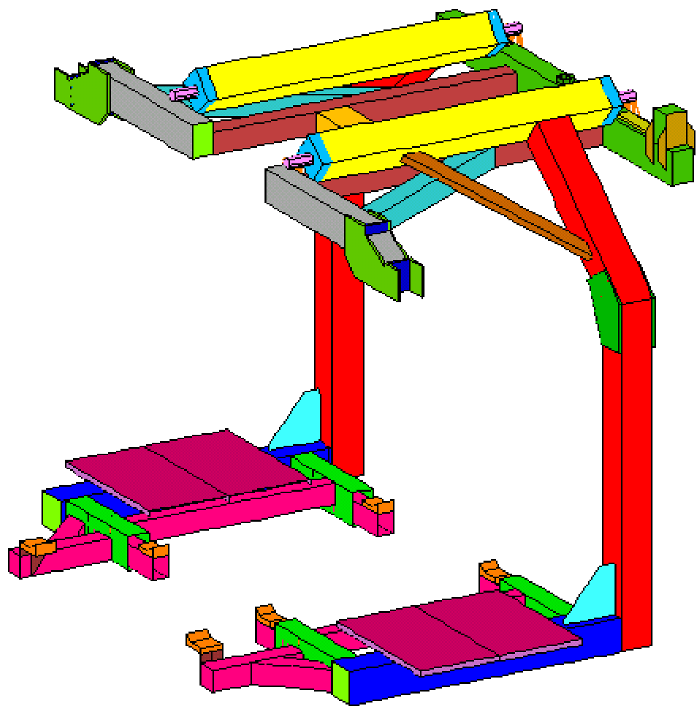
Structural Analysis of Automotive Carrier



Prepared for:

Prepared by: Pinnacle Engineering, Inc.

April 14, 2003

37400 Garfield Rd., Ste. 30, Clinton Twp. MI 48036 • Phone (586) 226-3300 / Fax (586) 226-3998 - e-mail pinnacle@pinenginc.com

Structural Analysis of Automotive Carrier

Prepared For:

Prepared By: Pinnacle Engineering, Inc.

April 14, 2003

Introduction:

An analysis of an automotive carrier used for final assembly was conducted to understand the stress and deflection that is present under product loading.

Five load cases were considered to understand the structural integrity of the carrier. They are identified as follows:

1. Stress and deflection due to product load and carrier weight with the product being supported on the front and middle supports.

2. Stress and deflection due to product load and carrier weight with the product being supported on the front and rear supports.

3. Stress and deflection due to product load only with the product being supported on the front and middle supports.

4. Stress and deflection due to product load only with the product being supported on the front and rear supports.

5. Stress and deflection of the empty carrier.

Fatigue life calculations were also conducted in order to compute the life expectancy based on 10 jobs per hour system throughput.

Conclusions and recommendations are contained on page 8 at the end of this report.

42850 Garfield Rd., Ste. 105, Clinton Twp. MI 48038 • Phone (586) 226-3300 / Fax (586) 226-3998 - e-mail pinnacle@pinenginc.com

TABLE OF CONTENTS

CONTENTS: **PAGE:**

APPENDICES:

Finite Element Model of the Carrier:

A finite element model of the carrier assembly was created using 2-D & 3-D Auto Cad files of the carrier design. Approximately 30,000 solid and plate elements were used to create the model.

Table 1 shows the material data used in the finite element analysis.

TABLE 1. Material data used for the finite element analysis.

Material	Young's modulus	Specific Gravity	Mass Density	Poisson's ratio
A-36 Steel	$30x10^6$ psi	0.283 lb/in^3	0.000728 lbm/in^3	0.29

A picture of the solid model can be seen in Figure 1.

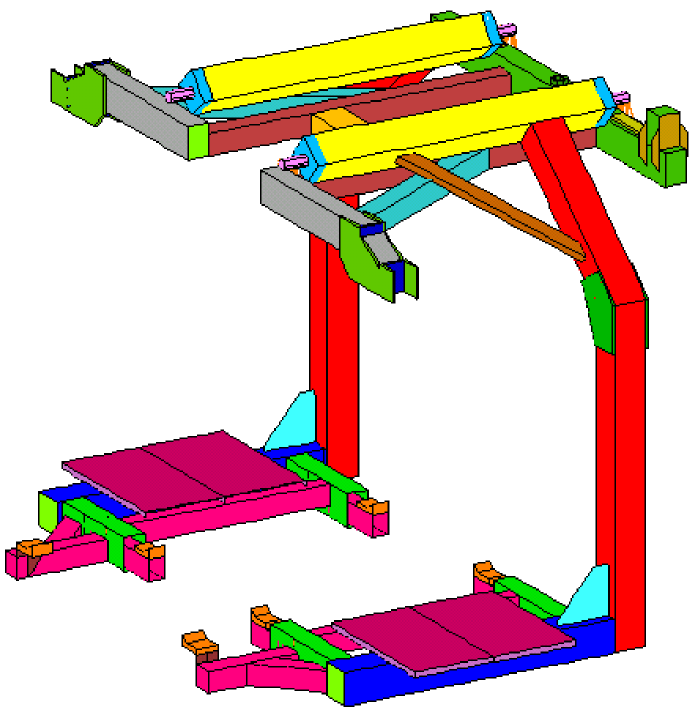
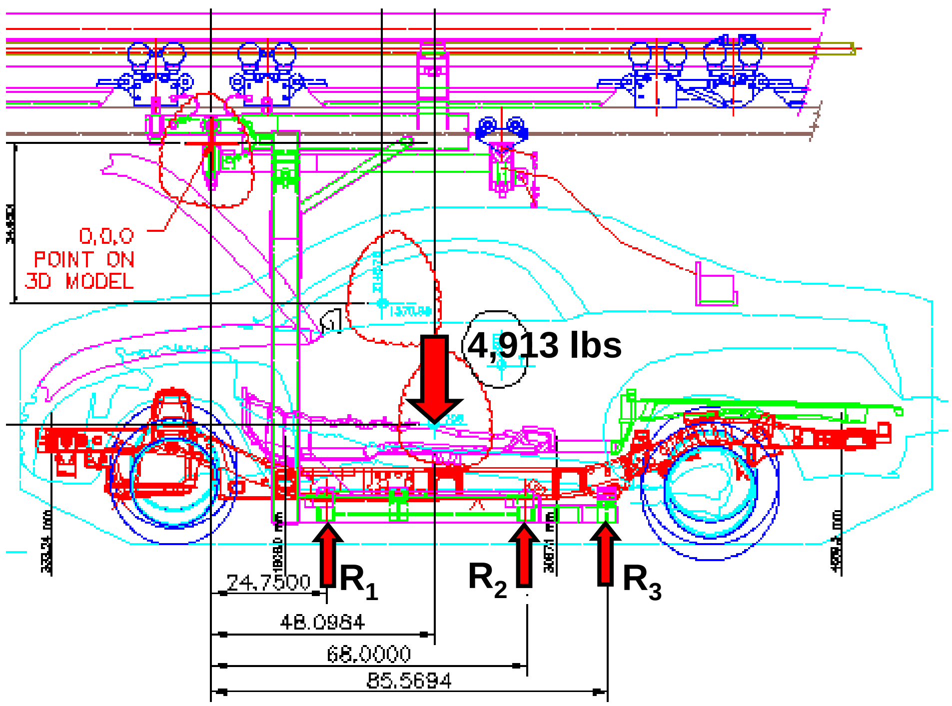


Figure 1. Isometric view of the carrier finite element model.

The finite element model (FEM) of the carrier was constrained by holding the upper frame at the front and in the two rear corners.

Loading of the carrier was determined by considering two cases. (It is difficult to predict what percent of the product is carried between the middle and rear support due to manufacturing tolerances). Since the front and center support points are on a slide, there is clearance and the possibility that the product weight is mostly carried by the front and middle supports, or the front and rear supports. Therefore, both cases were considered to create an upper and lower bound. Figure 2 shows a side view of the carrier and product and the support locations. Supporting calculations can be found in Appendix F.



Load Case 1	**R1=2,261 lbs**	**R2=2652 lbs**	
Load Case 2	**R1=3,027 lbs**		**R3=1,886 lbs**

Figure 2. Location and values of the support loads applied to the carrier model.

Figures 3 and 4 show the loading on the finite element model.

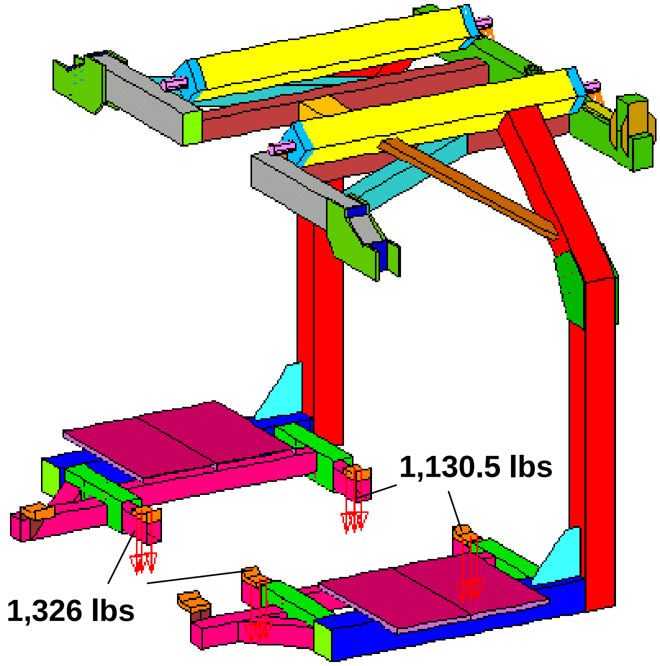


Figure 3. Loading of the carrier for Load Case 1. Product load supported at front and <u>middle</u> support.

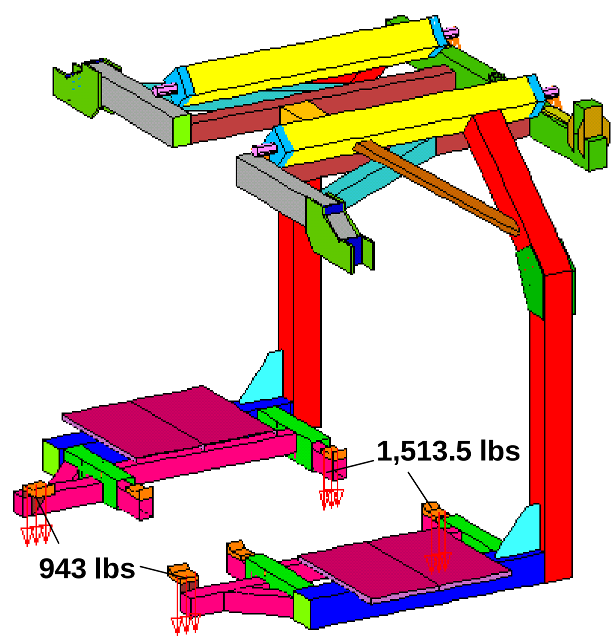


Figure 4. Loading of the carrier for Load Case 2. Product load supported at front and <u>rear</u> support.

Static Finite Element Results:

After the finite element model was solved, the maximum deflection, downward deflection, and Von-Mises stress were recorded. The finite element results of deflection and stress are summarized in Table 2. The finite element contour plots for the static results can be found in Appendices A-E. Appendix F shows the load calculations used to determine the applied forces shown in Figures 3 & 4.

TABLE 2. Static stress and deflection of the Carrier

LOAD CASE	LOAD CASE DESCRIPTION	Resultant Deflection (inches)	Downward Deflection (inches)	Von-Mises Stress (psi)	Appendix
1	Product load and Carrier Weight with the product being support on the front and middle supports.	0.8020"	0.7260"	14,040	A1-A4
2	Product load and Carrier Weight with the product being support on the front and rear supports.	0.8023"	0.7210"	13,430	B1-B4
3	Force of product load only with the product being support on the front and middle supports.*	0.6949"	0.6253"	12,000	C1-C4
4	Force of product load only with the product being support on the front and rear supports.*	0.6836"	0.6240"	11,490	D1-D4
5	Empty Carrier under it's own weight - No Product Load	0.1573"	0.1083"	7,562	E1-E4

***= this data can be experimentally validated by using an indicator or other measuring device by "zeroing" the measuring device with an empty carrier and then loading the product.**

Fatigue Life Calculations:

To determine the maximum allowable load that can be repeatedly applied, the endurance limit is computed. For most steel materials, if the cyclical stress is below the endurance limit, failure will not occur. This is used as a safe design criteria.

The endurance limit of both components can be estimated by the following equation:

$$S_e = k_a k_b k_c k_d k_e S_e'$$

where
S_e = endurance limit
S_e' = endurance limit of test specimen
k_a = surface factor
k_b = size factor
k_c = load factor
k_d = temperature factor
k_e = miscellaneous-effects factor

S_e'=0.504*S_u for steels with an ultimate strength less than 200,000 psi. The 1020 steel considered in this analysis falls in this range.

k_a=Surface Finish Factor=$a*S_{ut}^b$. For hot rolled surfaces, the factor **a** is 14.4 and the exponent **b** is -0.718

k_b=Size Factor =1

k_c=Load Factor=1 for bending stresses

k_d=Temperature Factor = 1 for ambient temperature

k_e= Miscellaneous effects/Stress Concentration Factor=0.75

Using these factors, the fatigue strengths were computed in Appendix G. The modified endurance limits are shown in Table 3.

TABLE 3 - Computed Endurance Limit for this application.

	Young's modulus	**Ultimate Strength**	**Endurance Limit**
1020 H.R.S.	$30x10^6$ psi	58,000 psi	17,106 psi

The life of the carrier was estimated using the stress result from the finite element study. To compute the life, the following equation was used:

$$N = \left(\frac{S_a}{a} \right)^{\frac{1}{b}}$$

where:

$$a = \frac{(0.9 S_{ut})^2}{S_e} \text{ and } b = \frac{-1}{3} \log\left(\frac{.9 S_{ut}}{S_e} \right)$$

The estimated life of this carrier, assuming 10 jobs per hour with 25 carriers in the system is theoretically over 1,000 years. The primary explanation for this is twofold: 1) The material has an ultimate strength of 58 ksi and the carrier only bears a stress of 14,000 psi and 2) The annual number of cycles this carrier sees is very small when compared to other assembly components.

Conclusions:

1. The carrier was analyzed under normal operating loads and found to have resultant deflections not exceeding 0.08023” for all load cases. The downward deflections will not exceed 0.0726”.

2. The carrier stresses were computed and under normal operating loads, the stress should not exceed 14,040 psi.

3. The fatigue life was computed and based on each carrier producing 3.2 cars per shift, this carrier will not experience fatigue failure if properly fabricated.

Recommendations

1. Make sure quality control procedures are in place to insure that carriers are properly fabricated.

2. Make sure the system is properly controlled to minimize shock while loading the car onto the carrier.

References:

Shigley, J. E., and Mischke, C. R.,
Mechanical Engineering Design, McGraw-Hill Book Company, 1989

Higdon, A., Ohlsen, E. H., Stiles, W. B, Weese, J. A., and Riley, W. F.,
Mechanics of Materials, John Wiley and Sons, 1985

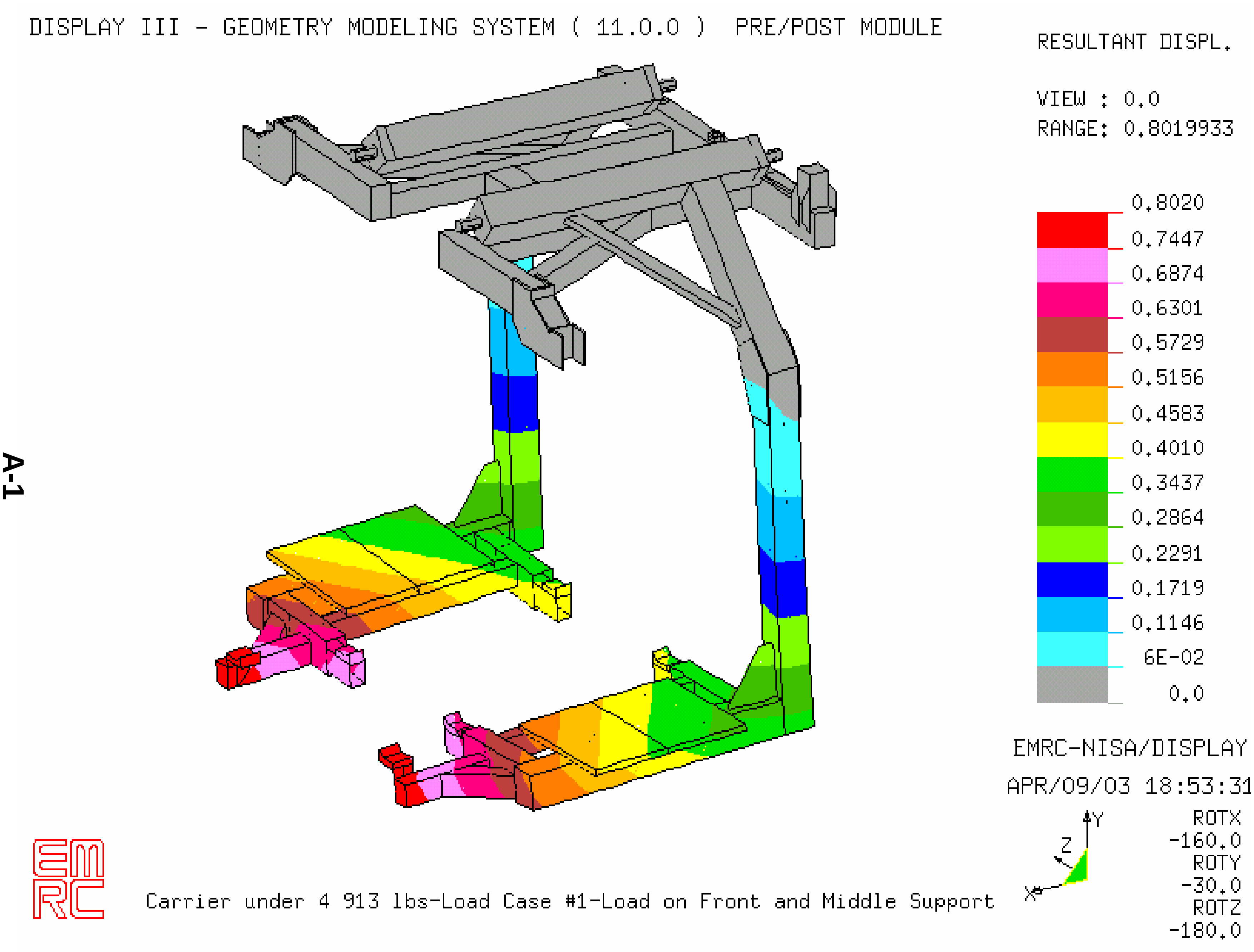
DISCLAIMER

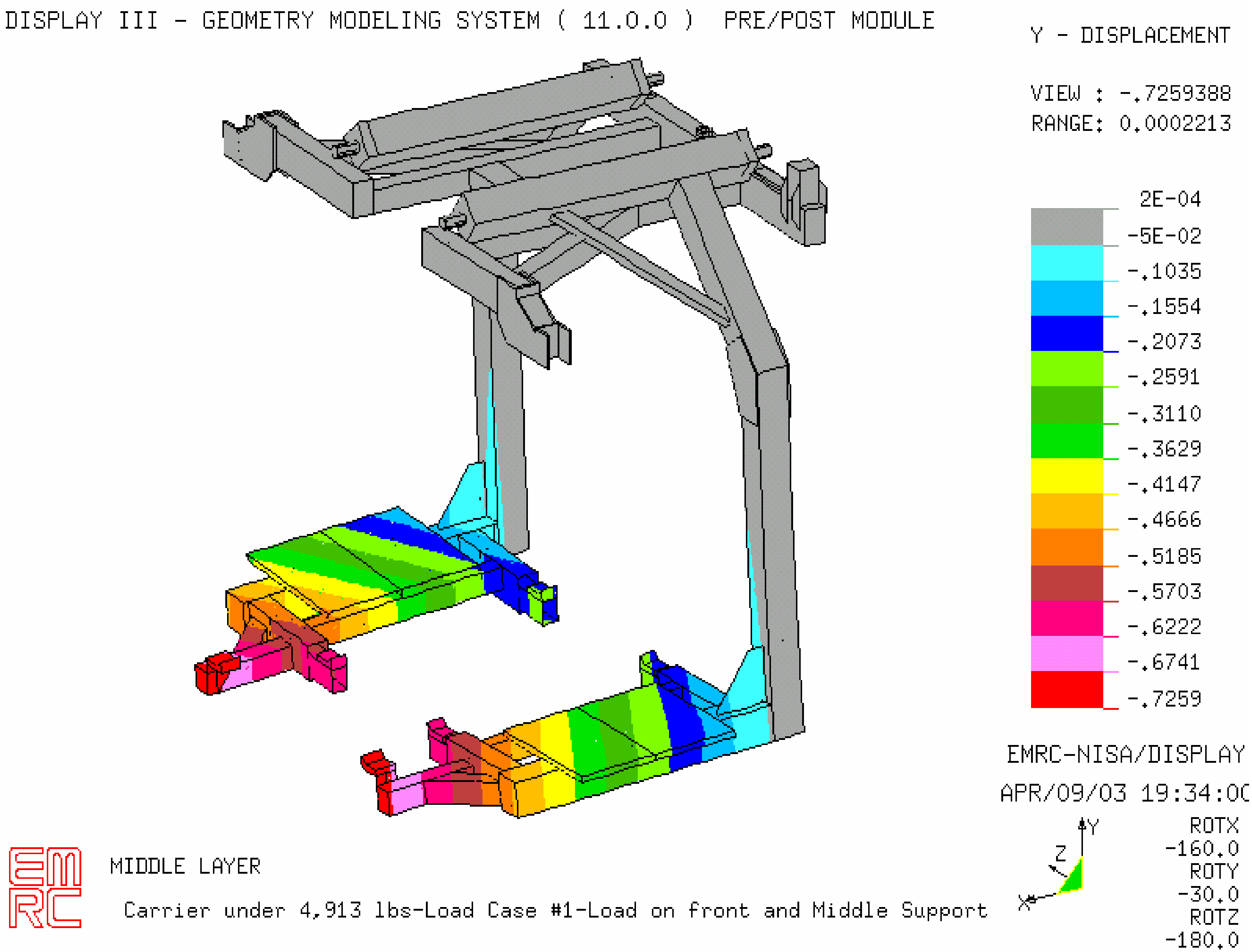
Pinnacle Engineering, Inc. makes no warranty and assumes no liability for the accuracy or validity of any results contained in this report. PEI shall not be liable for loss of profit, loss of business, or other financial loss that may be caused directly or indirectly by the calculations, data, conclusions, and recommendations when used for any purpose or use, or due to any defect or deficiency therein.

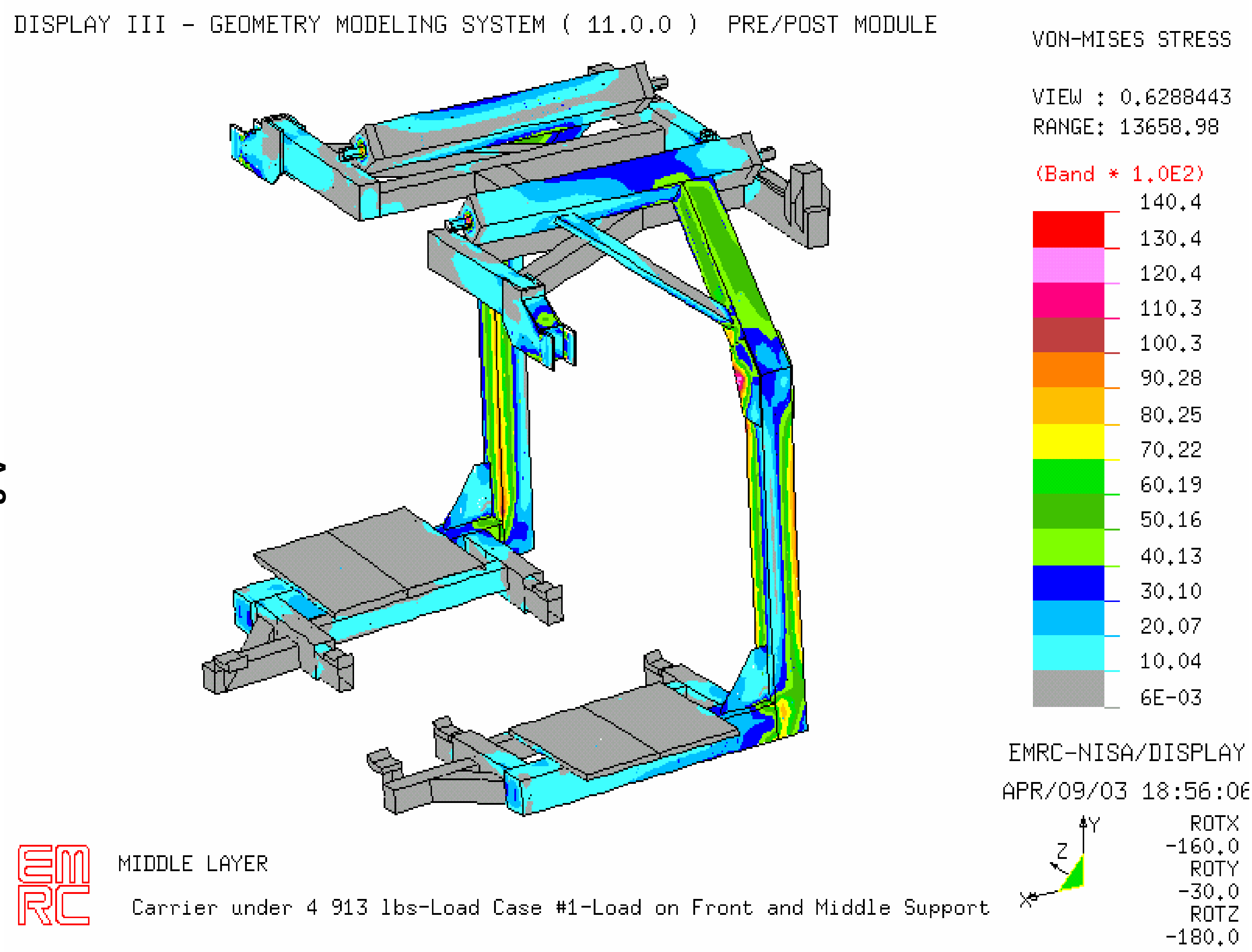
Any questions relating to the use or interpretation of this report and its application should be directed to:

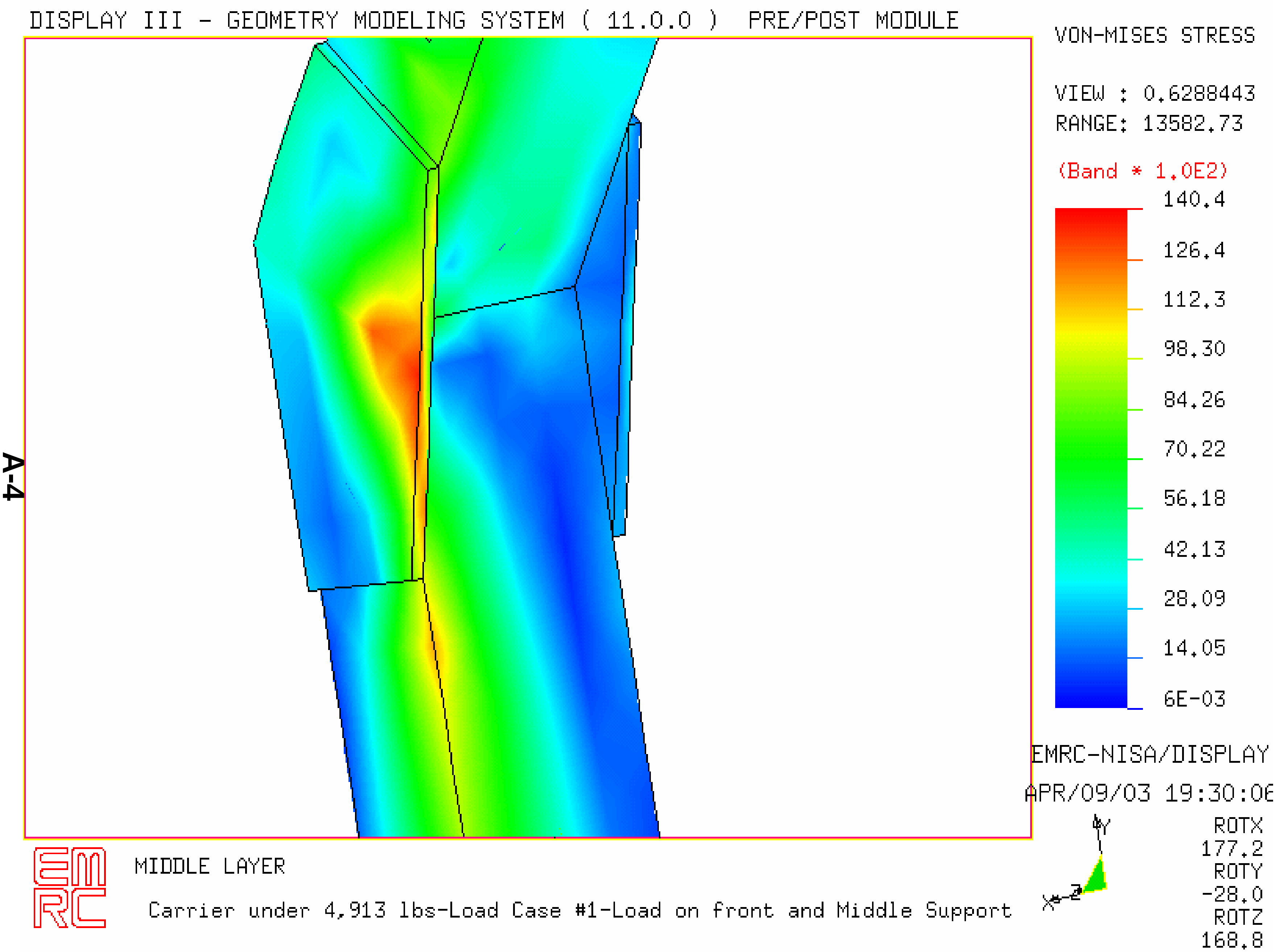
Pinnacle Engineering, Inc.
42850 Garfield
Suite 105
Clinton Twp., MI 48038

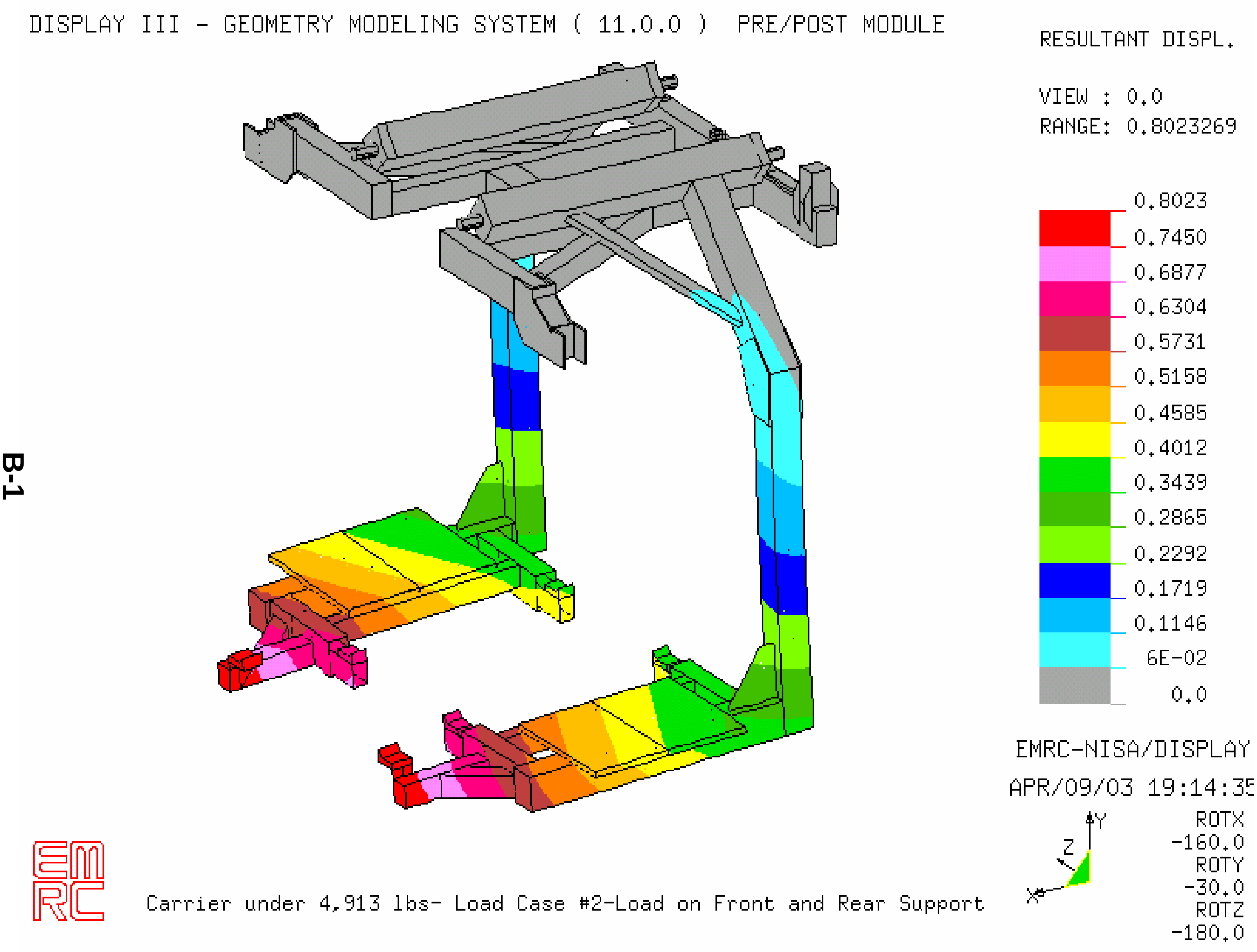
Tel (586) 226-3300

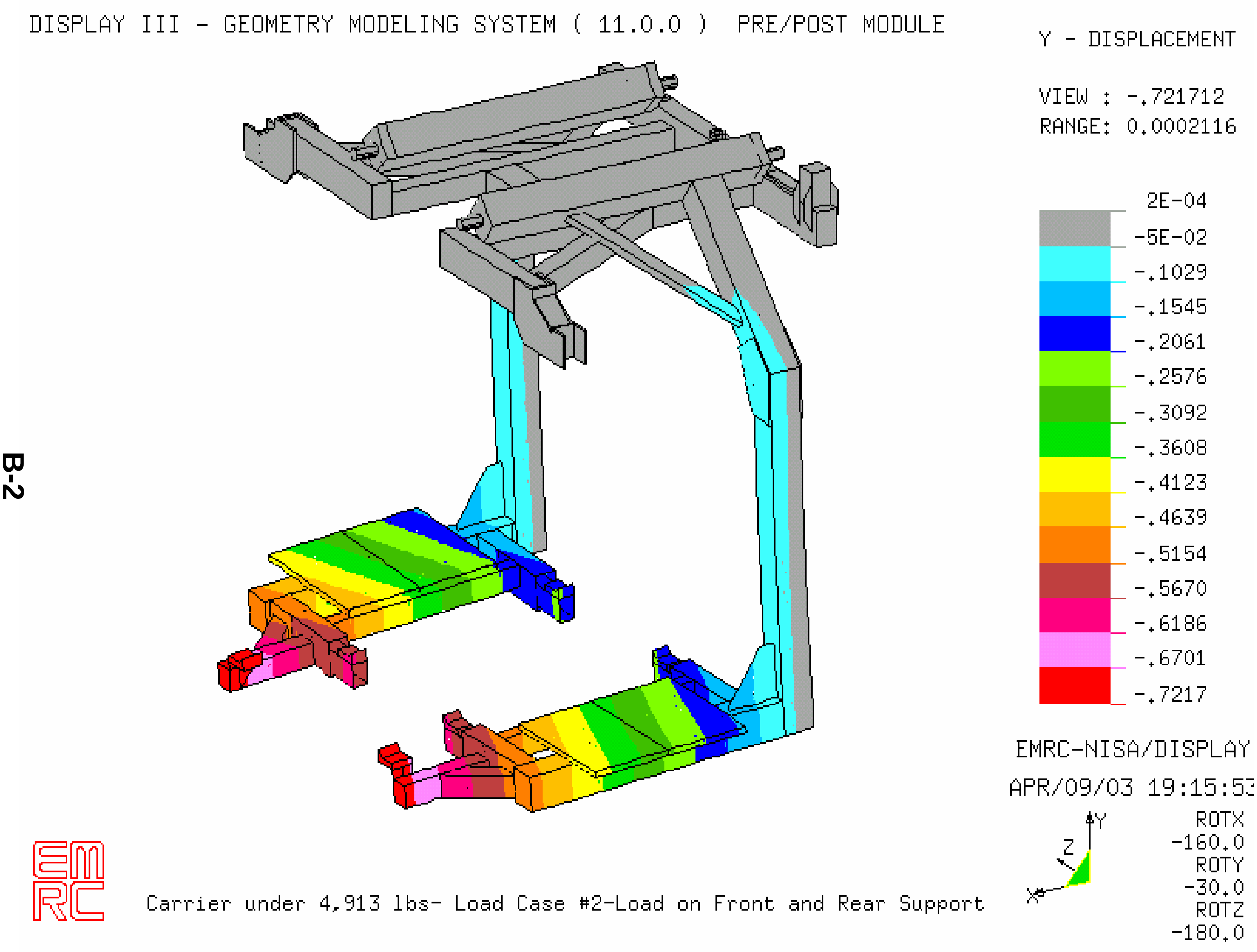

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
RESULTANT DISPL.
VIEW : 0.0
RANGE: 0.8019933
0.8020
0.7447
0.6874
0.6301
0.5729
0.5156
0.4583
0.4010
0.3437
0.2864
0.2291
0.1719
0.1146
6E-02
0.0
EMRC-NISA/DISPLAY
APR/09/03 18:53:31
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0
EMRC
Carrier under 4 913 lbs-Load Case #1-Load on Front and Middle Support

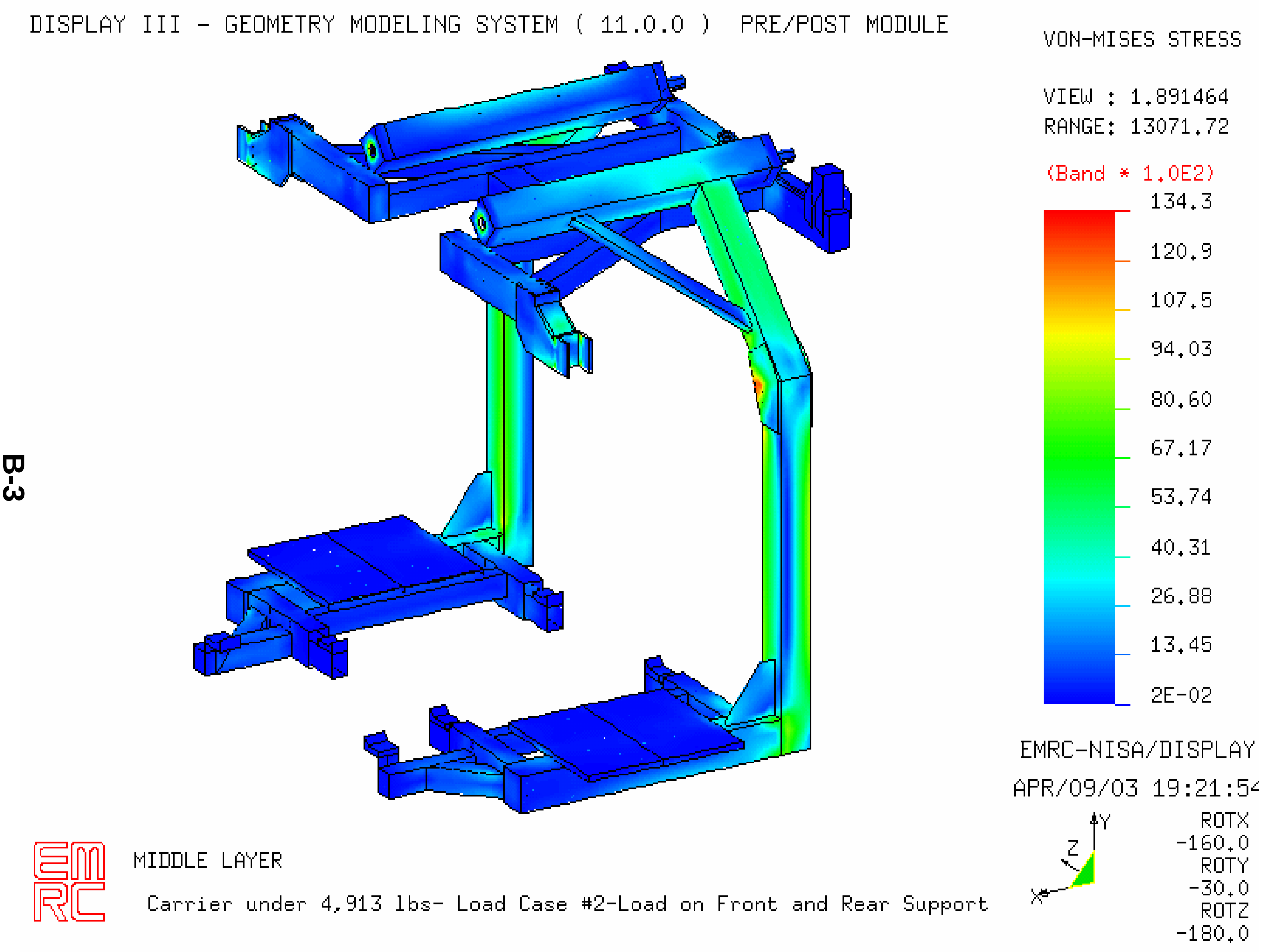

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
Y - DISPLACEMENT
VIEW : -.7259388
RANGE: 0.0002213
2E-04
-5E-02
-.1035
-.1554
-.2073
-.2591
-.3110
-.3629
-.4147
-.4666
-.5185
-.5703
-.6222
-.6741
-.7259
EMRC-NISA/DISPLAY
APR/09/03 19:34:0C
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0
EMRC
MIDDLE LAYER
Carrier under 4,913 lbs-Load Case #1-Load on front and Middle Support

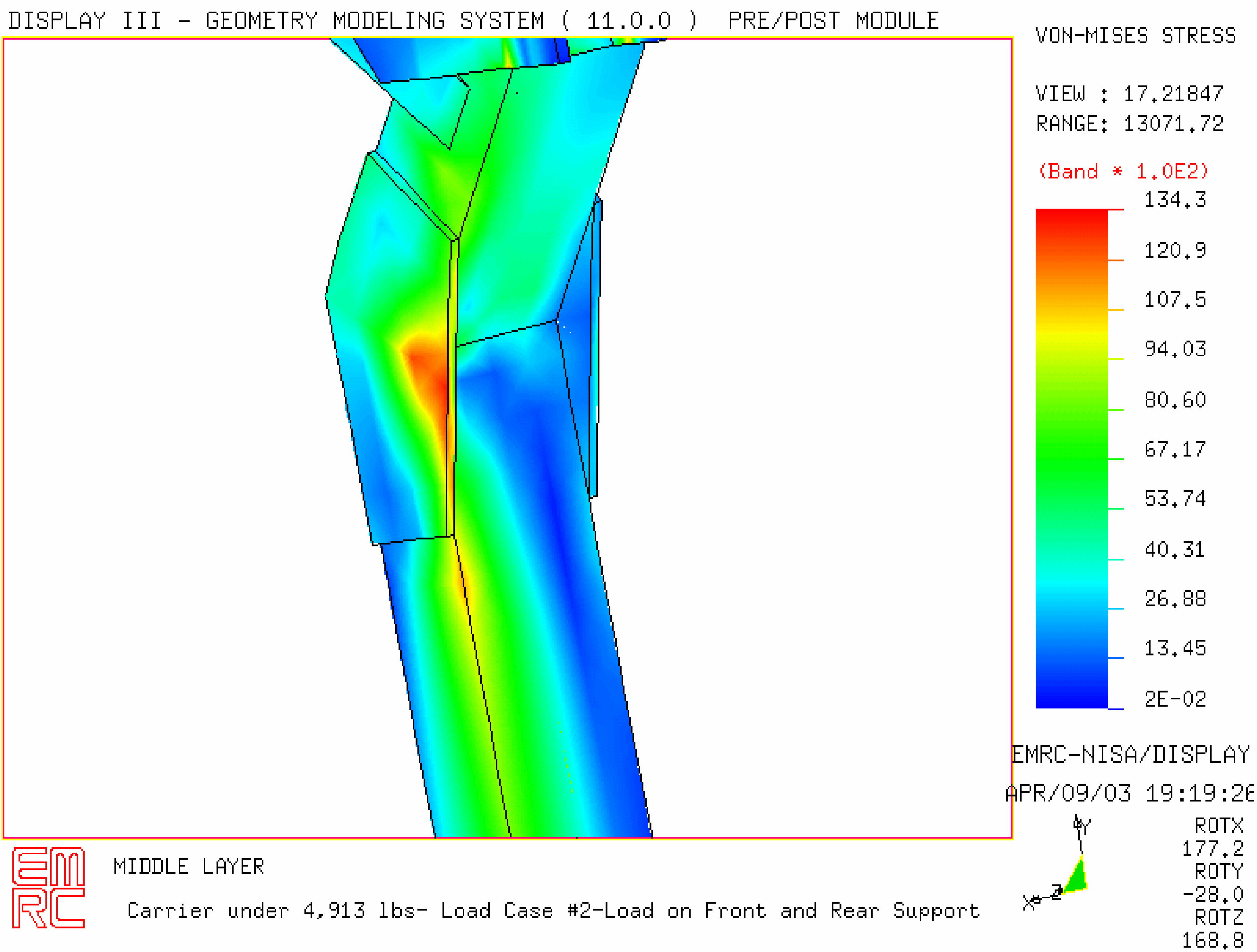

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
VON-MISES STRESS
VIEW : 0.6288443
RANGE: 13658.98
(Band * 1.0E2)
140.4
130.4
120.4
110.3
100.3
90.28
80.25
70.22
60.19
50.16
40.13
30.10
20.07
10.04
6E-03
EMRC-NISA/DISPLAY
APR/09/03 18:56:06
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0
MIDDLE LAYER
Carrier under 4 913 lbs-Load Case #1-Load on Front and Middle Support

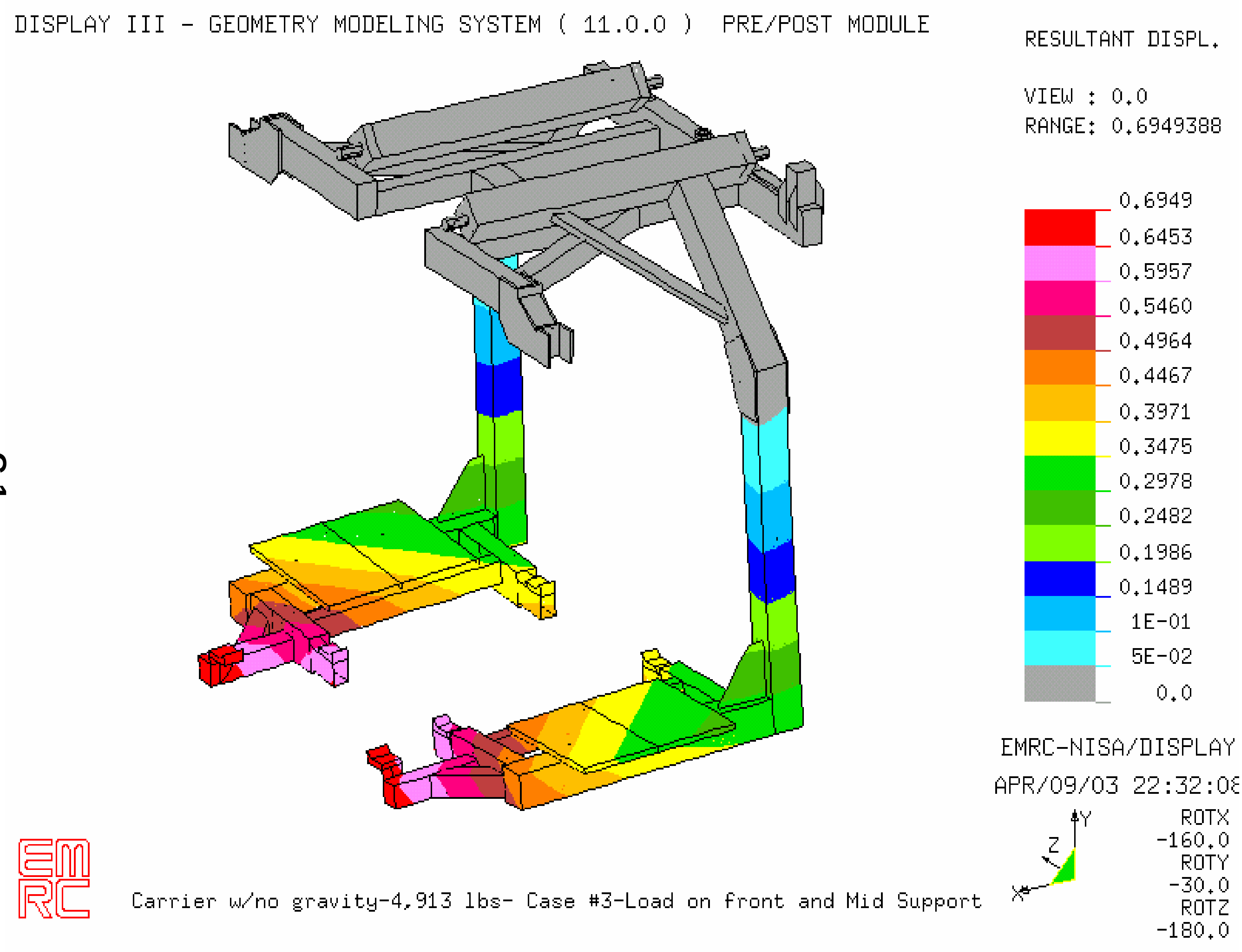

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
VON-MISES STRESS
VIEW : 0.6288443
RANGE: 13582.73
(Band * 1.0E2)
140.4
126.4
112.3
98.30
84.26
70.22
56.18
42.13
28.09
14.05
6E-03
EMRC-NISA/DISPLAY
APR/09/03 19:30:06
ROTX
177.2
ROTY
-28.0
ROTZ
168.8
MIDDLE LAYER
Carrier under 4,913 lbs-Load Case #1-Load on front and Middle Support

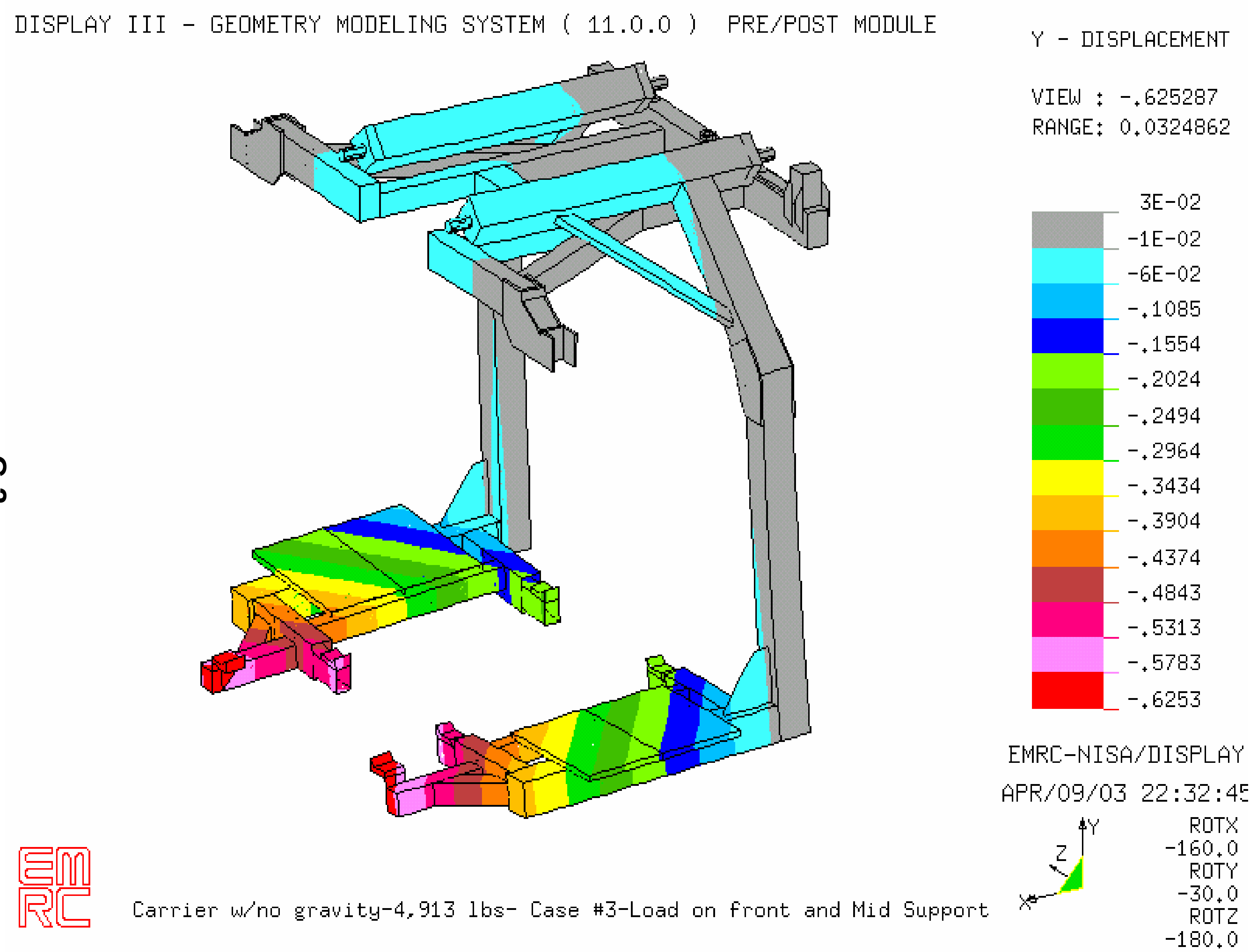

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
RESULTANT DISPL.
VIEW : 0.0
RANGE: 0.8023269
0.8023
0.7450
0.6877
0.6304
0.5731
0.5158
0.4585
0.4012
0.3439
0.2865
0.2292
0.1719
0.1146
6E-02
0.0
EMRC-NISA/DISPLAY
APR/09/03 19:14:35
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0
Carrier under 4,913 lbs- Load Case #2-Load on Front and Rear Support

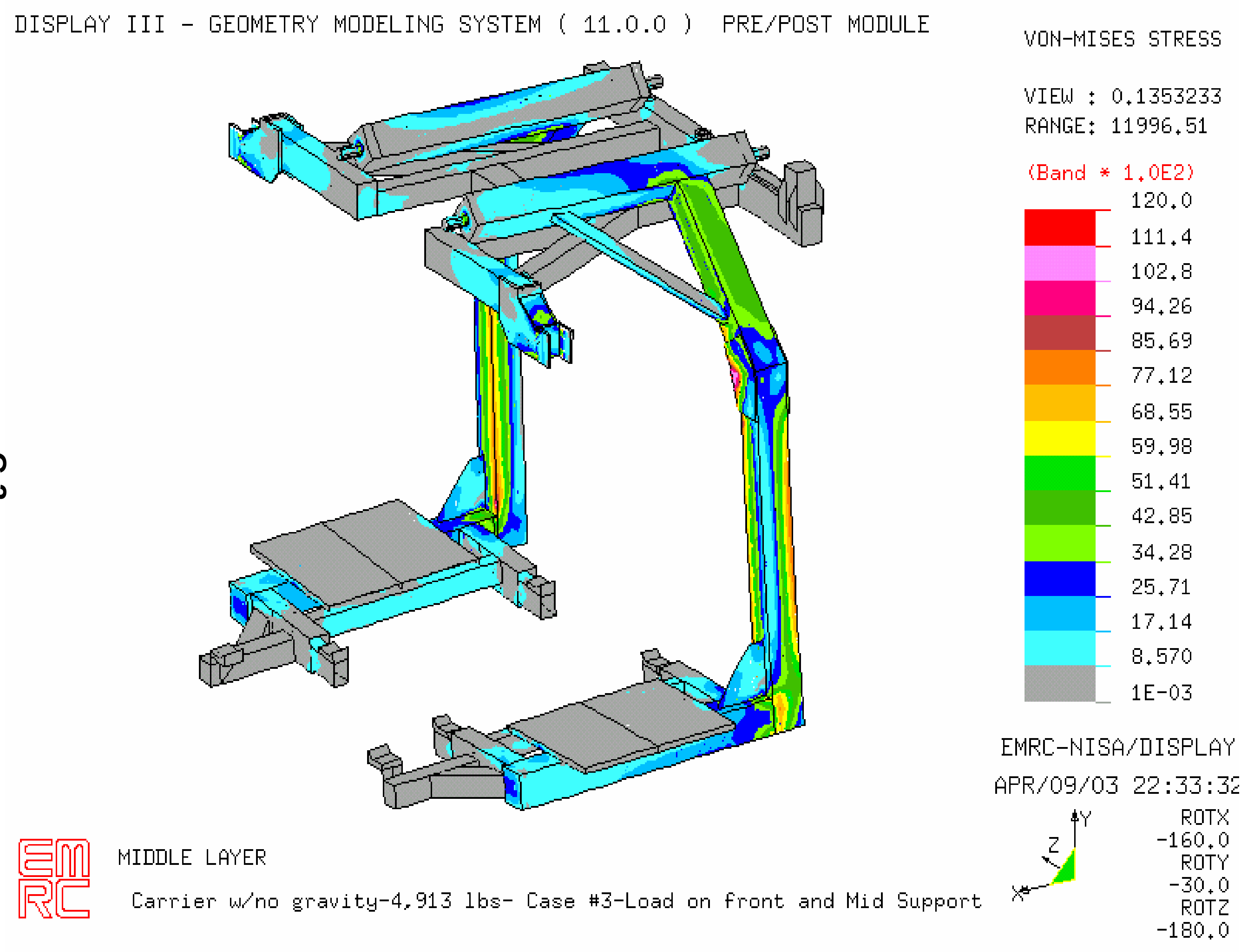

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
Y - DISPLACEMENT
VIEW : -.721712
RANGE: 0.0002116
2E-04
-5E-02
-.1029
-.1545
-.2061
-.2576
-.3092
-.3608
-.4123
-.4639
-.5154
-.5670
-.6186
-.6701
-.7217
EMRC-NISA/DISPLAY
APR/09/03 19:15:53
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0
EMRC
Carrier under 4,913 lbs- Load Case #2-Load on Front and Rear Support

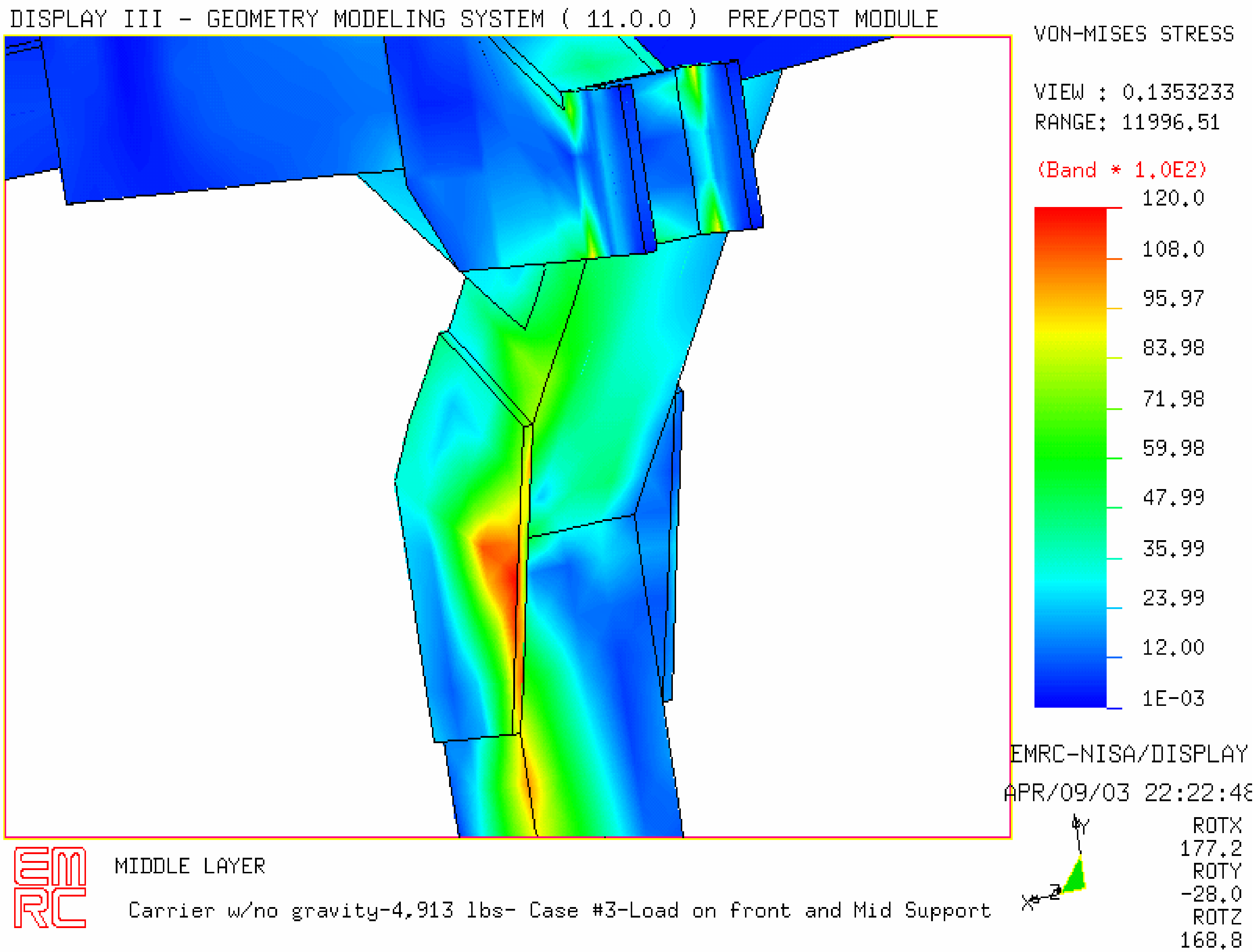

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
VON-MISES STRESS
VIEW : 1.891464
RANGE: 13071.72
(Band * 1.0E2)
134.3
120.9
107.5
94.03
80.60
67.17
53.74
40.31
26.88
13.45
2E-02
EMRC-NISA/DISPLAY
APR/09/03 19:21:54
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0
MIDDLE LAYER
Carrier under 4,913 lbs- Load Case #2-Load on Front and Rear Support

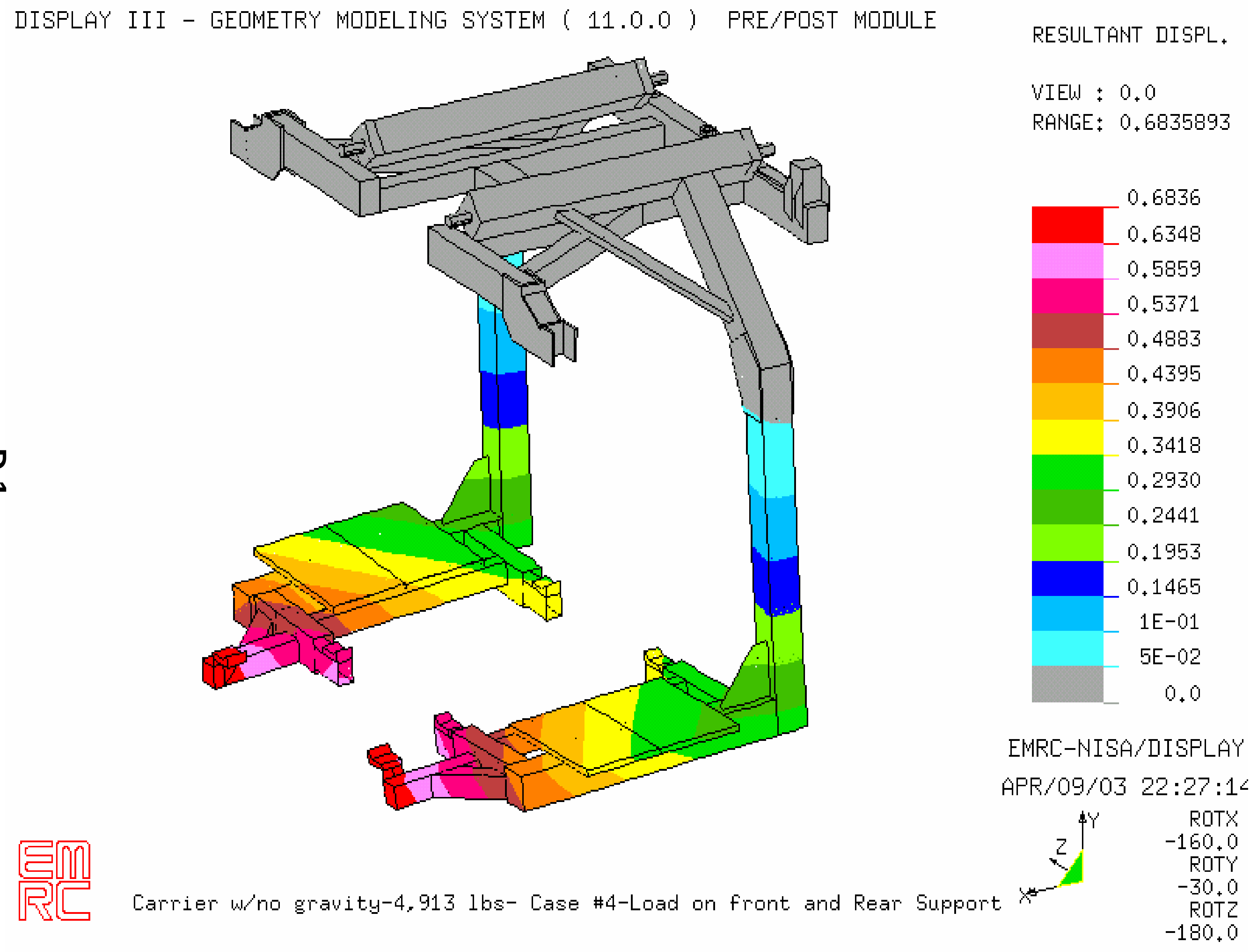

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
VON-MISES STRESS
VIEW : 17.21847
RANGE: 13071.72
(Band * 1.0E2)
134.3
120.9
107.5
94.03
80.60
67.17
53.74
40.31
26.88
13.45
2E-02
EMRC-NISA/DISPLAY
APR/09/03 19:19:26
ROTX
177.2
ROTY
-28.0
ROTZ
168.8
MIDDLE LAYER
Carrier under 4,913 lbs- Load Case #2-Load on Front and Rear Support

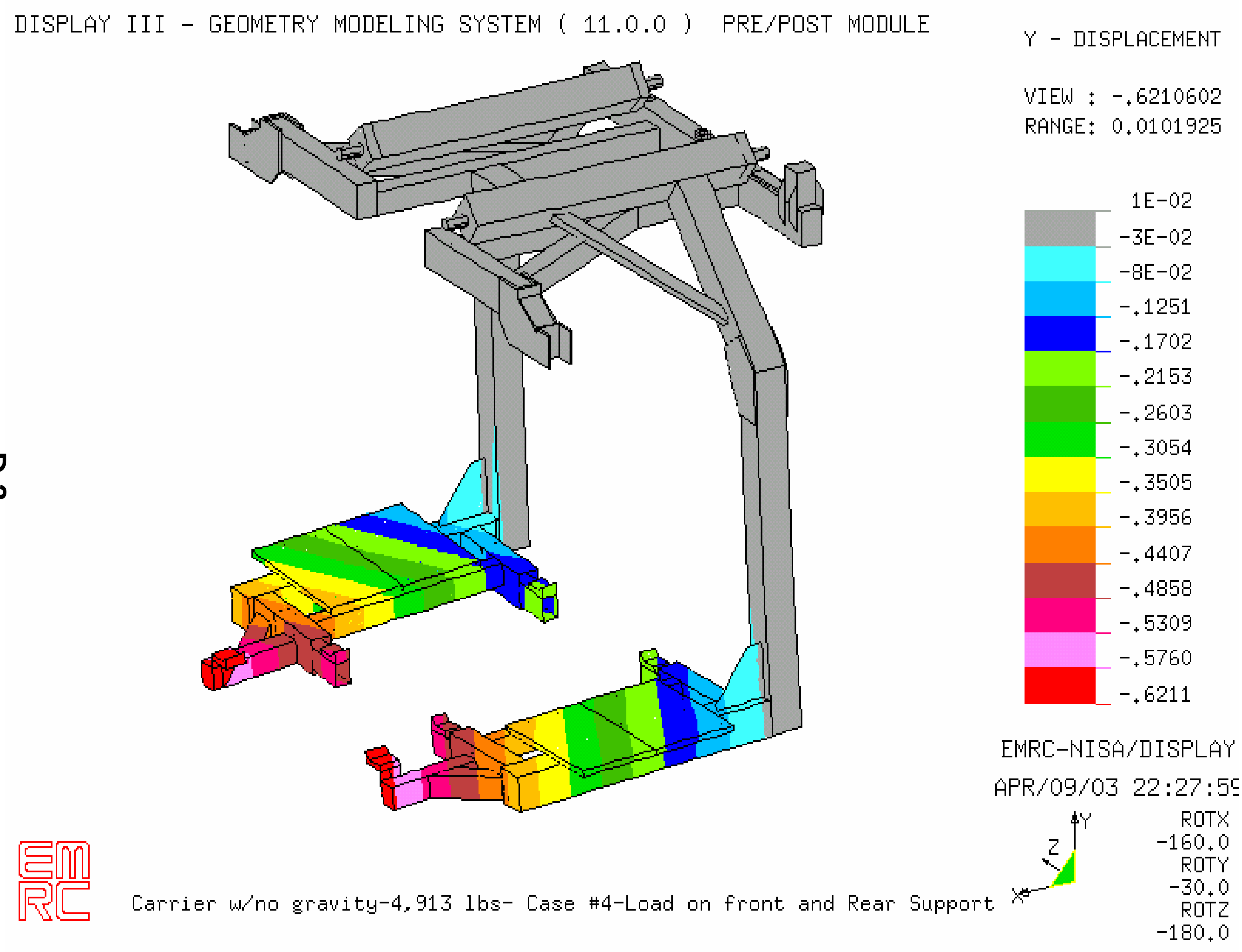

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
RESULTANT DISPL.
VIEW : 0.0
RANGE: 0.6949388
0.6949
0.6453
0.5957
0.5460
0.4964
0.4467
0.3971
0.3475
0.2978
0.2482
0.1986
0.1489
1E-01
5E-02
0.0
EMRC-NISA/DISPLAY
APR/09/03 22:32:0
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0
EMRC
Carrier w/no gravity-4,913 lbs- Case #3-Load on front and Mid Support

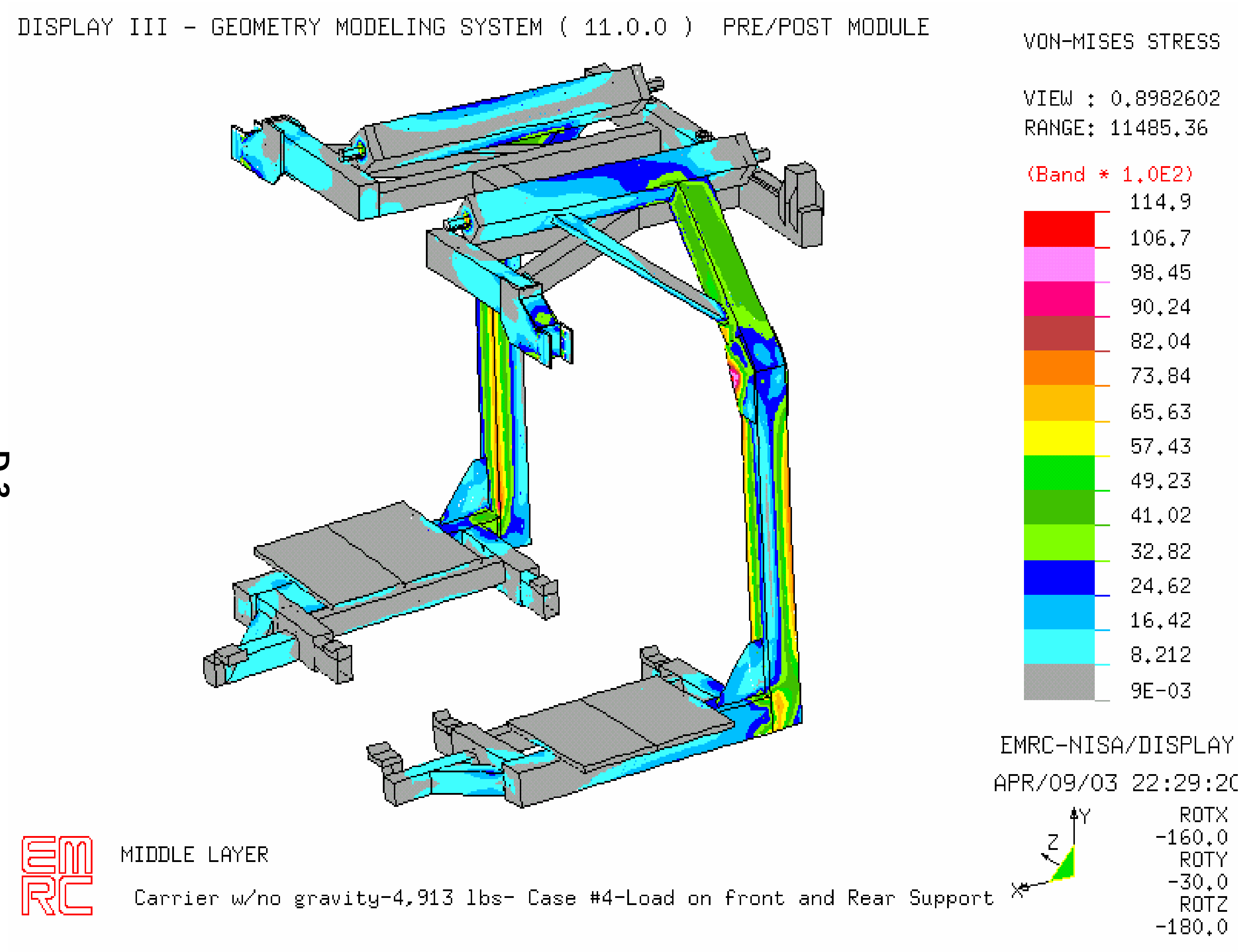

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
Y - DISPLACEMENT
VIEW : -.625287
RANGE: 0.0324862
3E-02
-1E-02
-6E-02
-.1085
-.1554
-.2024
-.2494
-.2964
-.3434
-.3904
-.4374
-.4843
-.5313
-.5783
-.6253
EMRC-NISA/DISPLAY
APR/09/03 22:32:45
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0
EMRC
Carrier w/no gravity-4,913 lbs- Case #3-Load on front and Mid Support

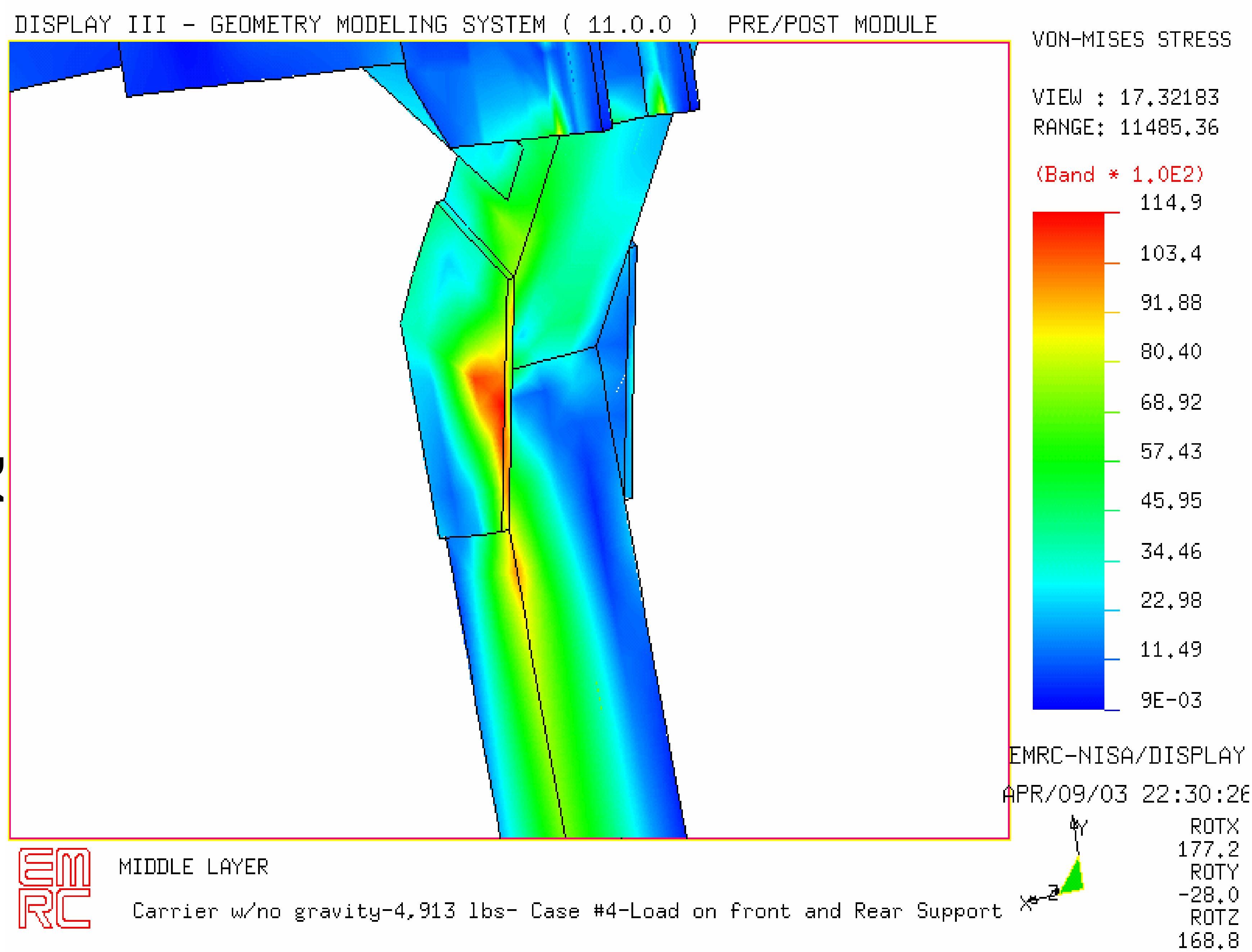

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
VON-MISES STRESS
VIEW : 0.1353233
RANGE: 11996.51
(Band * 1.0E2)
120.0
111.4
102.8
94.26
85.69
77.12
68.55
59.98
51.41
42.85
34.28
25.71
17.14
8.570
1E-03
EMRC-NISA/DISPLAY
APR/09/03 22:33:32
MIDDLE LAYER
Carrier w/no gravity-4,913 lbs- Case #3-Load on front and Mid Support
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0

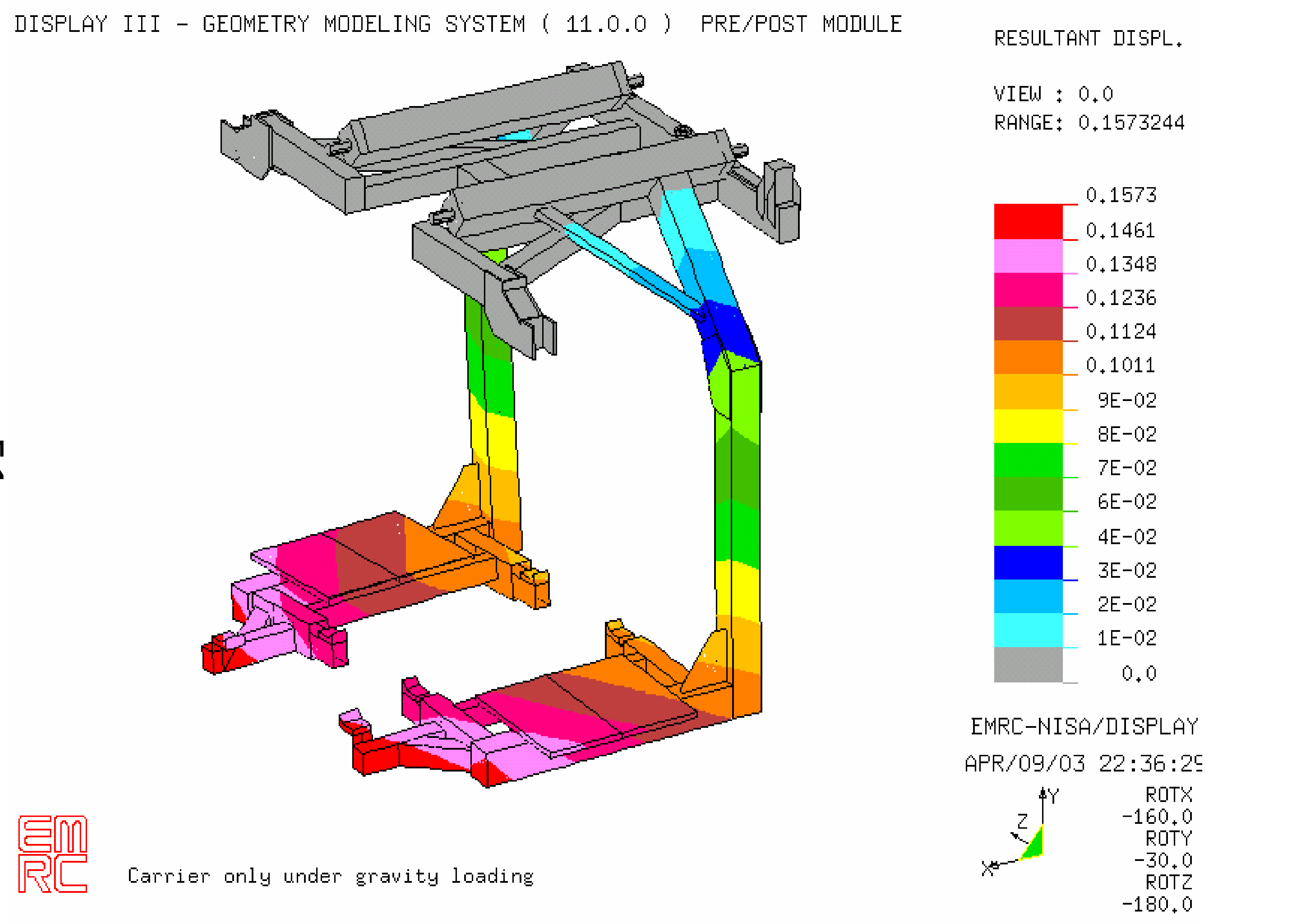

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
VON-MISES STRESS
VIEW : 0.1353233
RANGE: 11996.51
(Band * 1.0E2)
120.0
108.0
95.97
83.98
71.98
59.98
47.99
35.99
23.99
12.00
1E-03
EMRC-NISA/DISPLAY
APR/09/03 22:22:48
ROTX
177.2
ROTY
-28.0
ROTZ
168.8
EM RC
MIDDLE LAYER
Carrier w/no gravity-4.913 lbs- Case #3-Load on front and Mid Support

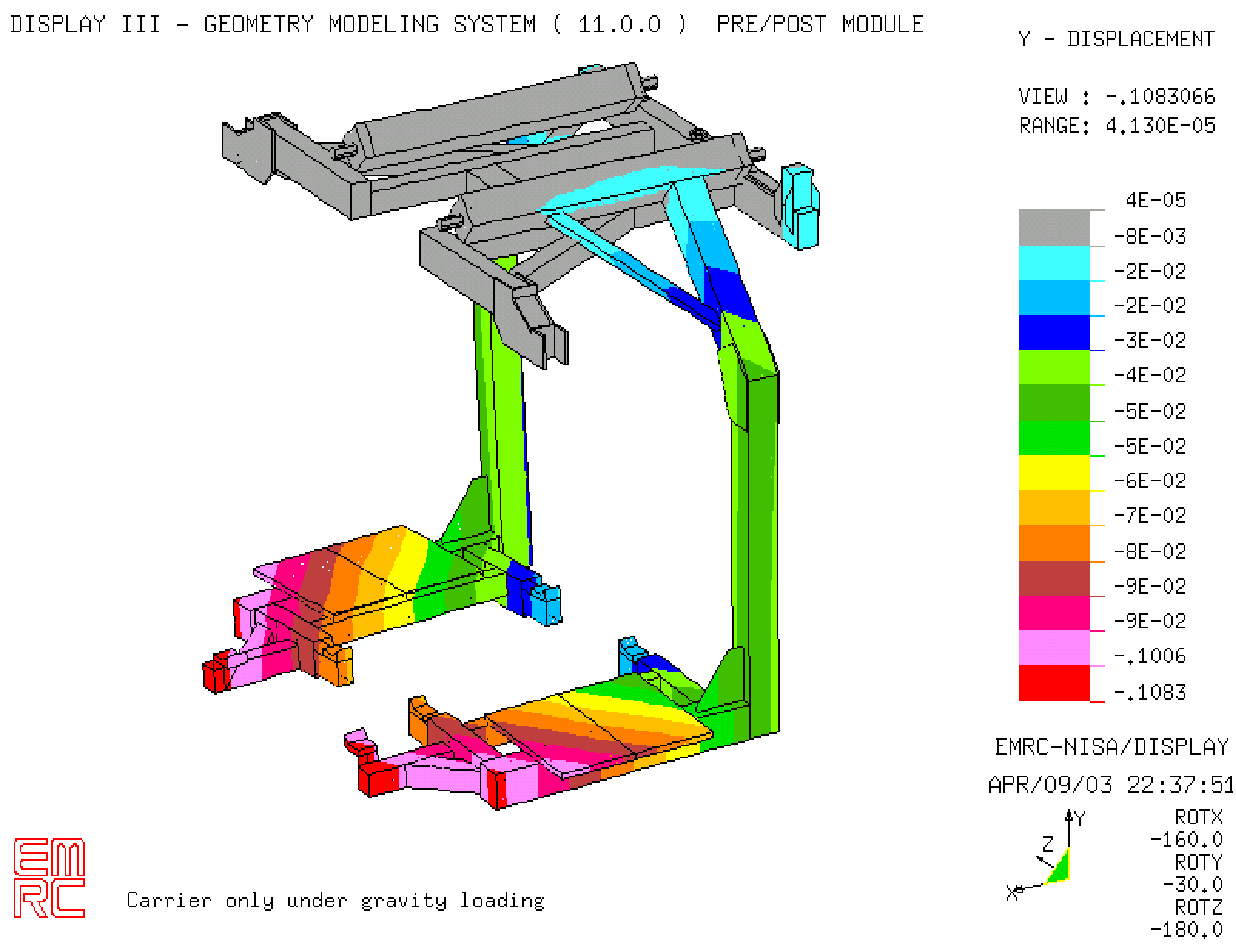

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
RESULTANT DISPL.
VIEW : 0.0
RANGE: 0.6835893
0.6836
0.6348
0.5859
0.5371
0.4883
0.4395
0.3906
0.3418
0.2930
0.2441
0.1953
0.1465
1E-01
5E-02
0.0
EMRC-NISA/DISPLAY
APR/09/03 22:27:14
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0
Carrier w/no gravity-4,913 lbs- Case #4-Load on front and Rear Support


DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
Y - DISPLACEMENT
VIEW : -.6210602
RANGE: 0.0101925
1E-02
-3E-02
-8E-02
-.1251
-.1702
-.2153
-.2603
-.3054
-.3505
-.3956
-.4407
-.4858
-.5309
-.5760
-.6211
EMRC-NISA/DISPLAY
APR/09/03 22:27:59
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0
EMRC
Carrier w/no gravity-4,913 lbs- Case #4-Load on front and Rear Support

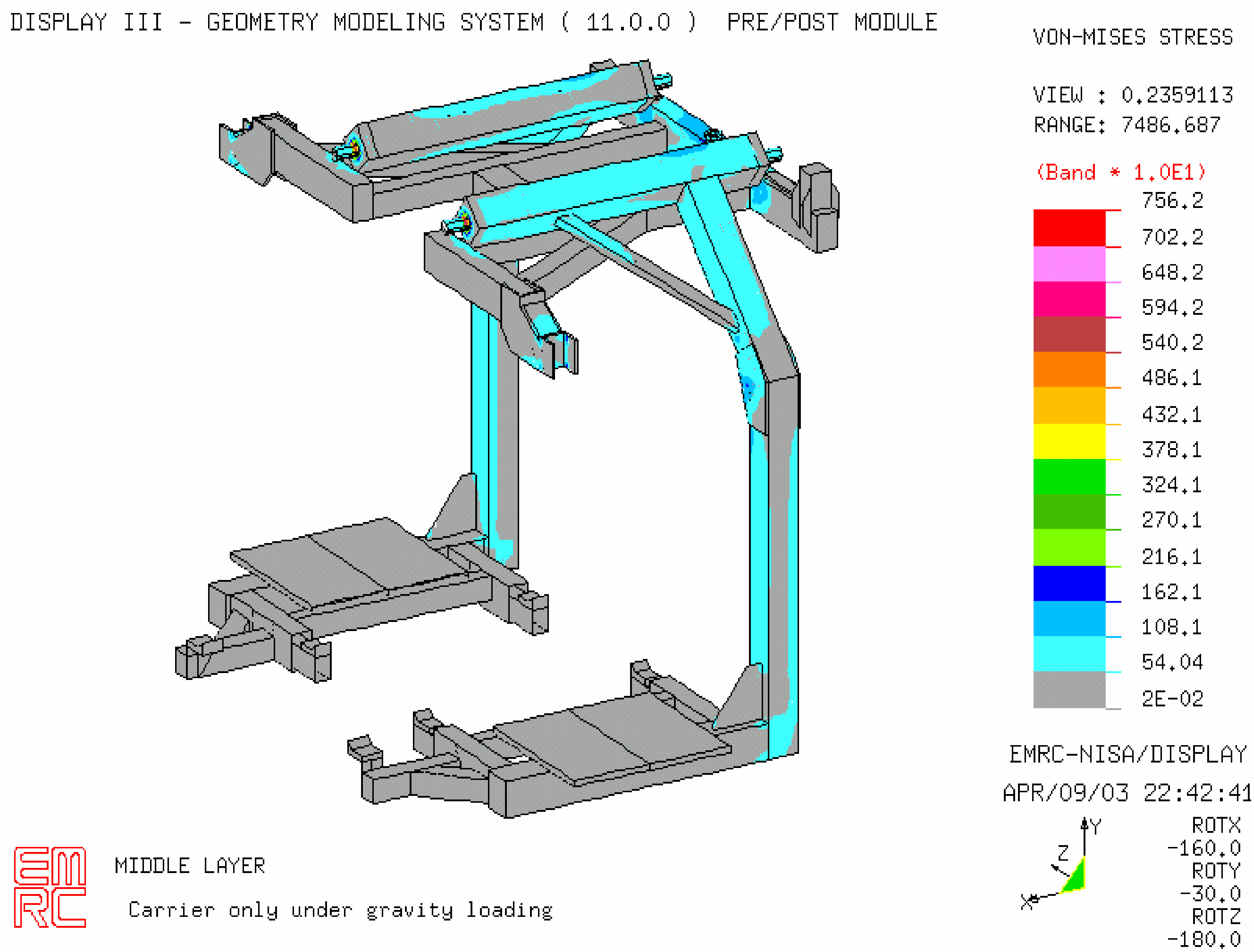

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
VON-MISES STRESS
VIEW : 0.8982602
RANGE: 11485.36
(Band * 1.0E2)
114.9
106.7
98.45
90.24
82.04
73.84
65.63
57.43
49.23
41.02
32.82
24.62
16.42
8.212
9E-03
EMRC-NISA/DISPLAY
APR/09/03 22:29:2C
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0
MIDDLE LAYER
Carrier w/no gravity-4,913 lbs- Case #4-Load on front and Rear Support

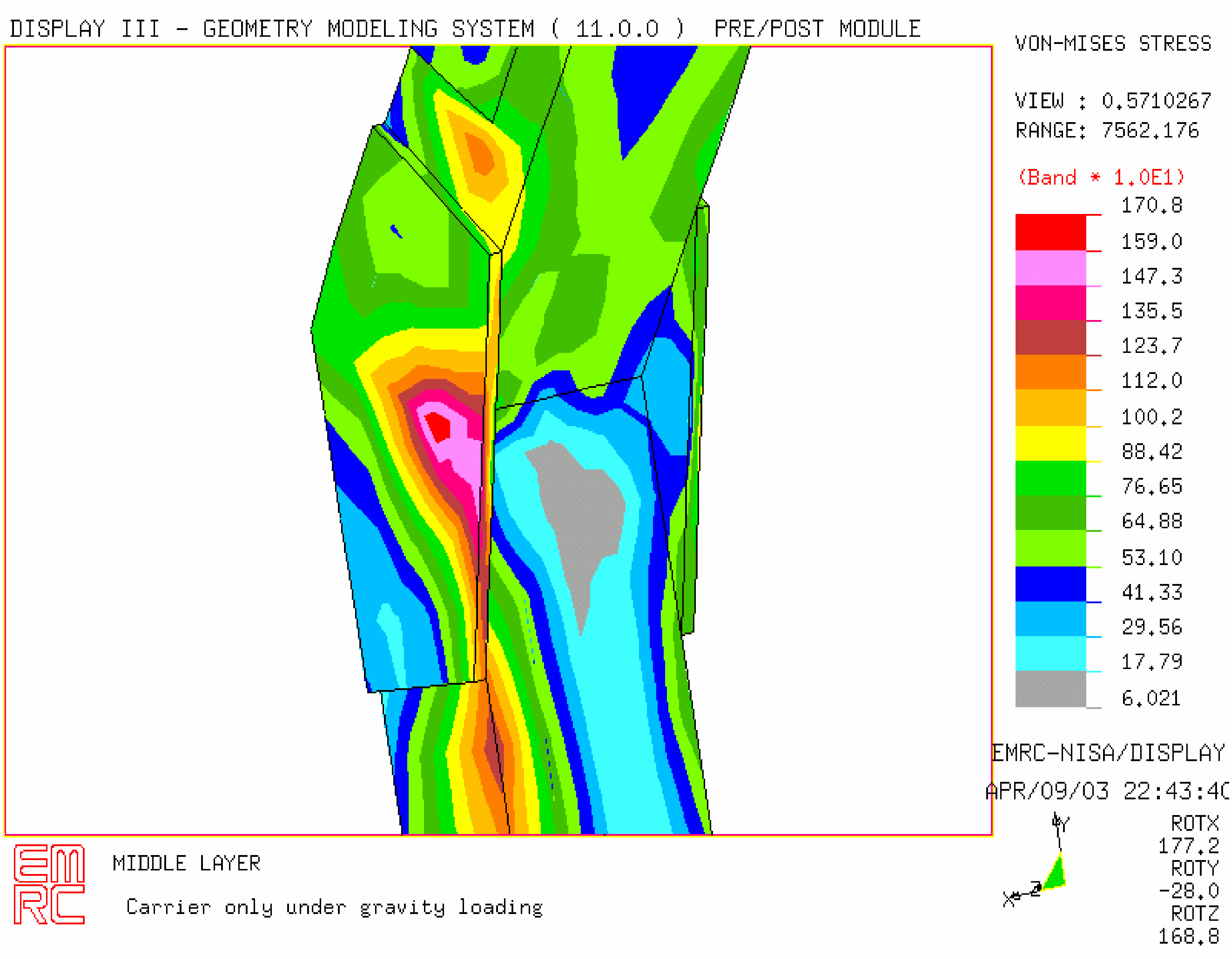

DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
VON-MISES STRESS
VIEW : 17.32183
RANGE: 11485.36
(Band * 1.0E2)
114.9
103.4
91.88
80.40
68.92
57.43
45.95
34.46
22.98
11.49
9E-03
EMRC-NISA/DISPLAY
APR/09/03 22:30:26
ROTX
177.2
ROTY
-28.0
ROTZ
168.8
EM
RC
MIDDLE LAYER
Carrier w/no gravity-4,913 lbs- Case #4-Load on front and Rear Support


DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
RESULTANT DISPL.
VIEW : 0.0
RANGE: 0.1573244
0.1573
0.1461
0.1348
0.1236
0.1124
0.1011
9E-02
8E-02
7E-02
6E-02
4E-02
3E-02
2E-02
1E-02
0.0
EMRC-NISA/DISPLAY
APR/09/03 22:36:29
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0
EMRC
Carrier only under gravity loading


DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
Y - DISPLACEMENT
VIEW : -.1083066
RANGE: 4.130E-05
4E-05
-8E-03
-2E-02
-2E-02
-3E-02
-4E-02
-5E-02
-5E-02
-6E-02
-7E-02
-8E-02
-9E-02
-9E-02
-.1006
-.1083
EMRC-NISA/DISPLAY
APR/09/03 22:37:51
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0
EMRC
Carrier only under gravity loading

E-3


DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
VON-MISES STRESS
VIEW : 0.2359113
RANGE: 7486.687
(Band * 1.0E1)
756.2
702.2
648.2
594.2
540.2
486.1
432.1
378.1
324.1
270.1
216.1
162.1
108.1
54.04
2E-02
EMRC-NISA/DISPLAY
APR/09/03 22:42:41
Y
Z
X
ROTX
-160.0
ROTY
-30.0
ROTZ
-180.0
EM
RC
MIDDLE LAYER
Carrier only under gravity loading


DISPLAY III - GEOMETRY MODELING SYSTEM (11.0.0) PRE/POST MODULE
VON-MISES STRESS
VIEW : 0.5710267
RANGE: 7562.176
(Band * 1.0E1)
170.8
159.0
147.3
135.5
123.7
112.0
100.2
88.42
76.65
64.88
53.10
41.33
29.56
17.79
6.021
EMRC-NISA/DISPLAY
APR/09/03 22:43:40
ROTX
177.2
ROTY
-28.0
ROTZ
168.8
MIDDLE LAYER
Carrier only under gravity loading

E-4

Calculations for Carrier Loading
April 9, 2003

1) Define product load and distances between product C.G. and Suport Points:

Define Load:

$F\_load := 4913 \cdot lbf$

Define distance between front support and C.G.

$L1 := 48.0984 \cdot in - 24.75 \cdot in$ $\quad L1 = 23.348 \cdot in$

Define distance between front support and middle support

$L2 := 68 \cdot in - 24.75 \cdot in$ $\quad L2 = 43.25 \cdot in$

Define distance between front support and rear support

$L3 := 85.5694 \cdot in - 24.75 \cdot in$

2) Compute Reaction Forces for Load Case 1 - Front and Middle Support take 100% of Load

$R_2 := \frac{F\_load \cdot L1}{L2}$ $\quad R_2 = 2.652 \cdot 10^3 \cdot lbf$

$R_1 := F\_load - R_2$ $\quad R_1 = 2.261 \cdot 10^3 \cdot lbf$

3) Compute Reaction Forces for Load Case 2 - Front and Rear Support take 100% of Load

$R_3 := \frac{F\_load \cdot L1}{L3}$ $\quad R_3 = 1.886 \cdot 10^3 \cdot lbf$

$R_1 := F\_load - R_3$ $\quad R_1 = 3.027 \cdot 10^3 \cdot lbf$

ANALYSIS OF CARRIER FABRICATION:

By: Solid Mechanics Consulting, Inc. April 11, 2003

FATIGUE CALCULATIONS

Step 1: Define ultimate strength of Carrier material in ksi

S_ut_1020 := 58 Carrier Structural Members

Step 2: Compute material endurance limits in ksi

Se_prime_1020 := 0.504·S_ut_1020 Se_prime_1020 = 29.232

Step 3: Define surface factor

a := 14.4 (Hot rolled material) b := -0.718 (Hot rolled material)

$ka\_1020 := a \cdot S\_ut\_1020^{b}$

ka_1020 = 0.78

Step 4: Define Size factor

kb := 1

Step 5: Define Load factor - 1 for bending

kc := 1.0

Step 6: Define Temperature factor - 1 for ambient

kd := 1.0

Step 7: Misc. effects factor - 0.75 - FEA takes care of stress concentration - add factor for mesh sensitivity

ke := 0.75

Step 8: Compute final Endurance limit for the components (in ksi)

Se_1020 := Se_prime_1020·ka_1020·kb·kc·kd·ke Se_1020 = 17.106

Compute Life based on Endurance Limit and FEA Stress:

$$A\_R\_1020 := \frac{.9 \cdot (S\_ut\_1020)^2}{Se\_1020} \qquad A\_R\_1020 = 176.994$$

$$B\_R\_1020 := \frac{-1}{3} \cdot \log\left(\left(\frac{.9 \cdot S\_ut\_1020}{Se\_1020}\right)\right) \qquad B\_R\_1020 = -0.162$$

Define Stress Values from FEA:

$$\sigma\_carrier\_From\_FEA := 14.04$$

$$N\_Carrier := \left(\frac{\sigma\_carrier\_From\_FEA}{A\_R\_1020}\right)^{\frac{1}{B\_R\_1020}}$$

$$N\_Carrier = 6.522 \cdot 10^{6}$$

Estimate Life Based on Production Rates:

$$Number\_Carriers := 25$$

$$Production\_Rates := \frac{10}{hr}$$

$$Cycles\_per\_hour := \frac{Production\_Rates}{Number\_Carriers}$$

$$Cycles\_per\_hour = 0.4 \cdot hr^{-1}$$

$$Cycles\_per\_year := Cycles\_per\_hour \cdot 8 \cdot 3 \cdot 7 \cdot 52 \cdot hr$$

$$Cycles\_per\_year = 3.494 \cdot 10^{3}$$

$$Life\_in\_years := \frac{N\_Carrier}{Cycles\_per\_year}$$

$$Life\_in\_years = 1.866 \cdot 10^{3}$$