-41212	41215	57060	57071
19	101.250	-29509	-1672	421447	-40467	40475	10958	10990	11439	11469	-40948	40956	55943	55968
20	106.875	-26413	-4016	399530	-37232	37286	10819	11004	11974	12142	-38387	38440	52172	52326
21	112.500	-23958	-5796	362305	-33456	33581	9498	9930	11166	11536	-35124	35243	47936	48285
22	118.125	-21463	-7144	314527	-29072	29291	7609	8406	9665	10304	-31128	31332	42887	43478
23	123.750	-19670	-8191	257685	-24525	24865	4855	6352	7212	8293	-26882	27192	37895	38770
24	129.375	-16472	-8810	193452	-18881	19389	2409	5021	4944	6622	-21416	21864	30919	32150
25	135.000	-14051	-8915	126629	-13541	14256	-510	4487	2055	4908	-16106	16711	24414	25990
26	140.625	-11795	-8644	61410	-8436	9478	-3359	5474	-872	4409	-10923	11747	18064	20025
27	146.250	-10392	-8142	-1820	-3913	5646	-6479	7652	-4137	5804	-6255	7463	12847	15209
28	151.875	-7920	-7329	-59425	754	3741	-8674	9416	-6565	7519	-1355	3907	13688	15527
29	157.500	-6387	-6150	-110366	4488	5440	-10875	11301	-9105	9610	2718	4104	14953	16168
30	163.125	-5129	-4756	-150839	7408	7781	-12537	12761	-11169	11419	6040	6491	15786	16487
31	168.750	-4854	-3298	-181975	9253	9399	-14107	14204	-13159	13262	8305	8467	17009	17326
32	174.375	-3678	-1726	-199884	10718	10753	-14396	14422	-13900	13926	10222	10258	16483	16574

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FH MODULE ENDPLATE BRACKET PIN LOADS -- DWT + THERMAL, NO FRICTION

I.D.	ANGLE	HOOP	SHEAR	MOMENT	F1	VR1	F2	VR2	F3	VR3	F4	VR4	MAX F	MAX VR
1	0.000	-54011	0	520294	-54755	54755	744	744	744	744	-54755	54755	81760	81760
2	5.625	-54937	-517	514340	-54838	54839	-99	277	25	260	-54962	54963	82493	82494
3	11.250	-55723	-8235	491566	-53090	53250	-2633	4887	-656	4169	-55067	55220	83916	84319
4	16.875	-55639	-9747	429035	-49532	49771	-6107	7813	-3768	6160	-51871	52099	80860	81445
5	22.500	-55298	-5836	361014	-46203	46295	-9095	9552	-7695	8229	-47603	47693	75953	76177
6	28.125	-53155	-6152	310927	-42422	42533	-10733	11165	-9256	9754	-43899	44006	71214	71479
7	33.750	-50846	-15238	250225	-36940	37717	-13906	15857	-10249	12771	-40597	41306	67848	69539
8	39.375	-47702	-9269	152576	-30876	31222	-16826	17452	-14601	15319	-33101	33424	58064	58799
9	45.000	-45074	2288	89900	-27606	27630	-17468	17505	-18017	18053	-27057	27081	50418	50470
10	50.625	-42602	19047	91083	-28444	29996	-14158	17063	-18729	21011	-23873	25703	52031	55408
11	56.250	-42305	13501	178057	-32269	32968	-10036	12095	-13276	14894	-29029	29803	55042	56673
12	61.875	-41585	17861	234217	-35427	36536	-6158	10848	-10444	13742	-31141	32396	58363	61035
13	67.500	-41553	20001	314994	-39976	41208	-1577	10124	-6377	11861	-35176	36570	63153	66244
14	73.125	-40708	15126	408335	-43947	44593	3239	8227	-391	7573	-40317	41020	66116	67824
15	78.750	-39728	10613	477821	-46621	46922	6893	8699	4346	6859	-44074	44393	67759	68585
16	84.375	-38359	6437	523969	-47897	48005	9538	10066	7993	8617	-46352	46464	67849	68154
17	90.000	-36835	-940	550270	-47652	47655	10817	10828	11043	11053	-47878	47880	66408	66415
18	95.625	-33928	-4354	537103	-45087	45140	11159	11369	12204	12397	-46132	46183	63618	63767
19	101.250	-31057	-7209	508475	-41782	41937	10725	11315	12455	12966	-43512	43661	59906	60338
20	106.875	-28035	-9553	466031	-37726	38027	9691	10804	11984	12901	-40019	40303	55183	56003
21	112.500	-25164	-11440	413203	-33247	33735	8083	9902	10828	12246	-35992	36444	49947	51240
22	118.125	-21581	-12796	350248	-27935	28658	6354	9017	9425	11391	-31006	31659	43332	45182
23	123.750	-18299	-13571	282331	-22579	23576	4280	8022	7537	10141	-25836	26712	36614	39048
24	129.375	-15143	-13842	211499	-17190	18531	2047	7217	5369	8760	-20512	21649	29745	32808
25	135.000	-12359	-13688	141146	-12065	13871	-294	6850	2991	7469	-15350	16806	23172	26913
26	140.625	-9250	-13074	71732	-6882	9492	-2368	6953	770	6582	-10020	11963	16213	20828
27	146.250	-6670	-12005	6961	-2266	6416	-4404	7445	-1523	6193	-5147	7907	9922	15575
28	151.875	-4415	-10574	-51683	1818	5591	-6233	8173	-3695	6450	-720	5336	9709	14355
29	157.500	-2656	-8867	-102043	5178	6817	-7834	9002	-5706	7226	3050	5381	10226	13535
30	163.125	-219	-6994	-144376	8430	9126	-8649	9329	-6970	7798	6751	7603	9598	11876
31	168.750	1843	-4680	-173807	10753	11004	-8910	9212	-7787	8131	9630	9910	12236	13100
32	174.375	3681	-2130	-188477	12148	12195	-8467	8534	-7956	8027	11637	11686	14244	14403

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EM MODULE ENDPLATE BRACKET PIN LOADS -- DWT + THERMAL, NO FRICTION

I.D.	ANGLE	HOOP	SHEAR	MOMENT	F1	VR1	F2	VR2	F3	VR3	F4	VR4	MAX F	MAX VR
1	0.000	-8740	0	4791	-5199	5199	-3541	3541	-3541	3541	-5199	5199	9569	9569
2	5.625	-8730	992	2637	-4959	4983	-3771	3804	-4046	4076	-4684	4710	9461	9513
3	11.250	-8653	-199	4061	-5002	5003	-3651	3653	-3596	3597	-5057	5058	9411	9413
4	16.875	-8561	-1374	1229	-4303	4357	-4258	4313	-3878	3938	-4683	4734	9154	9257
5	22.500	-8188	100	-5847	-3096	3096	-5092	5092	-5120	5120	-3068	3069	9228	9228
6	28.125	-8067	125	-7479	-2756	2757	-5311	5311	-5345	5346	-2722	2723	9396	9397
7	33.750	-7787	-946	-8965	-2211	2261	-5576	5596	-5314	5335	-2473	2518	9601	9647
8	39.375	-7511	-1600	-14259	-1066	1333	-6445	6494	-6002	6055	-1509	1708	10422	10544
9	45.000	-7009	3933	-21806	-275	1986	-6734	7015	-7823	8066	814	2128	11872	12507
10	50.625	-7171	2458	-9194	-2335	2638	-4836	4990	-5517	5652	-1654	2061	9443	9758
11	56.250	-7126	2551	1718	-4214	4402	-2912	3180	-3619	3837	-3507	3732	8130	8521
12	61.875	-7115	1675	9439	-5423	5487	-1692	1888	-2156	2313	-4959	5029	9212	9363
13	67.500	-6860	840	14006	-5970	5985	-890	984	-1122	1198	-5738	5753	9517	9554
14	73.125	-6661	60	15678	-6052	6052	-609	610	-625	626	-6036	6036	9391	9391
15	78.750	-6241	-659	14572	-5551	5561	-690	764	-507	605	-5734	5743	8945	8970
16	84.375	-5875	-1361	11044	-4660	4710	-1215	1392	-838	1079	-5037	5083	8163	8276
17	90.000	-5287	1641	5271	-3783	3871	-1504	1713	-1958	2123	-3329	3428	6654	6853
18	95.625	-5182	1137	10336	-4537	4573	-645	860	-960	1115	-4222	4261	7286	7374
19	101.250	-4886	690	13637	-4899	4911	13	345	-178	388	-4708	4720	7437	7469
20	106.875	-4661	300	15483	-5052	5054	391	418	308	342	-4969	4971	7424	7430
21	112.500	-4302	-30	15957	-4909	4909	607	607	615	615	-4917	4917	7072	7072
22	118.125	-4036	-298	15408	-4643	4646	607	625	690	706	-4726	4728	6785	6792
23	123.750	-3655	-505	13929	-4168	4176	513	572	653	700	-4308	4316	6206	6226
24	129.375	-3381	-653	11867	-3654	3668	273	426	454	559	-3835	3849	5616	5653
25	135.000	-3011	-743	9315	-3015	3038	4	372	210	427	-3221	3242	4829	4886
26	140.625	-2761	-780	6581	-2411	2443	-350	524	-134	412	-2627	2656	4116	4189
27	146.250	-2435	-767	3760	-1762	1803	-673	775	-461	599	-1974	2011	3298	3386
28	151.875	-2239	-710	1099	-1211	1262	-1028	1087	-831	904	-1408	1452	2626	2720
29	157.500	-1981	-616	-1315	-678	744	-1303	1339	-1133	1174	-848	902	2379	2458
30	163.125	-1862	-490	-3309	-290	380	-1572	1591	-1436	1457	-426	492	2570	2617
31	168.750	-1691	-340	-4818	35	174	-1726	1735	-1632	1641	-59	180	2619	2641
32	174.375	-1665	-174	-5746	186	205	-1851	1853	-1803	1805	138	163	2708	2713

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ZERO FRICTION CONDITION:

(MAX EQU-3 PIN LOAD = 89921 #)

(MAX EQN-3 PIN LOAD = 84319#)

(MAX EQN-3 PIN LOAD = 12507 #)

CH MODULE ENDPLATE BRACKET PIN LOADS -- DWT ONLY + FRICTION

I.D.	ANGLE	HOOP	SHEAR	MOMENT	F1	VR1	F2	VR2	F3	VR3	F4	VR4	MAX F	MAX VR
1	0.000	18547	-349	90518	3750	3754	14797	14798	14898	14899	3649	3653	24222	24224
2	5.625	16708	-553	68763	4199	4208	12509	12512	12668	12671	4040	4049	21102	21109
3	11.250	18960	1935	82056	4149	4260	14811	14843	14255	14287	4705	4804	24570	24646
4	16.875	19341	1211	94513	3676	3726	15665	15677	15316	15328	4025	4070	25510	25538
5	22.500	19989	-331	103900	3644	3648	16345	16346	16440	16441	3549	3553	26482	26484
6	28.125	20769	1351	102210	3896	3954	16873	16866	16484	16498	4285	4338	27452	27485
7	33.750	21726	4497	114800	3147	3867	18579	18715	17286	17431	4440	4977	30089	30423
8	39.375	22629	-106	150311	2074	2074	20555	20555	20586	20586	2043	2044	31916	31916
9	45.000	56857	-6959	-157791	39146	39301	17711	18049	19713	20017	37144	37307	68576	68928
10	50.625	58816	-16013	-200003	44028	44750	14788	16817	19395	20983	39421	40226	75739	77413
11	56.250	-28865	64649	-1131510	45946	56178	-74811	81496	-93411	98846	64546	72188	117143	133798
12	61.875	-32771	44242	-663161	18088	28575	-50859	55461	-63587	67325	30816	37934	86337	97013
13	67.500	-34890	23636	-345452	428	11826	-35318	37243	-42118	43745	7228	13853	62963	67253
14	73.125	-35384	19475	-178138	-9524	13621	-25860	27633	-31463	32936	-3921	10497	51957	55487
15	78.750	-35296	15441	-46003	-17036	18704	-18260	19825	-22702	23979	-12594	14772	42571	45285
16	84.375	-34438	11693	57066	-22415	23165	-12023	13369	-15387	16460	-19051	19928	41316	42939
17	90.000	-33353	8259	131760	-25978	26305	-7375	8452	-9751	10589	-23602	23961	43843	44614
18	95.625	-31925	5154	182888	-27966	28085	-3959	4724	-5442	6021	-26483	26608	44670	44966
19	101.250	-30317	2390	212138	-28566	28591	-1751	2120	-2439	2716	-27878	27904	44068	44133
20	106.875	-28319	7	221067	-27774	27774	-545	545	-547	547	-27772	27772	41934	41934
21	112.500	-26227	-1970	213631	-25986	26004	-241	1014	325	1037	-26552	26571	39949	39998
22	118.125	-24110	-3550	193522	-23461	23528	-649	1890	373	1814	-24483	24547	37048	37218
23	123.750	-21970	-4748	163009	-20340	20478	-1630	2880	-264	2389	-21706	21836	33374	33710
24	129.375	-19737	-5555	124250	-16721	16950	-3016	4100	-1418	3119	-18319	18528	28987	29514
25	135.000	-17643	-5986	80872	-12941	13282	-4702	5574	-2980	4224	-14663	14965	24345	25070
26	140.625	-15636	-6071	36003	-9162	9652	-6474	7151	-4728	5618	-10908	11323	19600	20518
27	146.250	-13835	-5841	-8760	-5538	6261	-8297	8796	-6617	7233	-7218	7787	16055	17084
28	151.875	-12193	-5325	-50535	-2219	3466	-9974	10324	-8442	8852	-3751	4600	16837	17659
29	157.500	-10846	-4565	-87554	625	2367	-11471	11696	-10158	10411	-688	2384	17551	18135
30	163.125	-9713	-3605	-117992	2928	3438	-12641	12769	-11604	11743	1891	2612	18016	18373
31	168.750	-8915	-2490	-141433	4610	4775	-13525	13582	-12809	12869	3894	4088	18341	18509
32	174.375	-8419	-1269	-154899	5512	5548	-13931	13945	-13566	13580	5147	5186	18323	18367

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FH MODULE ENOPLATE BRACKET PIN LOADS -- QWT ONLY + FRICTION

I.D.	ANGLE	HOOP	SHEAR	MOMENT	F1	VR1	F2	VR2	F3	VR3	F4	VR4	MAX F	MAX VR
1	0.000	-20614	1503	299145	-26442	26452	5828	5876	5467	5518	-26081	26092	36929	36960
2	5.625	-20447	-1399	296306	-25859	25868	5412	5457	5747	5790	-26194	26204	36586	36612
3	11.250	-19773	-5655	279115	-24094	24259	4321	5164	5678	6343	-25451	25608	36016	36458
4	16.875	-18476	-6355	239885	-21269	21505	2793	4231	4318	5361	-22794	23015	32795	33405
5	22.500	-16951	-6588	197450	-18216	18511	1265	3528	2846	4353	-19797	20069	29063	29800
6	28.125	-15188	-10647	153015	-14477	15425	-711	5371	1844	5634	-17032	17845	25904	28007
7	33.750	-12891	-14003	88003	-9459	11768	-3432	7798	-72	7002	-12819	14607	20945	25195
8	39.375	-10040	-11172	7050	-4055	6903	-5985	8187	-3303	6490	-6737	8751	13097	17215
9	45.000	-43218	758	-413348	345	513	-43563	43565	-43745	43747	527	649	65445	65450
10	50.625	-41409	14737	-424561	170	7370	-41579	42227	-45116	45714	3707	8249	67589	69177
11	56.250	-40715	9329	-359556	-2301	5201	-38414	38696	-40653	40920	-62	4665	62130	62827
12	61.875	-39316	17078	-321542	-4558	9680	-34758	35791	-38856	39783	-460	8551	60564	62925
13	67.500	-38681	26933	-242623	-9633	16557	-29048	32018	-35512	37980	-3169	13834	58085	64025
14	73.125	-38847	22336	-110975	-16185	19664	-22662	25264	-28022	30166	-10825	15553	50126	54878
15	78.750	-38957	17971	-3509	-21448	23254	-17509	19680	-21822	23600	-17135	19348	43457	47026
16	84.375	-37882	13875	81778	-24967	25913	-12915	14660	-16245	17664	-21637	22722	45573	47639
17	90.000	-36835	8934	146418	-27299	27662	-9536	10531	-11681	12506	-25154	25548	46788	47633
18	95.625	-35169	5499	185882	-28158	28292	-7011	7531	-8331	8773	-26838	26979	46402	46727
19	101.250	-33287	2474	208444	-28057	28085	-5230	5374	-5823	5953	-27464	27491	44998	45066
20	106.875	-31172	-133	216278	-27105	27105	-4067	4068	-4035	4036	-27137	27137	42739	42739
21	112.500	-28942	-2319	211675	-25482	25508	-3160	3649	-2903	3126	-26039	26064	40788	40854
22	118.125	-26491	-4064	196194	-23222	23310	-3270	3850	-2294	3065	-24197	24282	37930	38147
23	123.750	-24057	-5362	172835	-20603	20777	-3454	4372	-2167	3447	-21890	22053	34562	34975
24	129.375	-21642	-6234	143762	-17740	18012	-3902	4994	-2406	3937	-19236	19487	30805	31430
25	135.000	-19340	-6706	111139	-14793	15168	-4547	5650	-2938	4458	-16402	16741	26877	27701
26	140.625	-17094	-6793	76693	-11822	12300	-5272	6271	-3642	4980	-13452	13875	22815	23804
27	146.250	-15073	-6522	42677	-9030	9601	-6043	6867	-4478	5539	-10595	11086	18914	20007
28	151.875	-13279	-5938	10836	-6505	7150	-6774	7396	-5349	6118	-7930	8468	15282	16395
29	157.500	-11778	-5089	-17443	-4348	5038	-7430	7854	-6209	6710	-5569	6123	13930	14830
30	163.125	-10516	-4019	-40601	-2610	3294	-7906	8157	-6941	7226	-3575	4101	13646	14225
31	168.750	-9607	-2772	-57790	-1389	1962	-8218	8334	-7553	7679	-2054	2478	13354	13639
32	174.375	-9040	-1408	-68132	-717	1005	-8323	8352	-7985	8016	-1055	1269	13012	13088

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EM MODULE ENDPLATE BRACKET PIN LOADS -- DWT ONLY + FRICTION

I.D.	ANGLE	HOOP	SHEAR	MOMENT	F1	VR1	F2	VR2	F3	VR3	F4	VR4	MAX F	MAX VR
1	0.000	-12510	0	25207	-10618	10618	-1892	1892	-1892	1892	-10618	10618	16873	16873
2	5.625	-12438	1215	22399	-10264	10282	-2174	2257	-2511	2583	-9927	9946	16651	16695
3	11.250	-12410	-340	23960	-10305	10306	-2105	2112	-2011	2018	-10399	10400	16651	16654
4	16.875	-12241	-1069	19961	-9427	9442	-2814	2864	-2518	2574	-9723	9738	15992	16027
5	22.500	-11927	-1666	13324	-8039	8082	-3888	3976	-3427	3527	-8500	8541	14694	14788
6	28.125	-11569	-715	4634	-6488	6497	-5081	5094	-4883	4897	-6686	6695	12569	12589
7	33.750	-11232	-2124	-502	-5235	5342	-5997	6090	-5403	5512	-5823	5919	11907	12095
8	39.375	-10780	-3158	-10700	-3101	3480	-7679	7840	-6805	6985	-3975	4277	13506	13871
9	45.000	-7328	-1926	-13611	-1042	1419	-6286	6360	-5753	5833	-1575	1846	10217	10397
10	50.625	-6828	334	-22192	381	416	-7209	7210	-7301	7303	473	502	10761	10766
11	56.250	-6534	-525	-22476	696	743	-7230	7234	-7084	7089	550	610	10569	10582
12	61.875	-6169	2051	-25869	1109	1510	-7278	7350	-7846	7912	1677	1965	11214	11400
13	67.500	-6018	3024	-19719	-15	1512	-6003	6191	-6840	7006	822	1721	10268	10704
14	73.125	-5975	2321	-10018	-1575	1956	-4400	4550	-5043	5174	-932	1489	8352	8668
15	78.750	-5832	1659	-2763	-2668	2794	-3164	3271	-3624	3718	-2208	2359	6770	6970
16	84.375	-5643	1045	2161	-3340	3381	-2303	2361	-2592	2644	-3051	3095	6306	6392
17	90.000	-5372	1634	4955	-3770	3857	-1602	1798	-2055	2211	-3317	3416	6682	6879
18	95.625	-5182	1131	10001	-4478	4514	-704	903	-1017	1163	-4165	4203	7226	7314
19	101.250	-4929	683	13269	-4856	4868	-73	349	-263	431	-4666	4679	7415	7446
20	106.875	-4659	294	15104	-4984	4986	325	357	244	285	-4903	4905	7354	7360
21	112.500	-4347	-36	15567	-4863	4863	516	516	526	526	-4873	4873	7051	7051
22	118.125	-4033	-304	14985	-4568	4570	535	556	619	637	-4652	4655	6711	6718
23	123.750	-3698	-510	13498	-4114	4122	416	488	558	613	-4256	4263	6175	6196
24	129.375	-3376	-658	11404	-3571	3586	195	382	377	500	-3753	3767	5532	5571
25	135.000	-3052	-748	8848	-2954	2977	-98	387	109	390	-3161	3183	4790	4849
26	140.625	-2756	-784	6084	-2322	2355	-434	585	-216	448	-2540	2570	4026	4102
27	146.250	-2475	-771	3263	-1695	1739	-780	870	-566	685	-1909	1948	3253	3343
28	151.875	-2233	-713	577	-1118	1173	-1115	1171	-918	985	-1315	1363	2530	2629
29	157.500	-2020	-618	-1834	-607	681	-1413	1446	-1242	1280	-778	837	2509	2584
30	163.125	-1856	-492	-3849	-194	313	-1662	1680	-1526	1546	-330	412	2658	2704
31	168.750	-1730	-341	-5351	108	202	-1838	1846	-1744	1752	14	171	2751	2772
32	174.375	-1659	-175	-6296	284	298	-1943	1945	-1895	1897	236	252	2797	2803

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STICK-SLIP CONDITION =

<u>BRACKET</u>	<u>PIN</u>	<u>BEARING</u>	<u>TEAR-OUT</u>
CH	1	56178	44028
	2	81496	20555
	3	90846	20983
	4	72188	72188

(MAX EQN 3 PIN LOAD = 133798#)

FH	1	28292	6903
	2	38696	5876
	3	45714	6343
	4	27491	13834

(MAX EQN 3 PIN LOAD = 69177#)

EM	1	10618	743
	2	7840	516
	3	7912	637
	4	10618	1965

(MAX EQN 3 PIN LOAD = 16695#)

PIN STRESSES

Allowables: AISI 304 stainless steel and Inconel 718 are not standard AISC-approved fastener materials. The allowables ^{for these materials} in shear for a bearing connection will be based on a survey of the standard AISC allowables:

<u>Material</u>	<u>F_y</u>	<u>F_u</u>	<u>Allowable F_v</u>	<u>F_v/F_y</u>	<u>F_v/F_u</u>
A-502, Gr. 1	40	60	17.5	.44	.29
A-502, Gr. 2	50	70	22.0	.44	.31
A-307, Gr. A	36	60	10.0	.27	.17
A-325 } (a)	81	105	30.0	.37	.29
A-490 }	130	150	40.0	.31	.27
A-449 (b)	58-92	90-120	20-26	.34-.28	.22

Notes: (a) for threads excluded from shear planes
(b) Mat'l strength varies with fastener size.

An allowable $F_v = 0.20 F_u$ would be appropriate. Then the following allowables apply:

<u>Material</u>	<u>F_u</u>	<u>$F_v = .20 F_u$</u>
AISI Type 304 SS. - Annealed cond.	75.0	15.0
A-193/A-320, Grade 8, Class 2 only		
(solution treated and $\phi \leq 3/4"$ - 125.0		25.0
Strain hardened Type 304 $\phi \geq 1/2"$ - 90.0		18.0
for bolting applications)		
INCONEL 718, Precipitation-hardened	180.0	36.0
Nickel-based alloy		

42-381 50 SHEETS 5 SQUARE
 42-382 100 SHEETS 5 SQUARE
 42-389 200 SHEETS 5 SQUARE

EM: $P = (8066)(1.25) = 10100^{\#}$

CH: 2' $\emptyset$ pin,

$$f_v = \frac{73350}{(\pi_d)(2)^2} = 23350 \text{ psi}$$

$\leq$
 $>$
 $>$

$F_v - \text{INC. 718}$
 $F_v - \text{ANN. 304}$
 $F_v - \text{A-193/320}$

FH: 2" ϕ pin

$$f_v = \frac{69030}{(\pi/4)(2)^2} = 21975 \text{ psi}$$

$\leq F_v - \text{INK 718}$
 $> F_v - \text{ANN. 304}$
 $> F_v - \text{A-193/320}$

EM = 3/4" ϕ pin

$$F_V = \frac{10100}{(.75)^2 (\pi/4)} = 22860 \text{ psi} \begin{aligned} &\leq F_V - \text{Inv. 718} \\ &\leq F_V - A-193/320 \\ &> F_V - A-285/304 \end{aligned}$$

∴ Inconel 718 or A-193/320 Gr. E, Cl. 2
are acceptable.

B) Use the nominal loads (Eqn' 2) from the assumed friction load case, with $LF = 1.25$:

$$CH, P = (98846)(1.25) = 123558 \#$$

$$FH, P = (45714)(1.25) = 57143 \#$$

$$EM, P = (10618)(1.25) = 13273 \#$$

Stresses:

CH: 2" ϕ pin

$$f_v = \frac{123558}{(\pi/4)(2)^2} = 39330 \text{ psi} \geq F_v - \text{Inc. 71B}$$

$$\geq F_v - \text{Ann. 304}$$

$$\geq F_v - A-193/4-320$$

FH: 2" ϕ pin

$$f_v = \frac{57143}{(\pi/4)(2)^2} = 18190 \text{ psi} \leq F_v - \text{Inc. 71B}$$

$$\approx F_v - A-193/320$$

$$\geq F_v - \text{Ann. 304}$$

EM: 3/4" ϕ pin

$$f_v = \frac{13273}{(\pi/4)(3/4)^2} = 30045 \text{ psi} \leq F_v - \text{Inc. 71B}$$

$$\geq F_v - A-193/320$$

$$\geq F_v - \text{Ann. 304}$$

$\therefore$ Recommend preventing the occurrence of frictional loadings, although Inconel 71B is acceptable for the FH and EM application, and also for the CH ring with a reduced safety factor.

CC-MOD-04

Endplate Bracket Pin Hole Stresses

END PLATE BRACKET PIN HOLE STRESSES1) CRITERIA AND JUSTIFICATION

The pin loadings determined in calc CC-MOD-03 are applied to the pin holes located in the end plate brackets. Three modes of failure of the bracket, as a result of these loadings, may be identified. These are bearing, shear tear-out and ^{net} tension failure. The AISC provides allowable stresses and/or minimum hole-to-hole and ^{hole-to-}edge distance requirements to prevent such failures from occurring. The design material is annealed Type 304 stainless plate with $S_y \geq 30$ ksi and $S_u \geq 75$ ksi. These are in the range of ^{mechanical properties of the} materials of construction used in applications for which the AISC criteria were developed, namely plain carbon steel (A-36 and A-529) and some high strength low-alloy steels (A-441 Grade 40 or A-572 Grade 42). The Type 304 stainless in the annealed condition probably strain-hardens more than the typical construction grade steels, especially the HSLA grades,

but this may be less the case at ^{the} cryogenic temperatures that the D-D structure will experience. The AISC criteria were therefore applied directly. Bearing allowables from MIL-HDBK-5 are also cited.

The AISC Specifications and Commentary are reviewed, below, for application to the brackets.

BEARING =

- 1.5.1.5.1 - On projected area of pins in reamed, drilled or bored holes,

$$F_p = .90 F_y$$

- COMM 1.5.1.5.1 - The allowable of 90% yield is intended to prevent instability of the plate material beyond the hole.

- 1.5.1.5.3 - On projected area of bolts and rivets in shear connections, $F_p = 1.5 F_u$.

Since the bracket connectors are not shear connections, 1.5.1.5.3 is not applicable.

Then maximum bearing force, where bearing stress $F_p = P/d \cdot t$, d = pin diameter and t = plate thickness is, per 1.5.1.5.1,

$$P_b \leq .90 dt F_y$$

SHEAR :

- 1.5.1.2.2 - For coped-flange beam connections and any application of shear through a line of fastener holes plus tension on a perpendicular plane, $F_v = .30 F_u$.
- COMM. 1.5.1.2 - The above is conservative. The commentary allows for treating the shear and tension areas separately. The allowable capacity in tearing failure mode is then

$$\max P_{tf} \leq .30 A_v F_u + .50 A_t F_u$$
 where A_v and A_t are the net shear and tension areas, respectively.

TENSION :

- 1.5.1.1.1 - Except for pin-connected members:

$$F_t = .60 F_y \text{ on gross area}$$

$$F_t = .50 F_u \text{ on effective net}$$
 - For pin-connected members:

$$F_t = .45 F_y \text{ on the net area.}$$
- COMM 1.5.1.1 - The $.60 F_y$ allowable is intended to prevent excess "stretch" of tension members resulting in load redistribution. Since holes are "short," yield on the gross area is not a practical limit state. This can therefore be disregarded. The $.45 F_u$ allowable

is applicable to eyebars. Justification exists in other criteria (COMM 1.5.1.2 and 1.16.5) to disregard this ^{and the .5F_u allowable} as not applicable to the end plate brackets.

EFFECTIVE AREAS :

- 1.14.2.3 - Riveted and bolted gusset and splice plates, effective net area is equal to the actual net area, but for design purposes is not more than 85% of the gross area.

The brackets may be construed as a form of splice plate. This requirement will be observed.

- 1.14.4 - In computing net area, the hole to be taken as $1/16$ " greater than the nominal fastener diameter.

This is standard fabrication allowance. Due to the tight clearances in the module pin holes, this will be disregarded.

- 1.14.5 - For pin-connected plates:

Minimum net area beyond the pin hole parallel to the member axis to be not less than $2/3$ of the net area across the pin hole, i.e. $C \geq \frac{2}{3} \times 2B$.

Also, transverse distance from pin hole edge to plate edge to be less than $4 \times$ plate thickness, and pin hole diameter to be at least $1.25 \times$ above distance.

$$E \leq 4t$$

$$d \geq 1.25 E \quad \text{or} \quad E \leq .80 d$$

$$\therefore e = E + \frac{d}{2}, \text{ so } \frac{e}{d} \leq 1.30.$$

- COMM 1.14.5 - This is interpreted to apply to thermally cut plates that substitute for and perform the function of forged eyebars. The brackets do not perform the function of eyebars, and other criteria are considered more applicable (see 1.5.1.2 & 1.16.5).

MINIMUM EDGE DISTANCE:

- 1.16.5.1 - Distance from a hole center to an edge to be not less than per Table 1.16.5.1 and § 1.16.5.2 or .3.
- 1.16.5.2 - Along the line of transmitted force (in the direction of the force) the edge distance (hole $\nless$ to plate edge)

$$e \geq \frac{2P}{F_u t} \quad (\text{Eqn 1.16-2})$$

- 1.16.5.3 - At end connections (beam ends) designed for shear only, edge distance to the end of the beam web, $e \geq \frac{2P_R}{F_{ut}}$, (Eqn 1.16-3).

- COMM 1.16.5 - The commentary states that a linear relationship exists between the ratio of critical bearing stress to tensile strength and the ratio of fastener spacing or edge distance (a line with the force) to fastener diameter, or

$$\frac{F_{pu}}{F_u} = \frac{le}{d}$$

Equation 1.16-2 is based

on the above with a Safety Factor $SF=2$:

$$\frac{2F_p}{F_u} = \frac{e}{d}, \quad F_p = P/dt$$

$$\text{so } e = \frac{2F_p \cdot d}{F_u} = \frac{P}{dt} \cdot \frac{2d}{F_u} = \frac{2P}{F_{ut}} \quad (1.16-2).$$

So the maximum load with $SF=2$ based on Eqn 1.16-2 is $P \leq \frac{1}{2} e \cdot t \cdot F_u$.

For 1.16-3, P_R is divided by the number of fasteners. The distinction between 1.16-2 and 1.16-3 is as shown below:

In addition to the above, MIL-HDBK-5 gives bearing strength to yield and ultimate conditions in a tear-out mode for edge distance ratios (typically) of $e/d = 1.5$ and 2.0 . Values of e/d between 1.5 and 2.0 may be interpolated linearly.

SUMMARY

$$\text{BEARING: } P_b \leq .90 d t F_y \quad (\text{EQ. 1})$$

$$\text{TEAR-OUT: } P_t \leq .50 e t F_u \quad (\text{EQ. 2})$$

$$\text{TEAR-OUT: } P_t \leq (.30 A_v + .50 A_t) F_u \quad (\text{EQ. 3})$$

$$\text{where } A_v = (e_v - \frac{d}{2}) t \leq .85 \cdot A_{\text{gross}}$$

$$\text{and } A_t = (e_t - \frac{d}{2}) t \leq .85 \cdot A_{\text{gross}}$$

MIL-HDBK-5: (Annealed condition)

$$F_{br}, \quad e/d = 1.5 : \text{Not cited}$$

$$e/d = 2.0 : 150 \text{ ksi}$$

$$F_{by}, \quad e/d = 1.5 : \text{Not cited}$$

$$e/d = 2.0 : 50 \text{ ksi}$$

2) LOADS

Pin loads were determined in calculation CC-MOD-03. Loads identified as "bearing" are resultant loads in compression only. Loads identified as "tearing" are resultants that act effectively in a tensile or shear tear-out mode.

The applied loads will include an arbitrary load factor $LF = 1.25$. The loads are summarized below:

<u>LOAD CASE</u>	<u>LOADING</u>	<u>CH</u>	<u>FH</u>	<u>EM</u>
NO FRICTION	BEARING	58680 [#]	55220 [#]	8070 [#]
	X LF=1.25	<u>73350</u>	<u>69030</u>	<u>10100</u>
	TEAR-OUT	30690	12970	2130
	X LF=1.25	<u>38370</u>	<u>16220</u>	<u>2670</u>
FRICTION	BEARING	98846	45714	10618
	X LF=1.25	<u>123558</u>	<u>57143</u>	<u>13273</u>
	TEAR-OUT	72188	13834	1965
	X LF=1.25	<u>90235</u>	<u>17293</u>	<u>2456</u>

3) CALCULATIONS of LOAD CAPACITIESA) CH BRACKET

$$d = 2.0"$$

$$e_1 = 2.0"$$

$$e_2 = 1.9375"$$

$$t = 1\frac{1}{2}"$$

Per Table 1.16.5.1, $\min e > 1.25d = 2.5" > 1.9375"$
 $> 2.0"$

$\therefore$ not in compliance w/ T.1.16.5.1

Bearing: $P_b = (.9)(2.0)(1.5)(30) = \underline{81.0} \text{ kips}$ $> 73.4 \text{ k} - \text{OK}$
 $< 123.6 \text{ k} - \text{N.A.}$

Tearing: $P_t = (.5)(1.9375)(1.5)(75) = \underline{109.0} \text{ k}$ $> 38.4 \text{ k} - \text{OK}$
 $> 90.2 \text{ k} - \text{OK}$

and: $P_{t\phi} = (.3 + .5)(1.9375 - 1.0)(1.5)(75)$
 $= \underline{84.4} \text{ k}$ $> 38.4 \text{ k} - \text{OK}$
 $< 90.2 \text{ k} - \text{N.A.}$

Check areas: $\frac{8.625 - 2.0 - 2.0}{8.625} = .536 < .85 - \text{OK}$

$\frac{6.5 - 2.0}{6.5} = .692 < .85 - \text{OK}$

Results: 1) Does not meet specs per Table 1.16.5.1

2) Acceptable for no friction case

3) Not Acceptable for friction case

B) FH BRACKET

$$d = 2.0''$$

$$e_1 = e_2 = 2.0''$$

$$t = 1/4''$$

Per Table 1.16.5.1, $\min e > 1.25d = 2.5'' > 2.0''$

$\therefore$ not in compliance w/ T. 1.16.5.1

Bearing, $P_b = (.9)(2.0)(1.25)(30) = \underline{67.5^k} < 69.0^k - NA$
 $> 57.1^k - OK$

Tearing: $P_t = (.5)(2.0)(1.25)(75) = \underline{93.75^k} > 16.2^k - OK$
 $> 17.3^k - OK$

and $P_{tf} = (.3 + .5)(2.0 - 1.0)(1.25)(75)$
 $= \underline{75.0^k} > 16.2^k - OK$
 $> 17.3^k - OK$

Check areas: $\frac{6.5 - 2.0 - 2.0}{6.5} = .529 < .85 - OK.$

$\frac{6.5 - 2.0}{6.5} = .692 < .85 - OK.$

- Results:
- 1) Not in compliance w/ Table 1.16.5.1
 - 2) Acceptable for friction load case
 - 3) Acceptable with 2% overload on bearing for no-friction case, by engineering judgement.

c) EM BRACKET

$$d = .754"$$

$$e_1 = .861"$$

$$e_2 = .750"$$

$$t = .75"$$

Per Table 1.16.5.1, min $e = 1.0" > .861"$
 $> .75"$

$\therefore$ not in compliance w/ T-1.16.5.1

Bearing, $P_b = (.9)(.750)(.75)(30) = \underline{15.2k} > 10.1k - OK$
 $> 13.3k - OK$

Tearing: $P_t = (.5)(.750)(.75)(75) = \underline{21.1k} > 2.3k - OK$
 $> 2.5k - OK$

and, $P_{tf} = (.3 + .5)(.75 - \frac{.75}{2})(.75)(75)$
 $= \underline{16.875k} > 2.3k - OK$
 $> 2.5k - OK$

Check areas: $\frac{3.10 - .75 - .75}{3.10} = .516 < .85 - OK$

$\frac{2.375 - .75}{2.375} = .684 < .85 - OK$

- Results:
- 1) Not in compliance with Table 1.16.5.1
 - 2) Acceptable for friction loads
 - 3) Acceptable for no-friction loads

CC-MOD-05

Endplate Bracket Bending Stresses

END PLATE BRACKET BENDING STRESSES

The loads calculated in CC-MOD-02 result in bending and shear loads distributed along the length of the bracket. This calculation estimates the stresses due to these loads.

Bearing and shear tear-out stresses at the pin holes were evaluated in calc CC-MOD-04.

The distribution of shear and bending loads is as shown below:

The distribution applies even in the unlikely case described in calc. CC-MOD-02 in which all loads on one side go to a single pin instead of 2 pins.

The cross-sectional depth varies with distance from the midpoint of the member,

$$h(x) = H + 2(R - \sqrt{R^2 - (x - x_0)^2})$$

The bending moment also varies with the distance from the midpoint,

$$\begin{aligned} M(x) &= \frac{F_3 B}{2} - 2 \cdot \frac{F_3 B}{2A} \left(\frac{A}{2} - x \right) \\ &= \frac{F_3 B}{2} \left(\frac{2x}{A} \right) = \frac{F_3 B}{A} \cdot x \end{aligned}$$

Then the bending stress as a function of x is:

$$\begin{aligned} f_b &= \frac{6M(x)}{t h(x)^2} = \frac{6 F_3 B \cdot x}{A t \cdot h(x)^2} \\ &= \frac{6 F_3 \frac{B \cdot x}{A t}}{[H + 2(R - \sqrt{R^2 - (x - x_0)^2})]^2}, \quad x \geq x_0 \end{aligned}$$

The allowable bending stress in tension per 1.5.1.4.5 is $F_b = .60 F_y = (.6)(30) = 18 \text{ ksi}$.

In compression, the allowable may be reduced to prevent lateral buckling, per 1.5.1.4.5, where

$$F_b = \left[\frac{2}{3} - \frac{F_y (l/r_T)^2}{1530 \times 10^3 C_b} \right] F_y$$

$$\text{for } \sqrt{\frac{102 \times 10^3 C_b}{F_y}} \leq \frac{l}{r_T} \leq \sqrt{\frac{510 \times 10^3 C_b}{F_y}},$$

$$\text{or } F_b = .60 F_y \text{ for } \frac{l}{r_T} < \sqrt{\frac{102 \times 10^3 C_b}{F_y}}$$

$$\text{or } F_b = \frac{170 \times 10^3 C_b}{(l/r_T)^2} \text{ for } \frac{l}{r_T} > \sqrt{\frac{50 \times 10^3 C_b}{F_y}}$$

Parameters, l = distance braced against twisting
= dimension A

$r_T = r$ for a section comprising the
compression flange (none) plus $\frac{1}{3}$
compression web area, about an
axis in-plane

$$= \sqrt{\frac{I}{A}} = \sqrt{\frac{\frac{1}{12} \left(\frac{1}{3} h(x) \right) t^3}{\left(\frac{1}{3} h(x) \right) (t)}} = \frac{t}{\sqrt{12}}$$

$$C_b = 1.75 + 1.05 \frac{M_1}{M_2} + 0.3 \left(\frac{M_1}{M_2} \right)^2 \leq 2.3 \text{ max}$$

& $M_1 = M_2$ for reversed curvature bending.

Alternatively, check whether the plate is
fully effective for unstiffened compression
due to bending, per § 1.9.1.2, where the
ratio of width-to-thickness (C/t) is
not greater than:

$$\frac{C}{t} < \frac{76}{\sqrt{F_y}} = \frac{76}{\sqrt{30}} = 13.88 \text{ (conservative, could use } 95/\sqrt{F_y} \text{.)}$$

The allowable for shear, per 1.5.1.2.1

$$\text{is } F_v = 0.40 F_y = 12.0 \text{ ksi,}$$

$$\text{where } f_v = \frac{F_3 B/A}{H \cdot t}$$

1) CH BRACKET

$$H = 3.0", x_0 = 0, R = 8.0", t = 1\frac{1}{2}"$$

$$A = 16.239", B = 4.672", C = 8\frac{5}{8}"$$

$$\max F_s = 45755 \# \times 1.25 \text{ (no friction)}$$

$$1.9.1.2 - \frac{C}{t} = \frac{8.625}{1.5} = 575 < 13.88$$

$\therefore$ fully effective

$$1.5.4.1.5 - l = 16.239$$

$$r_T = \frac{1.5}{\sqrt{12}} = .433 \quad \left. \vphantom{r_T} \right\} \frac{l}{r_T} = 37.50$$

$$C_b = 1.75 + (1.05)(1) + (.3)(1)^2$$

$$= 3.10 > 2.3 \text{ max value}$$

$$\sqrt{\frac{(102 \times 10^3)(2.3)}{30}} = 88.42 > 37.50$$

$$\therefore F_b = .60 F_y = (.6)(30) = \underline{18.0 \text{ ksi}}$$

$$\begin{aligned} \text{Then } f_b &= \frac{(6)(45.8) \left(\frac{4.672}{16.239} \right) (1.25) \times / 1.50}{[3.0 + 2(B - \sqrt{64 - x^2})]^2} \\ &= \frac{65.88 x}{(19.0 - 2\sqrt{64 - x^2})^2} \end{aligned}$$

$\frac{x}{.0}$ in	$\frac{f_b}{-0-}$ ksi
1.0	6.74
2.0	10.71
3.0	11.38
4.0	9.96
5.0	7.77
6.0	5.58 < 18.0 ksi, Ok

$$\text{At } x = \frac{A}{2},$$

$$f_b = \frac{(6)(\frac{1}{2})(45.8)(4.672)(1.25)}{(1.5)(8.625)^2} = 7.19 \text{ ksi} < 18.0$$

- OK

1.5.1.2.1 -

$$f_v = \frac{(45.8)(\frac{4.672}{16.239})(1.25)}{(3.0)(1.5)} = 3.66 \text{ ksi} < 12.0 \text{ ksi}$$

- OK.

Considering friction, the maximum shear force was 64649#. This is a factor of 1.413 times greater than without friction, with a corresponding increase in all stresses.

$$\text{Then, } \max f_b = (1.413)(11.38) = 16.08 \leq 18.0 \text{ ksi, OK.}$$

$$\max f_v = (3.66)(1.413) = 5.17 \leq 12.0 \text{ ksi, OK.}$$

$$\text{At } x = \frac{A}{2},$$

$$f_b = \frac{(6)(\frac{1}{2})(45.8)(4.672)(1.25)}{(1.5)(8.625)^2} = 7.19 \text{ ksi} < 18.0$$

- OK

1.5.1.2.1 -

$$f_v = \frac{(45.8)(\frac{4.672}{16.239})(1.25)}{(3.0)(1.5)} = 3.66 \text{ ksi} < 12.0 \text{ ksi}$$

- OK.

Considering friction, the maximum shear force was 64649#. This is a factor of 1.413 times greater than without friction, with a corresponding increase in all stresses.

$$\text{Then, } \max f_b = (1.413)(11.38) = 16.08 \leq 18.0 \text{ ksi, OK.}$$

$$\max f_v = (3.66)(1.413) = 5.17 \leq 12.0 \text{ ksi, OK.}$$

$$\text{At } x = \frac{A}{2},$$

$$f_b = \frac{(6)(\frac{1}{2})(45.8)(4.672)(1.25)}{(1.5)(8.625)^2} = 7.19 \text{ ksi} < 18.0$$

- OK

1.5.1.2.1 -

$$f_v = \frac{(45.8)(\frac{4.672}{16.239})(1.25)}{(3.0)(1.5)} = 3.66 \text{ ksi} < 12.0 \text{ ksi}$$

- OK.

Considering friction, the maximum shear force was 64649#. This is a factor of 1.413 times greater than without friction, with a corresponding increase in all stresses.

$$\text{Then, } \max f_b = (1.413)(11.38) = 16.08 \leq 18.0 \text{ ksi, OK.}$$

$$\max f_v = (3.66)(1.413) = 5.17 \leq 12.0 \text{ ksi, OK.}$$

$$\text{At } x = \frac{A}{2},$$

$$f_b = \frac{(6)(\frac{1}{2})(45.8)(4.672)(1.25)}{(1.5)(8.625)^2} = 7.19 \text{ ksi} < 18.0$$

- OK

$$1.5.1.2.1 -$$

$$f_v = \frac{(45.8)(\frac{4.672}{16.239})(1.25)}{(3.0)(1.5)} = 3.66 \text{ ksi} < 12.0 \text{ ksi}$$

- OK.

Considering friction, The maximum shear force was 64649#. This is a factor of 1.413 times greater than without friction, with a corresponding increase in all stresses.

$$\text{Then, } \max f_b = (1.413)(11.38) = 16.08 \leq 18.0 \text{ ksi, OK.}$$

$$\max f_v = (3.66)(1.413) = 5.17 \leq 12.0 \text{ ksi, OK.}$$

2) FH BRACKET

$$H = 2.0", R = 10", x = .0", t = 1.25"$$

$$A = 18.750", B = 4.500", C = 8\frac{1}{2}"$$

$$\text{Max } F_s = 20001 \# \times 1.25 \text{ (no friction)}$$

$$1.9.1.2 - \frac{C}{t} = \frac{8.5}{1.25} = 6.8 < 13.88 - \text{fully effective}$$

$$1.5.4.1.5 - l = 18.75"$$

$$r_T = \frac{1.25}{\sqrt{12}} = .361$$

$$\frac{l}{r_T} = 51.96 < 88.42$$

$$\text{so } F_b = .60 F_y = 18.0 \text{ ksi}$$

$$\begin{aligned} \text{Then } f_b &= \frac{(6)(20.0)\left(\frac{4.5}{18.75}\right)(1.25) \times 1.25}{\left[2.0 + 2(10 - \sqrt{10^2 - x^2})\right]^2} \\ &= \frac{28.80 \cdot x}{(22.0 - 2\sqrt{100 - x^2})^2} \end{aligned}$$

x, in	f_b, ksi
.0	-0-
1.0	13.71
2.0	9.97
3.0	10.12
4.0	8.55
5.0	6.58
6.0	4.80
7.0	3.39

$$3.39 < 18.0 \text{ ksi, OK}$$

At $x = \frac{A}{2}$,

$$f_b = \frac{(6)(\frac{1}{2})(20.0)(4.5)(1.25)}{(1.25)(8.5)^2} = 3.75 \text{ ksi} < 18.0 \text{ ksi} \\ \text{---OK.}$$

1.5.1.2.1,

$$f_v = \frac{(20.0)(\frac{4.50}{18.75})(1.25)}{(1.25)(2.0)} = 2.40 \text{ ksi} < 12.0 \text{ ksi} \\ \text{---OK}$$

The maximum shear load with friction was 26933#, which is a factor 1.347 times greater than without friction, with a corresponding increase in all stresses.

$$\text{Then } \max f_b = (13.71)(1.347) = 18.46 \geq 18.0 \text{ ksi}$$

$$\text{and } \max f_v = (2.40)(1.347) = 3.23 \leq 12.0 \text{ ksi.}$$

The overload in bending is only 2.6%.

This can be accepted by engineering judgement.

3) EM BRACKET

$$H = 1.125", R = 1.50", x_0 = .517", t = \frac{3}{4}"$$

$$A = 5.778", B = 1.600", C = 3.100"$$

$$\max F_s = 3933 \# \rightarrow \text{use } 4.0 \text{ kips (no friction)}$$

$$1.9.1.2 - \frac{C}{t} = \frac{3.10}{.75} = 4.13 < 13.88 \therefore \text{fully effective}$$

$$1.5.4.1.5 - \ell = 5.778$$

$$r_T = \frac{.75}{\sqrt{12}} = .2165$$

$$K r_T = 26.69 < 88.42,$$

$$\therefore F_b = .60 F_y = 18.0 \text{ ksi}$$

$$\begin{aligned} \text{Then } f_b &= \frac{(6)(4.0)\left(\frac{1.60}{5.778}\right)(1.25)x / .75}{\left[1.125 + 2(1.5 -) 2.25 - (x - .517)^2\right]^2} \\ &= \frac{(11.08)x}{\left[4.125 - 2\sqrt{1.983 + 1.034x - x^2}\right]^2} \\ &\quad \text{(for } x \geq .517) \end{aligned}$$

x, in	f_b, ksi
0	-0-
0.517	4.53
1.0	6.72
1.5	4.81
2.0	1.64 < 18.0 ksi, -0k

$$\text{At } x = \frac{A}{2}, f_b = \frac{(6)\left(\frac{1}{2}\right)(4.0)(1.60)(1.25)}{(.75)(3.1)^2} = 3.34 \text{ ksi} < 18.0 \text{ ksi} \\ -0.k.$$

$$1.5.1.2.1 -$$

$$f_v = \frac{(4.0)\left(\frac{1.60}{5.778}\right)(1.25)}{(1.125)(.75)} = 1.64 \text{ ksi} < 12.0 \text{ ksi}, \\ -0.k.$$

The maximum shear force with friction was 315B#, which is a factor of .803 times the force without friction. This results in lower stresses. The ^{EM} bracket is therefore acceptable for these loads.

CC-MOD-06

Module Endplate Pin Hole Stresses

MODULE END PLATE PIN HOLE STRESSES1) CRITERIA AND JUSTIFICATION

The pin loadings determined in calc CC-MOD-03 are applied to the pin holes located near the corners of the end plates. An extensive review of AISC criteria addressing bearing, shear and tensile failure in the pin holes was performed in calc. CC-MOD-04. ^{for application} to the end plate bracket pin holes. The end plates are similar to the end plate brackets in all respects pertaining to these criteria. Therefore, the same criteria for acceptance will be applied to the end plates as were applied to the end plate brackets. These are as follows:

$$\text{Bearing: } P_b = .90 d t F_y \quad (\text{EQ'N 1})$$

$$\text{Tearing: } P_b = .50 e t F_u \quad (\text{EQ'N 2})$$

$$\& P_{tF} = (.30 A_v + .50 A_t) F_u \quad (\text{EQ'N 3})$$

$$\text{where } A_v = (e_v - \frac{d}{2}) t$$

$$\& A_t = (e_t - \frac{d}{2}) t$$

The end plates are fabricated from annealed 304 stainless, $F_y = 30 \text{ ksi}$, $F_u = 70 \text{ ksi}$. Refer to CC-MOD-04 page 8 for loads.

CH MODULE END PLATE

Due to the complex geometry of the end plate, the edge distances A, B, C, and D are only estimates. Assume no clearance between end plates, $A = D = \frac{1}{2}(4.672) = 2.336"$.

Approximate radius at inner pin holes is $R_i = [(67.225 + 2.165 \cos 20)^2 + 11.345^2]^{1/2} = 70.191$.

Then $\frac{1}{2}$ angle subtended by pin holes is

$$\alpha_i = \sin^{-1} \frac{11.345}{70.191} = 9.343^\circ$$

$$\alpha_D = \frac{22.5}{2} - 9.343 = 1.91^\circ$$

$$\therefore D = (\sin 1.91)(70.191) = 2.336" (\checkmark)$$

$$C_1 = \frac{70.191 - 67.225}{\cos 20} - 1.0 = 2.156"$$

$$C_2 = 2.156 - 1.74 \tan 20 = 1.523"$$

Approximate radius at outer pin holes,

$$R_o = [(67.225 + (2.165 + 15.963) \cos 20)^2 + (11.345 + 2.983)^2]^{1/2} = 85.478"$$

$$\text{Then } \alpha_0 = \sin^{-1} \frac{11.395 + 2.983}{85.478} = 9.684^\circ$$

$$\alpha_A = \frac{22.5}{2} - 9.684 = 1.526^\circ$$

$$\therefore A = (\sin 1.526)(85.478) = 2.337" (\checkmark)$$

$$B_2 = \frac{88.199 - 85.478}{\cos 20} - 1.0 = 1.896"$$

$$\& B_1 = 1.896 + 1.54 \tan 20 = 2.456"$$

Then at inner pin holes, effective area in radial and tangential planes are:

$$A_R = [(1.74)(1.523) + \frac{1}{2}(1.74)(2.156 - 1.523)](.90) = 2.881 \text{ in}^2$$

$$A_T = (2.336 - 1.0)(1.74)(.90) = 2.092 \text{ in}^2$$

The tearing load capacity

$$P_{tf} = [(.3)(2.881) + (.5)(2.092)](75) = \underline{143.3^k} > 38.4^k - \text{OK} > 90.2^k - \text{OK}$$

$$\text{In bearing, } T_b = (.90)(2.0)(1.74)(30) = \underline{94.0^k} > 73.4^k - \text{OK} < 123.6^k - \text{N.A.}$$

At the outer pin holes, effective areas are

$$A_R = [(1.74)(1.896) + (\frac{1}{2})(1.74)(2.456 - 1.896)](.90) = 3.408 \text{ in}^2$$

$$A_T = 2.092 \text{ in}^2$$

$$\therefore P_{tf} = [(.3)(3.408) + (.5)(2.092)](75) = \underline{155.1^k} > 38.4^k > 90.2^k$$

$$\text{Edge distances } A = D = 2.336", B_2 + \frac{d}{2} = 2.896",$$

$$\text{and } C_2 + \frac{d}{2} = 2.523", \text{ so based on EQN 2,}$$

$$P_t = (.5)(2.336)(1.74)(75)(.9) = \underline{137.2^k} > 38.4^k - \text{OK} > 90.2^k - \text{OK}$$

Per Table 1.16.5.1

$$\text{min } e = 1.25 \times d = 2.5" < B_2 + d, C_2 + d/2 > A, D$$

Check CH end plate cut-outs:

$$\begin{aligned} \text{dimension} \\ E &= \sqrt{(2.27 + .75)^2 + (1.861 + .75)^2} \\ &\quad - .75 - 1.00 \\ &= 2.242" \end{aligned}$$

edge distance

$$C = E + \frac{d}{2} = \underline{\underline{3.242"}}$$

The effective edge distance of $3.242"$ exceeds all other edge distances, so the ligament strength does not govern.

- Results :
- 1) Some edge distances not in compliance with Table 1.16.5.1
 - 2) Acceptable for all no-friction' loads
 - 3) Bearing stresses not acceptable for friction' load case

FH MODULE END PLATE

Unlike the CH end plate, the FH end plate is oriented in the vertical plane.

Approximate radius at the inner pin holes is $R_i = [(41.6 + 3.25)^2 + (6.627)^2]^{1/2} = 45.337"$

$$\text{so } B = 45.337 - 41.600 = 3.737"$$

Approximate radius at the outer pin hole:

$$R_o = [(41.6 + 3.25 + 18.39)^2 + (6.627 + 3.658)^2]^{1/2} = 64.071"$$

$$\text{so } A = 66.975 - 64.071 = 2.904"$$

At the inner pin holes, there are slots 5.500" x 1.366" between the pin holes and the inside diameter. The net ligament between the slots and holes is dimension "c":

$$a = 6.627 - 5.5 - .75 = .377"$$

$$b = 3.978 - 1.366 - 1.231 = 1.381"$$

$$c = \sqrt{(.377 + .5)^2 + (1.381 + .5)^2} - .500 - 1.000 = .575"$$

Then the areas in the radial and tangential planes are:

$$A_R = (.575)(1.240) = .713 \text{ in}^2 \text{ (conservative)}$$

$$A_T = (2.240 - 1.0)(1.240) = 1.538 \text{ in}^2$$

$$\text{Then } P_{tf} = [(.3)(1.538) + (.5)(.713)](75) = \underline{61.34}^k \begin{matrix} > 16.2^k - \text{OK} \\ > 17.3^k - \text{OK} \end{matrix}$$

At the outer pin holes,

$$A_R = (2.904 - 1.0)(1.24) = 2.361 \text{ in}^2$$

$$A_T = (2.240 - 1.0)(1.24) = 1.538 \text{ in}^2$$

$$P_{tf} = [(.3)(2.361) + (.5)(1.538)](75) = \underline{110.8}^k - \text{OK}$$

Edge distances are $A = 2.904"$, $B = 3.737"$, $C + d/2 = 1.575"$,

and $D = 2.240"$. The ligament $C + d/2$ must resist a compressive load in a tear-out mode:

$$P_t \leq (.5)(1.575)(1.24)(75) = \underline{73.24}^k \begin{matrix} > 69.0^k - \text{OK} \\ > 57.1^k - \text{OK} \end{matrix}$$

$$\text{Bearing, } P_b = (.90)(2.0)(1.24)(30) = \underline{66.96}^k \begin{matrix} < 69.0^k - \text{NA} \\ > 57.1^k - \text{OK} \end{matrix}$$

Table 1.16.5.1,

$$\min e = 1\frac{5}{8}" > C + d/2, \\ < A, B, D$$

Results: 1) Edge distance to cut-outs not in compliance w/ Table 1.16.5.1

2) Acceptable for all friction loads

3) Bearing overload by 3% for no-friction loads. Acceptable by engineering judgement.

EM MODULE END PLATE

The EM end plate is oriented in the vertical plane.

Spacing between holes on the end plate bracket is 1.600", so $A = .800"$.

Dimension $B \approx 8.026 - (5.75 + 1.138) = 1.138"$ (consecr.),

$$C = 2.570 - 1.875 - \frac{.75}{2} = .320$$

$$D = 1.138"$$

Then at the inner pin hole radius, the radial and tangential ^{effective} areas are:

$$A_R = (1.138 - .375)(.740) = .565 \text{ in}^2$$

$$\& A_{T_1} = (.800 - .375)(.740) = .315 \text{ in}^2$$

$$\text{or } A_{T_2} = (.320)(.740) = .237 \text{ in}^2$$

$$\text{Then } P_{ef} = [(3 \times .565) + (.5 \times .237)](75) = \underline{22.7 \text{ k}} > 10.1 \text{ k} - \text{OK}$$

Note that the ligament dimension C must resist a compressive load in tear-out mode.

At the outer pin holes, radial and tangential effective areas are

$$A_R = (1.138 - .375)(.74) = .565 \text{ in}^2$$

$$A_T = (.800 - .375)(.74) = .315 \text{ in}^2$$

$$\text{Then } P_{ef} = (.3)(.565) + (.5)(.315)(75) = \underline{24.5 \text{ K}} - \text{OK}$$

Edge distances are $A = 1.80"$, $B = D = 1.138"$,
and $C + \frac{d}{2} = .695"$. So capacity per EQ'N 2 is

$$P_t = (.50)(.695)(.74)(75) = \underline{19.3 \text{ K}} > 10.1 \text{ K} - \text{OK}$$

$$> 13.3 \text{ K} - \text{OK}$$

$$\text{Bearing, } P_b = (.90)(.75)(.74)(30) = \underline{15.0 \text{ K}} > 10.1 \text{ K} - \text{OK}$$

$$> 13.3 \text{ K} - \text{OK}$$

Table 1.16.5.1,

$$\min e = 1.0", > A, C + \frac{d}{2}$$

$$< B, D$$

Results: 1) Some edge dimensions not in compliance with Table 1.16.5.1

2) Acceptable for all friction loads

3) Acceptable for all no-friction loads

CC-MOD-07

CH Module Bending and Buckling Analysis

CH MODULE BENDING & BUCKLING ANALYSIS

The endplates of the CH Module are canted inward at 20° angles, such that in the lower 180° arc of the CH ring assembly, the module experiences a bending load:

Strap tension, $T = 123312 \text{ \#/strap}$

$$\therefore w_0 \approx T/R = \frac{123312}{88.199} = 1400 \text{ \#/in}$$

$$\therefore P \approx (1400)(88.199)(22.5)\left(\frac{\pi}{180}\right) = 48425 \text{ \#}$$

$$\text{Moment arm } a = (20.974)(\tan 20) = 7.634 \text{ \#}$$

$$\therefore M = P \cdot a = (48425)(7.634) = 369677 \text{ in-}\#$$

Conservatively use $M = 400 \times 10^3 \text{ in-}\#$

Cross-section through module skin:

$$\text{Dim. } b = 18.780 \text{ \#}, 25 = 18.53 \text{ \#}$$

Neglecting the side contributions,

$$\bar{y} \approx \frac{(33.9) \frac{(.1875)^2}{2} + (26.69)(.1875)(18.53 + .1875)}{(33.9 + 26.69)(.1875)}$$

$$= \frac{94.265}{11.361} = 8.3 \text{ \#}$$

* REVERSE OF NOMENCLATURE PER FERMILAB DRAWINGS

Disregarding The contribution of The sidewalks due to The likelihood of wrinkling,

$$I = \frac{1}{2}(26.69 + 33.90)(.1875)^3 + (26.69 \times .1875)(18.53 + 2(.1875) - 8.3 - \frac{.1875}{2})^2 + (33.90 \times .1875)(8.3 - \frac{.1875}{2})^2 = 981 \text{ in}^4$$

$$\therefore \sigma_b = \frac{(400000)(18.53 + 2(.1875) - 8.3)}{981} = +4325 \text{ psi (TENSION) ON "TOP" SKIN}$$

$$\text{or } \sigma_b = \frac{(400000)(8.3)}{981} = -3385 \text{ psi (COMPRESSION) ON "BOTTOM" SKIN}$$

In The event that The bottom skin buckles or the side skins wrinkle, the moment may be resisted by a force couple on The end plates consisting of tension in the upper skin, and reaction at The bottom of The end plates. Then the force is (conservatively):

$$F = \frac{400000}{18.53 + 2(.1875)} = 21160 \#$$

The upper skin tension is then

$$\sigma_t = \frac{21160}{(26.69 \times .1875)} = +4230 \text{ psi}$$

This is acceptable by engineering judgement.

Calculate the critical buckling stress of the lower sheet, assuming simply-supported edge conditions all-around:

$$a = 87.522" \quad a/b = 2.582$$

$$b = 33.90" \quad b/h = 180.8$$

$$h = .1875"$$

From Formulas for Stress & Strain, R.J. Roark, Fourth Ed., Table XVI, Case A:

$$\sigma_{cr} = K \frac{E}{(1-\nu^2)} \left(\frac{h}{b}\right)^2, \quad K \approx 3.35$$

$$= \frac{(3.35)(29 \times 10^6)}{(.91 \times 181)^2} = \underline{3260} \text{ psi}$$

This is slightly less than the calculated compression stress of 3385 psi. Thus buckling may or may not occur, depending on the actual plate thickness, the tendency for the module self weight to mitigate the estimated moment of 400000 in.-#, weld quality and strength, and actual loading. However, buckling or wrinkling of the bottom and side skins will not be critical to structural integrity because the modules are "packed" internally to very small clearances. Thus the buckled skins are supported by the module contents which consist of thick metal plates.

CC-MOD-08

Bearing Loads on Transition Pieces and G-10

BEARING LOADS ON TRANSITION PIECES & G-101) FH-CH SPACERS

Assume The total FH & EM module assembly weights are supported at the interface between FH & CH assemblies between the support angles of $\pm 56.25^\circ$ relative to BDC:

Total FH & EM weight

$$W = 292000 + 43200 = 336000 \#$$

$$w = \frac{336000}{(2 \times 56.25) \left(\frac{\pi}{180} \right) (67.225)} = 2545 \#/\text{in}$$

There are 5 complete FH modules within this arc of support. Assuming 2 spacers per module yields 10 effective spacers.

Effective compression area is:

$$A_1 = (1.110)(4.00) - (0.767)^2 \frac{\pi}{4} = 3.978 \text{ in}^2$$

$$A_2 = (1.64)(4) - (0.406)^2 \frac{\pi}{4} = 6.426 \text{ in}^2$$

Bearing stress is

$$\sigma_{br} = \frac{336000}{(10)(3.978)} = 8445 \text{ psi}$$

Relative rotations ^{under loading} between adjacent modules and/or between the FH and CH modules or variations in thickness between adjacent spacers may result in one or more spacers

becoming inactive, so estimate the maximum bearing stress using a factor of 2 for deadweight loading:

$$\max \sigma_{br} = (2)(8445) = 16890 \text{ psi} < 0.90 F_y \text{ per AISC 1.5.1.5.1}$$

The material is Type 304 stainless steel. This material has a very high coefficient of friction. It is therefore possible that the FH ring may "stick" against the CH ring, probably at the ^{angular} locations where radial deflection of the CH ring are a minimum, which is at $\theta = \pm 56.25^\circ$ coincident with the supports.

A coefficient of friction $\mu = 1.0$ is not unreasonable for 304 SS with its high nickel content.

Assuming the entire FH & EM weights are supported by only 2 such spacers at each of these locations,

$$P \approx \frac{1}{4}(336000) = 84000 \text{ \#/spacer piece}$$

$$N = (84000)(\cos 56.25) = 46670 \text{ \#}$$

$$\sigma_{br} = \frac{46670}{3.978} = 11731 \text{ psi} < .90 F_y$$

$$F = (84000)(\sin 56.25) = 69840 \text{ \#/spacer}$$

$$\tau = \frac{69840}{3.978} = 17556 \text{ psi} > .40 F_y$$

$$\approx \frac{1}{\sqrt{3}} F_y = \text{yield strength in shear}$$

This represents a worst-case condition.

Structural integrity is not compromised, however.

If the postulates high coefficients of friction develop, it is probable that it would develop on both sides of the spacer. The tangential load would not be applied to the 3/8-16 UNC fastener. However, it seems probable that some load may go through the fastener, resulting in elongation of the hole or shear deformation in the fastener. This would not affect structural integrity, by engineering judgement. It would merely enable the structure to relieve itself and "settle in" to a more stable load distribution.

These same comments apply to the EM-FH transition pieces analyzed on the next sheet.

EM-FH SPACERS

The EM assembly will be considered to be supported within the support arc $\pm 56.25^\circ$ with respect to BDC. There are approximately 9 EM modules with 2 spacers per module within this arc. Proceeding as for the CH-FH spacers,

$$W = 43200 \#$$

$$A_1 = (.65 \times 2.00) - (.767)^2 \frac{\pi}{4} = .838 \text{ in}^2$$

$$A_2 = (1.110 \times 2.00) - (.406)^2 \frac{\pi}{4} = 2.091 \text{ in}^2$$

$$\sigma_{br} = \frac{43200}{(2 \times 9) (.838)} = 2865 \text{ psi}$$

Estimate the maximum bearing stress with a factor of 2,

$$\max \sigma_{br} = (2 \times 2865) = 5730 \text{ psi} < .90 F_y \text{ per AISC 1.5.1.5.1}$$

Consider a localized "sticking" situation similar to the FH & CH rings per the previous pages of this calc:

$$P = \frac{1}{4} (43200) = 10800 \# / \text{spacer}$$

$$N = (10800) (\cos 56.25) = 6000 \#$$

$$\sigma_{br} = 6000 / .838 = 7160 \text{ psi} < .90 F_y$$

$$\frac{1}{4} F = (10800) (\sin 56.25) = 8980 \#$$

$$\tau = 8980 / .838 = 10715 \text{ psi} < .40 F_y$$

ASSEMBLY - SUPPORT INTERFACE

Thin strips of G-10 insulation are placed between the CH rings and the support members. There is no metal-metal contact.

Effective bearing edge width,

$$t_{eff} = \frac{1.74 - .20}{\cos 20^\circ} = 1.64"$$

Length of support arc,

$$S = (112^\circ) \left(\frac{\pi}{180} \right) (88.2") = 172"$$

Nominal bearing stress is then

$$\sigma_{brg} = \frac{(600000 \#)}{(2)(172)(1.64)} = 1065 \text{ psi}$$

Assume localized bearing stress is four times this value, $\sigma_{br} = 4260$. Compressive strength of G-10 (per ASTM D-709, Grade G-10) is 35-60 ksi, depending on fiber orientation. $\therefore$ Bearing stresses are acceptable.