John Corini - PE

Key To Successful Tower Installations:

Under Stack

And

Over Guy

Tom Wagner
N1MM

KE1IH BACKGROUND

- First Licensed as KA1MDG in 1983
- One of The YCCC “Smaller” Guns

- Practicing Design/Structure Engineer of 25 years
- Currently an Aerospace Composite Structures Engineer for Pratt and Whitney

- Registered Professional Engineer in Mass.
- Have Design and “Stamped” Towers in Ma., Ct and NY.

A Look At Computer Modeling Amateur Radio Towers - KE1IH

Topics of Discussion:

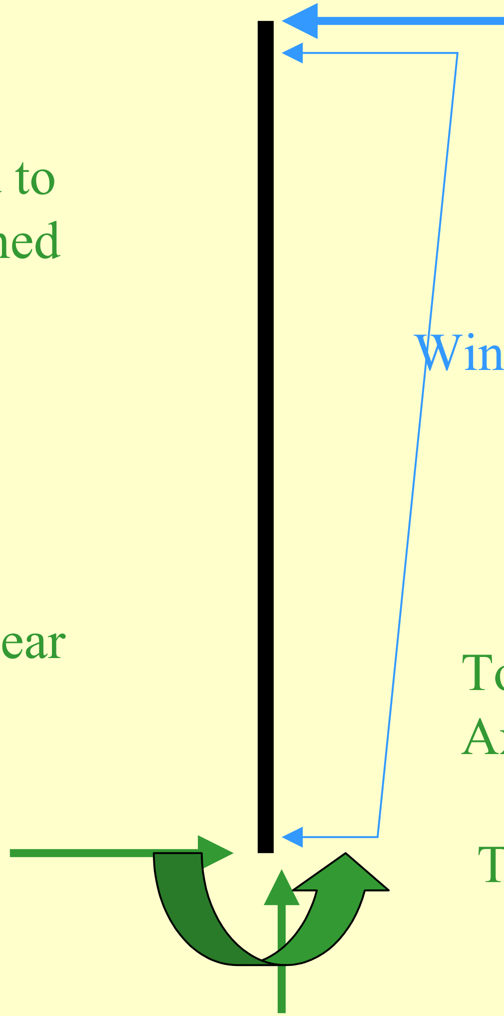
- Free Standing Tower
- Wind Loading Calculations
- Guy Wire Tension
- Importance of Mast Length
- Guyed Tower – Beam Properties Method
- Guyed Tower – Beam Element method
- Questions

Free Standing Tower Free Body Diagram

Loads in Blue, are Known

Antenna and Mast Forces

Loads in Green need to be determined



Wind Load

Tower Base Reaction Shear Force

Tower Base Reaction Axial Force

Tower Base Moment Reaction

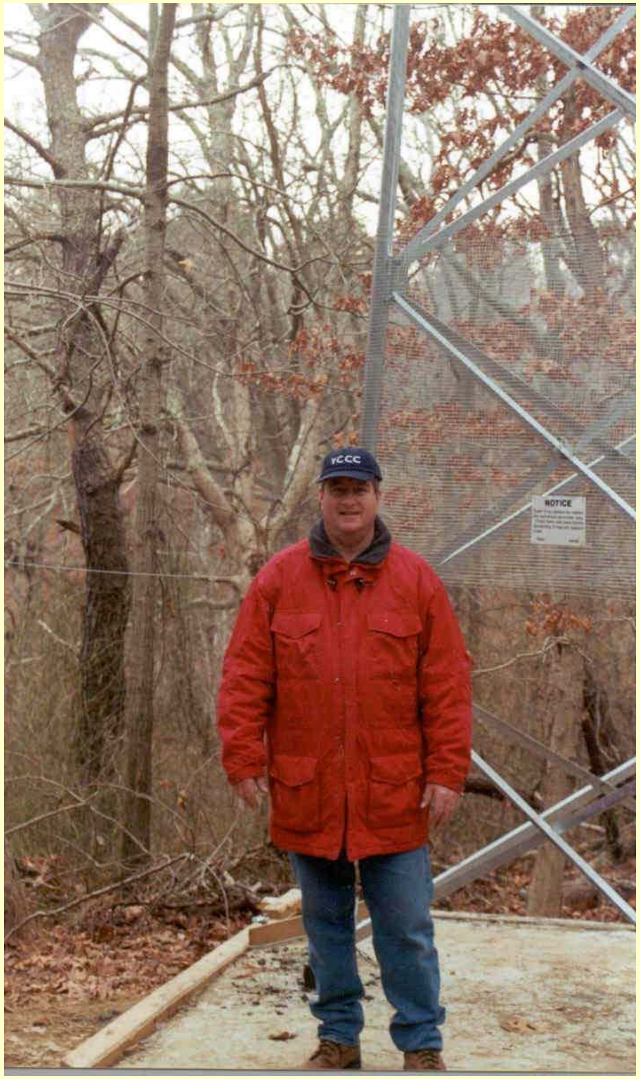
An Extreme Ham Tower

This 70 foot tower was originally to be
100 feet – designed to withstand 110 MPH
The Tower Steel is over 6 1/2 feet wide at the base

Typical Bolted Brace

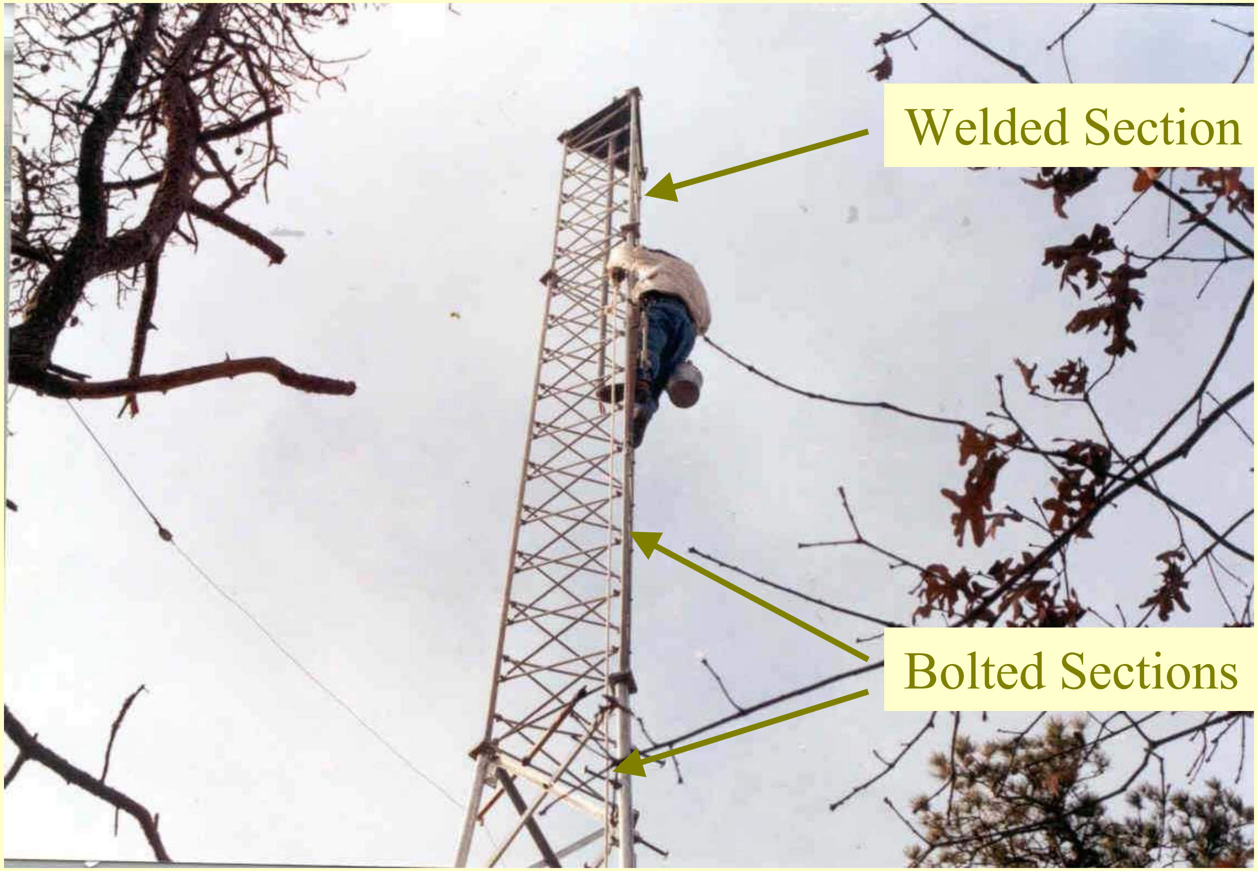
An Extreme Ham Tower

The Concrete Base is 8’ 6” wide on each side and over 7 feet deep. There is over 18 Yards of Concrete in the base and it weighs over 70,000# (35 tons).



This tower model has 400 nodes and 992 elements

The deflection at the top to the tower is 28", the deflection at the top of the mast is 48"



Wind Loading Comparison

	EIA 110 MPH WIND – NO ICE		EIA 100 MPH WIND – NO ICE		EIA 82.5 MPH WIND – ¼" Radial ICE		MASS CODE 90 MPH WIND NO ICE	
Tower Section MEDIAN HEIGHT	Max Pressure	Max Force	Max Pressure	Max Force	Max Pressure	Max Force	Max Pressure	Max Force
10	31	973	26	804	17	673	21	588
30	31	804	26	664	17	576	21	476
50	35	550	29	434	20	480	31	430
70	38	535	32	443	22	510	31	380
90	41	421	34	348	24	425	31	280

100 Foot Free Standing Tower Results

Max Stress

Tower Section	Tower Section Element	110 MPH Wind Load NOICE		AISC Maximum Allowable Load or Stress	
		Maximum Tower Leg Load	Maximum Tower Leg Stress	Max Allowable Tower Leg Load	Max. Allowable Tower Leg Stress
7N	12	43,977 pounds	29,775 psi	50,685 pounds	34,310 psi
6N	31	46,980 pounds	31,808 psi	50,686 pounds	34,310 psi
5N	62	49,030 pounds	28,962 psi	55,624 pounds	34,150 psi
4N	102	31,270 pounds	25,485 psi	40,389 pounds	32,910 psi
3WN	163	17,029 pounds	24,680 psi	22,423 pounds	32,480 psi

	Tower Section Element	82.5 MPH Wind Load - 1/4 " Radial Ice		AISC Maximum Allowable Load or Stress	
		Maximum Tower Leg Load	Maximum Tower Leg Stress	Tower Section	Max. Allowable Tower Leg Stress
7N	12	34,530 pounds	23,378 psi	50,685 pounds	34,310 psi
6N	31	35,950 pounds	24,340 psi	50,686 pounds	34,310 psi
5N	62	37,390 pounds	22,086 psi	55,624 pounds	34,150 psi
4N	102	22,780 pounds	18,566 psi	40,389 pounds	32,910 psi
3WN	163	11,430 pounds	16,565 psi	22,423 pounds	32,480 psi

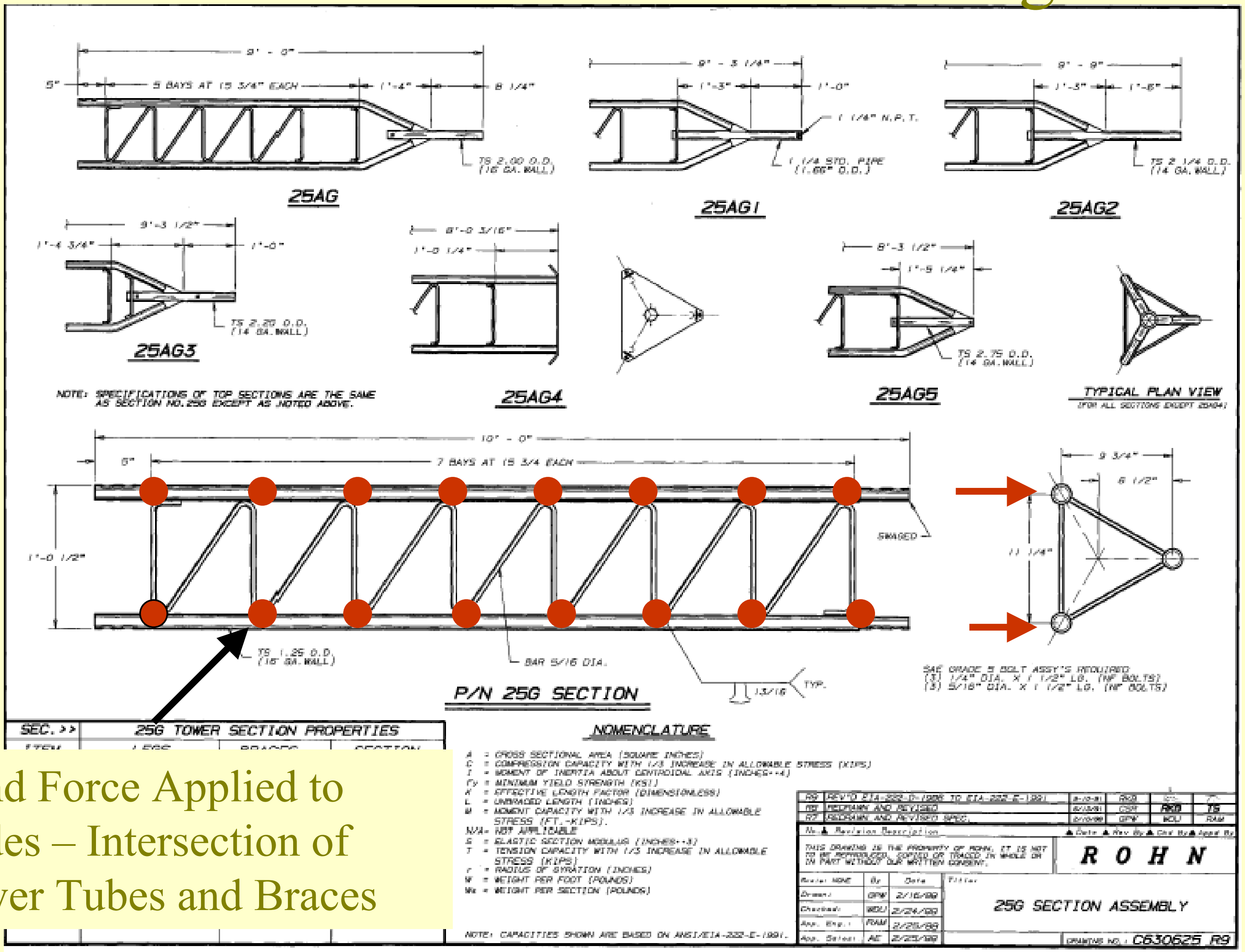
Guyed Tower Free Body Diagram

Loads in Blue, are Known

Loads in Red are unknown

Loads in Green need to be determined

Tower Section Nodal Loadings



Wind Force Applied to Nodes – Intersection of Tower Tubes and Braces

Wind Loading ASCE/EIA RS-222

EIA-222-F Wind Loads												
				90	Total height of Tower and Mast							
				90	V = Wind Speed in MPH - ASCE Exposure B							
				0.166667	Mast Width							
				1.169881	G = Wind Gust Factor - Exposure B - ASCE							
				0.211649	Af = Tower section area perpindulcar to wind - Ft^2 - per foot							2.539792
				0.850694	At = Total tower section area							10.20833
				0.248796	e = ratio of tower free area to total tower area							0.248796
				2.441117	cf - Wind force coeficient - ASCE							
				0.601569	r - coeficient for round members							
									F= qz*Af*L*coef*G			
			qz - Velocity Pressure			Wind force Coef						
Height		Kz	- Pounds/Ft^2					F - Wind Force - pounds				Wind Force per tower section node
				L								
10	7.5	0.654872	15.88632	10		1.4685		108.9367				6.05
20	25	0.923741	22.40872	10		1.4685		153.6626				8.54
30	35	1.016954	24.66994	10		1.4685		169.1683				9.40
40	45	1.092661	26.50649	10		1.4685		181.7621				10.10
50	55	1.157139	28.07063	10		1.4685		192.4878				10.69
60	65	1.213708	29.44293	10		1.4685		201.898				11.22
70	75	1.26436	30.67168	10		1.4685		210.3239				11.68
80	85	1.310393	31.78837	10		1.4685		217.9814				12.11
85	85	1.310393	31.78837	14		1.2		104.1281		Mast Wind Force		7.44
Antenna wind forces												

Antenna Drag Force Calculations

Calculation of Drag Forces of Antenna

Boom Drag Force

$Cd := 1.2$ = Drag Force Coefficient

$A := 24.8 \cdot \left(\frac{2}{12}\right)$ = Boom Length X Boom Diameter - Sqare Feet

$\rho := .0763$ Density of Air at 60 deg F

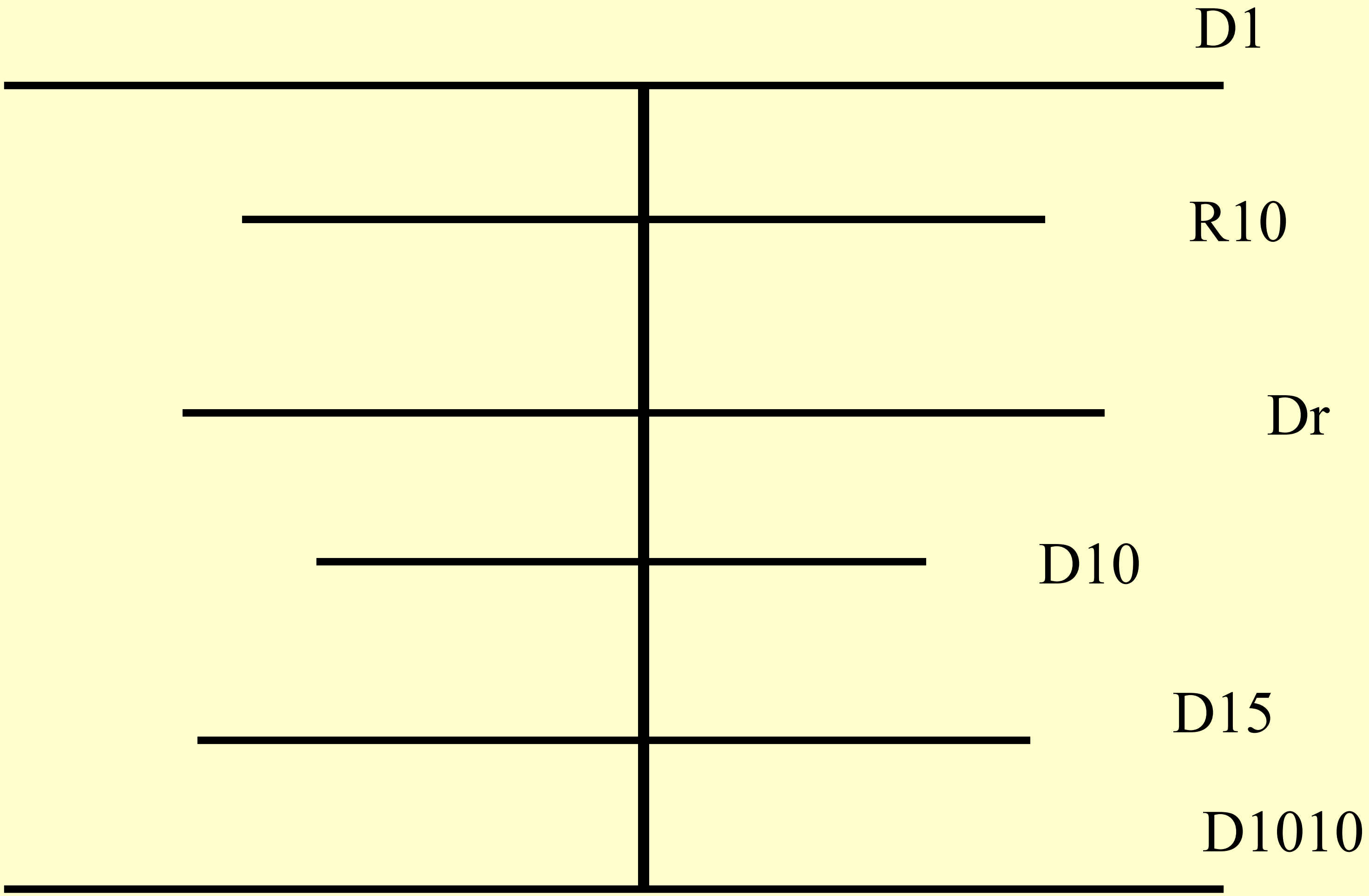
$v := \frac{100 \cdot 5280}{60^2}$ $v = 146.667$

$g := 32.2$ Acceleration due to Gaverity

Boom Drag Force = $Df := \frac{Cd \cdot A \cdot \rho \cdot v^2}{2 \cdot g}$ $Df = 126.411$ pounds

Stagnaton Pressure - 100 mph = $Sp := \frac{Df}{A}$ $Sp = 30.583$

Antenna Wind Loading – Cont.



Antenna Drag Force Calculations Continued

TH6DXX – CW LOW

$$D1 := \left[\left(\frac{95.5}{12}\cdot 2\cdot\frac{1.25}{12}\right)+\left(\frac{35.5}{12}\cdot\frac{1.13}{12}\cdot 2\right)+\left(\frac{41.5}{12}\cdot\frac{7}{16\cdot 12}\cdot 2\right)\right] \qquad D1 = 2.467$$

$$R10 := \left(\frac{55}{12}\cdot\frac{7}{8\cdot 12}\cdot 2\right)+\left(\frac{23.5}{12}\cdot\frac{5}{8\cdot 12}\cdot 2\right)+\left(\frac{36.5}{12}\cdot\frac{7}{16\cdot 12}\cdot 2\right) \qquad R10 = 1.094$$

$$Dr := \left[\left(\frac{48.5}{12}\cdot 2\cdot\frac{1.25}{12}\right)+\left(\frac{39.5}{12}\cdot\frac{1.13}{12}\cdot 2\right)+\left(\frac{32.5}{12}\cdot\frac{7}{16\cdot 12}\cdot 2\right)\right]+\left(\frac{6}{12}\cdot\frac{1}{12}\cdot 2\right) \qquad Dr = 1.743$$

$$D10 := \frac{53}{12}\cdot\frac{7}{8\cdot 12}\cdot 2+\frac{45.5}{12}\cdot\frac{7}{16\cdot 12}\cdot 2 \qquad D10 = 0.921$$

$$D15 := \left(\frac{55}{12}\cdot\frac{7}{8\cdot 12}\cdot 2\right)+\left(\frac{23.5}{12}\cdot\frac{5}{8\cdot 12}\cdot 2\right)+\left(\frac{48.5}{12}\cdot\frac{7}{16\cdot 12}\cdot 2\right) \qquad D15 = 1.167$$

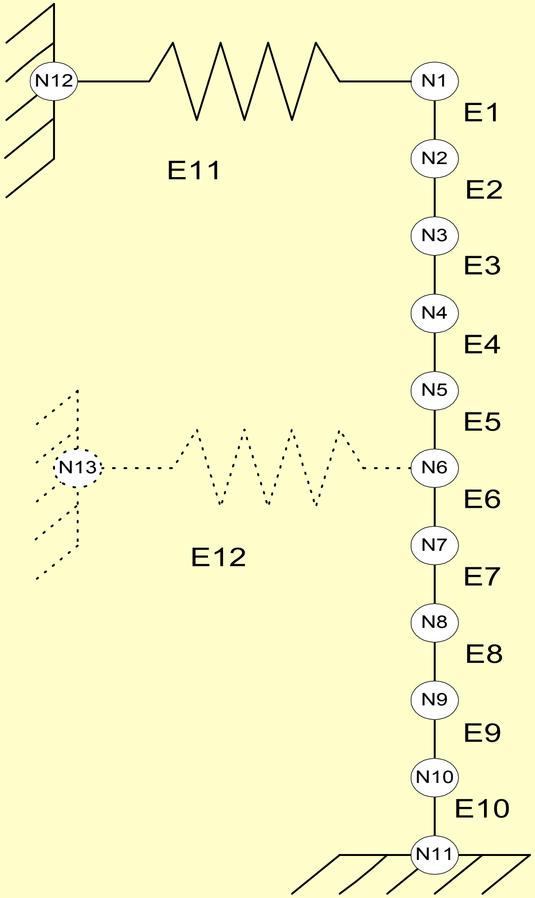
$$D1010 := \left[\left(\frac{48}{12}\cdot 2\cdot\frac{1.25}{12}\right)+\left(\frac{29}{12}\cdot\frac{1.13}{12}\cdot 2\right)+\left(\frac{72.5}{12}\cdot\frac{7}{16\cdot 12}\cdot 2\right)\right] \qquad D1020 = 1.729$$

$$At := D1020 + D15 + D10 + Dr + R10 + D1 \qquad At = 9.121$$

8.09 square feet per hy-gain

Antenna Drag Force Based Upon the Elmenets = $Dfe := At\cdot Sp \qquad Dfe = 278.947$

Importance of Pretension in Guy Wires



Beam-Column Condition	Exact Solution	NISA Solution	% Difference NISA - Exact
Simple - Simple Supports	7903.90	7,904.02	1.000015
Fixed - Free Supports	1975.97	1,975.98	1.000005
Fixed - Fixed Supports	31,615.6	31,622.3	1.00021
Fixed - Hinged Supports	16,166.4	16,170.3	1.00024
Guyed Column - Ks = 0	1,975.96	1,976.0	1.000010
Guyed Column - Ks = 1	2,460.30	2,460.33	1.000012
Guyed Column - Ks = 10	6,587.10	6,587.2	1.0000076
Guyed Column - Ks = 100	15,612.0	15,613.0	1.000060
Guyed Column - Ks = 1,000	16,125.0	16,126.1	1.000066
Guyed Column - Ks = 10,000	16,164.9	16,166.0	1.000066
Guyed Column - Ks = 100,000	16,168.8	16,169.9	1.000066
Guyed Column - Ks = 1,000,000		16,170.3	1.000066
Guyed Column - Ks = 10,000,000	16,169.2	16,170.3	1.000066

Guy Wire Stiffness verses Buckling Load - Single Guy

Beam-Column Condition	NISA Solution
Fixed - Free Supports	1976.03
Guyed Column - Ks = 0	1,975.98
Guyed Column - Ks = 1	2,028.74
Guyed Column - Ks = 10	2,499.66
Guyed Column - Ks = 100	6,762.03
Guyed Column - Ks = 1,000	21,132.5
Guyed Column - Ks = 10,000	39,157.0
Guyed Column - Ks = 100,000	40,789.8
Guyed Column - Ks = 1,000,000	40,923.7
Guyed Column - Ks = 10,000,000	40,936.9
Guyed Column - Simple Supports at Guy Locations	40,938.3
Guyed Column - Fixed Supports at Guy Locations	126,488.

Guy Wire Stiffness verses Buckling Load - 2 Guys

This Information Was Published By the CSME in 1997

Minimum Practical Guy Wire Stiffness

Importance of Pretension in Guy Wires Continued

Stiffness of ¼” EHS Guy Wire

$P := 400$ Preload - pounds

$E := 29000000$ Modulas of Elasticity of Steel - pounds/square insches

$d := .08$ Diameter of Wires in Guy Wire - in

$A := 7 \cdot \left(\frac{d^2 \cdot \pi}{4} \right)$ $A = 0.035$ Cross Sectional Area of Guy Wire - in

$L := 95 \cdot 12$ Length of Longest Guy - in

$\delta := \frac{P \cdot L}{A \cdot E}$ $\delta = 0.447$

$K := \frac{P}{\delta}$ $K = 895.078$

Importance of Pretension in Guy Wires Continued

Using The Same Methodology:

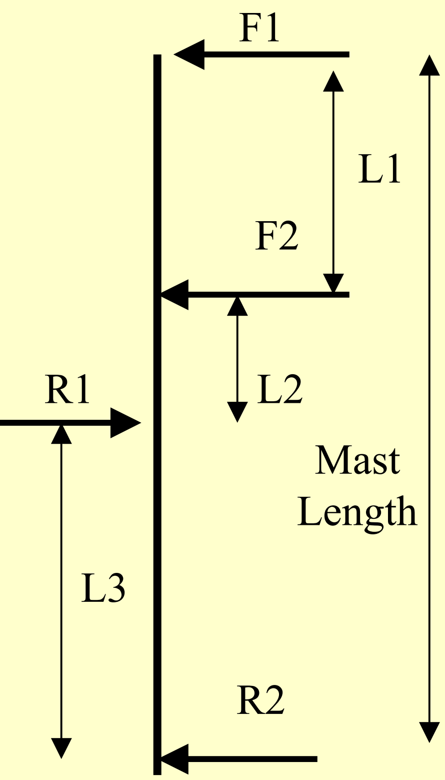
The Stiffness of 3/16" Guy Wires:

- 537 #/in or a Decrease of ~ 360 #/in

The Stiffness of 5/16" Guy Wires:

- 1512 #/in or an Increase of ~ 610 #/in

Importance of Mast Length



F1 = Wind Force of Antenna 1

F1 = Wind Force of Antenna 2

L1 = Distance Between Antenna 1 and 2 = 10'

L2 = Distance Between Antenna 1 and Tower Thrust Bearing = 2'

L3 = Distance Between the Tower Thrust Bearing and the Antenna Rotor = 8'

Overall Mast Length = 20'

$F1 := 200 \qquad F2 := 200 \qquad L1 := 10 \qquad L2 := 2 \qquad L3 := 8$

$$R1 := \frac{(F2 \cdot (L2 + L3) + (F1 \cdot (L1 + L2 + L3)}{L3}$$

$R2 := (R1 - (F1 + F2)) \qquad R2 = 151 \qquad R1 = 551$

R1 = The Force at the Thrust Bearing

R2 = The Force at the Rotor

Importance of Mast Length

Using The Same Methodology:

For a 16’ Mast With 6’ in the Tower:

- Radial Load At The Thrust Bearing, R1 = 900#, an Increase of 350#
- Radial Load At The Rotator, R2 = 500#, an increase of 350#

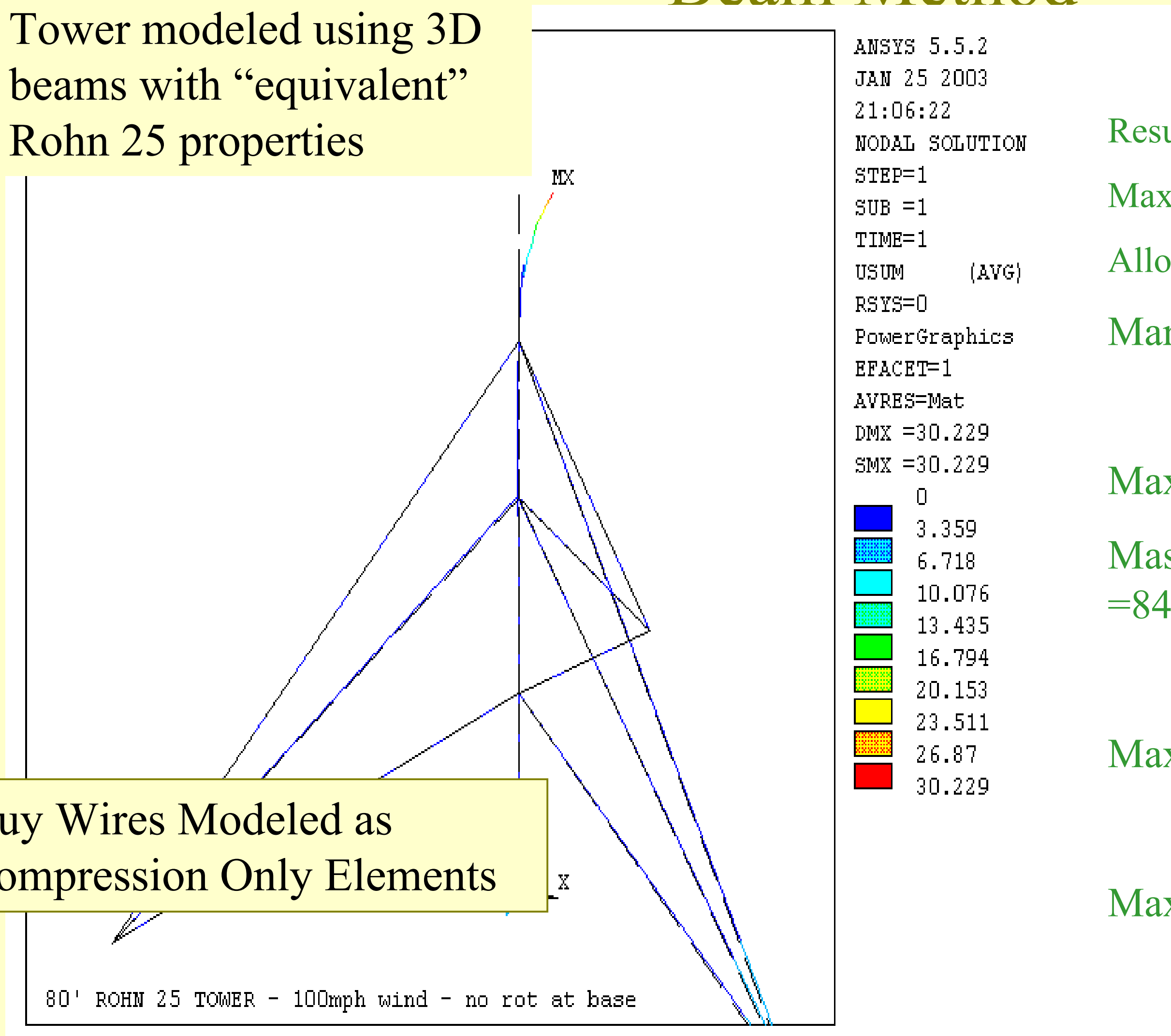
For a 14’ Mast With 4’ in the Tower:

- Radial Load At The Thrust Bearing, R1 = 1600# , an Increase of 1050#
- Radial Load At The Rotator, R2 = 1200#, an increase of 1050#

Conclusion: Longer Length of Mast in The Tower a Major Benefit

Computer Model of Rohn 25 Tower
Beam Method

Tower modeled using 3D beams with “equivalent” Rohn 25 properties



Guy Wires Modeled as Compression Only Elements

Results:

Max Tower Moment = 2800 ft/#

Allowable Moment = 6720 ft/#

Margin of Safety = 2800/6720 = .42

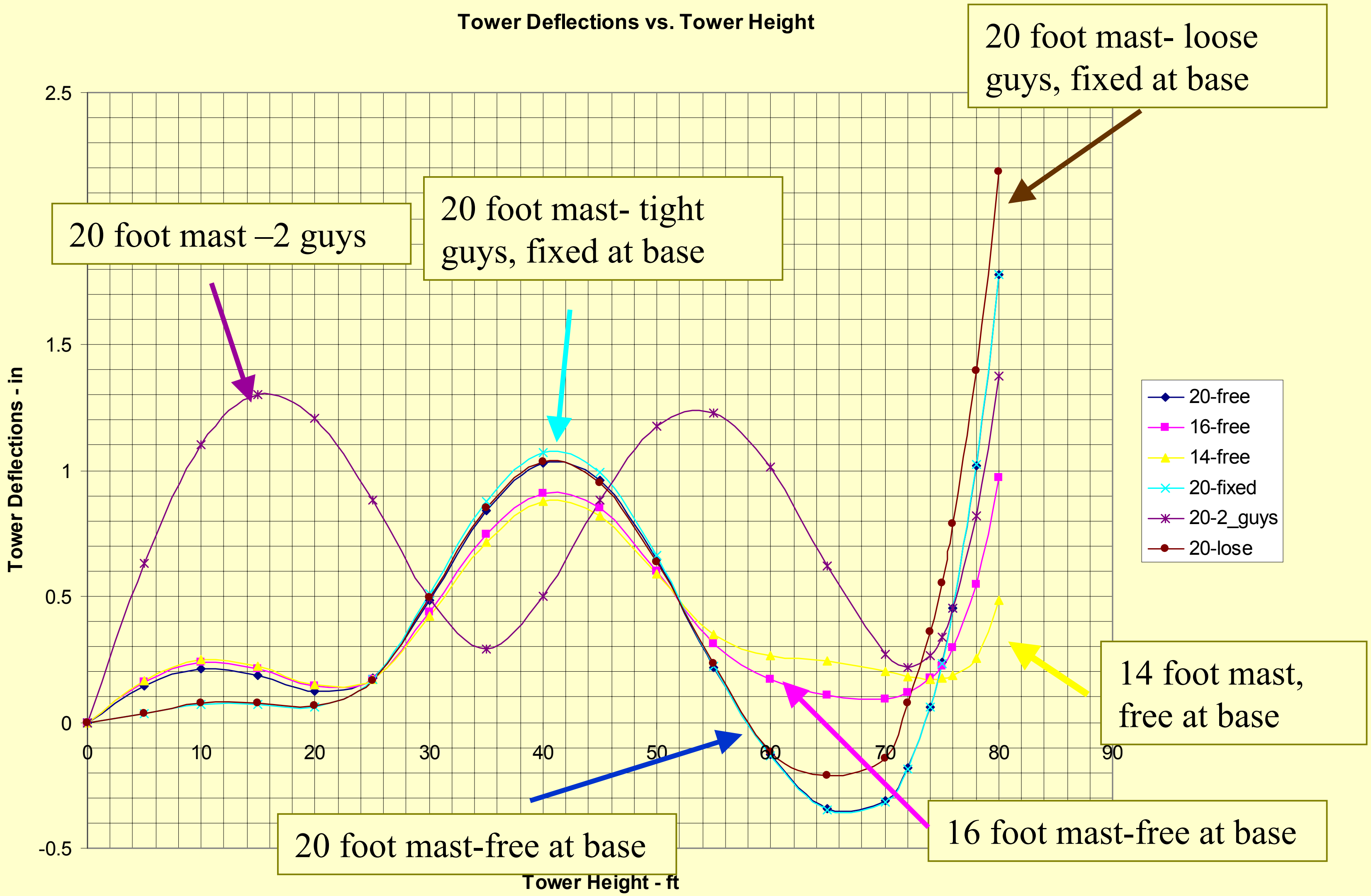
Max Mast Moment = 28800 in/#

Mast Bending Stress = Mmax/S =84,850 #/in^2

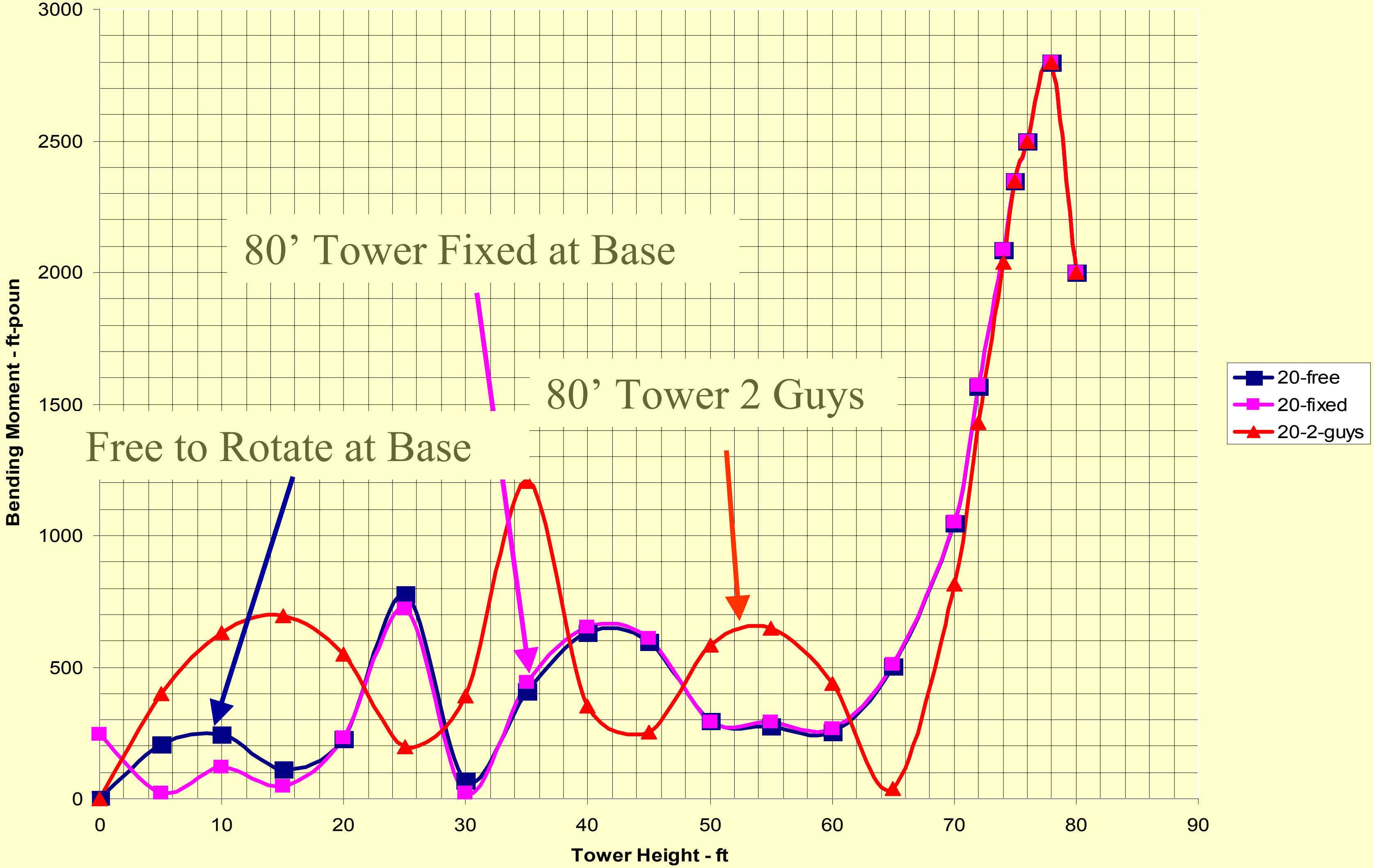
Max Guy Wire Force= 430#

Max Deflection (mast) = 30.3”

Tower Deflection FEM Results

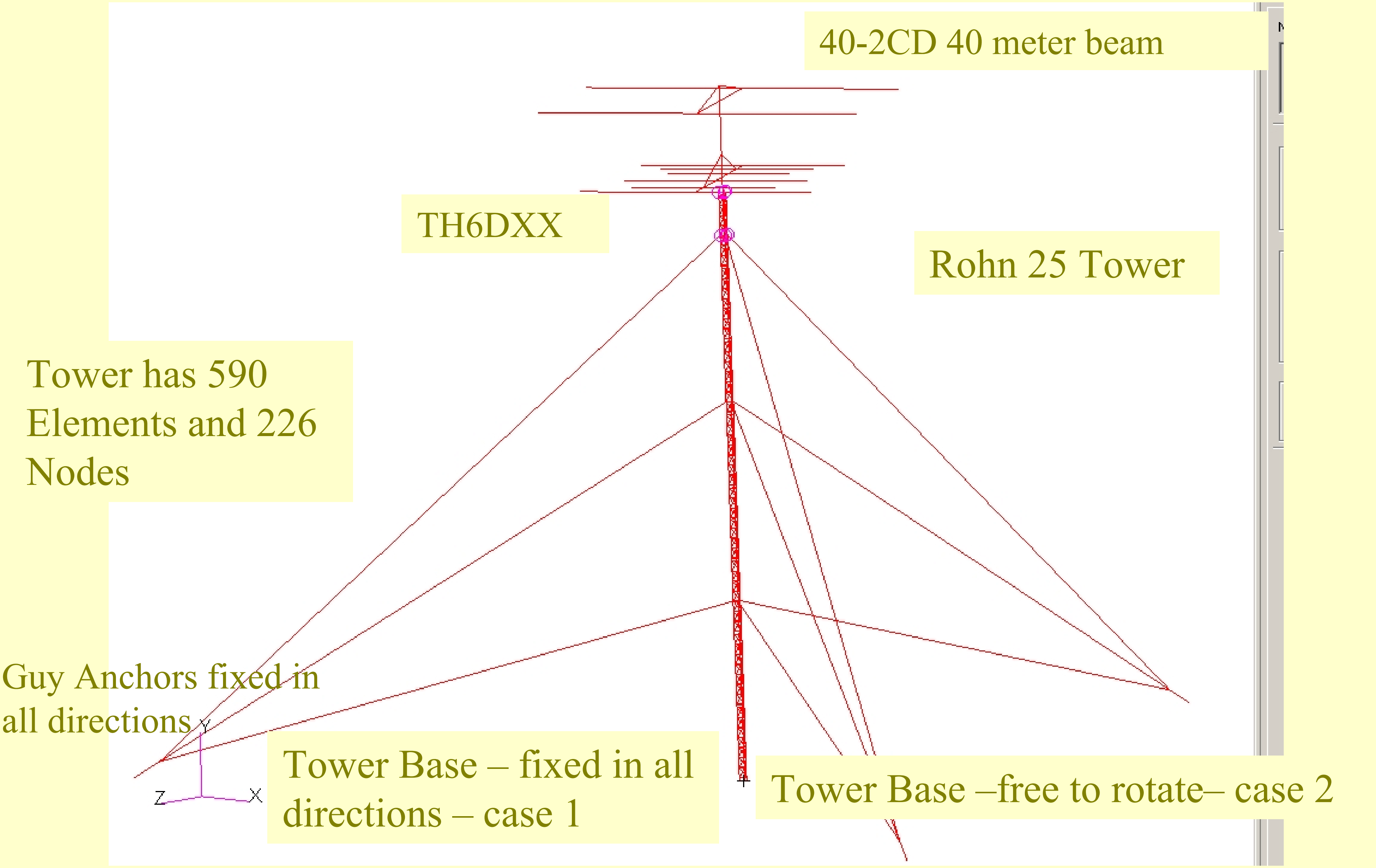


Tower Bending Moments

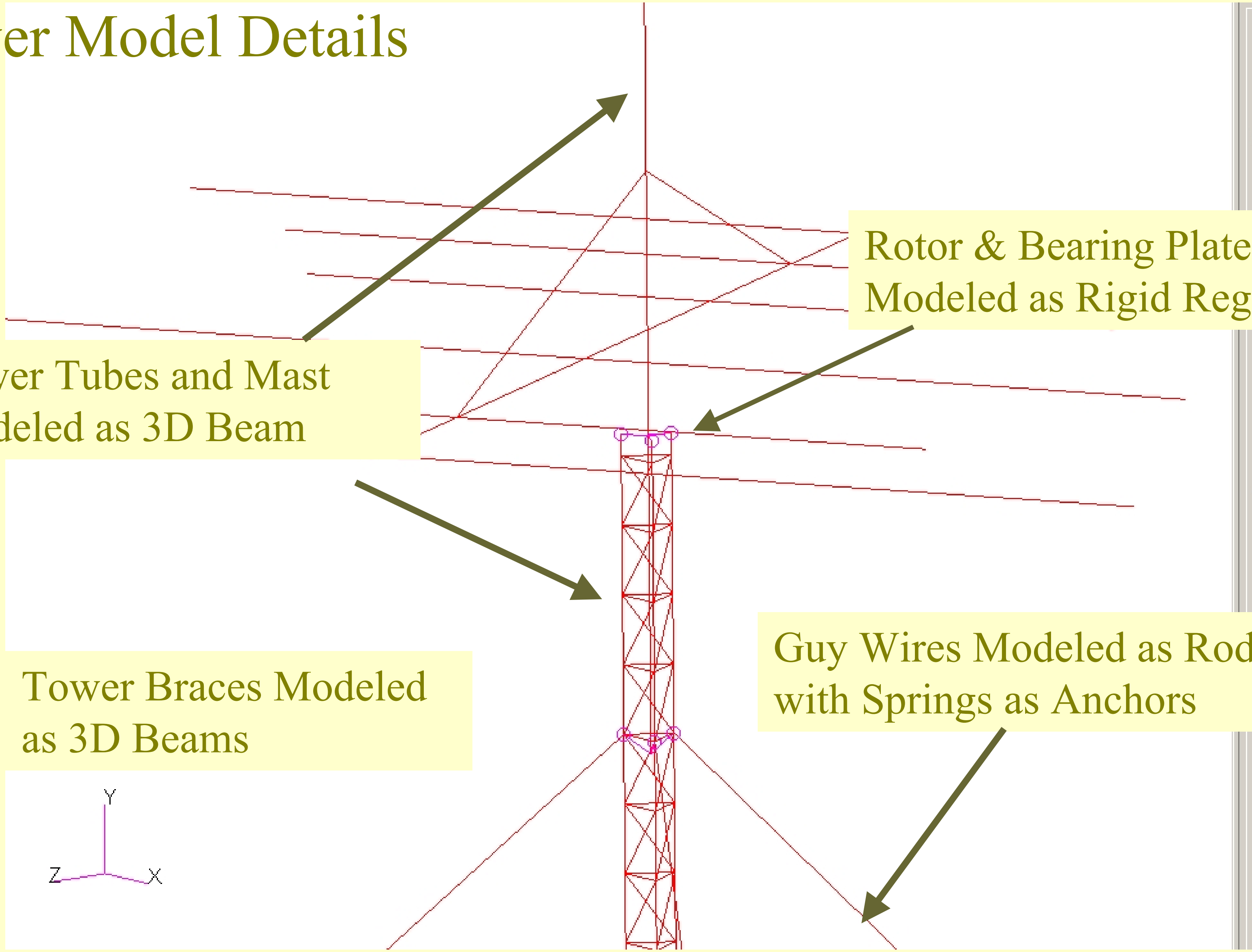


80’ Rohn 25 at KE1IH QTH

NASTRAN FEM MODEL of TOWER and ANTENAS



Tower Model Details



Tower Tubes and Mast Modeled as 3D Beam

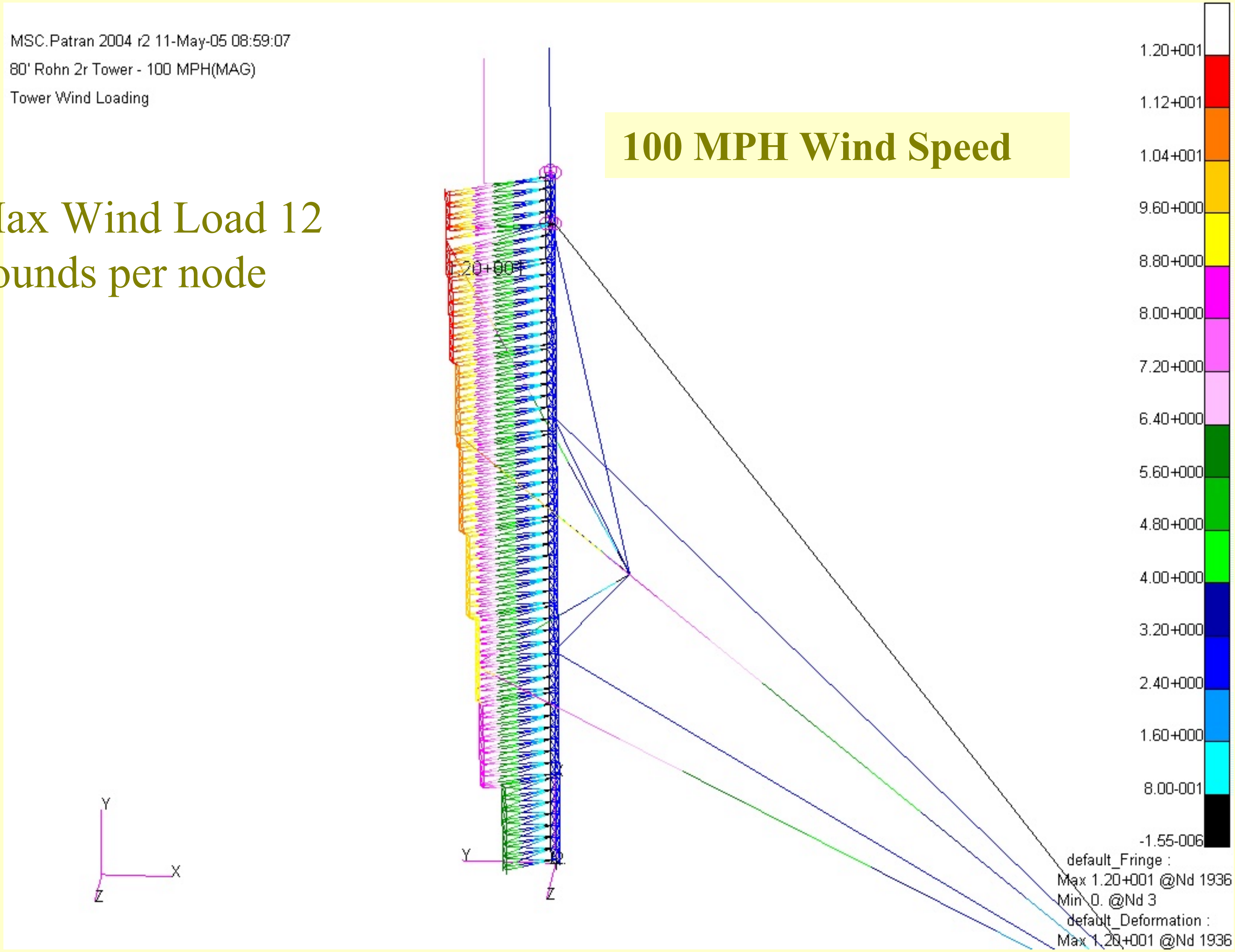
Rotor & Bearing Plates Modeled as Rigid Regions

Tower Braces Modeled as 3D Beams

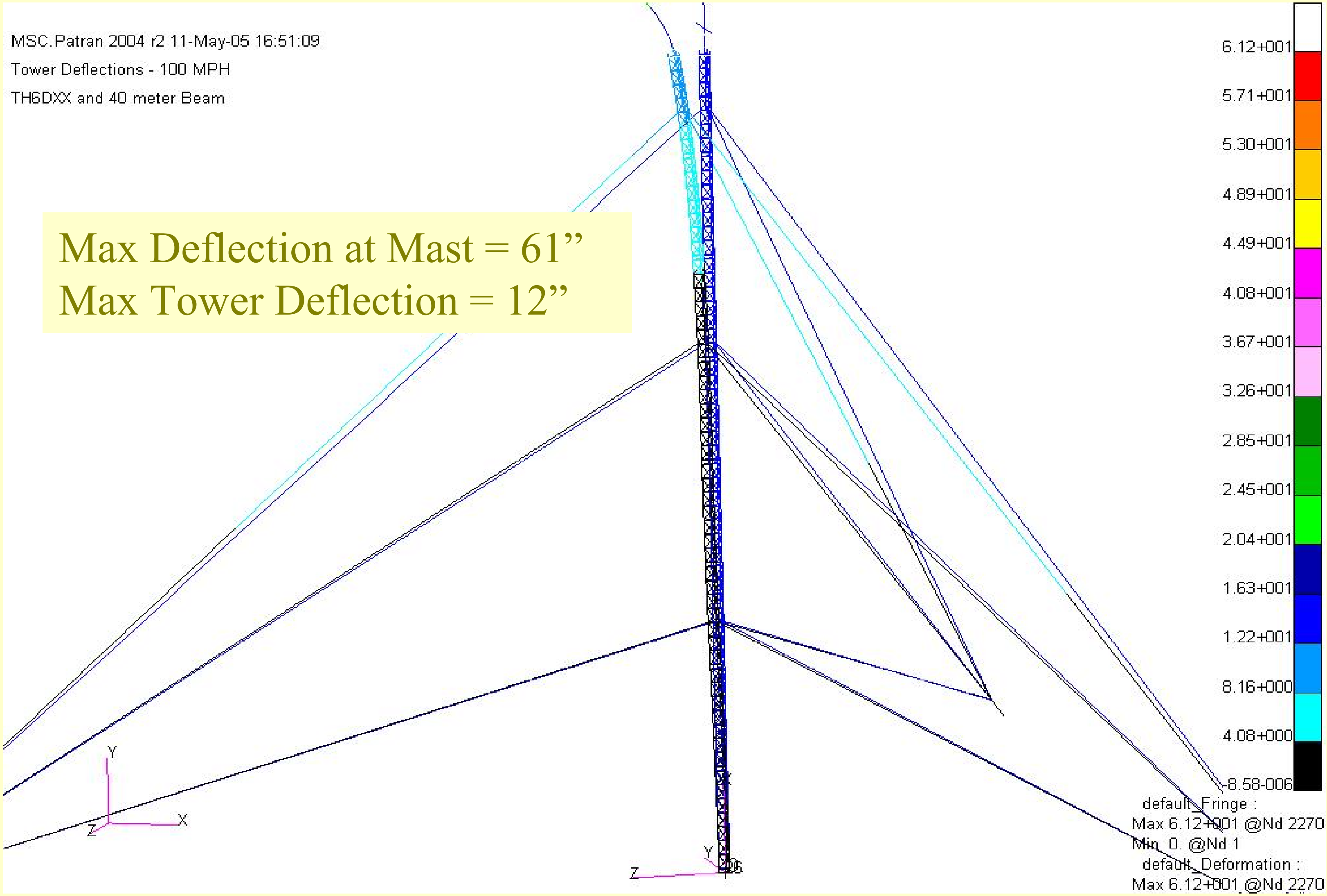
Guy Wires Modeled as Rods, with Springs as Anchors

Tower Wind Load Distribution

Max Wind Load 12 pounds per node

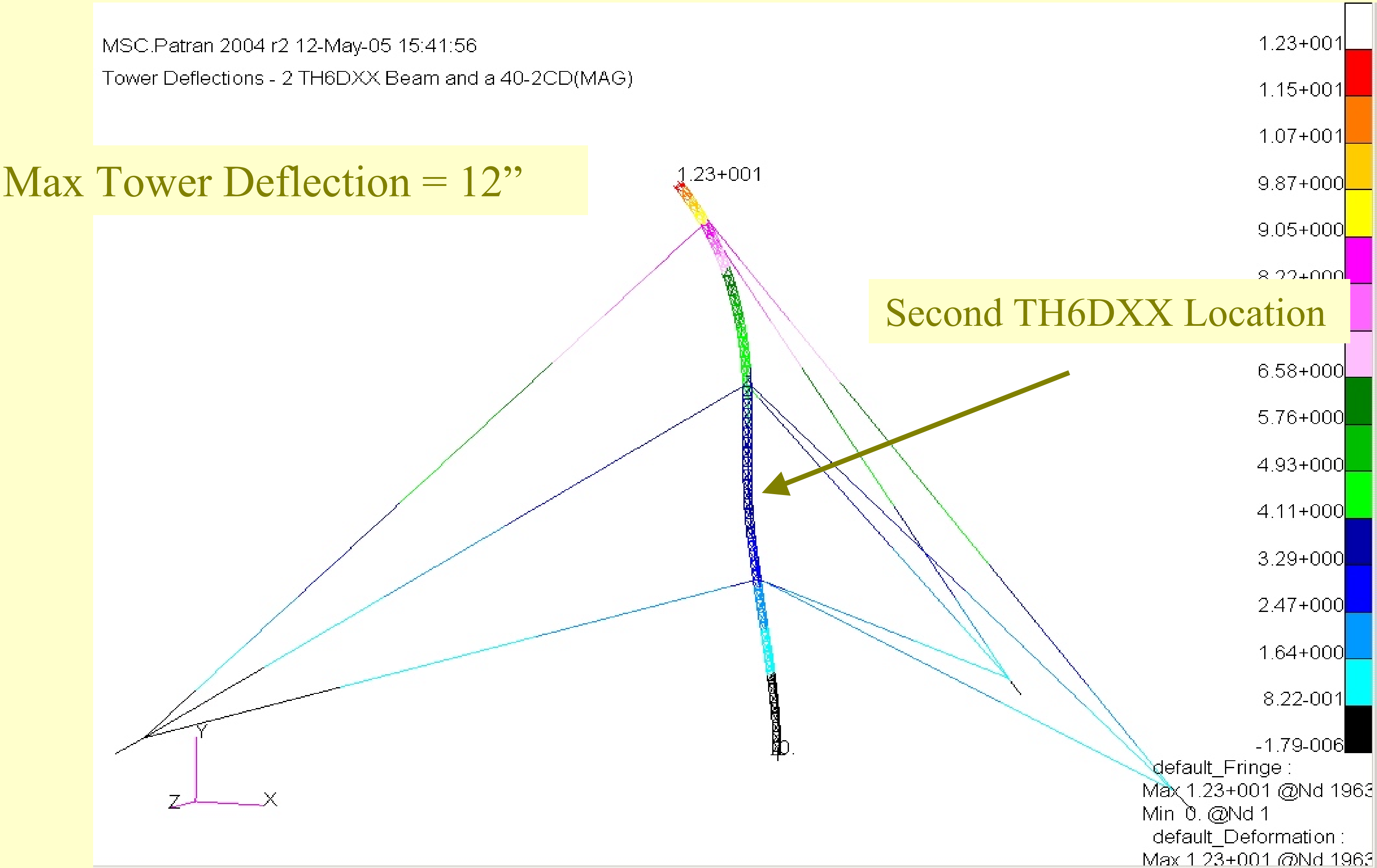


Tower Deflections Due To Wind



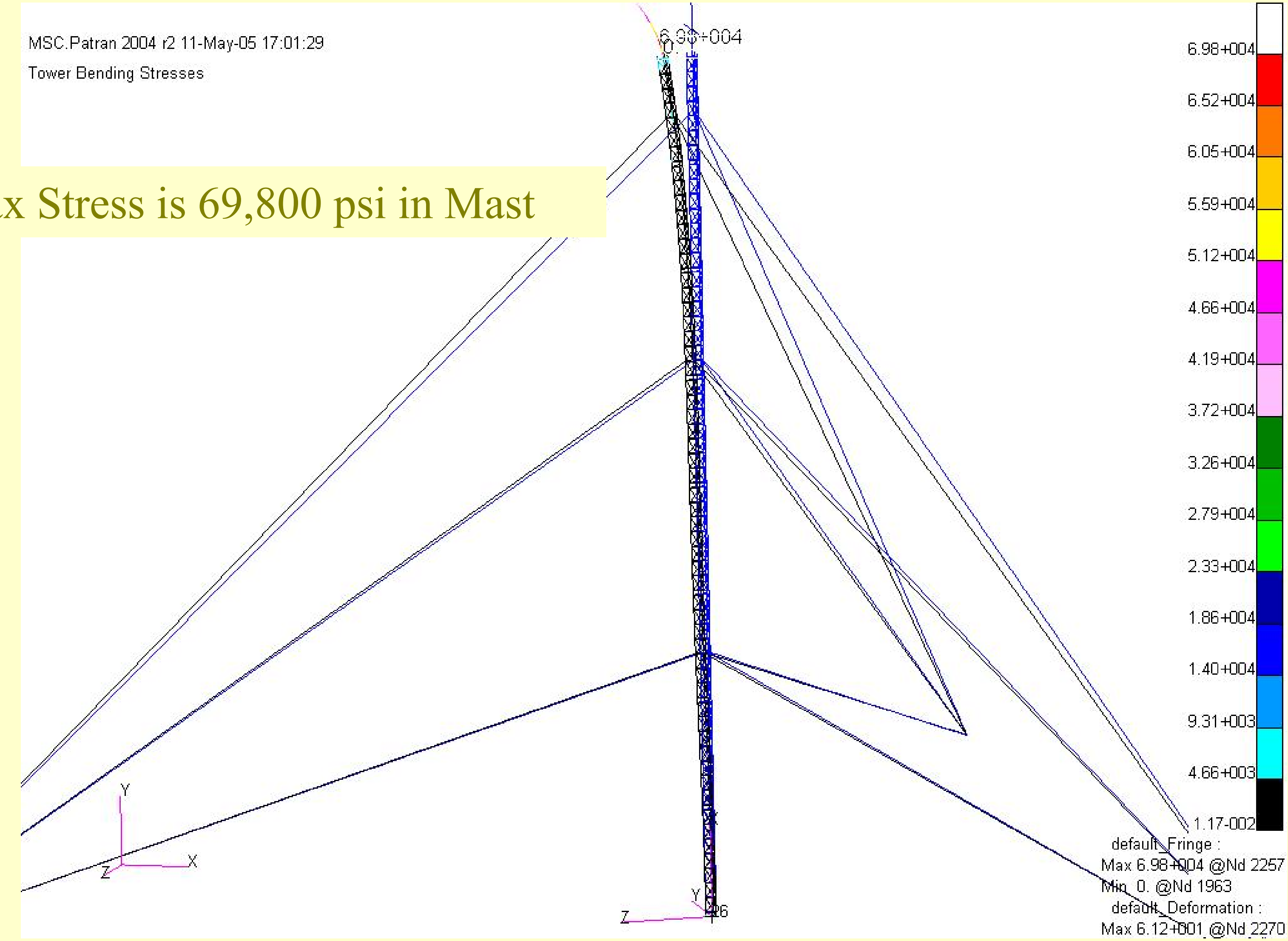
Max Deflection at Mast = 61”
Max Tower Deflection = 12”

Tower Deflections – Second TH6DXX

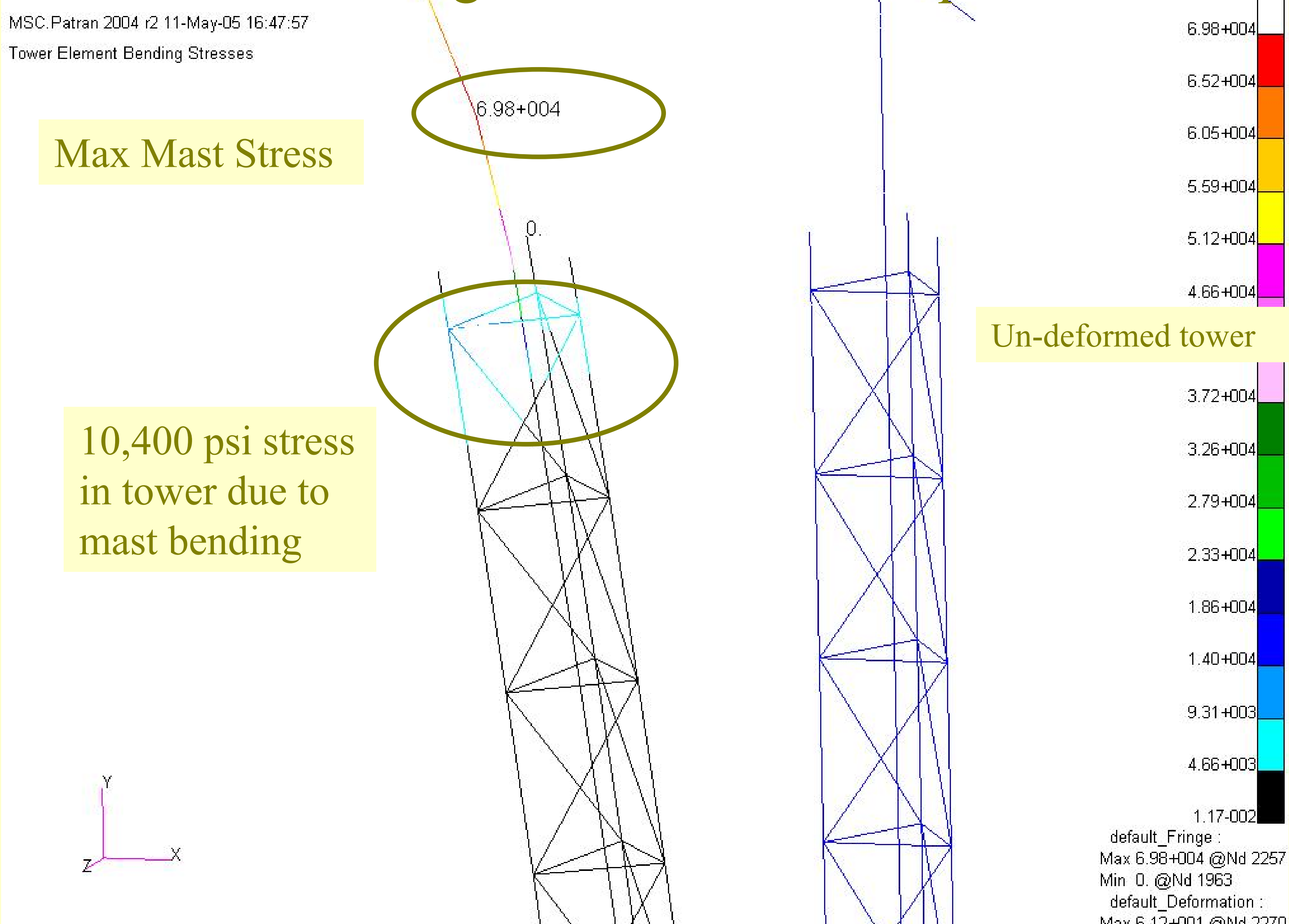


Tower Bending Stress Due to Wind

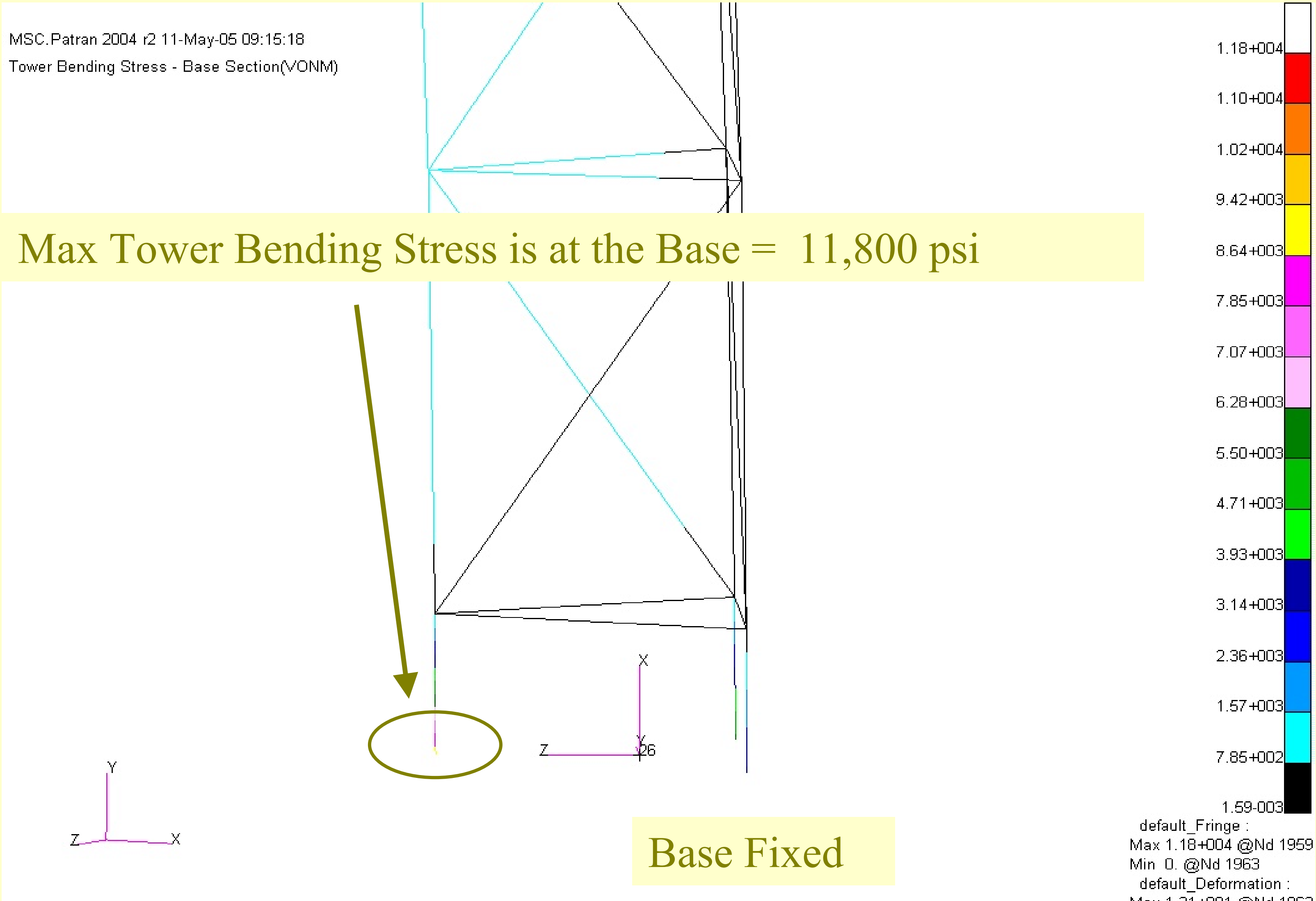
Max Stress is 69,800 psi in Mast



Bending Stress at Tower Top



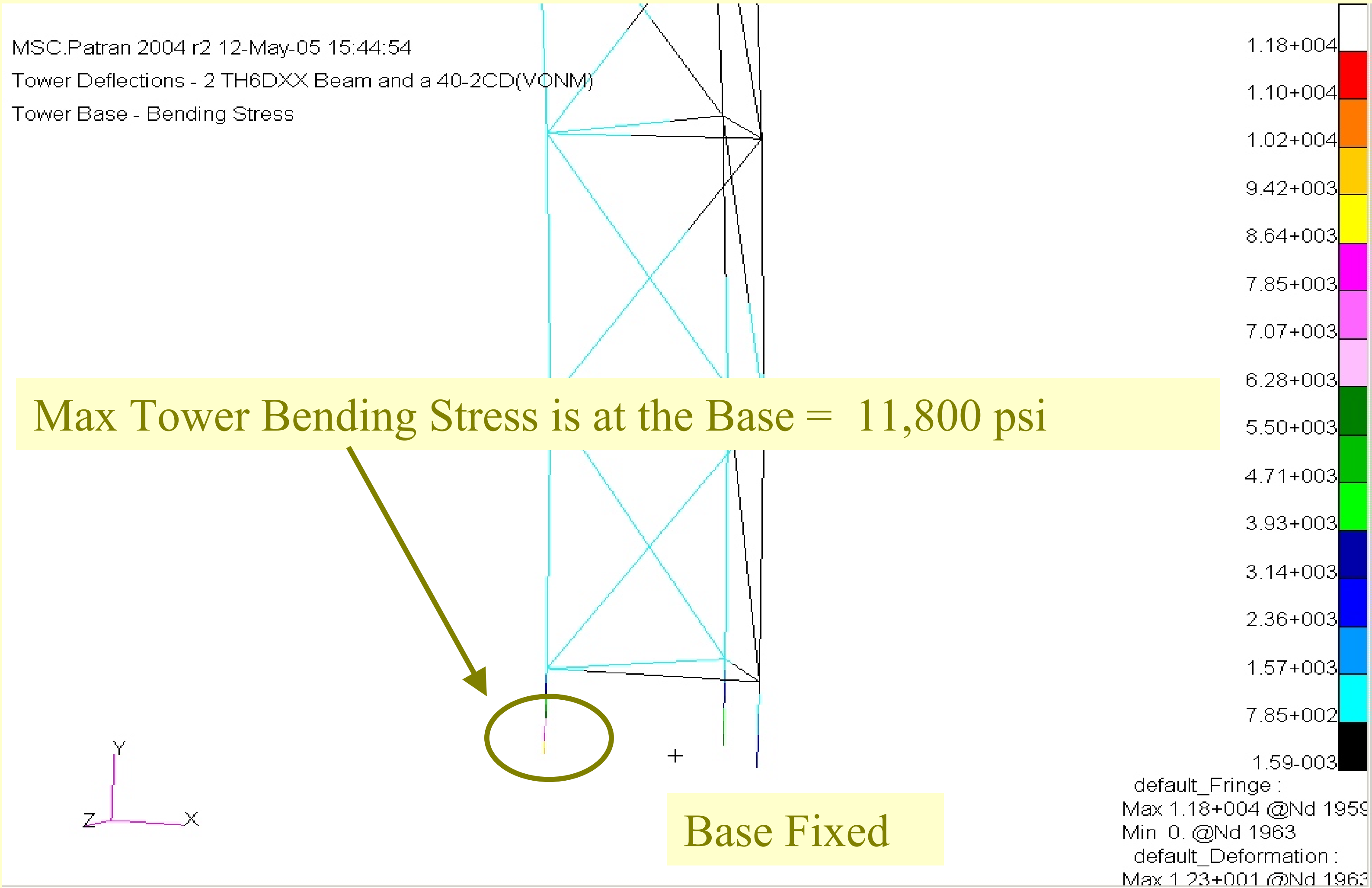
Tower Base Bending Stress – Single TH6DXX



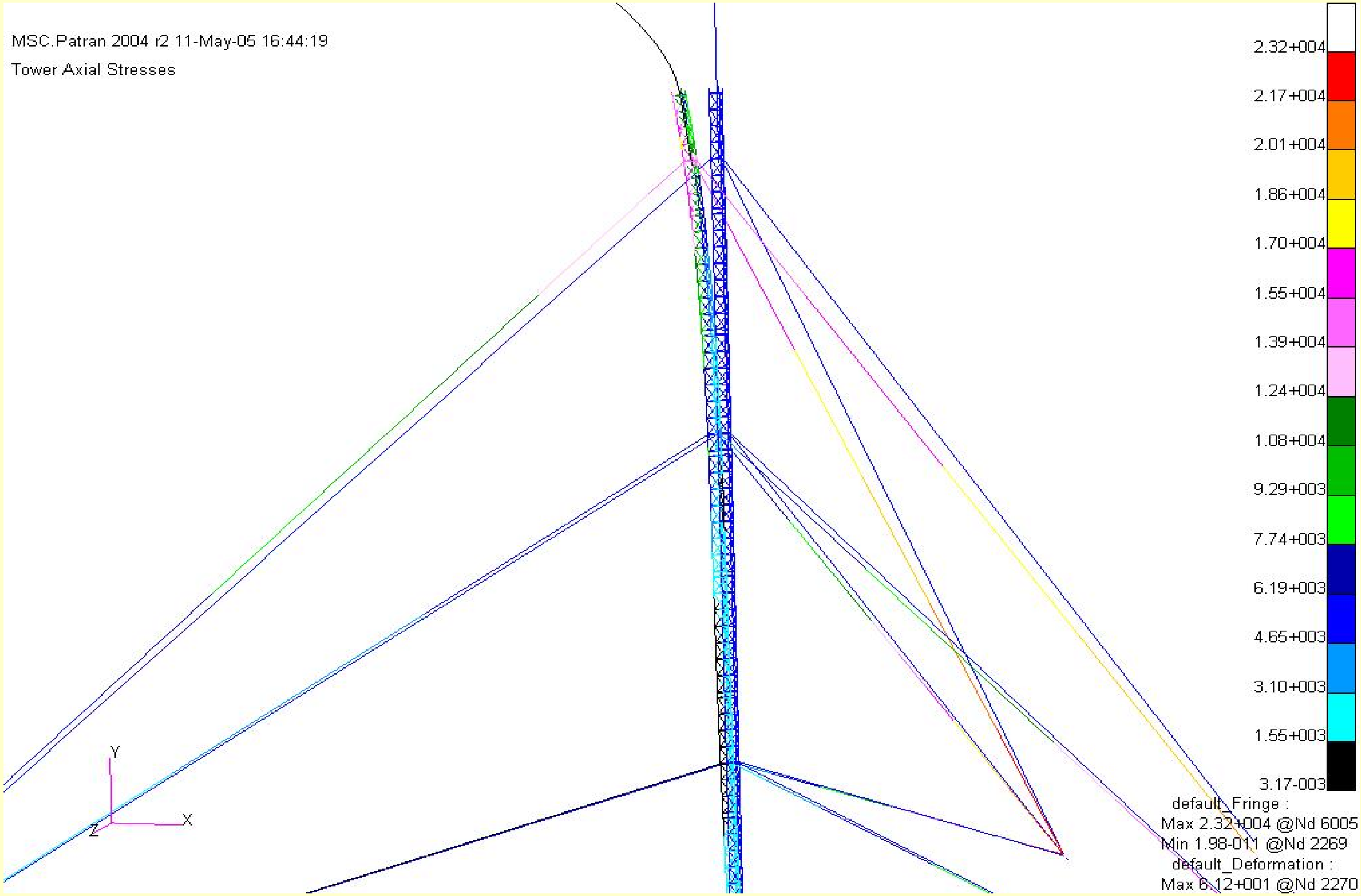
Max Tower Bending Stress is at the Base = 11,800 psi

Base Fixed

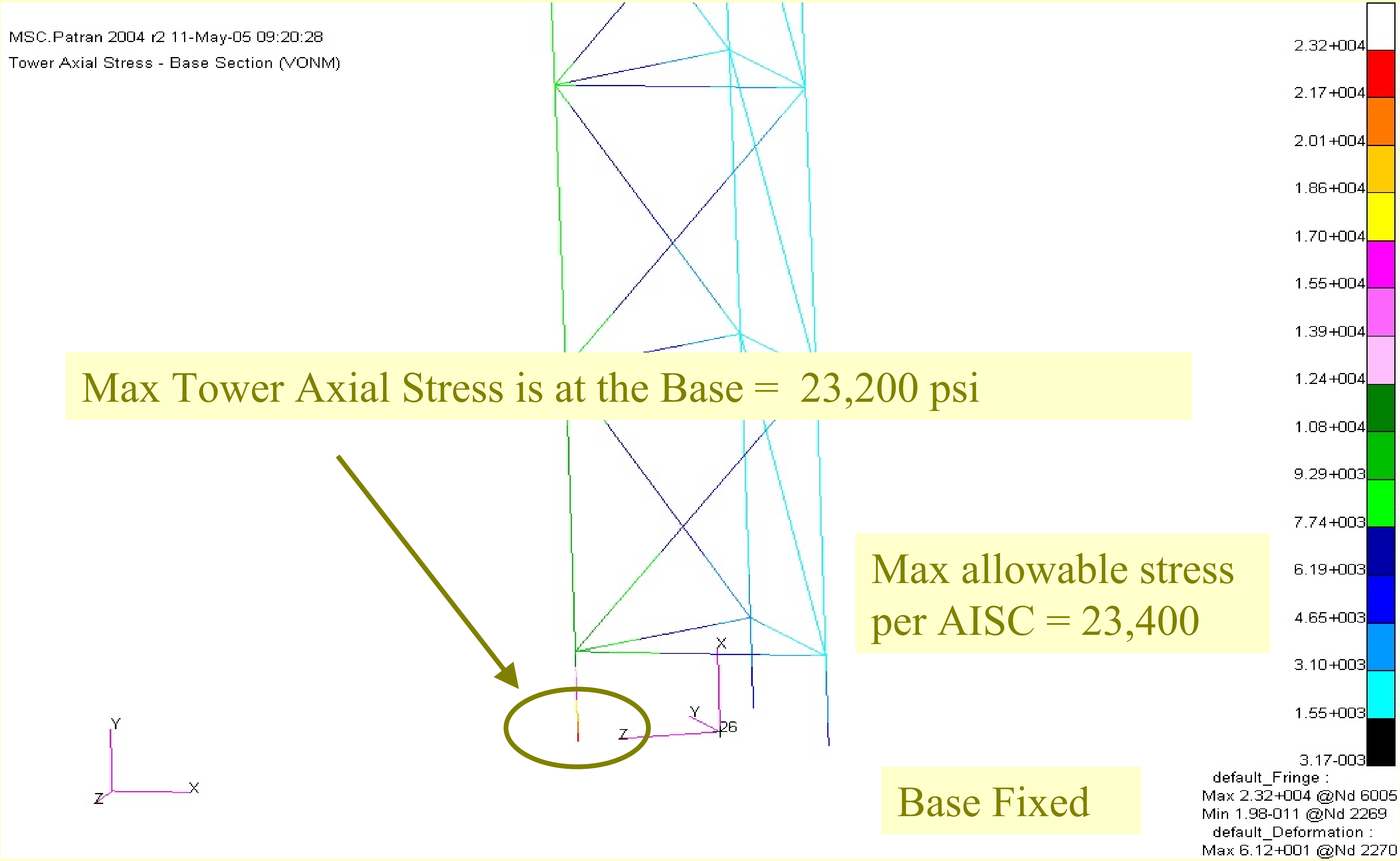
Tower Base Bending Stress – 2 TH6DXX



Tower Axial Stress



Tower Base Stress- Single TH6DXX

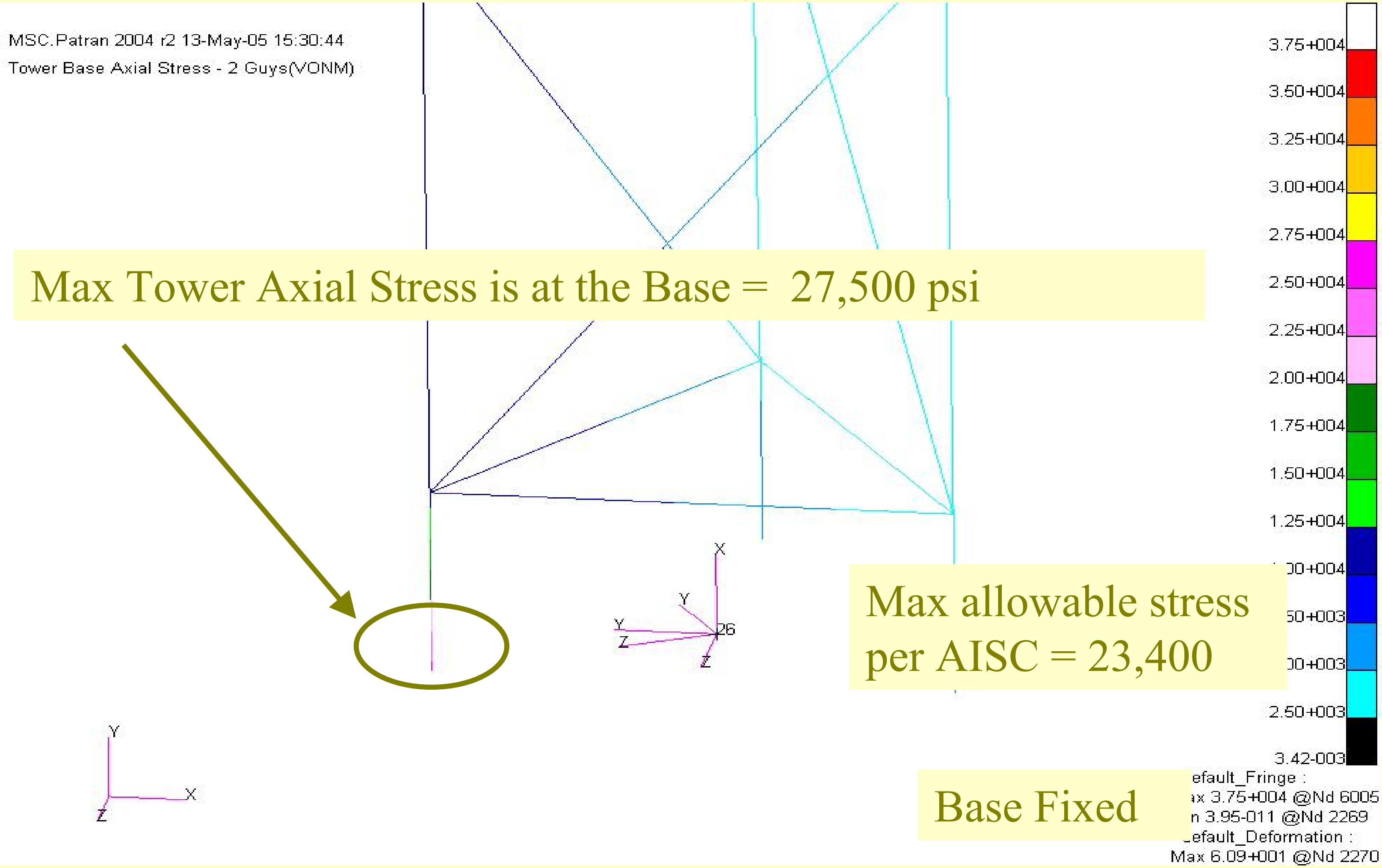


Max Tower Axial Stress is at the Base = 23,200 psi

Max allowable stress per AISC = 23,400

Base Fixed

Tower Base Stress- Single TH6DXX 2 Guys

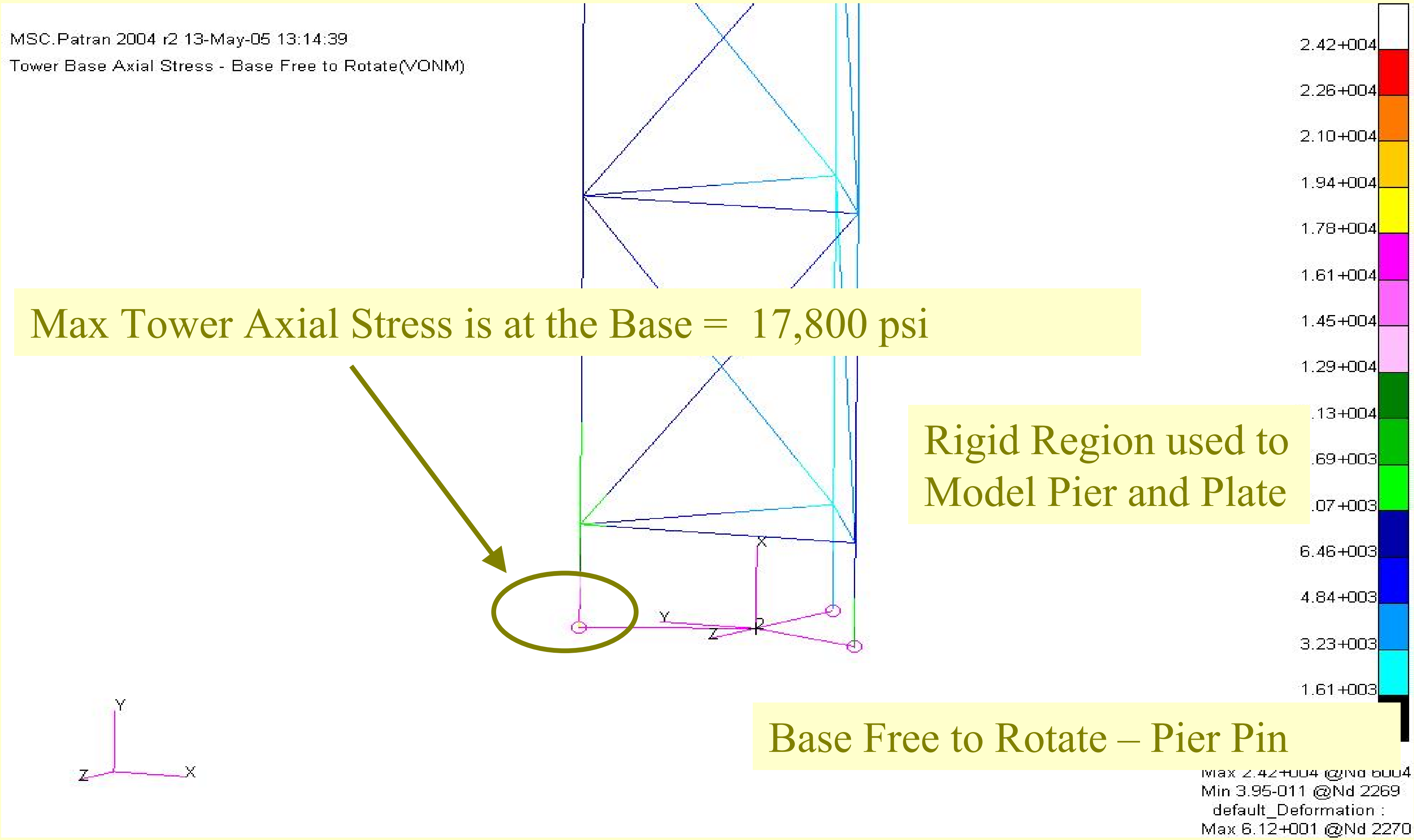


Max Tower Axial Stress is at the Base = 27,500 psi

Max allowable stress per AISC = 23,400

Base Fixed

Tower Base Stress- 2 TH6DXX

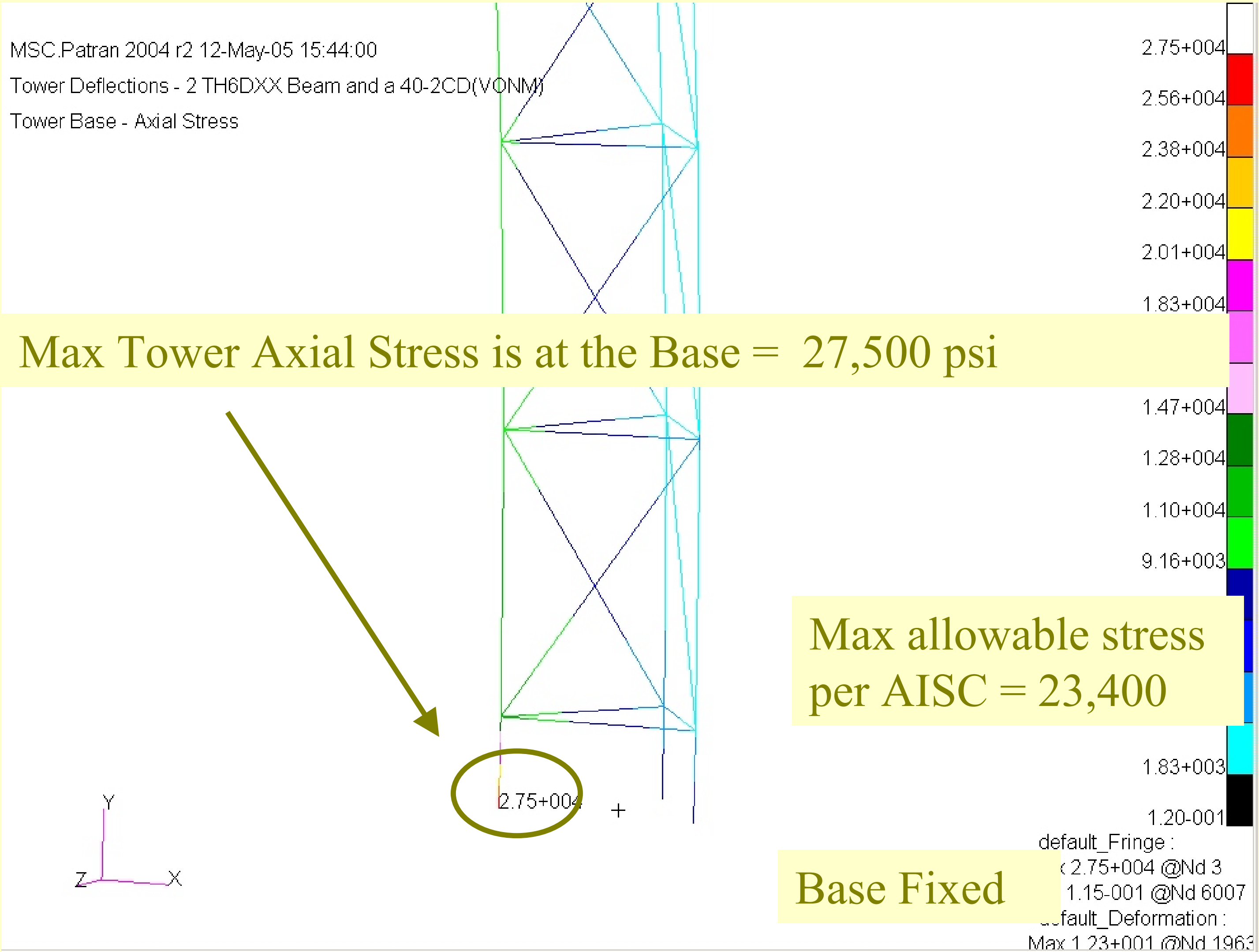


Max Tower Axial Stress is at the Base = 17,800 psi

Rigid Region used to Model Pier and Plate

Base Free to Rotate – Pier Pin

Tower Base Axial Stress – 2 TH6DXX

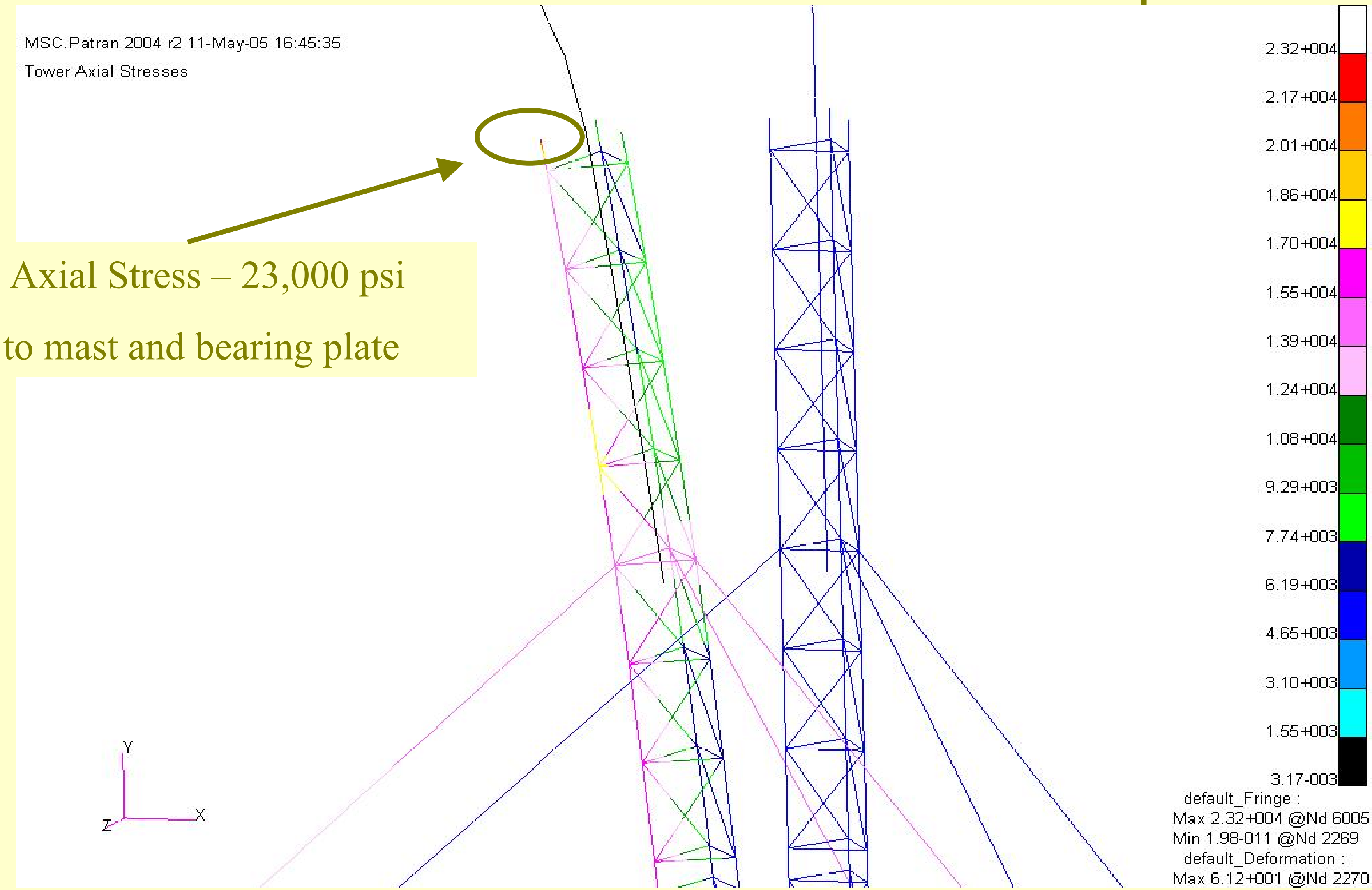


Max Tower Axial Stress is at the Base = 27,500 psi

Max allowable stress per AISC = 23,400

Base Fixed

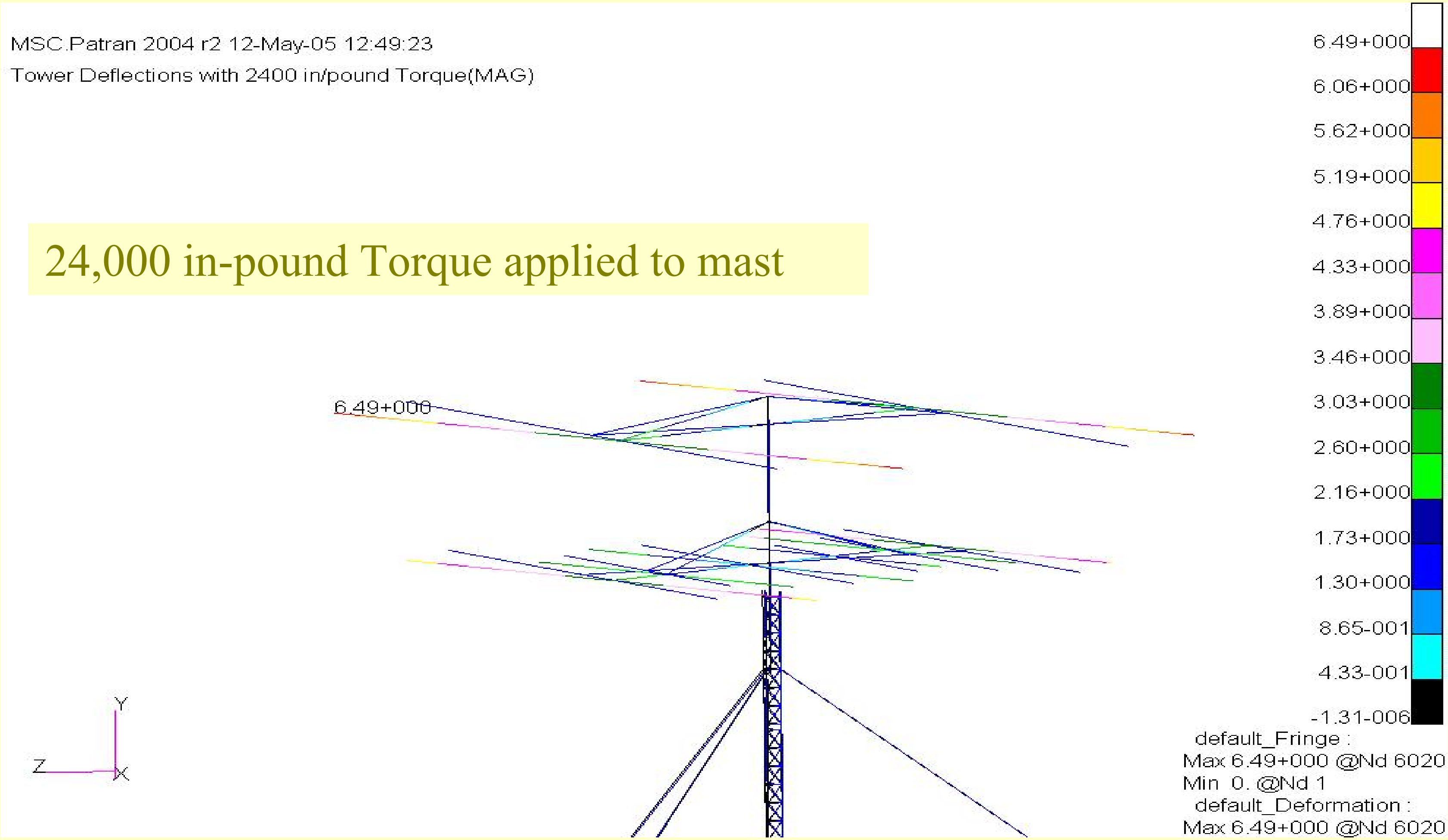
Tower Axial Stress at Tower Top



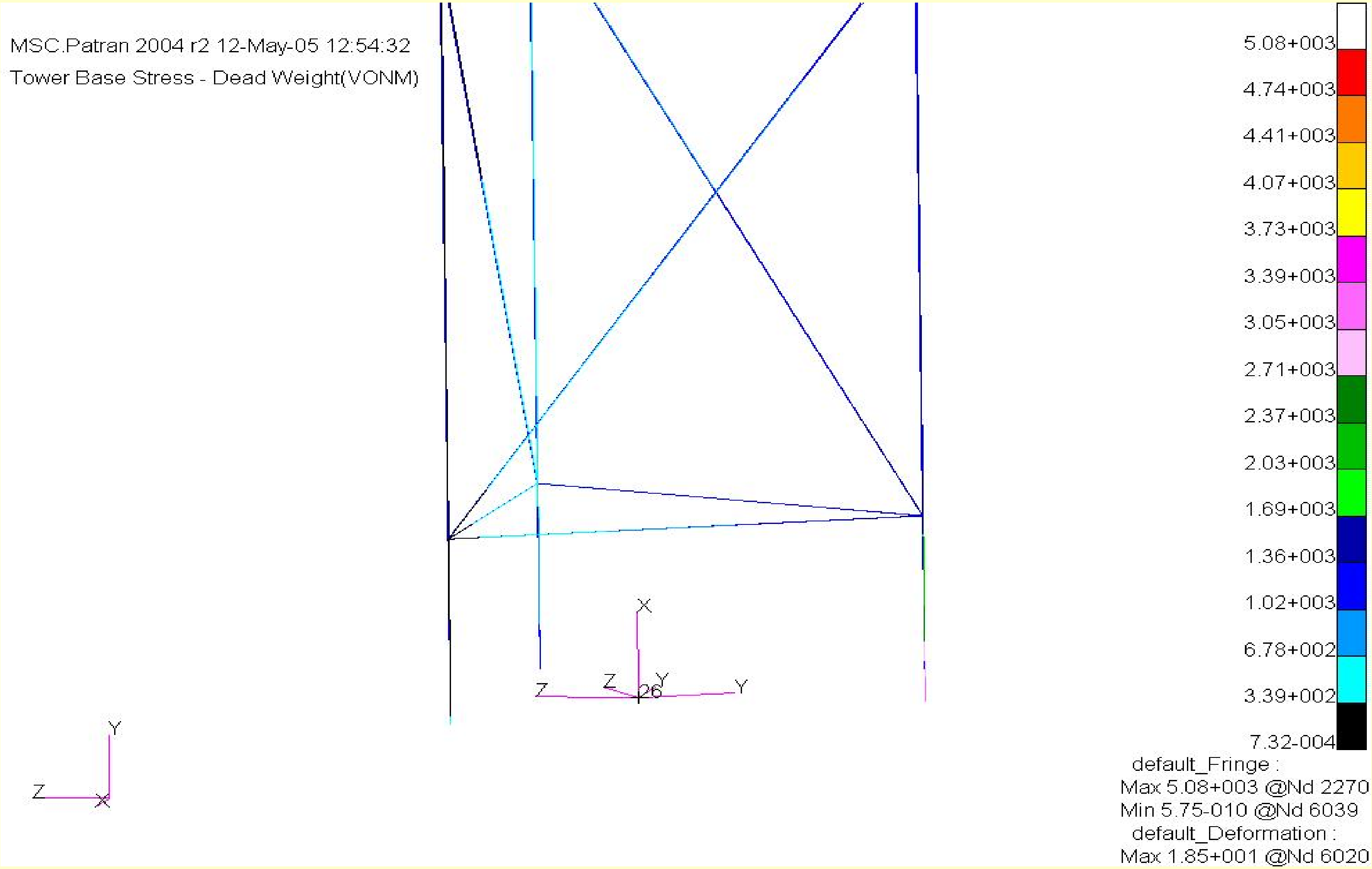
Max Axial Stress – 23,000 psi

Due to mast and bearing plate

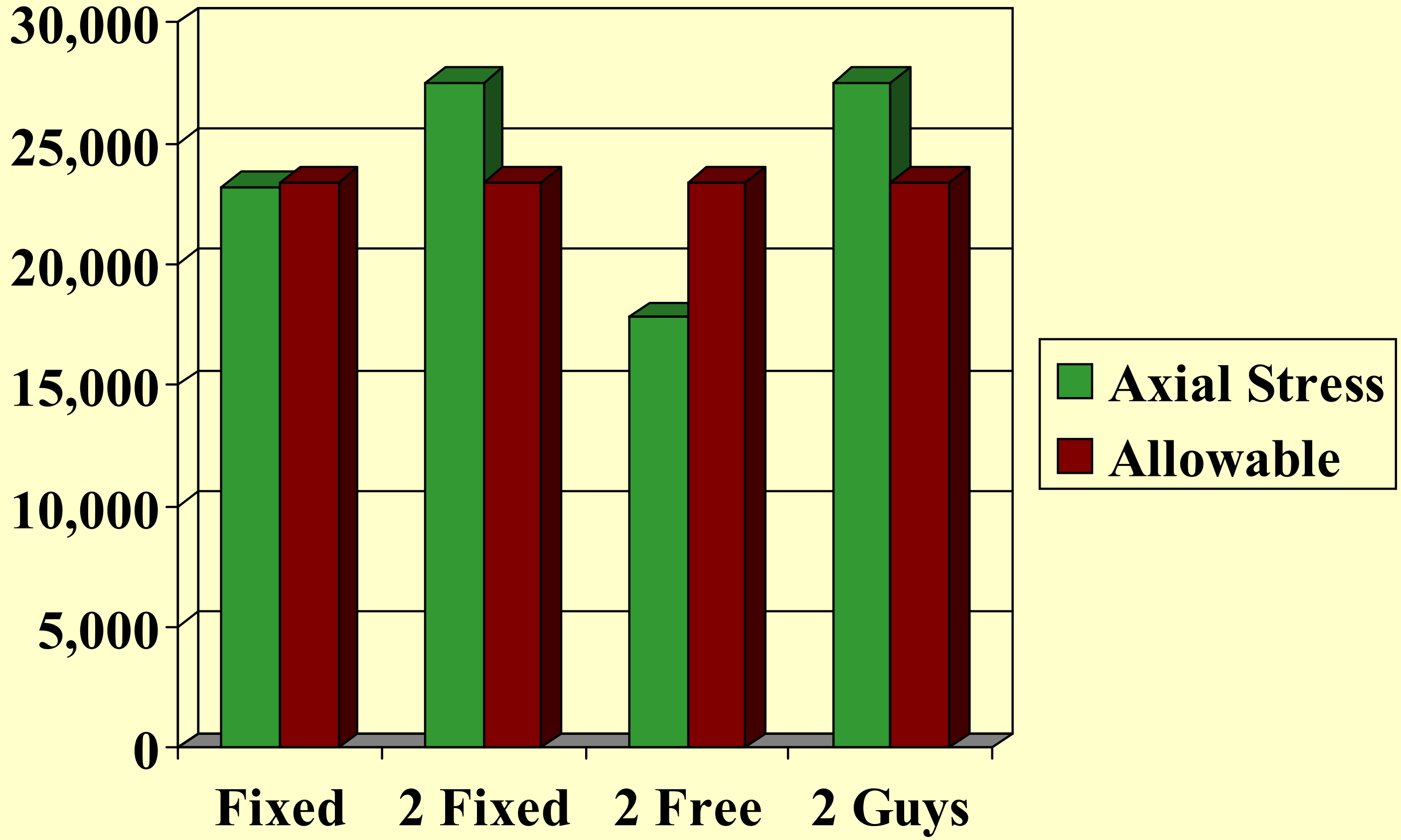
Antenna and Mast Rotations Due to Torque



Tower Base Stress Due to Self Weight



Summary of Tower Base Axial Stress



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