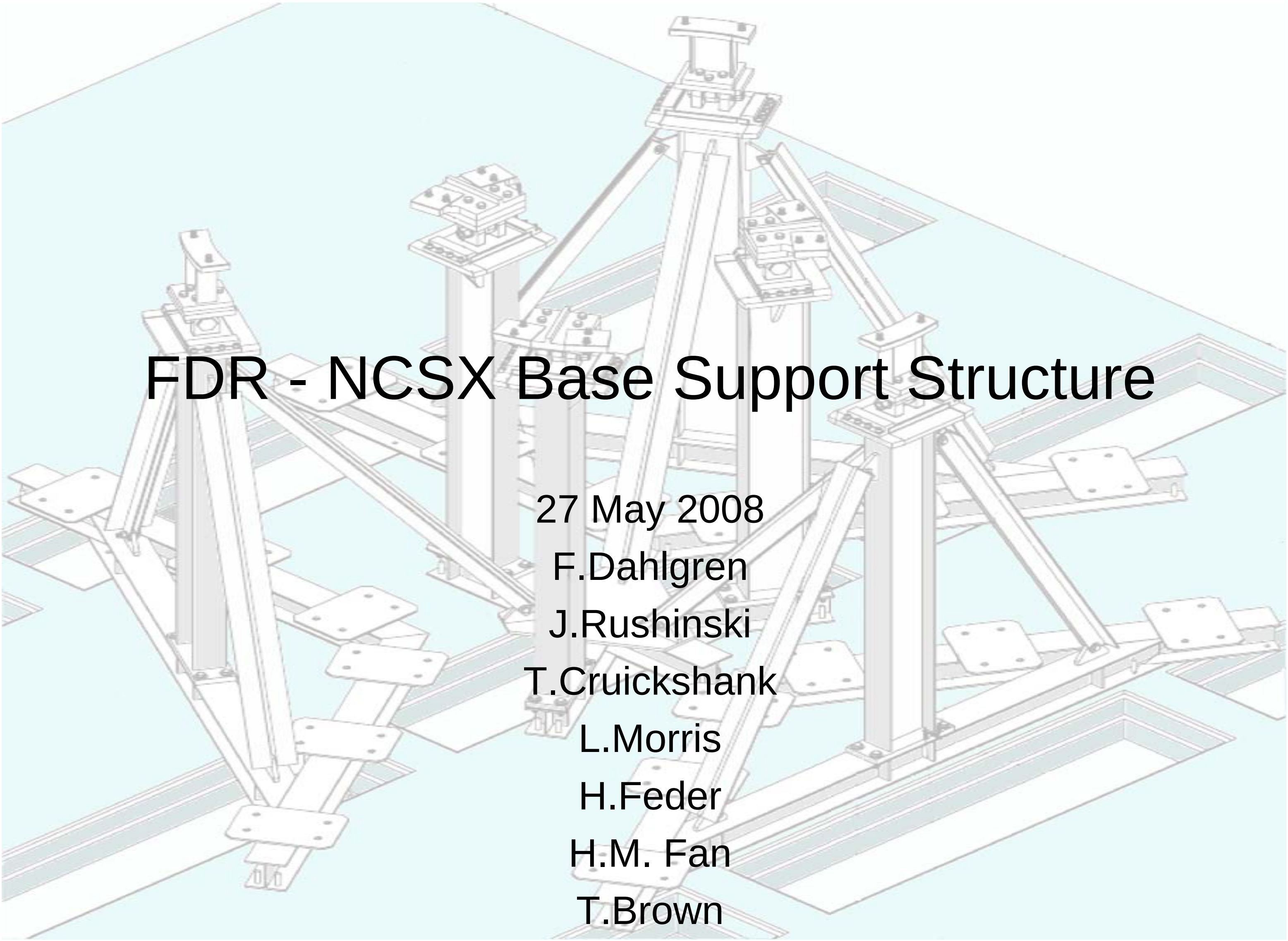


FDR - NCSX Base Support Structure

27 May 2008

F.Dahlgren

J.Rushinski

T.Cruickshank

L.Morris

H.Feder

H.M. Fan

T.Brown

Charge for the FDR of the NCSX Base Structure:

1. Are all required analyses complete and formally checked and adequate to establish that the proposed design is feasible and meets established design criteria?
2. Are the drawings and documentation adequate to support the procurement and/ or manufacturing process, installation, and ready for sign-off?
3. Is the design of the base structure compatible with the machine assembly fixtures and plans?
4. Is the Product Specification (CSPEC) complete and satisfactory?
5. Are the interfaces adequately defined?
6. Is the Work Planning form current, and have the applicable requirements been satisfied?
7. Have the chits from the PDR been resolved?
8. Are updated cost and schedule estimates available?

Functional (SRD) requirements:

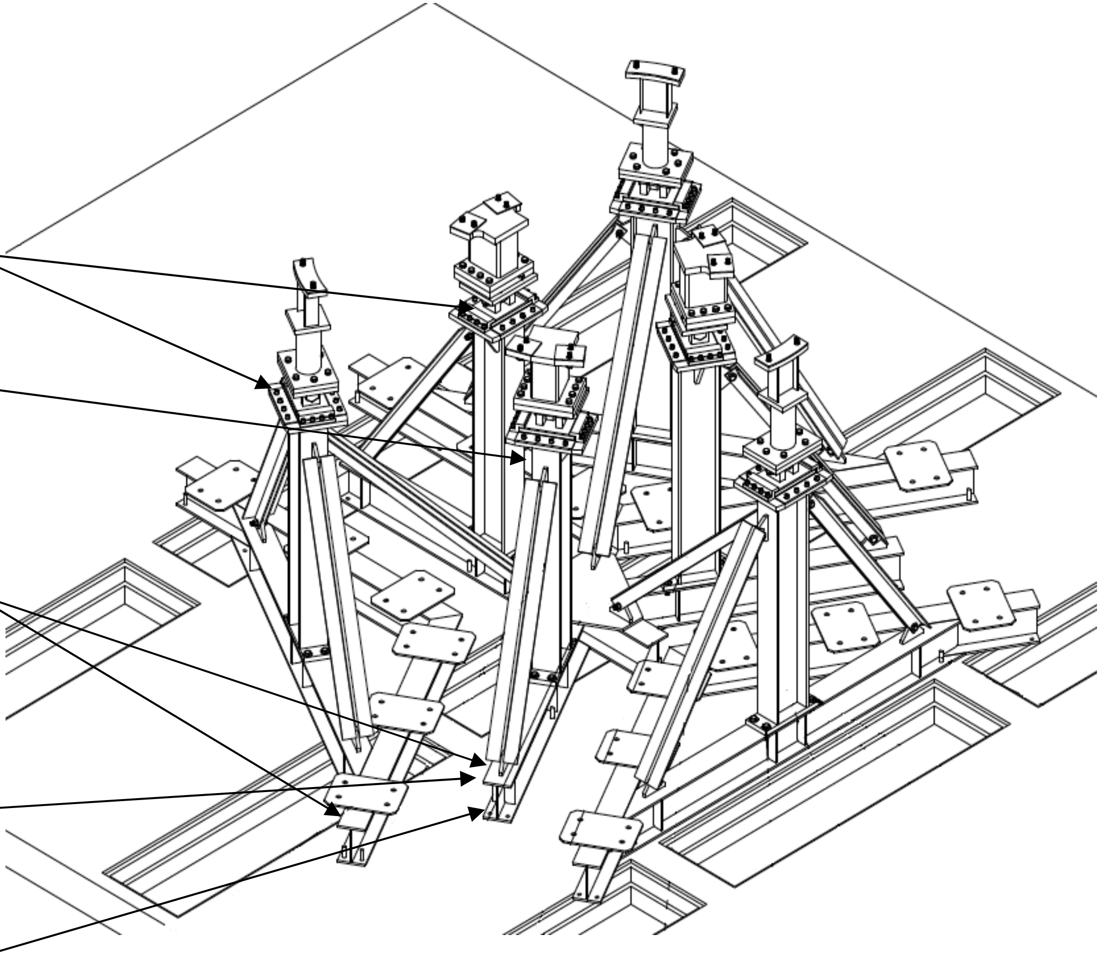
- It must provide the gravity load path from the machine core to the test cell floor at EL 98’ - 6”
- It must have a relative magnetic permeability less than 1.05 (ref.GRD para.3.3.1.1.b)
- It must meet the NCSX Structural Design Criteria (NCSX-CRIT-CRYO-00).
- It must meet the NCSX Seismic Design Criteria (NCSX-CRIT-SEIS-00).
- It must provide clearance to accommodate the three period assembly tooling.
- It must not exceed the maximum test cell floor loading of 4,500 lbs/sq.ft.

Main Project GRD Design Requirements:

3.2.4.2 Design Life

a. The facility shall have a design life of >10 years when operated per the reference scenarios defined in Section 3.2.1.5.3.3.1.

b. The facility shall be designed for the following maximum number of pulses when operated per the reference scenarios defined in Section 3.2.1.5.3.3.1 and based on the factors for fatigue life specified in the NCSX Structural and Cryogenic Design Criteria Document:
- 100 per day;
- 13,000 per year; and
- 130,000 lifetime.



Design Changes From the PDR:

- Reduced the column heights to 77.25”
- Moved the inner A-A columns radially inboard to a radius of 29.5” to accommodate the cryostat.
- Increased the base beams from 8WF-35 to 12WF-50 sections
- Lengthened the base beams supporting the inner A-A columns to provide a more stable anchoring.
- Added additional anchors to A-A base.

Base Beams:
Laser Welded 304 ss - 12WF-50
(0.64” thick flg., 0.31” thick web)

Columns:
Laser Welded 304 ss - 12WF-50
(0.64” thick flg., 0.31” thick web)

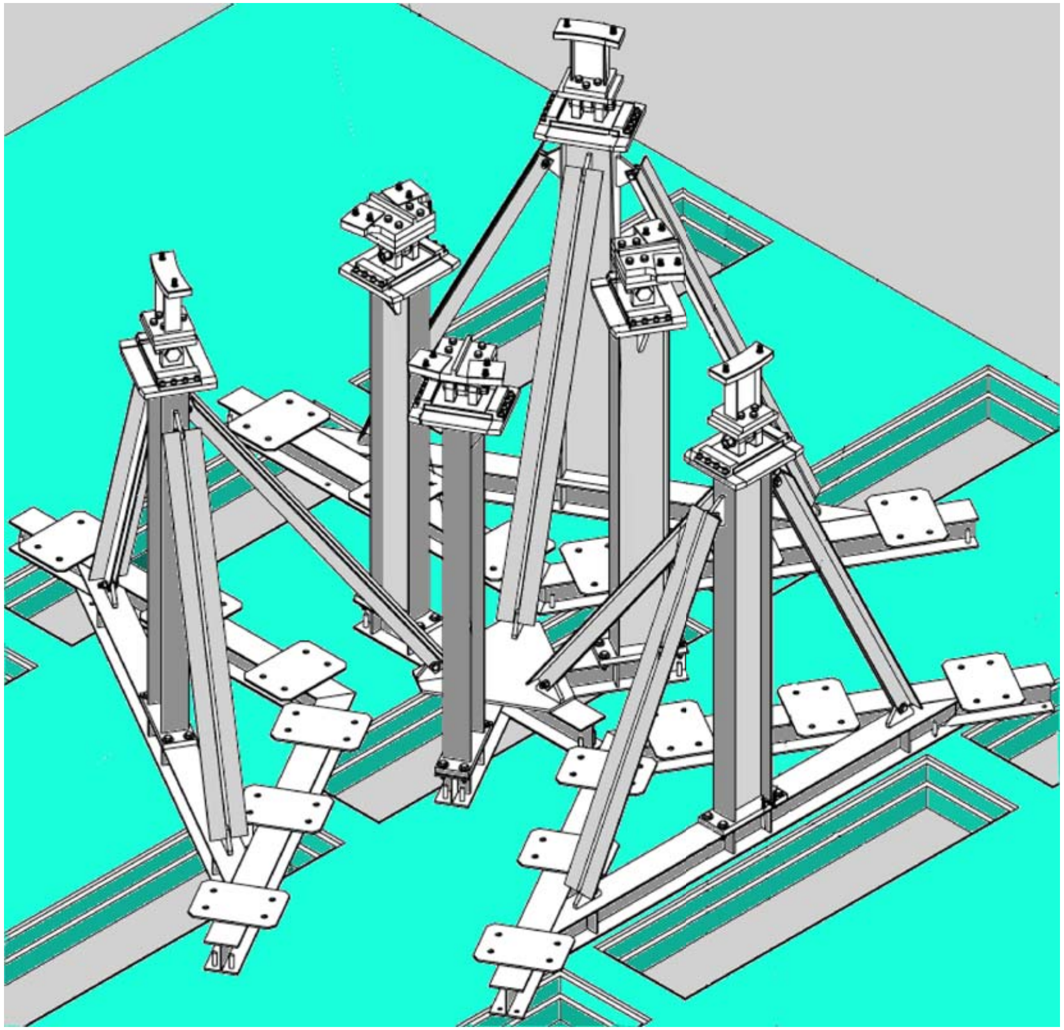
Lateral Bracing:
316 ss Rolled angles - 4” x 4” x 3/8”

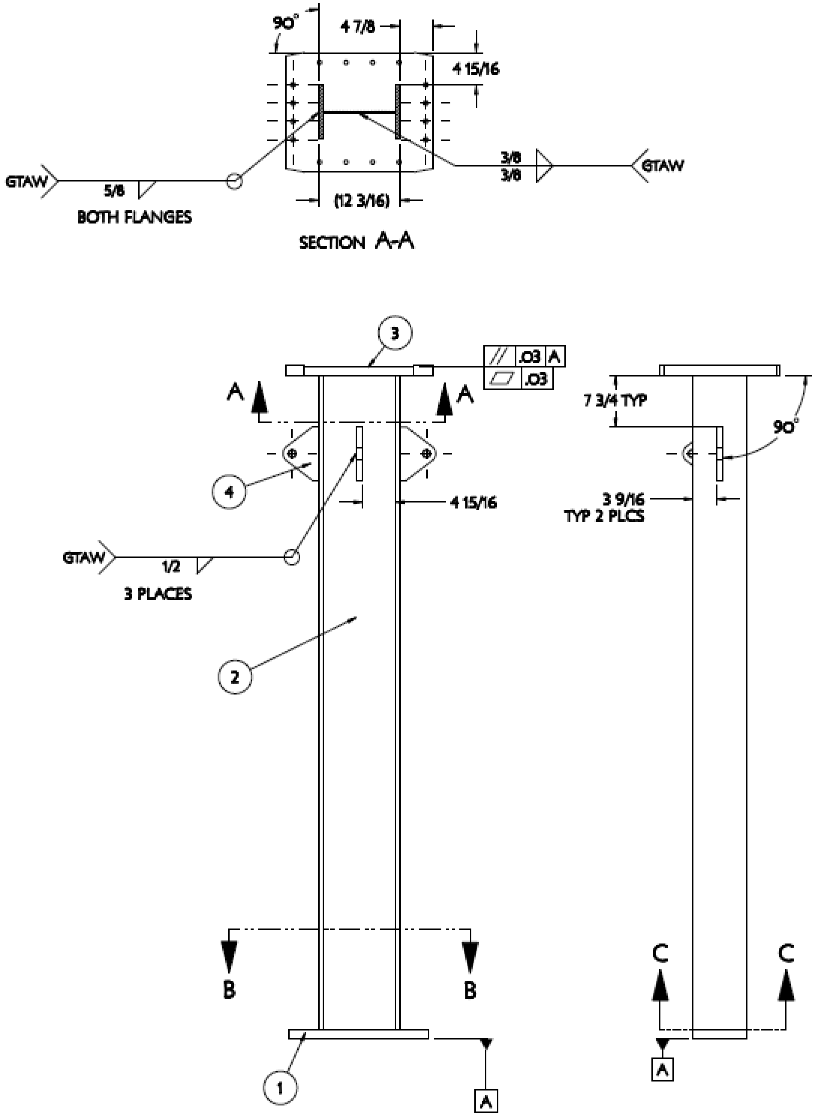
Base & Top plates:
304L 1.5” thk. Solution annealed plate

Gussets:
304L 0.63” thk. Solution annealed plate

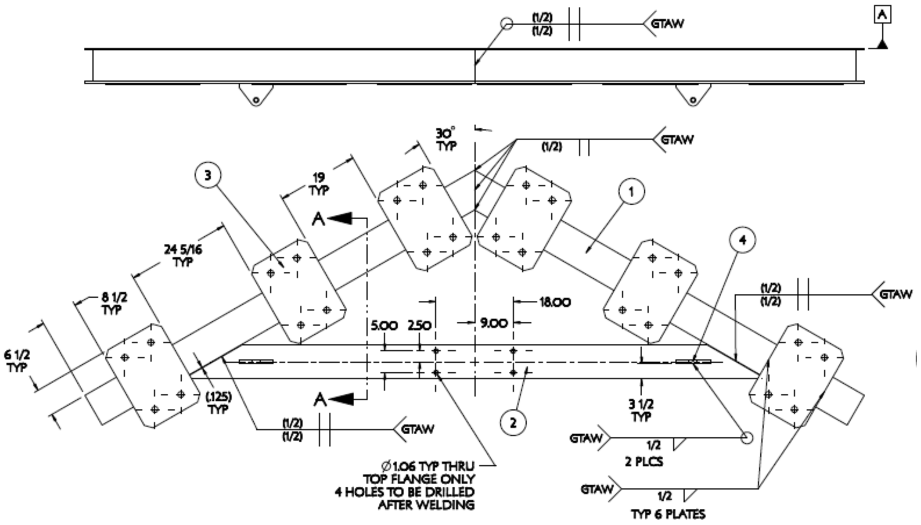
Anchors:
1-8 x 9” 316ss Wedge-Stud Anchors,
McMaster-Carr #97799A730

Weld filler:
ER316L-Mn (Stellalloy weld alloy)
or flux cored alternative with μ<1.05





Typical column detail



Typical base weldment detail

Installation will require pre-assembly in the test cell to shim and/or grout level the base frames with surface A & top pedestals, and to locate exact positions of wedge anchors.

Stainless Structurals,LLC is the preferred vendor For the laser welded beams and rolled angles.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Alternate: Hilti HSLG-R - M20:

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

FEA Analysis:

Loads and modeling considerations:

Gravity Loads with 1g static vertical downward, B.C.: Symmetry at the floor perimeter & attached @ the test-cell anchor points. Fixed support at basement column bases. Contact elements at the base beam/test-cell floor interface.

Horizontal seismic loading using static 0.171g acceleration ($F_P = 0.171 \text{ x } W_P$) per the NCSX/IBC2000 criteria*. The vertical seismic loading used was 1.1g.

B.C.: Same as static gravity.

Various static load distributions (inner to outer supports) based on load shifting due to cooldown and EM loading of the MCWF.

* Para 3.1 - NCSX-CRIT-SEIS-(Rev. 0)

Model Features:

Beams, columns, & plates modeled with 8-node brick element (solid45).

Lateral braces are beam188 elements with 4” angle sections.

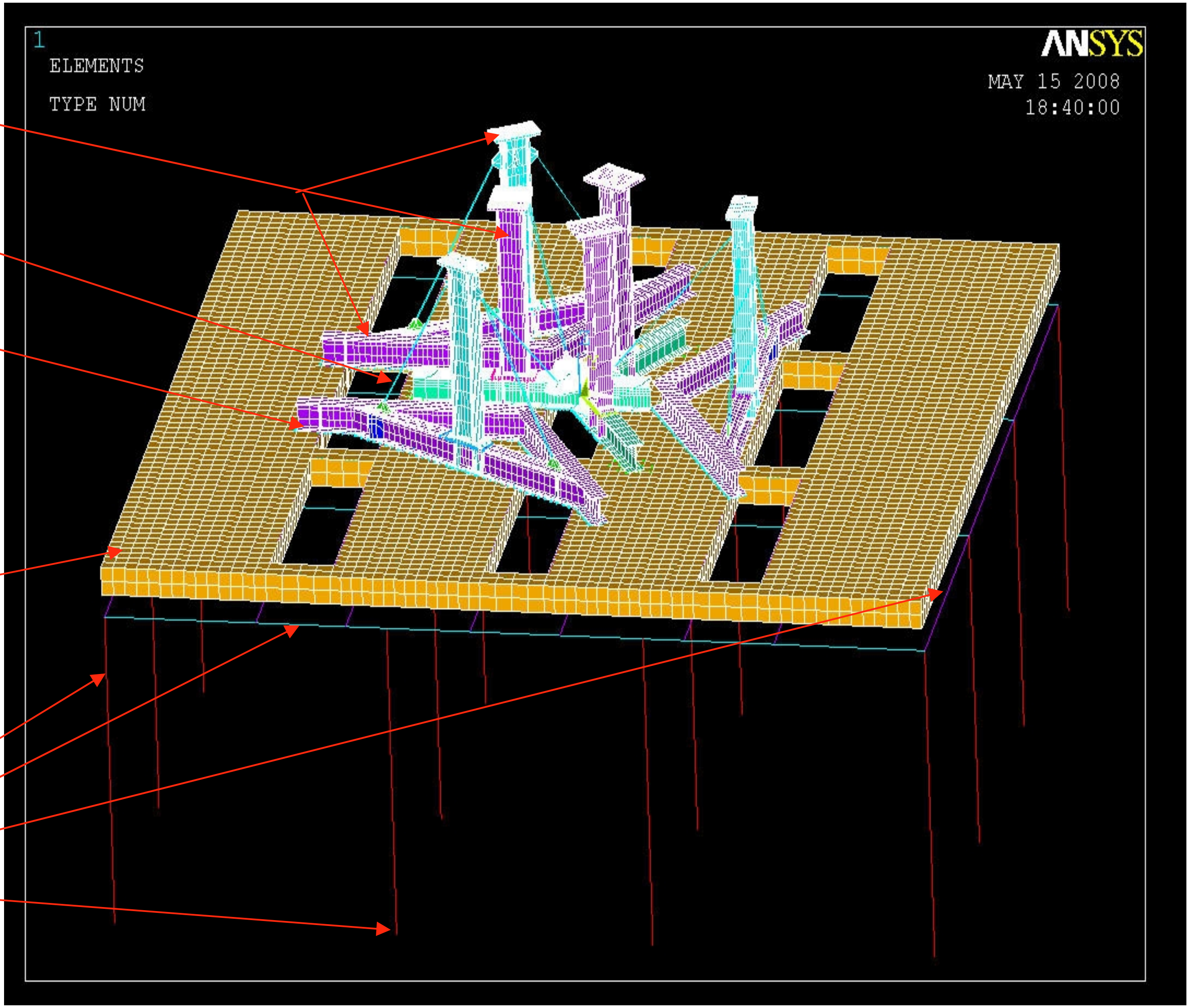
Floor anchor points modeled with coupled nodes.

Base beam-floor interface modeled with standard contact elements (μ = 0.2)

Test cell floor 12” R.C. modeled with 20 node bricks (solid186).

Building Steel modeled with beam188 beam elements
  Sections:
    P3-columns 14WF-127
    G1-girders 27WF-124
    S1-stringers 12WF-106

Bldg. columns are fixed at the basement floor level and rotation symmetry boundary conditions are employed around the reinforced concrete test cell floor perimeter to approximate the full building structure.



ANSYS FEA Model of the base support structure

Most severe loadings selected from H.M. Fans' integrated model results:

Loads	Items	Unit	Model 1R	Remarks		Comments
DL, EM & Cooldown	D max	mm	5.829	unsel Type255-spring	Dmax at TF coil mid-hight	
• stellalloy E=145GPa	DZ	mm	(-4.307 to -1.167)	unsel Type255-spring	Dzmax at PF coil (near center)	
• Regular PF shim	Seqv	Pa	5.00E+08	PowerGraphics OFF	TF bracket?	6.86E+08
• PF shim COF effect	Seqv	ksi	7.25E+01	PowerGraphics OFF	ALPX=9.829E-6	
• TF shim COF effect	OB reaction	N	1.90E+05		ALPX=9.829E-6	node=467718
New support springs	OB reaction	kip	4.28E+01	**Total weight**		node=467718
Run: h6-emdlco-2T-HB000s	IB reaction	N	1.67E+05	3.570E+05	**SS shim on PF6 sup.**	node=467717
w/PF6 link	IB reaction	kip	3.75E+01	8.026E+01		node=467717
DL, EM & Cooldown	D max	mm	6.838	unsel Type255-spring	Dmax at TF coil mid-hight	
• stellalloy E=145GPa	DZ	mm	(-4.330 to -1.190)	unsel Type255-spring	Dzmax at PF coil (near center)	
• Regular PF shim	Seqv	Pa	4.97E+08	PowerGraphics OFF	TF bracket?	6.82E+08
• PF shim COF effect	Seqv	ksi	7.21E+01	PowerGraphics OFF	ALPX=9.829E-6	
• TF shim COF effect	OB reaction	N	1.89E+05		ALPX=9.829E-6	node=467718
New support springs	OB reaction	kip	4.26E+01	**Total weight**		node=467718
Run: h6-emdlco-2T-HB440s	IB reaction	N	1.67E+05	3.562E+05	**SS shim on PF6 sup.**	node=467717
w/PF6 link	IB reaction	kip	3.75E+01	8.007E+01		node=467717
DL, EM & Cooldown	D max	mm	6.26	unsel Type255-spring	Dmax at TF coil mid-hight	
• stellalloy E=145GPa	DZ	mm	(-4.066 to -1.446)	unsel Type255-spring	Dzmax at PF6 coil	
• Regular PF shim	Seqv	Pa	5.03E+08	PowerGraphics OFF	TF bracket?	6.84E+08
• PF shim COF effect	Seqv	ksi	7.30E+01	PowerGraphics OFF	ALPX=9.829E-6	
• TF shim COF effect	OB reaction	N	1.89E+05		ALPX=9.829E-6	node=467718
New support springs	OB reaction	kip	4.25E+01	**Total weight**		node=467718
Run: h6-emdlco-17T-Om000s	IB reaction	N	1.67E+05	3.564E+05	**SS shim on PF6 sup.**	node=467717
w/PF6 link	IB reaction	kip	3.76E+01	8.013E+01		node=467717
DL, EM & Cooldown	D max	mm	5.699	unsel Type255-spring	Dmax at TF coil mid-hight	
• stellalloy E=145GPa	DZ	mm	(-4.154 to -1.471)	unsel Type255-spring	Dzmax at PF6 coil	4.188 Tesla
• Regular PF shim	Seqv	Pa	4.90E+08	PowerGraphics OFF	TF bracket?	6.69E+08
• PF shim COF effect	Seqv	ksi	7.11E+01	PowerGraphics OFF	ALPX=9.829E-6	
• TF shim COF effect	OB reaction	N	1.89E+05		ALPX=9.829E-6	node=467718
New support springs	OB reaction	kip	4.25E+01	**Total weight**		node=467718
Run: h6-emdlco-17T-Om440s	IB reaction	N	1.68E+05	3.570E+05	**SS shim on PF6 sup.**	node=467717
w/PF6 link	IB reaction	kip	3.77E+01	8.027E+01		node=467717
DL, EM & Cooldown	D max	mm	9.664	unsel Type255-spring	Dmax at TF coil mid-hight	
• stellalloy E=145GPa	DZ	mm	(-4.131 to -1.395)	unsel Type255-spring	Dzmax at PF6 coil	4.654 Tesla
• Regular PF shim	Seqv	Pa	4.96E+08	PowerGraphics OFF	TF bracket	6.76E+08
• PF shim COF effect	Seqv	ksi	7.19E+01	PowerGraphics OFF	ALPX=9.829E-6	
• TF shim COF effect	OB reaction	N	1.87E+05		ALPX=9.829E-6	node=467718
New support springs	OB reaction	kip	4.21E+01	**Total weight**		node=467718
Run: h6-emdlco-17T-iota065	IB reaction	N	1.66E+05	3.530E+05	**SS shim on PF6 sup.**	node=467717
w/PF6 link	IB reaction	kip	3.73E+01	7.937E+01		node=467717

Loads	Items	Unit	Model 1R	Remarks		Comments
DL, EM & Cooldown	D max	mm	9.296	unsel Type255-spring	Dmax at TF coil mid-hight	
• stellalloy E=145GPa	DZ	mm	(-3.939 to -1.453)	unsel Type255-spring	Dzmax at PF6 coil	3.692 Tesla
• Regular PF shim	Seqv	Pa	4.85E+08	PowerGraphics OFF	TF bracket	6.58E+08
• PF shim COF effect	Seqv	ksi	7.04E+01	PowerGraphics OFF	ALPX=9.829E-6	
• TF shim COF effect	OB reaction	N	1.84E+05		ALPX=9.829E-6	node=467718
New support springs	OB reaction	kip	4.13E+01	**Total weight**		node=467718
Run: h6-emdlco-17T-iota019	IB reaction	N	1.64E+05	3.478E+05	**SS shim on PF6 sup.**	node=467717
w/PF6 link	IB reaction	kip	3.69E+01	7.819E+01		node=467717
DL, EM & Cooldown	D max	mm	5.671	unsel Type255-spring	Dmax at TF coil mid-hight	
• stellalloy E=145GPa	DZ	mm	(-4..039 to -1.386)	unsel Type255-spring	Dzmax at PF6 coil	4.77 Tesla
• Regular PF shim	Seqv	Pa	4.95E+08	PowerGraphics OFF	TF bracket?	6.77E+08
• PF shim COF effect	Seqv	ksi	7.18E+01	PowerGraphics OFF	ALPX=9.829E-6	
• TF shim COF effect	OB reaction	N	1.90E+05		ALPX=9.829E-6	node=467718
New support springs	OB reaction	kip	4.26E+01	**Total weight**		node=467718
Run: h6-emdlco-17T-shear01	IB reaction	N	1.67E+05	3.570E+05	**SS shim on PF6 sup.**	node=467717
w/PF6 link	IB reaction	kip	3.76E+01	8.026E+01		node=467717
DL, EM & Cooldown	D max	mm	4.86	unsel Type255-spring	Dmax at TF coil mid-hight	
• stellalloy E=145GPa	DZ	mm	(-3.629 to -1.978)	unsel Type255-spring	Dzmax at PF6 bracket	1.571 Tesla
• Regular PF shim	Seqv	Pa	4.72E+08	PowerGraphics OFF	TF bracket	6.31E+08
• PF shim COF effect	Seqv	ksi	6.85E+01	PowerGraphics OFF	ALPX=9.829E-6	
• TF shim COF effect	OB reaction	N	1.80E+05		ALPX=9.829E-6	node=467718
New support springs	OB reaction	kip	4.05E+01	**Total weight**		node=467718
Run: h6-emdlco-05T-TF	IB reaction	N	1.64E+05	3.442E+05	**SS shim on PF6 sup.**	node=467717
w/PF6 link	IB reaction	kip	3.69E+01	7.739E+01		node=467717
EM & Cooldown	D max	mm	3.976	unsel Type255-spring	Dmax at TF coil mid-hight	
• stellalloy E=145GPa	DZ	mm	(-0.693 to 0.980)	unsel Type255-spring	Dzmax at PF6 bracket	1.571 Tesla
• Regular PF shim	Seqv	Pa	4.64E+08	PowerGraphics OFF	TF bracket	6.19E+08
• PF shim COF effect	Seqv	ksi	6.73E+01	PowerGraphics OFF	ALPX=9.829E-6	
• TF shim COF effect	OB reaction	N	-5.91E+03		ALPX=9.829E-6	node=467718
New support springs	OB reaction	kip	-1.33E+00	**Total weight**		node=467718
Run: h6-emco-05T-TFa	IB reaction	N	-6.96E+03	-1.287E+04	**SS shim on PF6 sup.**	node=467717
w/PF6 link	IB reaction	kip	-1.56E+00	-2.893E+00		node=467717
Cooldown	D max	mm	4.667	unsel Type255-spring	Dmax at TF coil mid-hight?	
• stellalloy E=145GPa	DZ	mm	(-0.820 to 0.879)	unsel Type255-spring	Dzmax at PF6 bracket?	0 Tesla
• Regular PF shim	Seqv	Pa	4.68E+08	PowerGraphics OFF	TF bracket?	6.26E+08
• PF shim COF effect	Seqv	ksi	6.79E+01	PowerGraphics OFF	ALPX=9.829E-6	
• TF shim COF effect	OB reaction	N	-1.27E+03		ALPX=9.829E-6	node=467718
New support springs	OB reaction	kip	-2.86E-01	**Total weight**		node=467718
Run: h6-co-05T-TFb	IB reaction	N	1.27E+03	0.000E+00	**SS shim on PF6 sup.**	node=467717
w/PF6 link	IB reaction	kip	2.86E-01	0.000E+00		node=467717
EM Load	D max	mm	0.708	unsel Type255-spring	Dmax at TF coil mid-hight?	
• stellalloy E=145GPa	DZ	mm	(0.006 to 0.244)	unsel Type255-spring	Dzmax at PF6 bracket?	1.571 Tesla
• Regular PF shim	Seqv	Pa	3.37E+07	PowerGraphics OFF	TF bracket?	4.59E+07
• PF shim COF effect	Seqv	ksi	4.89E+00	PowerGraphics OFF	ALPX=9.829E-6	
• TF shim COF effect	OB reaction	N	-7.18E+03		ALPX=9.829E-6	node=467718
New support springs	OB reaction	kip	-1.61E+00	**Total weight**		node=467718
Run: h6-em-05T-TFc	IB reaction	N	-5.69E+03	-1.287E+04	**SS shim on PF6 sup.**	node=467717
w/PF6 link	IB reaction	kip	-1.28E+00	-2.893E+00		node=467717

Loads	Items	Unit	Model 1R	Remarks	Comments	
DL, EM & Cooldown	D max	mm	6.838	unsel Type255-spring	Dmax at TF coil mid-hight	
• stellalloy E=145GPa	DZ	mm	(-4.330 to -1.190)	unsel Type255-spring	Dzmax at PF coil (near center)	
• Regular PF shim	Seqv	Pa	4.97E+08	PowerGraphics OFF	TF bracket?	6.82E+08
• PF shim COF effect	Seqv	ksi	7.21E+01	PowerGraphics OFF	ALPX=9.829E-6	
• TF shim COF effect	OB reaction	N	1.89E+05		ALPX=9.829E-6	node=467718
New support springs	OB reaction	kip	4.26E+01	**Total weight**		node=467718
Run: h6-emdlco-2T-HB440s	IB reaction	N	1.67E+05	3.562E+05	**SS shim on PF6 sup.**	node=467717
w/PF6 link	IB reaction	kip	3.75E+01	8.007E+01		node=467717

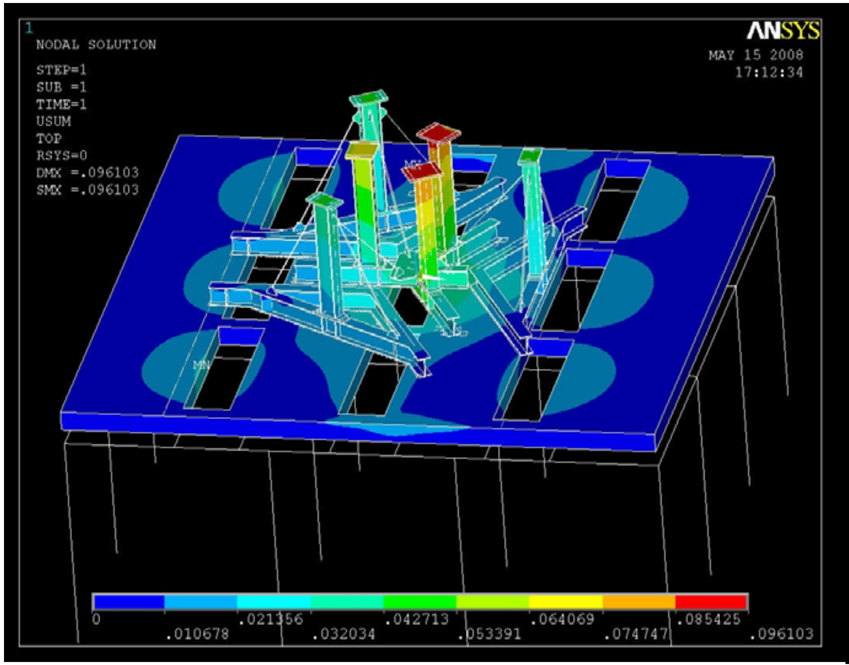
Static Load Summary:

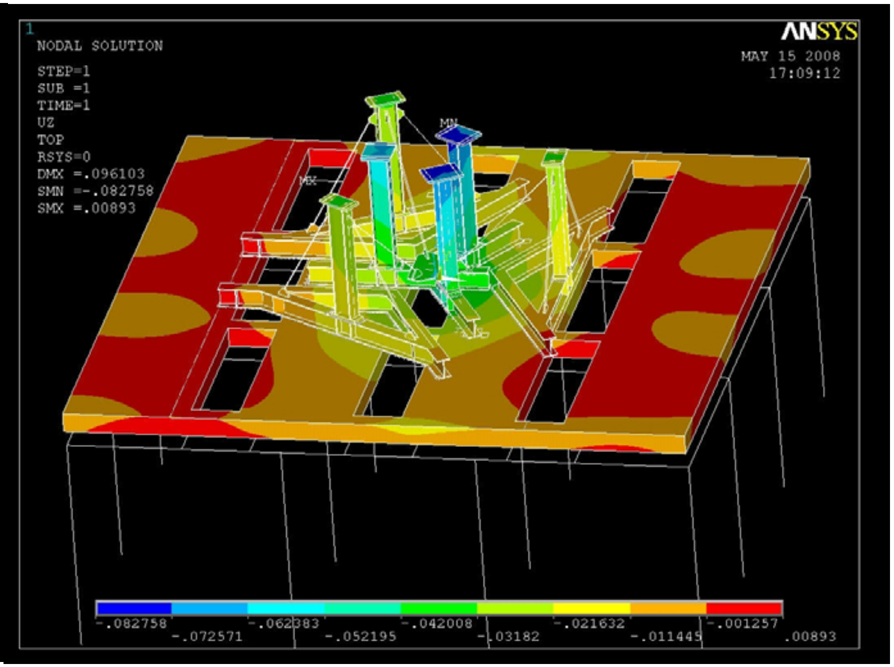
Loading	Outboard Z load (kips)	Inboard Z load (kips)
Gravity Only	-50.01	-50.02
EM Load	-1.54	+1.54
Cooldown	-1.68	+1.68

Note with elastic B.C.s on the global model, load shifting due to EM and cooldown is reduced significantly. Total machine weight estimate increased 25% to 300 kips.

For a 2Tesla Hi-beta EM, loads on the inboard columns are 46.9 kip, and on the outboard columns, 53.3 kips

FEA Results (normal R.T. gravity loading):

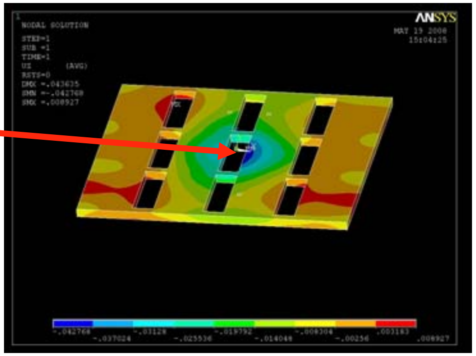




Peak Vector sum Displacement is 0.090”
(@ PDR Was: 0.050”)

Peak Vertical displacement is 0.083”
(@ PDR Was: 0.046”)

Note Test Cell floor deflects ~ 0.042” (node 6274)



SRSS & Vertical Displacements for Gravity

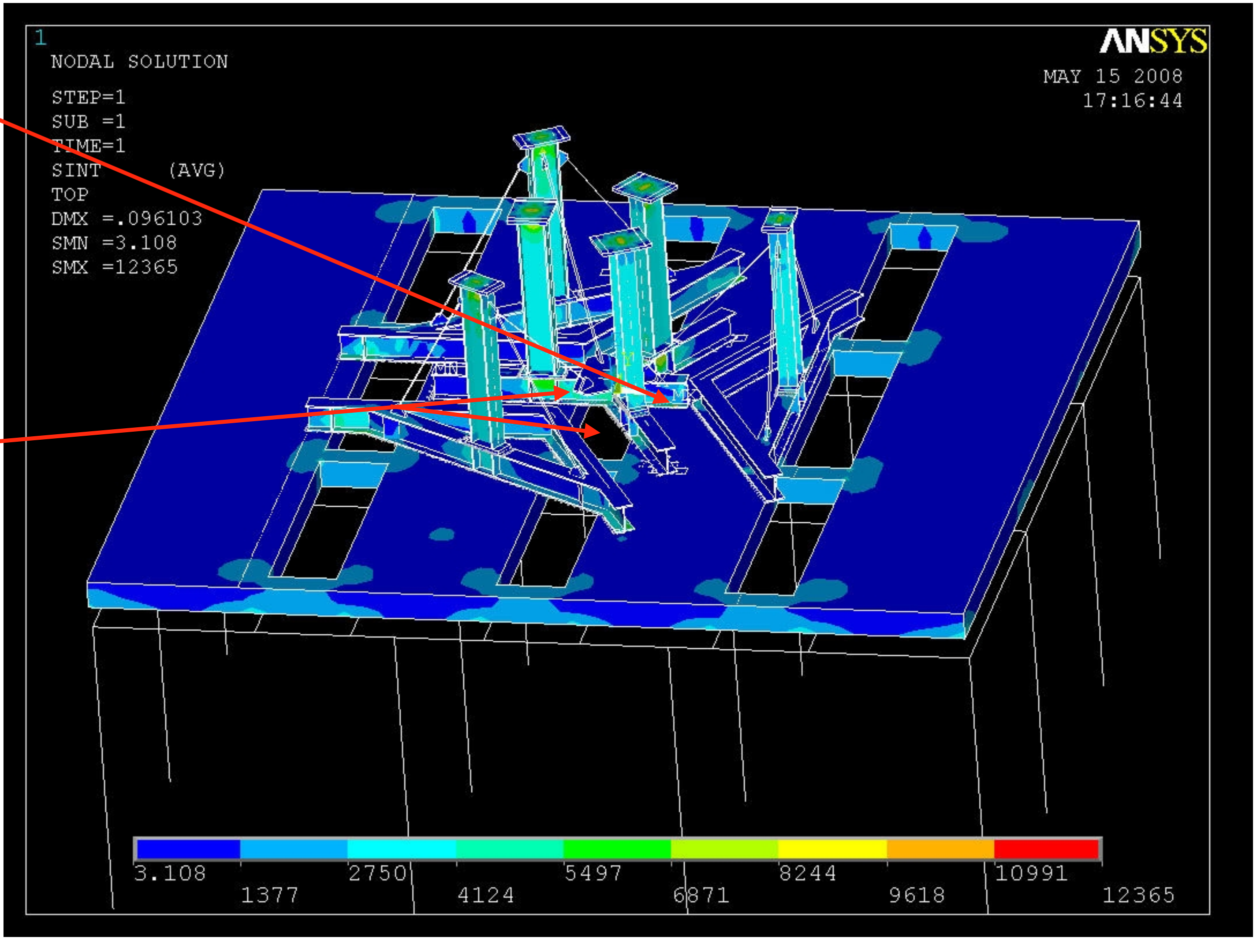
FEA Results (normal R.T. gravity loading):

Peak Stress @ Anchor support studs 12.4 ksi

Average Stress in columns is 4 - 5 ksi

Peak Stress in the base frame is 4 ksi at gussets

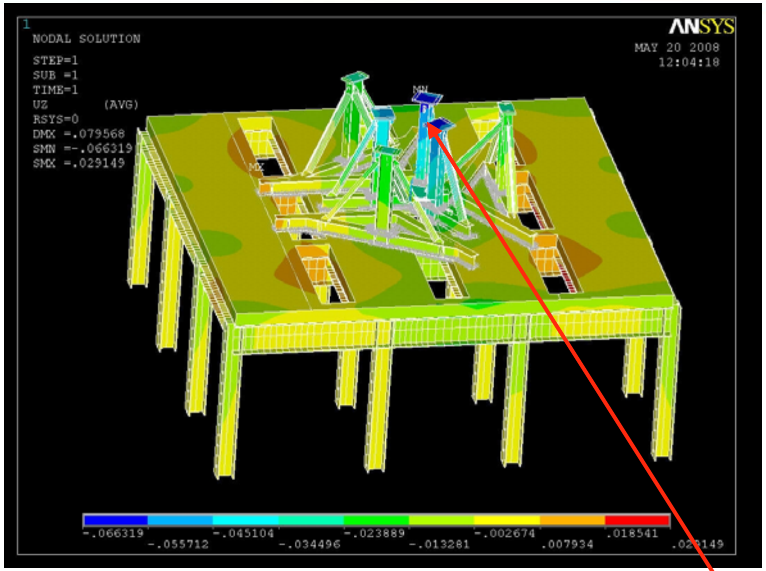
Calc. Stress in anchor studs is 4 - 5 ksi



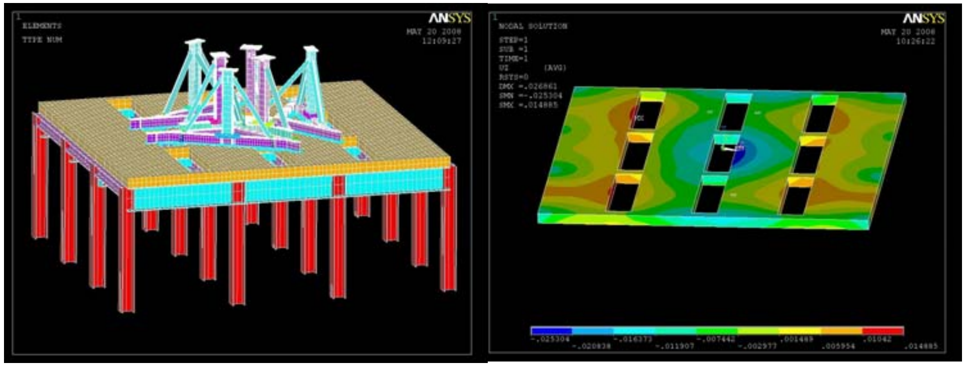
Tresca Stress contours for Gravity

Load Case 2:

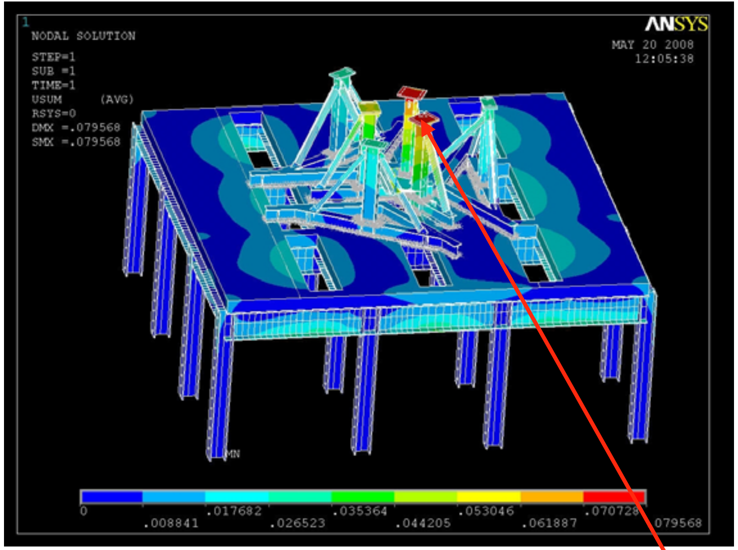
For load case 2 there was a minor model change, re-locating the girder, stringer, and top column nodes to be co-planar with the bottom nodes of the test cell floor slabs, and off-setting the beam origins to their proper heights. The model shown below, should more accurately represent the composite floor-beam stiffness.



Peak vertical displacement -0.066”



Note Test Cell floor deflects ~ 0.025” (node 6274)



Peak vector sum displacement 0.079”

L.C.2: SRSS & Vertical Displacements for Gravity + Cooldown + EM

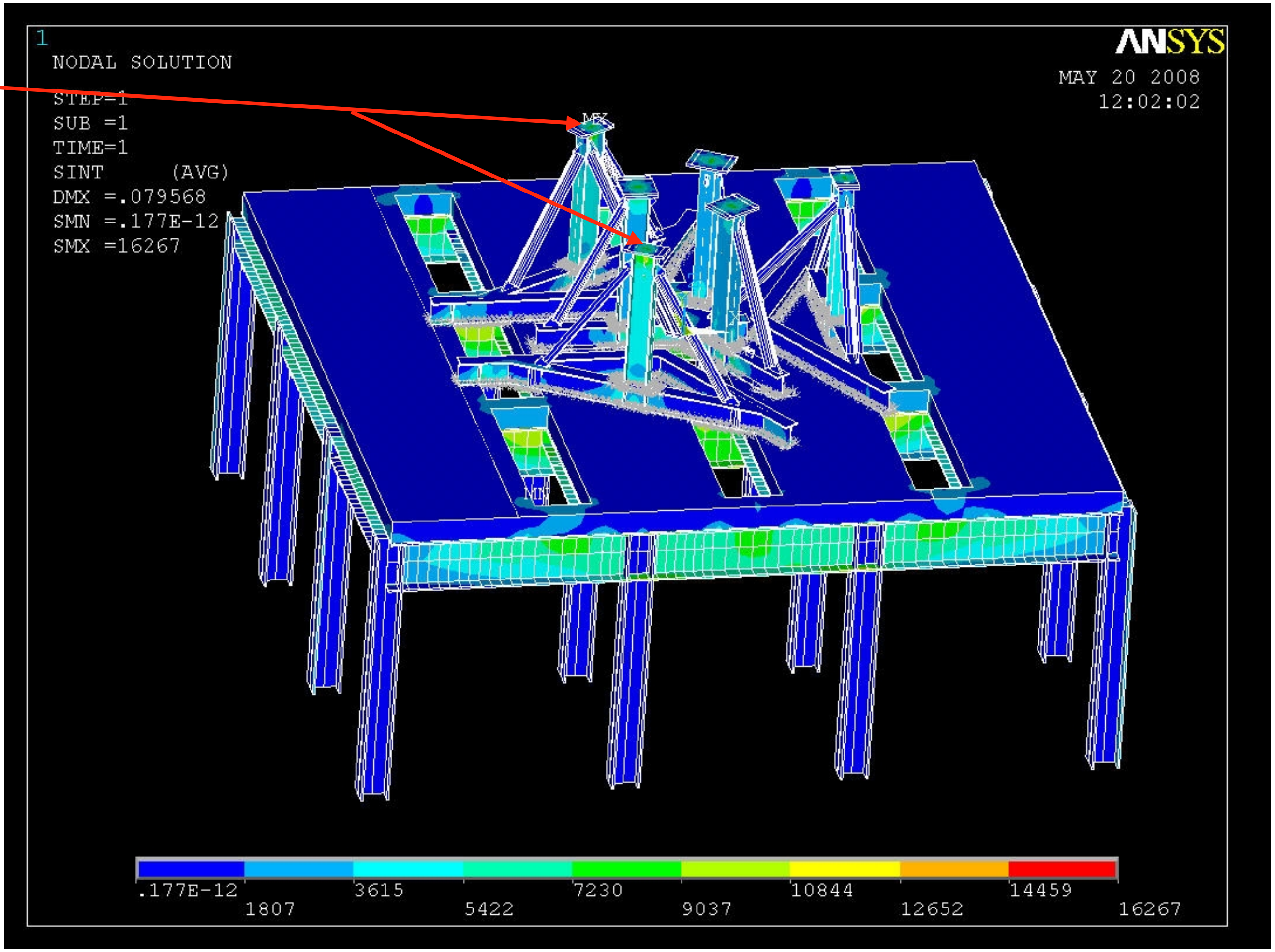
FEA Results (normal EM ops. 1.7T-High Beta):

Peak Stress @ pedestal 16.2 ksi (slightly higher bending there due to increased load)

Average Stress in columns is 3 - 12 ksi

Peak Stress in the base frame is 4.5 ksi at gussets

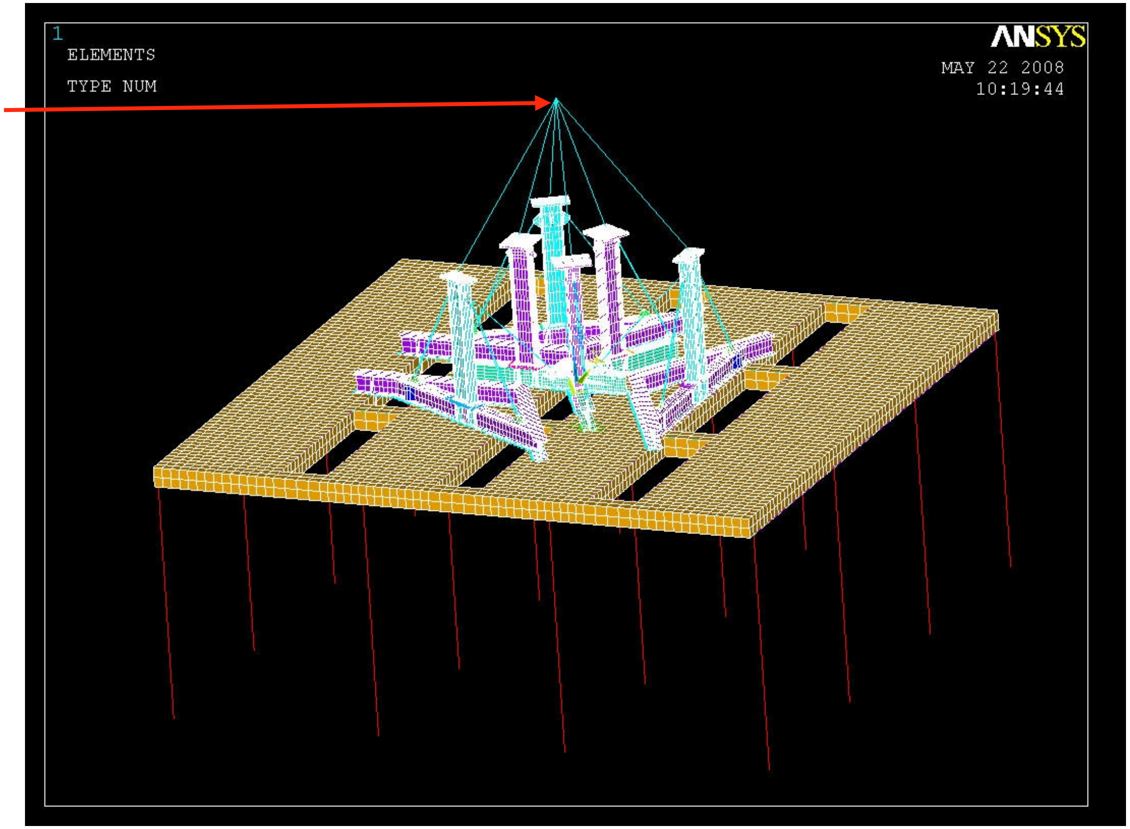
Calc. Stress in anchor studs is still ~4 - 6 ksi



L.C.2: Tresca Stress contours for Gravity + Cooldown + EM

FEA Model for seismic runs:

- Concentrated 300 kip (9317 slugs mass) located at the Stellarator core C.G.
- Static loading 0.171g horizontal, (per the NCSX/IBC2000 criteria).
- Stiff (nearly rigid) beams connect the mass to 6 master nodes just above the support column pedestal level.
- Utilized coupled nodes to master nodes at the sliding low friction surfaces (with the radial DOF uncoupled to simulate the low friction).
- A modal analysis was performed to determine the lowest natural frequency of the structure. (4.22 Hz).

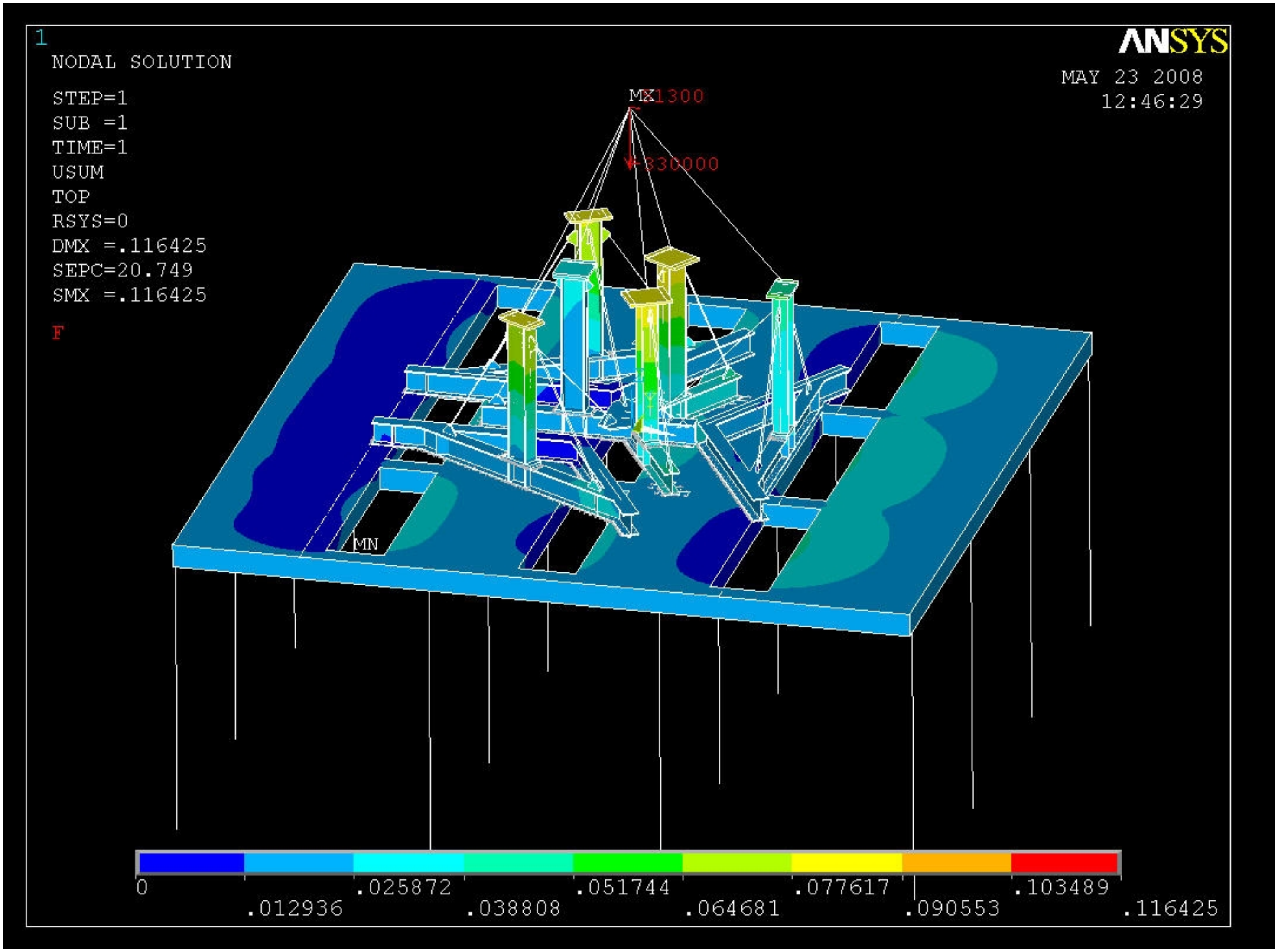


SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	4.2240	1	1	1
2	4.3585	1	2	2
3	19.375	1	3	3

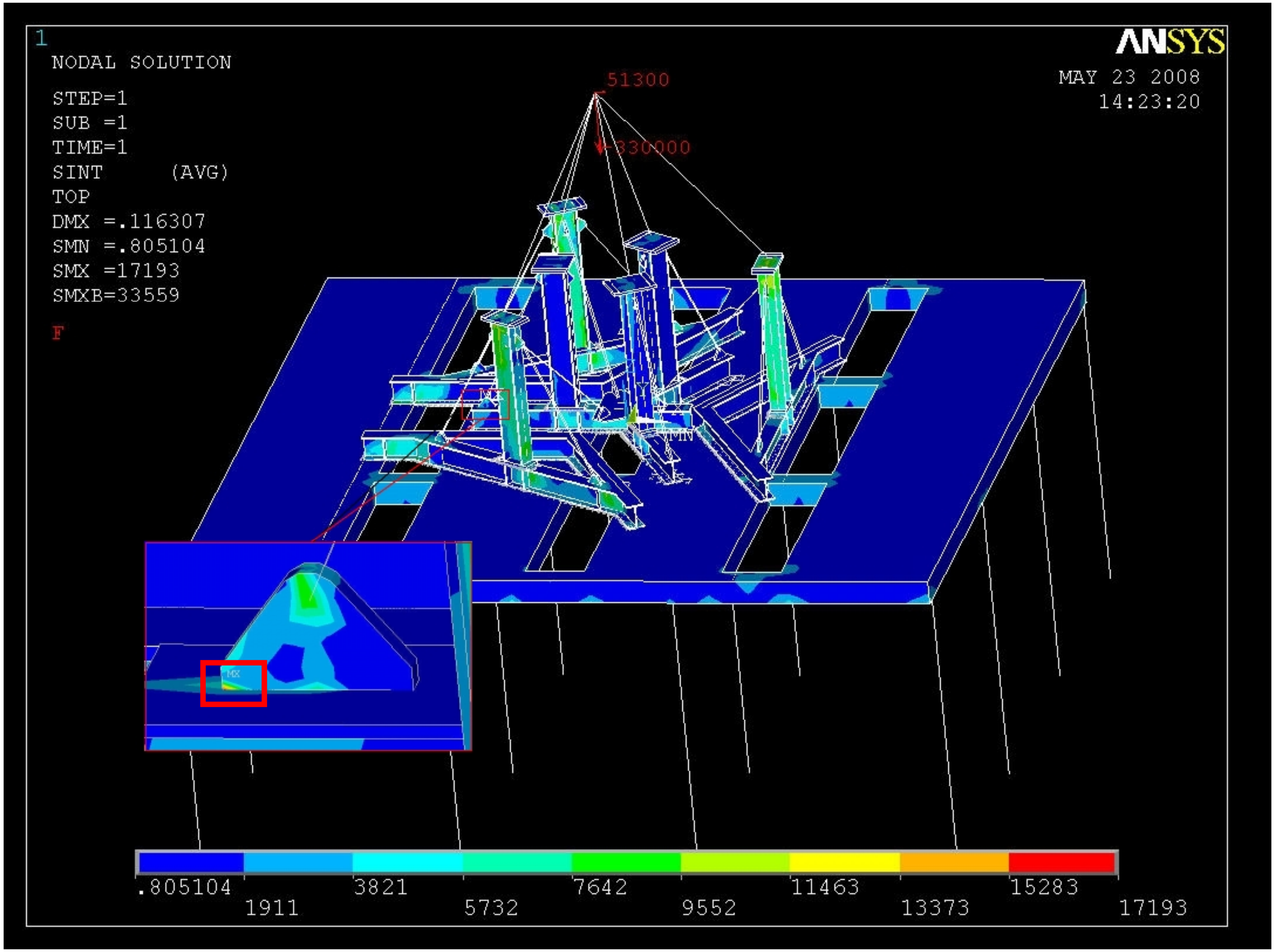
From NCSX-SEIS-CRIT-00:
For Non-Rigid (flexible) Equipment and Components in the NCSX Test Cell mounted to the test cell floor and made of steel or other metal material the seismic criteria is:
Fp = .171 x Wp

Modal Analysis Result: 1st flexible mode @ 4.2 Hz E-W (Y -0 deg.)

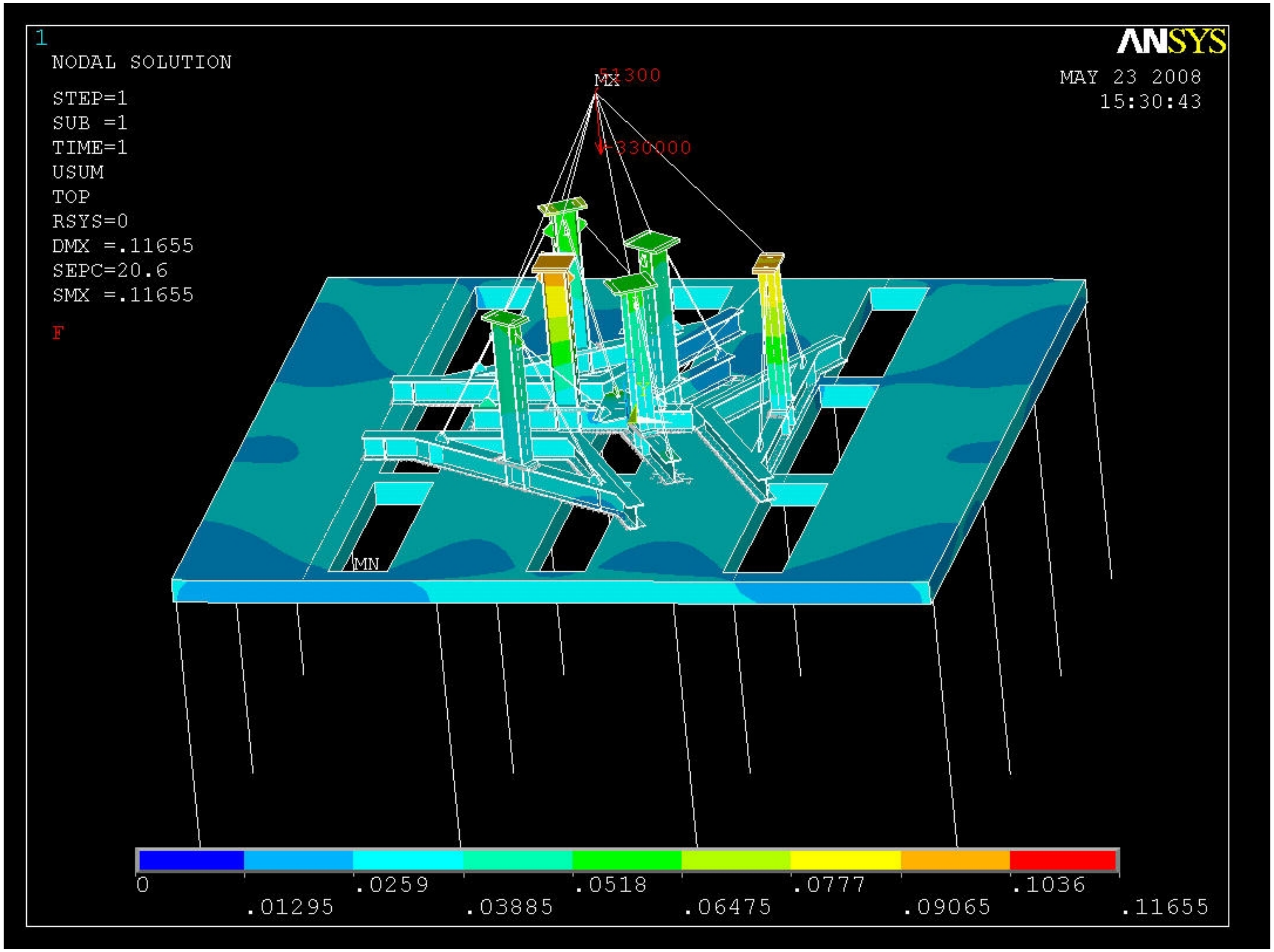
QuickTime™ and a
Microsoft Video 1 decompressor
are needed to see this picture.



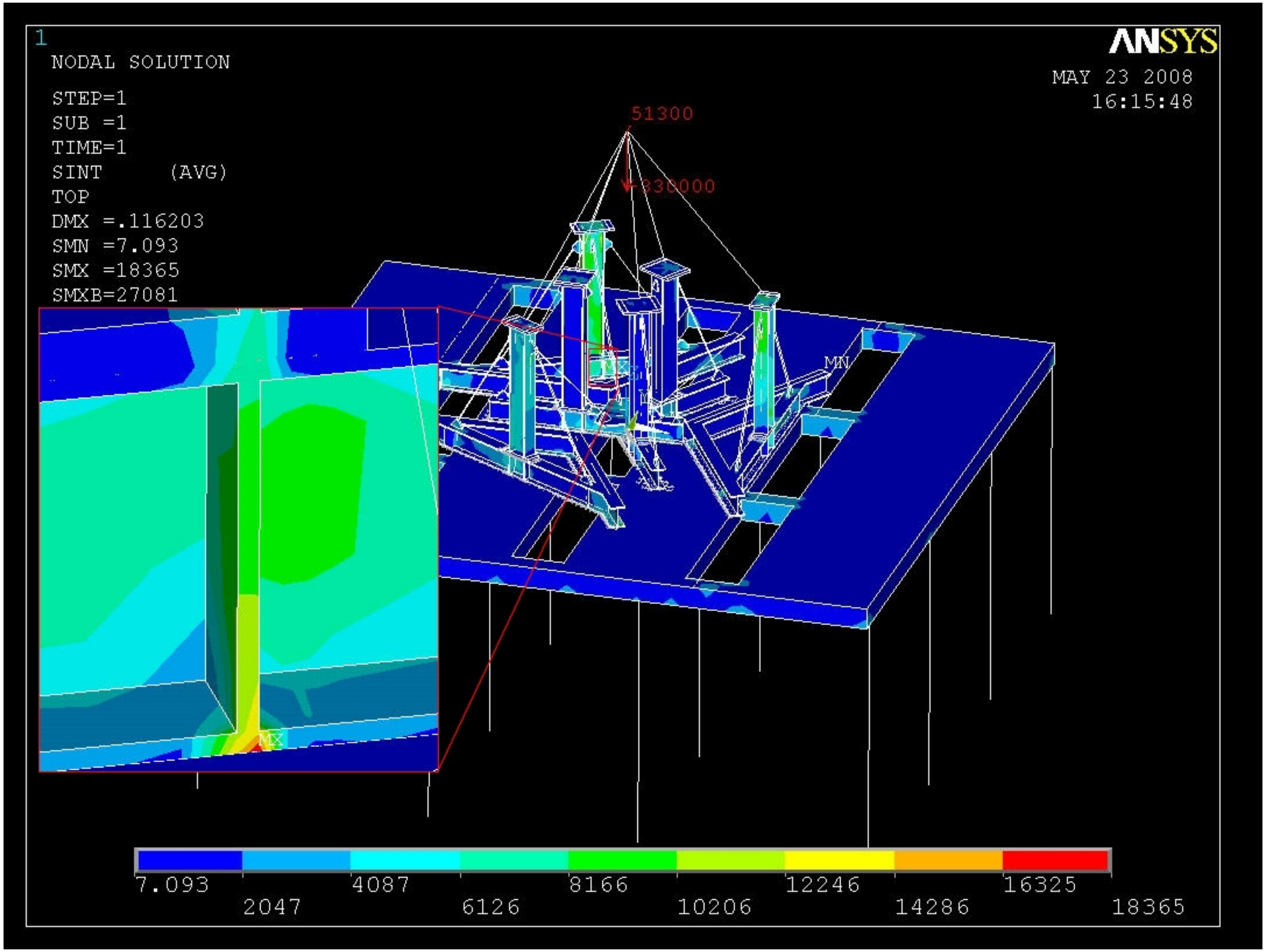
Results from E-W static lateral loading (0.171g): Peak displacement of C.G.”



Results from E-W static lateral loading (0.171g): Peak Tresca Stress 17.1 ksi
Location: Bending stress @ the base of lateral brace brackets



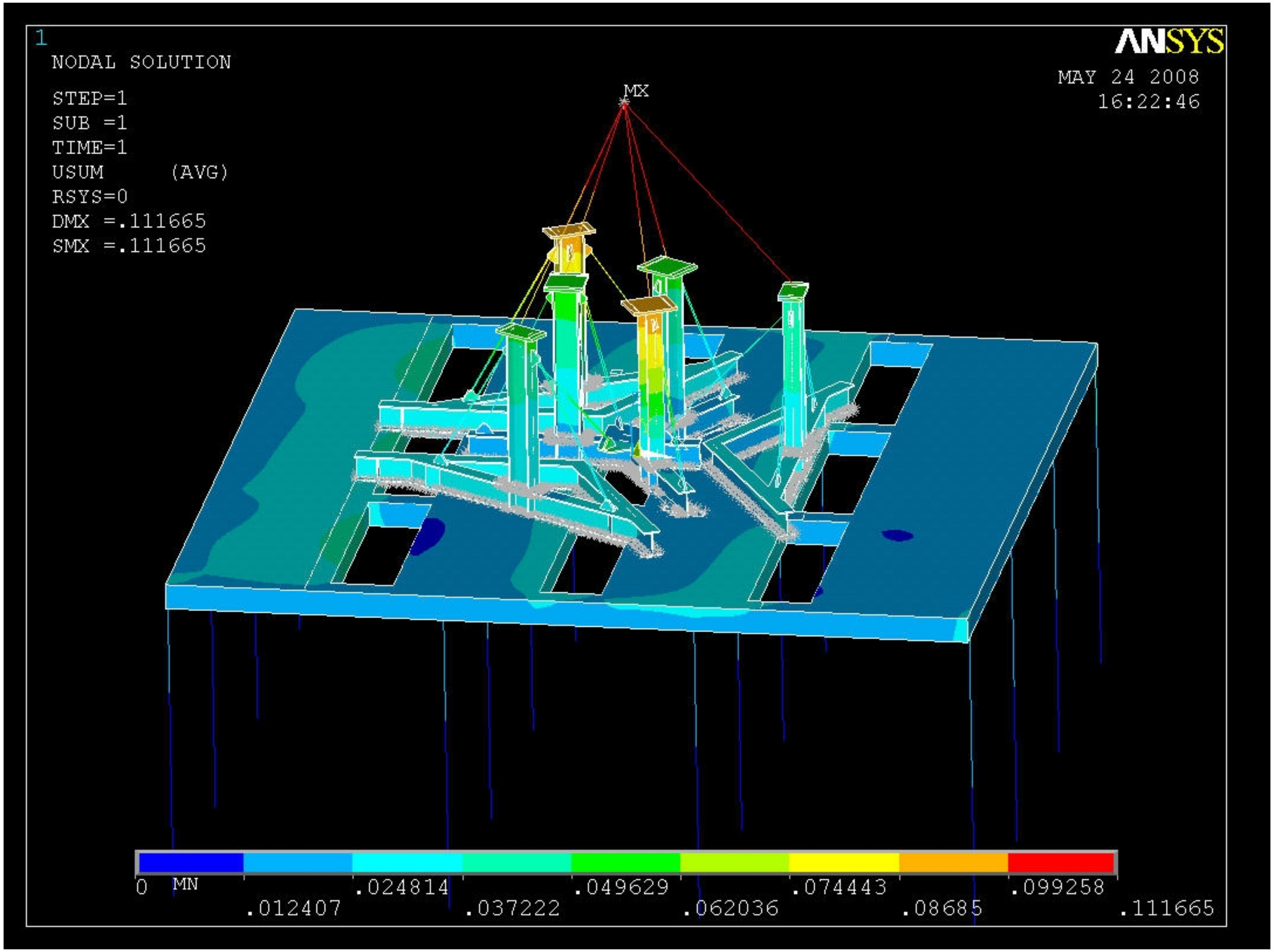
Results from N-S static lateral loading (0.171g): Peak displacement of C.G. 0.12”



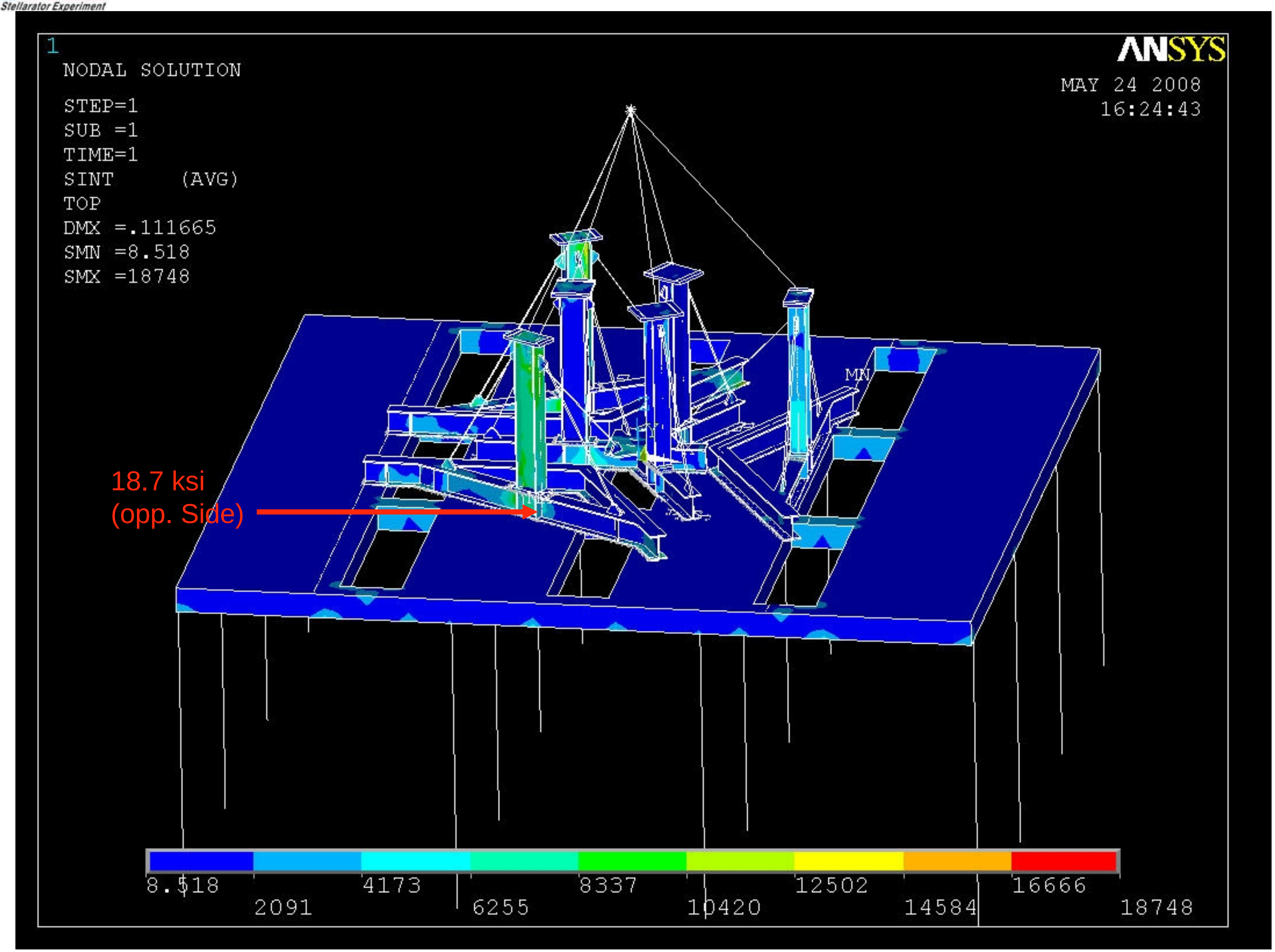
```
1
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
SINT      (AVG)
TOP
DMX =.116203
SMN =7.093
SMX =18365
SMXB=27081
```

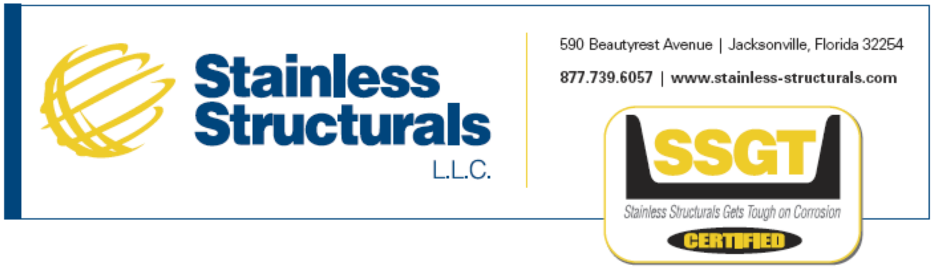
Results from N-S static lateral loading (0.171g): Peak Tresca Stress 18.4 ksi
Location: Bending stress @ the column-base of vertical gusset - Modeling issue?



Results from NE-SW static lateral loading (0.171g): Peak displacement of C.G. 0.11”



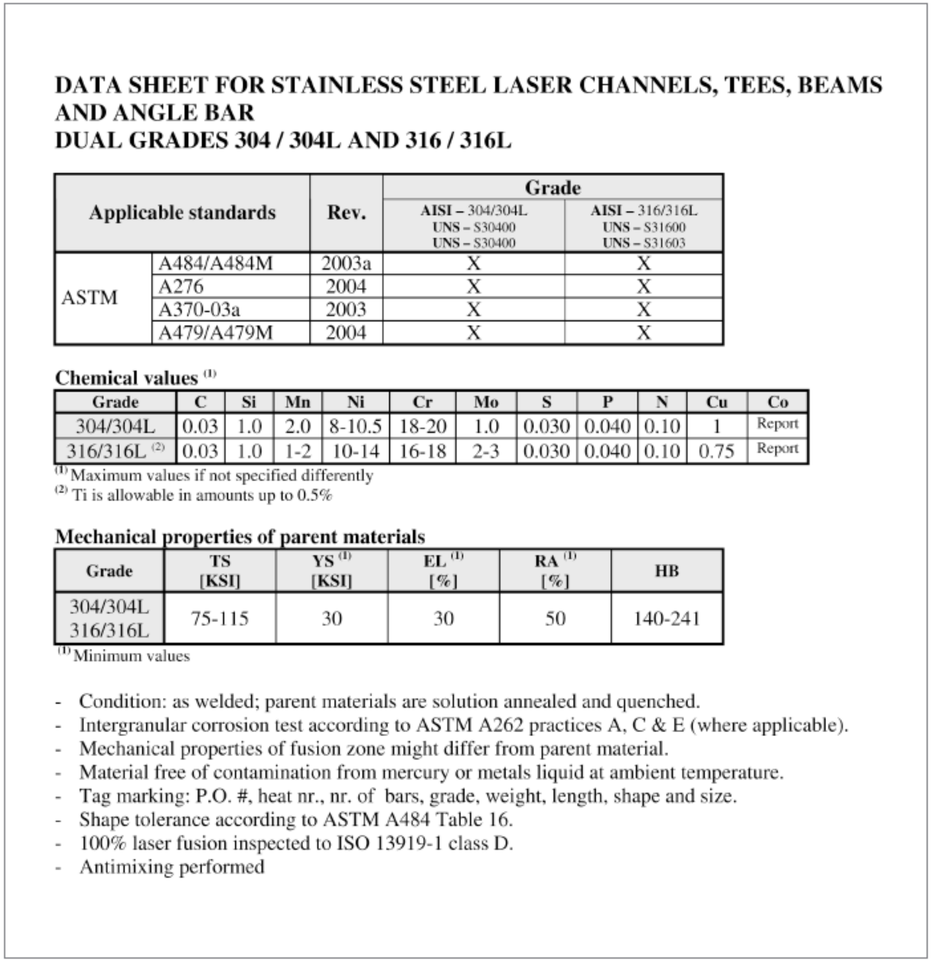
Results from NE-SW static lateral loading (0.171g): Peak Tresca Stress 18.7 ksi
Location: Bending stress @ the base of column base gusset.



Stainless Structurals L.L.C.

590 Beautyrest Avenue | Jacksonville, Florida 32254
877.739.6057 | www.stainless-structurals.com

SSGT
Stainless Structurals Gets Tough on Corrosion
CERTIFIED



DATA SHEET FOR STAINLESS STEEL LASER CHANNELS, TEES, BEAMS AND ANGLE BAR
DUAL GRADES 304 / 304L AND 316 / 316L

Applicable standards		Rev.	Grade	
			AISI – 304/304L **UNS –** S30400 **UNS –** S30400	**AISI –** 316/316L **UNS –** S31600 **UNS –** S31603
ASTM	A484/A484M	2003a	X	X
	A276	2004	X	X
	A370-03a	2003	X	X
	A479/A479M	2004	X	X

Chemical values (1)

Grade	C	Si	Mn	Ni	Cr	Mo	S	P	N	Cu	Co
304/304L	0.03	1.0	2.0	8-10.5	18-20	1.0	0.030	0.040	0.10	1	Report
316/316L (2)	0.03	1.0	1-2	10-14	16-18	2-3	0.030	0.040	0.10	0.75	Report

(1) Maximum values if not specified differently
(2) Ti is allowable in amounts up to 0.5%

Mechanical properties of parent materials

Grade	TS [KSI]	YS (1) [KSI]	EL (1) [%]	RA (1) [%]	HB
304/304L 316/316L	75-115	30	30	50	140-241

(1) Minimum values

- Condition: as welded; parent materials are solution annealed and quenched.
- Intergranular corrosion test according to ASTM A262 practices A, C & E (where applicable).
- Mechanical properties of fusion zone might differ from parent material.
- Material free of contamination from mercury or metals liquid at ambient temperature.
- Tag marking: P.O. #, heat nr., nr. of bars, grade, weight, length, shape and size.
- Shape tolerance according to ASTM A484 Table 16.
- 100% laser fusion inspected to ISO 13919-1 class D.
- Antimixing performed

Base materials of Structurals meet or exceed ASME BPV code requirements for minimum specified yield at 70 deg.F

ASME ASTM-A240 316L $S_{y\text{-min.}}$ > 25 ksi (assume 25 ksi)

Per NCSX-CRIT-CRYO-00, the stress allowable is the lesser of:

$$1/3\ S_{ult,}\ \text{or}\ 2/3\text{rd}\ S_{y\text{-min.}}$$

For all materials specified this will be:

S_m = 16.6 ksi (110 Gpa) @T = 70 ^{o}F

Design Load Requirements[1]:

Normal ops.: D + P + L + T + EM-N + IR
Off-Normal: D + P + L + T + EM-F + IR
Seismic: D + P + L + T + F_{DBE} + IR

D = 300,000lbs, -50kip per support (nominal)
T = -1.7 kip (on O.B. columns), +1.7 kip (I.B. columns)
P = 0
L = 0 (exception for anchor pre-loading)
EM-N = -1.5 (on O.B. columns), + 1.5 kip (I.B. columns)
F_{DBE} = 51.3 kip (for 0.171g static horizontal load)[2]
vertical acceleration not given in ref.2 (seismic requirements)
but the 10% used should exceed requirements
IR = 0

Definitions

D - Dead Loads (gravity)
P - Pressure
L - Pre-loads
T - Thermal loads
EM-N Electro-Magnetic Normal Ops.
EM-F “ “ Fault conditions
IR - Interaction Loads
F_{DBE} - Design Basis Earthquake Load
D_T - Peak column loading

Comparison with project allowable stresses:

- Normal ops. Max stress = 16.2 ksi; S_m is 16.6 ksi 2/3 25ksi (min.spec yield at R.T.)-but note local peak stress <<1.5 x S_m

- Seismic Max. stress = 18.6 ksi < Allowable 1.5xS_m = 25 ksi for local bending

- Off-Normal stress: EM-F not yet defined by project but based on most severe normal EM-N case ± 1.5 ksi and >2 margins on allowable, structure should be capable of handling fault conditions. One set of PF coil shorted fault conditions and stationary plasma disruption loadings are being evaluated.

1. NCSX-CRIT-CRYO-00
2. NCSX-CRIT-SEIS-00

For minimum embedment 4.5” in 4,000 lb R.C.

Seismic Loading on Anchors:
(w/o. 12 addition anchors)

Forces on concrete wedge studs:

NODE	FX	FY	FZ
16560	398.70	-2210.4	4315.8
16612	4552.2	-3412.6	-3288.6
17234	826.51	5147.6	-1534.6
17286	-492.71	667.62	52.423
19454	-3423.9	3347.4	340.46
19467	-2536.8	-3199.8	-955.54
21988	444.46	-2947.8	674.77
22070	-136.47	-3393.3	2775.4
22698	-799.82	6116.4	1872.8
27352	-3.9376	446.26	2409.3
27434	1713.6	-1165.6	2378.7
27982	5766.0	-5069.0	-450.61
28064	-687.22	618.00	-962.14
32724	-424.18	186.34	-697.50
32806	8688.9	7165.1	-462.25
33354	7462.7	4044.8	6025.2
33436	-1419.8	-1271.9	5776.6

Shear area of stud	.78 sq.in.
Max. Shear force	11,262 lbs (node 32806)
Max. Shear in stud	14.4 ksi
Max. pullout load	6.03 kip (node 33354)

Rated stud capacity	13,000 lbs pullout
Rated Shear cap.	22,920 lbs

Reduction for 3,000psi concrete 75%:

Stud capacity	9,750 lbs pullout
Shear capacity	17,190 lbs

For recommended stud spacing:

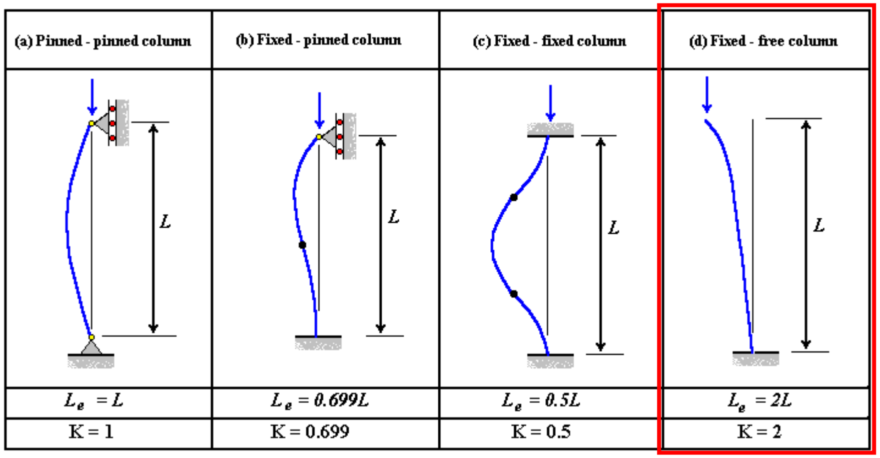
Margin on shear load	1.5x
Margin on pullout	1.6x

Reduction for stud less spacing 75% of rated values:

Margin on shear	~1.1x
Margin on pullout	~1.2x

Loading & stress on the anchors for all operating conditions are substantially less (~50%) than this DBE seismic loading

Column buckling:



Eulers formula:
for end condition (d): $F_{cr} = \pi^2 EI / 4L^2$

<u>WF12 x 50</u>
L = 77.25 in
I_{yy} = 56.3 in^4
E = 29e6 psi
A = 14.4 in^2

F_{cr} = 675,070lbs

(Note these values are for columns with no lateral bracing)

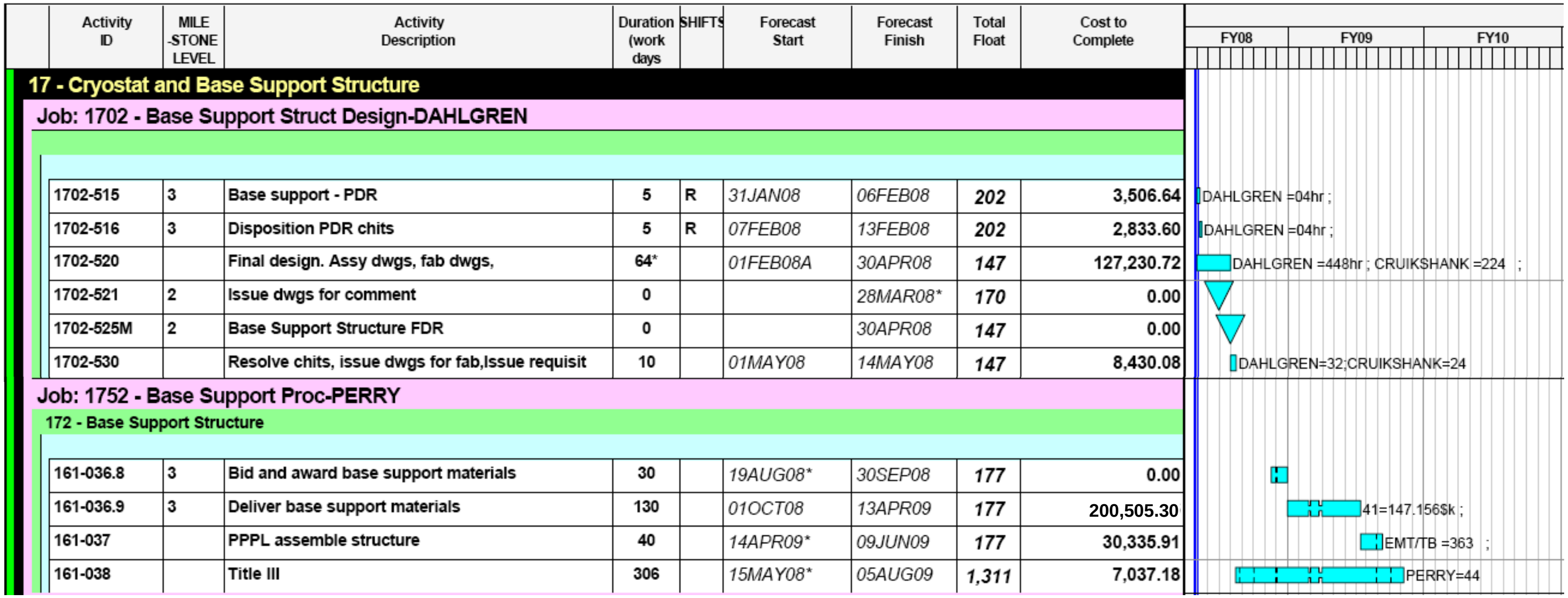
Buckling Margins:

For 100 kip loading:

WF12x50 margin = 6.7

For 25 ksi min. yield, the buckling stress for a WF12x50 column:
29.1 ksi
Probable failure mode is yielding

Cost & Schedule:



Activity ID	MILE-STONE LEVEL	Activity Description	Duration (work days	SHIFTS	Forecast Start	Forecast Finish	Total Float	Cost to Complete
17 - Cryostat and Base Support Structure								
Job: 1702 - Base Support Struct Design-DAHLGREN								
1702-515	3	Base support - PDR	5	R	31JAN08	06FEB08	202	3,506.64
1702-516	3	Disposition PDR chits	5	R	07FEB08	13FEB08	202	2,833.60
1702-520		Final design. Assy dwgs, fab dwgs,	64*		01FEB08A	30APR08	147	127,230.72
1702-521	2	Issue dwgs for comment	0			28MAR08*	170	0.00
1702-525M	2	Base Support Structure FDR	0			30APR08	147	0.00
1702-530		Resolve chits, issue dwgs for fab,Issue requisit	10		01MAY08	14MAY08	147	8,430.08
Job: 1752 - Base Support Proc-PERRY								
172 - Base Support Structure								
161-036.8	3	Bid and award base support materials	30		19AUG08*	30SEP08	177	0.00
161-036.9	3	Deliver base support materials	130		01OCT08	13APR09	177	200,505.30
161-037		PPPL assemble structure	40		14APR09*	09JUN09	177	30,335.91
161-038		Title III	306		15MAY08*	05AUG09	1,311	7,037.18

Base Support Structure

- Procure main columns & beams from Stainless Structurals, LLC (~ 13 weeks)
- Fabricate parts in-house (welding, drilling, & assembly).

Total: 230.5 k$
(FY'09)

Purchased parts:	**(ft.)**	**lbs./ft.**	**$/lb. (or per pkg.)**	**cost**
4 - W12 x 50 x 24' - 316L stainless steel (LW)	96	50	$9.20	$44,160.00
4 - W8 x 35 x 24' - 316L stainless steel (LW)	96	50	$9.20	$44,160.00
4 - W12 x 50 x 24' - 316L stainless steel (LW)	96	50	$9.20	$44,160.00
5 - 4" x 4" x 3/8" thk. Angle sections - 316L	120	9.2	$9.20	$10,156.80
3/4" - 316L plate 36" x 48" base hub plate	4	95	$7.50	$2,850.00
3/4" - 316L plate 36" x 48" top & bottom base column bases	4	95	$7.50	$2,850.00
Weld rod & roto-bores				$3,000.00
12 - Inconel 718 hex bolts 1-8 x 2.5" @ $55 ea.				$660.00
12 - Inconel 718 hex nuts 1-8 @ $38 ea.				$456.00
24 - 316 SS flat washers 1.03" ID @$4.26 ea.				$102.24
1 x 9" 316ss Hilti concrete anchors - 4 packs (Part#97799A730)		$231.80	24	$5,563.20
24 Heater elements with thermostat controllers Cat.#3654K22		$95.25	24	$2,286.00
Sub-Total:				**$160,404.24**
G& A on Materials @25%				$40,101.06
Total Materials		→		**$200,505.30**
	EMTB			
Labor - PPPL:	**hrs.**			
Welding *(4hrs @ 48 places)*	192			
Welding *(4hrs @ 24 places)*	96			
Cut & Drill plates	75			
	363			

Open chit from 1/17/07 peer review:

Coil Structure Pee Dahlgren/Reierser	1/17/07	1	Coil structure rests on cover plate for an A structure will be needed to carry loads [Perry]	Concur Resolved	Base Structure spans t and distributes the loa floor.

Coil Structure Pe Dahlgren/Reiers	1/17/07	3	Interface with base support structure at tops of columns. Columns pinned elevation when lateral motion occurs.	Concur Resolved	A sliding interface be pedestal and spheric housing has been im

Coil Structure P Dahlgren/Reiers	1/17/07	17	Consider coil fault conditions in the design of the structure. [Dudek]	Concur Resolved-I.P.	Fault conditions sho

Fault conditions are not explicitly defined in the GDR, but a single PF coil short, and stationary plasma disruption have been assumed as the primary credible fault modes for all defined operational scenarios. Modular coil faults (one coil out) may also need to be considered -minimal impact on base supports, but major issue for MCWF joints?

Disposition of Chits from the PDR

Design Review/QA Audit [Cog Engr/RLM/Chair]	Rvw Date	#	Chit / Audit Finding [Originator]	Review Board Recommendation	Project Disposition	Responsibility	Status	Due Date
Base Support Structure PDR Dahlgren/Heitzenroeder/Perry	3/6/08	1	Project has to define fault conditions. [Neilson]	Concur (RLM should define all loads that this structure must support.)	EM load shifts ~10% and are acceptable.		Compl.	5/27/08
Base Support Structure PDR Dahlgren/Heitzenroeder/Perry	3/6/08	2	Must include loads from all possible coil faults. [Perry]	Concur (RLM should define all loads that this structure must support.)	1 PF coil out is sustainable		Compl.	5/27/08
Base Support Structure PDR Dahlgren/Heitzenroeder/Perry	3/6/08	3	Base should document the interface requirements for the interface with the cryostat. [Perry]	Concur (RLM should document the interface requirements for the interface with the cryostat)	Reviewed Cryostat interfaces with suppts. at C-C & A-A joints		Compl.	5/27/08
Base Support Structure PDR Dahlgren/Heitzenroeder/Perry	3/6/08	4	The support column heights may (will) need to be adjusted to meet the cryostat thickness and cold to warm transition requirements. [Brown]	Concur (RLM should document the interface requirements for the interface with the cryostat)	Column height Reduced, & Inb'd. columns moved in to avoid interferences		Compl.	5/27/08
Base Support Structure PDR Dahlgren/Heitzenroeder/Perry	3/6/08	5	Address thermal isolation in the requirements (SRD) and the design. Also load measurements. [Neilson]	Concur (RLM should document the interface requirements)	Done		Compl.	5/27/08
Base Support Structure PDR Dahlgren/Heitzenroeder/Perry	3/6/08	6	Consider the next larger size beam to provide margin for future weight increases of cryostat, diagnostics, etc. [Heitzenroeder]	Concur	Base support beams were increased to WF12x50		Compl.	5/27/08
Base Support Structure PDR Dahlgren/Heitzenroeder/Perry	3/6/08	7	Load requirements need to be defined (including PF coils, cryostat, LN2, diagnostics, plasma facing components) and then controlled (by a systems engineers?) [Perry]	Concur (RLM should define all loads that this structure must support, and then establish a way to control this aspect of the NCSX configuration.	Load increased to 100kip max per column (outb'd. col.) & includes cryostat, pfcs, & est. for diagnostics		Compl.	5/27/08
Base Support Structure PDR Dahlgren/Heitzenroeder/Perry	3/6/08	8	Review the final machine weight as it may be higher than the values assumed. [Brown]	Concur (RLM should define all loads that this structure must support, and then establish a way to control this aspect of the NCSX configuration.	See item 7.		Compl.	5/27/08
Base Support Structure PDR Dahlgren/Heitzenroeder/Perry	3/6/08	9	Evaluate use of pipe instead of I-beam for columns. [Perry]	Concur	Low permeability and symm. welds req. WF columns.		Compl.	5/27/08
Base Support Structure PDR Dahlgren/Heitzenroeder/Perry	3/6/08	10	Cost estimates are for 35#, but 50# beams will be used to improve margins….. Need to update cost estimates. [Perry]	Concur	Done		Compl.	5/27/08

Fatigue Considerations:

The facility shall be designed for the following maximum number of pulses when operated per the reference scenarios defined in Section 3.2.1.5.3.3.1 and based on the factors for fatigue life specified in the NCSX Structural and Cryogenic Design Criteria Document:

- 100 per day;
- 13,000 per year; and
- 130,000 lifetime.

Max. operational load O.B. columns: 53.9

S max = 14.2 ksi, S min = 12.0 ksi

S mean = 13.1 ksi
Seq. = 2.67 ksi

20x life = 2.6e6 cycles

---> 26 ksi limit >> max stress intensity

Conclusion:
Fatigue life not a limiting
Factor in design

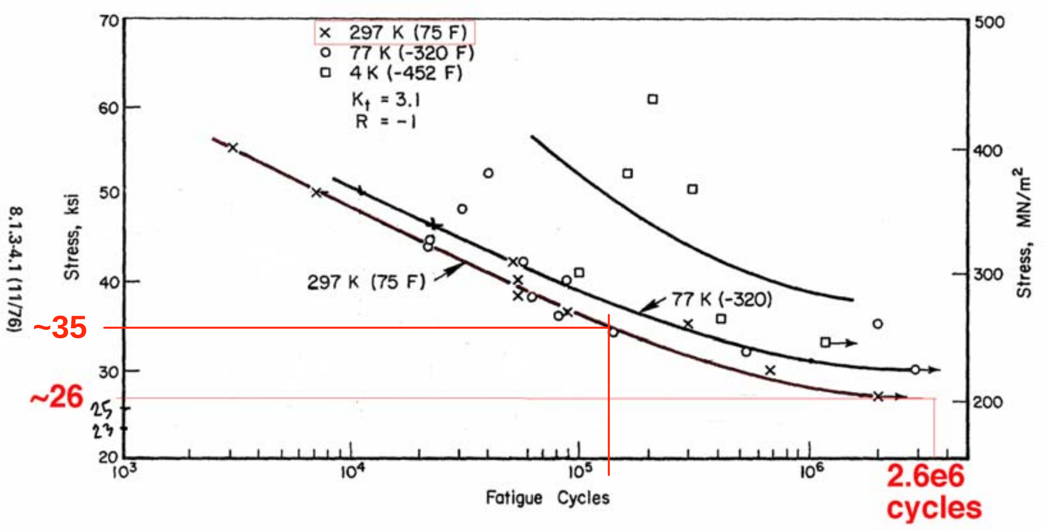
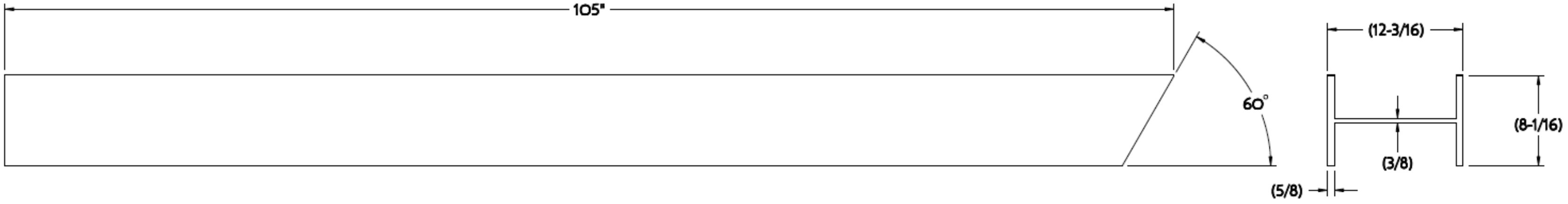


FIGURE 8.1.3-ME2.1. AXIAL FATIGUE LIFE CURVES FOR NOTCHED ANNEALED 304L STAINLESS STEEL BAR [95168]
[Up to 2.540 cm (1.000 in.) diameter]

Charge for the FDR of the NCSX Base Structure:

1. Are all required analyses complete and formally checked and adequate to establish that the proposed design is feasible and meets established design criteria?
2. Are the drawings and documentation adequate to support the procurement and/ or manufacturing process, installation, and ready for sign-off?
3. Is the design of the base structure compatible with the machine assembly fixtures and plans?
4. Is the Product Specification (CSPEC) complete and satisfactory?
5. Are the interfaces adequately defined?
6. Is the Work Planning form current, and have the applicable requirements been satisfied?
7. Have the chits from the PDR been resolved?
8. Are updated cost and schedule estimates available?

Backup Slides



① OUTER SUPPORT BASE ANGLED BEAM - W12" x 50#

Total area = (8 x 102) x 2 + 124 x 8 = 2624 sq. in.

For uniformly distributed loading:

P = 100 kip / 2,624 = 38 psi

If concentrated area under column only:

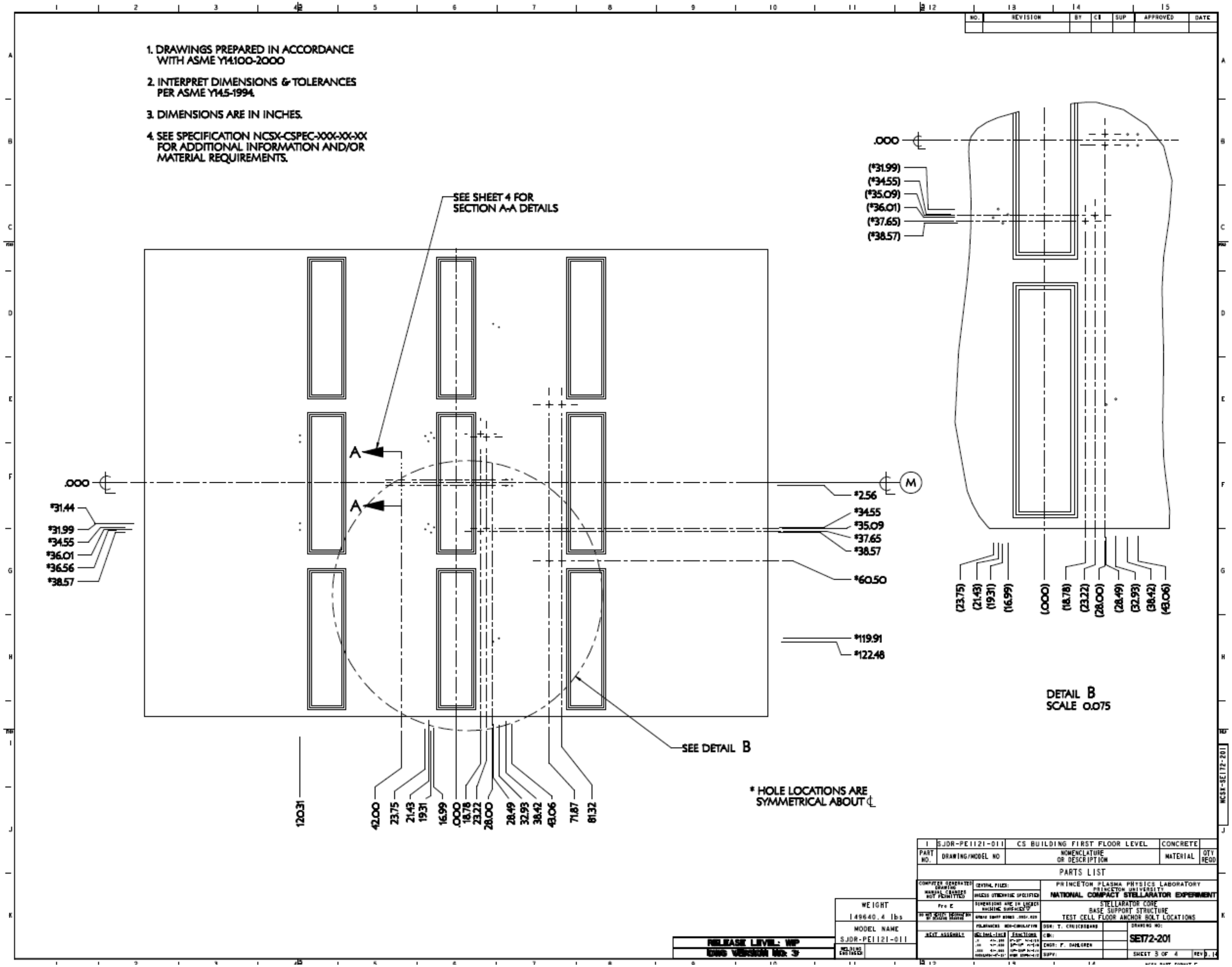
Area = 96 sq. in.

P = 100 kip / 96 = 1,041 psi

Floor rating: 4,500 psf; 3,000 psi concrete

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Strip heaters (4 per column) will be used to maintain R.T. (40 to 60 F) of columns



1. DRAWINGS PREPARED IN ACCORDANCE WITH ASME Y14.100-2000
2. INTERPRET DIMENSIONS & TOLERANCES PER ASME Y14.5-1994.
3. DIMENSIONS ARE IN INCHES.
4. SEE SPECIFICATION NCSX-CSPEC-XXX-XX-XX FOR ADDITIONAL INFORMATION AND/OR MATERIAL REQUIREMENTS.

SEE SHEET 4 FOR SECTION A-A DETAILS

* HOLE LOCATIONS ARE SYMMETRICAL ABOUT ℄

DETAIL B
SCALE 0.075

1	SJDR-PE1121-011	CS BUILDING FIRST FLOOR LEVEL	CONCRETE	
PART NO.	DRAWING/MODEL NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	QTY REQD

PARTS LIST

PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL COMPACT STELLARATOR EXPERIMENT

STELLARATOR CORE
BASE SUPPORT STRUCTURE
TEST CELL FLOOR ANCHOR BOLT LOCATIONS

WEIGHT 149640.4 lbs
MODEL NAME SJDR-PE1121-011
DSN: T. CRUICKSHANK
ENGR: F. DAHLGREN
DRAWING NO: SE172-201
SHEET 3 OF 4

RELEASE LEVEL: WIP
DWG VERSION NO: 3

Seismic Static Load Requirements:

For hazardous equipment when Ip > 1 use the following

Fp = .4*a.p*Sds*Wp*(1 + 2*z/h) / (Rp / Ip) Equation 16-67

Fp = the seismic force centered at the center of gravity of the component

Wp = component operating weight

a.p = component amplification select from table 1621.2 or 1621.3

For rigid structures whose natural frequency (Fn) is greater than 16.7 hz use a.p = 1 (ref. commentary Figure 1621.1.4)

For non rigid structures use a.p = 2.5

Fn = 1 / (2*p(W.p / K.p *g)^.5) Component Natural Frequency (1621.3.2)

g = Acceleration of gravity

K.p = Stiffness of the component and attachment in terms of load per unit deflection at the center of gravity

Rp = Component response modification factor select from table 1621.2 or 1621.3,

Represents the ability of a component to sustain permanent deformations without losing strength (= 2.5 for most components includes steel and copper , = 1.25 for low deformability elements such as ceramic, glass, or plain concrete)

z = Height in structure above base at point of attachment of component (height above grade)

h = Average roof height of structure relative to the base elevation

Ip = 1 for non hazardous equipment and 1.5 for hazardous equipment or life safety equipment required to function after an earthquake, from section 1621.1.6

For NCSX we simplify the equation to :

Fp = .096*a.p*Wp*(1 + 2*z/h)*Ip / Rp

With Basement Elevation = 0’

Test Cell Elevation = 13’3”

Top of Steel = 55’

For the Test Cell Floor z/h = .24

For C.G. of machine z/h = 28.5/55 = 0.519

a.p. = 1.0 (rigid structure)

Ip = 1.5

Rp = 2.5

Fp = (.096*(1.0)*(1 + 2*0.519)*1.5/2.5) * Wp = 0.1174 * Wp

If a.p. = 2.5 (non-rigid): Fp = (.096*(2.5.0)*(1 + 2*0.519)*1.5/2.5) * Wp = 0.293 * Wp

L = 48” shortest unsupported length

L/480 = 48/480 = 0.1” most restrictive

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.