Analysis of "Detroit" Seismic Joint System

for

EMSEAL Corporation

Prepared by

Haig Saadetian, P.Eng.

Senior Consultant

ROI Engineering Inc.

50 Ronson Drive, Suite 120

Toronto ON M9W 1B3

26-April-2009

Contents

Introduction

•EMSEAL Corporation requested ROI Engineering Inc. (ROIE) to analyze a Seismic Joint System (SJS) intended for the Detroit marketplace.

•The purpose of the analysis is to compute the stress and deflections for SJS assemblies when subjected to a vertical load from a bus in conjunction to a torque applied at the wheel patch with the SJS cover plate .

•The SJS assembly geometries were supplied to ROI Engineering Inc. via 2-D CAD files.

•The finite element (FE) method of analysis is used for this investigation.

•The FE code used is ANSYS/Workbench R12.0.

•The 3-D model developed for the FE analysis is shown in Figure 1.

Introduction (cont.)

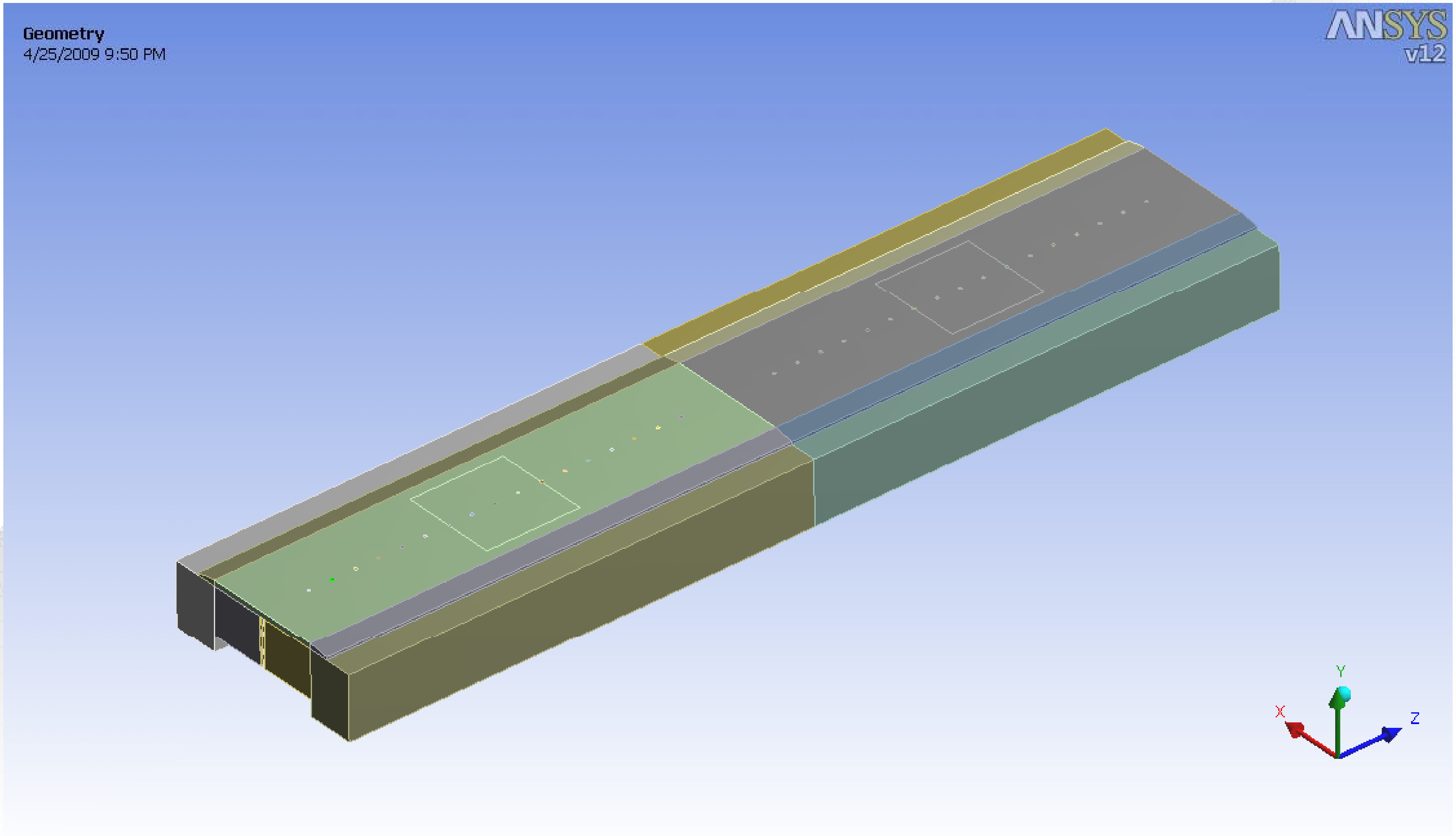


Figure 1. CAD Geometry for the SJS Configuration.

Introduction (cont.)

- The results reported are for the 304 SS cover plate (3/4 in. thick) attached to the 6061 aluminium spline at 17 locations with 3/8 in. self-tapping screws. A similar configuration with 9 self-tapping screws and 10 keyways in between the screw holes was also investigated.
- Two 60 in. lengths of the SJS assembly were modeled for analysis. The span of the cover plate is 15 in., total width is 20 in.
- The foam geometry is represented in this analysis since the foam will be reacting the lateral motion of the cover plate when subjected to a torque at the tyre patch. The tyre patch is a square 12 in. by 12 in.
- The boundary conditions and loading used are shown in Figure 2.
- The screws are modeled explicitly as 3/8 in. diameter cylinders.
- The magnitude of torque applied at the tyre patch is calculated from the empirical formula quoted in the text book “Car Suspension and Handling” by Donald Bastow, Geoffrey Howard and John P. Whitehead.

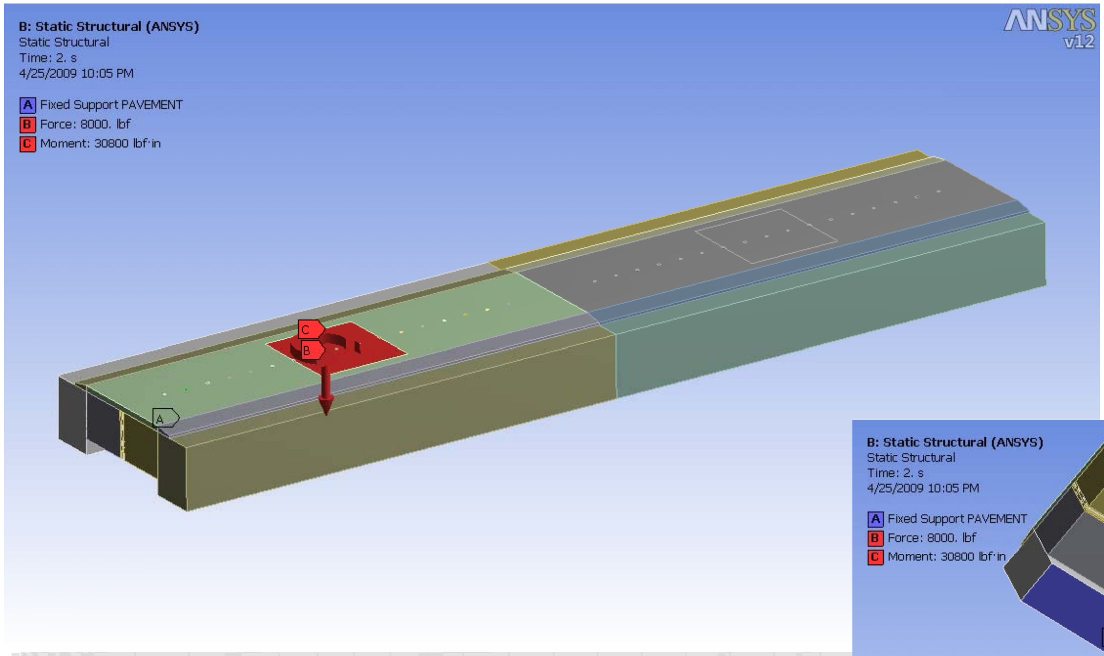
Introduction (cont.)

- The formula is credited to Gough and relates tyre patch torque (T) to tyre pressure (P), coefficient of friction (μ)and load on the wheel (W) as follows:

  - $T = \mu W^{3/2}/(3P^{1/2})$

- For a wheel load W of 8,000 lbf, tyre pressure P of 60 lbf/in.^{2} and coefficient of friction μ of 1.0 (worst condition of no slipping between bus tyre and cover plate) the value of torque T is 30,800 lbf-in.

Introduction (cont.)



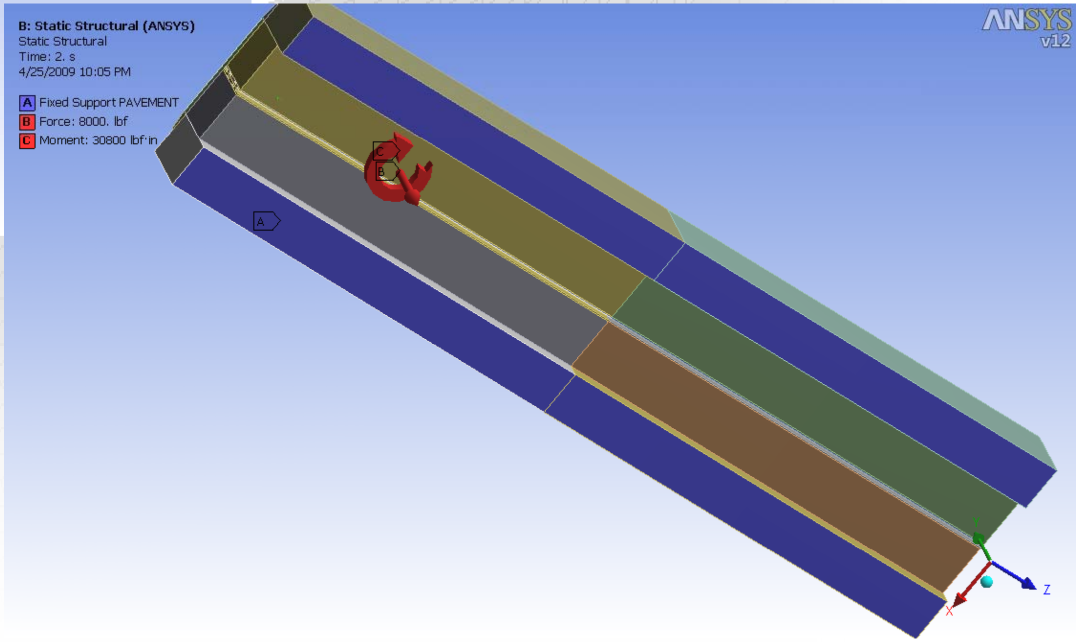


Figure 2. Boundary Conditions and Loads.

Finite Element Model

- High order hexahedra and tetrahedra solids (spline, foam,screws and pavement) and 8 node solid shell (cover plate) elements used for the FE mesh, three degrees of freedom (dof) at each node.
- Bonded contact between the spline and foam, foam and pavement, cover plate and screws, screws and spline.
- Non-linear frictionless contact between the cover plate and pavement support as well as cover plate and spline.
- No separation contact between the cover plate and foam.
- The base of the pavement block restrained against movement in all global X, Y and Z directions (see Figure 2).
- 12 in. by 12 in. area (see Figure 2) to represent the contact patch between car/bus tyre and cover plate. Load per tyre to be applied is 8,000 lbf as well as a torque of 30,800 lbf-in.
- The FE mesh is shown in Figure 3.

Finite Element Model (cont.)

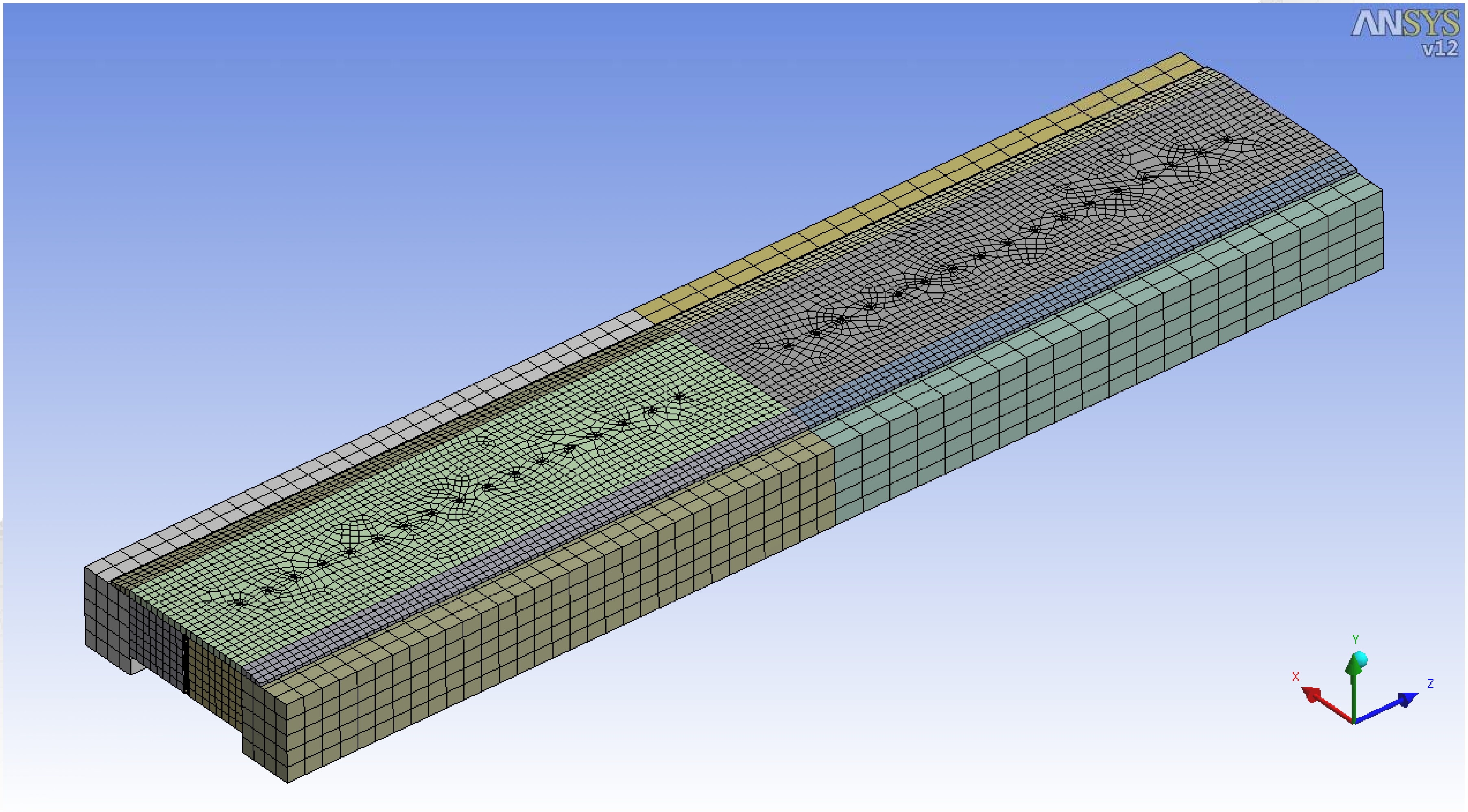


Figure 3. FE Mesh.

Finite Element Model (cont.)

•A total of 324,442 nodes, 147,309 elements were used for a dof count of 973,326 for the FE model.

•Large deflection analysis included (non-linear geometry) to account for stress state due to deflected geometric shape.

•Linear material properties used for all components. For the 304 SS cover plate and screws:

- •Modulus of Elasticity E = 29 x 10^6 lbf/in.^{2}
- •Poisson's ratio v = 0.3

•For the spline 6061 aluminium:

- •Modulus of Elasticity E = 10 x 10^6 lbf/in.^{2}
- •Poisson's ratio v = 0.33

Finite Element Model (cont.)

- For the pavement:
  - Modulus of Elasticity $E = 1 \times 10^6$ lbf/in.^{2}
  - Poisson's ratio $v = 0.25$
- For the foam:
  - Modulus of Elasticity $E = 20$ lbf/in.^{2}
  - Poisson's ratio $v = 0.25$

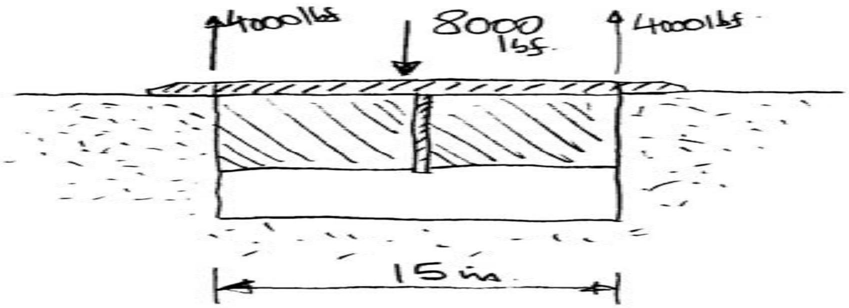
- Material strength properties used for calculation of safety margin:

•304 SS	yield strength	42,000 lbf/in.^{2}
	ultimate strength	90,000 lbf/in.^{2}
•6061 aluminium	yield strength	15,000 lbf/in.^{2}

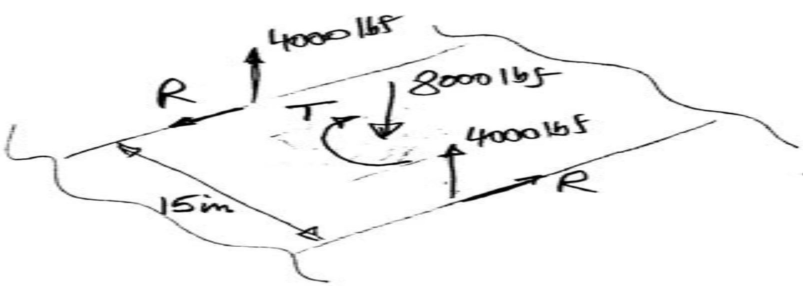
Finite Element Model (cont.)

- The analysis is done in two steps.
- At step 1 (Time = 1.0) the vertical load of 8,000 lbf is applied to the tyre patch.
- At step 2 (Time = 2.0) the vertical load from the tyre patch is kept constant at 8,000 lbf and a torque of 30,800 lbf-in. applied as well.
- Note that at any intermediate time step between Time=1.0 and Time=2.0 the effect of a torque between a minimum value of 0 lbf-in. and a maximum of 30,800 lbf-in. can be investigated.
- Advantage of this can be taken to evaluate the effect of friction between the cover plate and pavement. A calculation is presented in Figure 4 as to the magnitude of torque that will be reacted by the foam for a coefficient of friction of 0.3 between the cover plate and pavement.
- For a coefficient of friction of 0.3 the actual torque that will be reacted by the foam will be 30800-18000 = 12,800 lbf-in. Results can be viewed at Time = 1.4155 to represent this value of torque applied at the tyre patch.

Finite Element Model (cont.)



VERTICAL REACTION AT EACH EDGE WILL BE 4000 lbf.



$R = \mu \, 4000$ (μ = Coeff. of friction)

ASSUME $\mu = 0.3$

$R = 1200$ lbf

$T = 15 \times 1200 = 18\,000$ lbf-in.

THEREFORE TAKING FRICTION INTO ACCOUNT BETWEEN THE COVER PLATE AND PAVEMENT THE TORQUE APPLIED TO THE COVER PLATE FROM THE CAR/BUS WHEEL WILL BE RESISTED BY FRICTION BEFORE MOTION OF THE COVER PLATE TAKES PLACE.

FOR A TORQUE T OF 30,800 lbf-in. APPLIED BY THE WHEEL ON THE COVER PLATE, 18 000 lbf-in. WILL BE RESISTED BY FRICTION. VALUE OF TORQUE CAUSING ROTATION OF THE COVER PLATE IS THEREFORE 30,800 − 18,000 = 12,800 lbf-in.

Figure 4. Torque Calculation for Friction Between Cover Plate and Pavement.

Results

•A series of plots showing the von Mises equivalent stress contours as well as displacement contours are presented in Figures 5 to 25.

•Animation files are also presented to show the deformation patterns and non-linear nature of the assembly behavior. The animation files are shown at an exaggerated scale (x10) to demonstrate more vividly the non-linear effects at the contact locations.

Results (cont.)

Time = 2.0

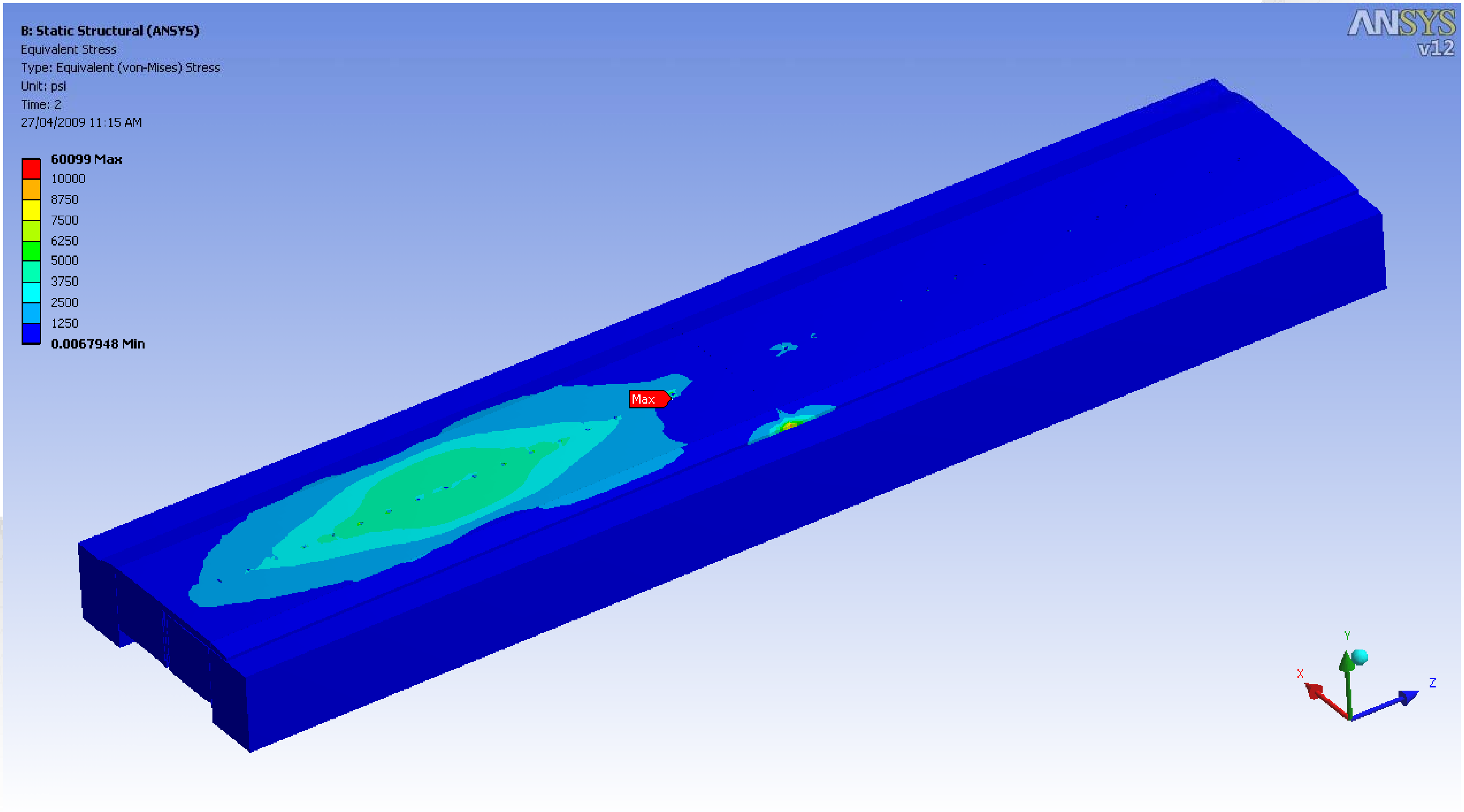


Figure 5. von Mises Equivalent Stress Contours, Complete Assembly.

Results (cont.)

Time = 1.4155

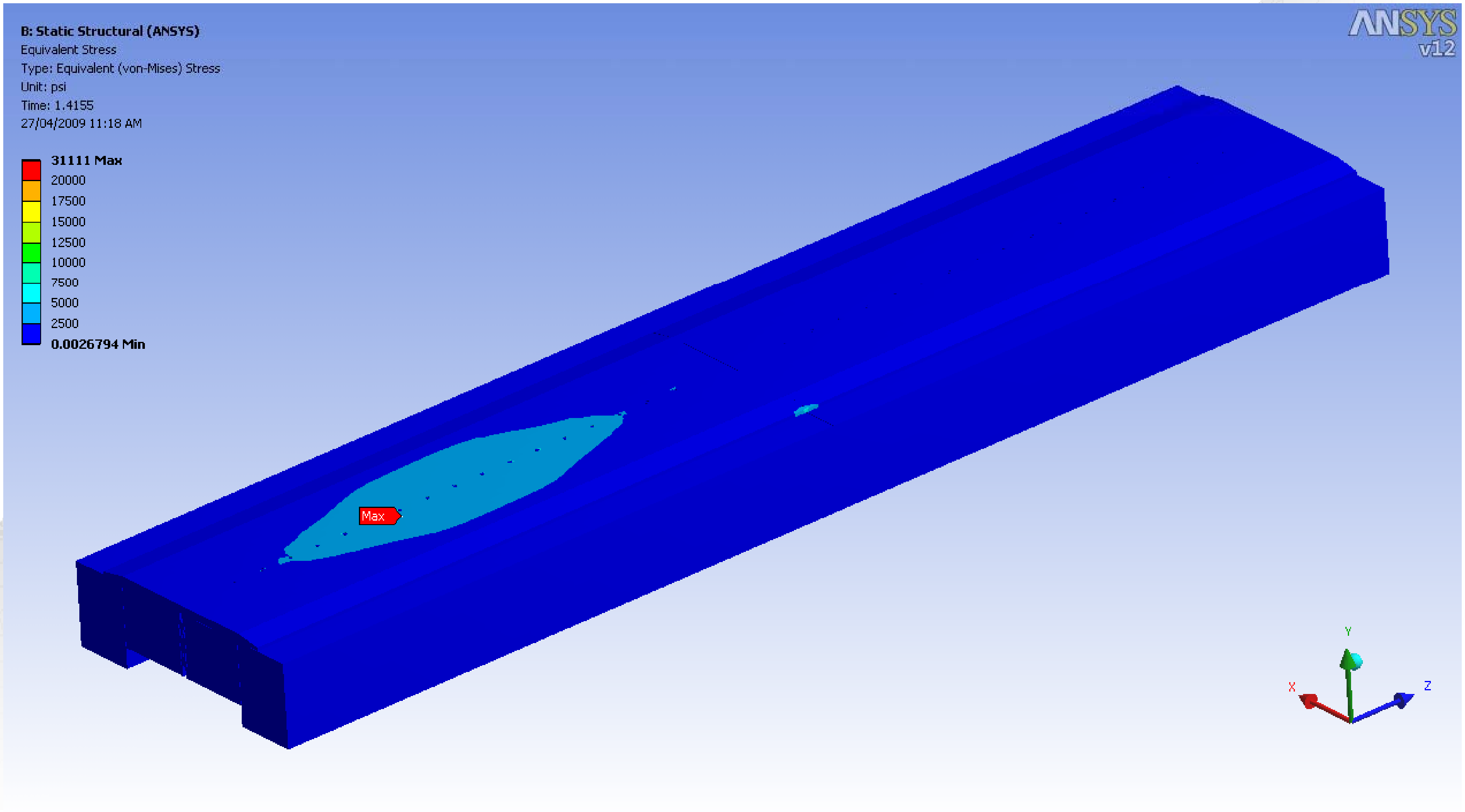


Figure 6. von Mises Equivalent Stress Contours, Complete Assembly.

Results (cont.)

Time = 1.0

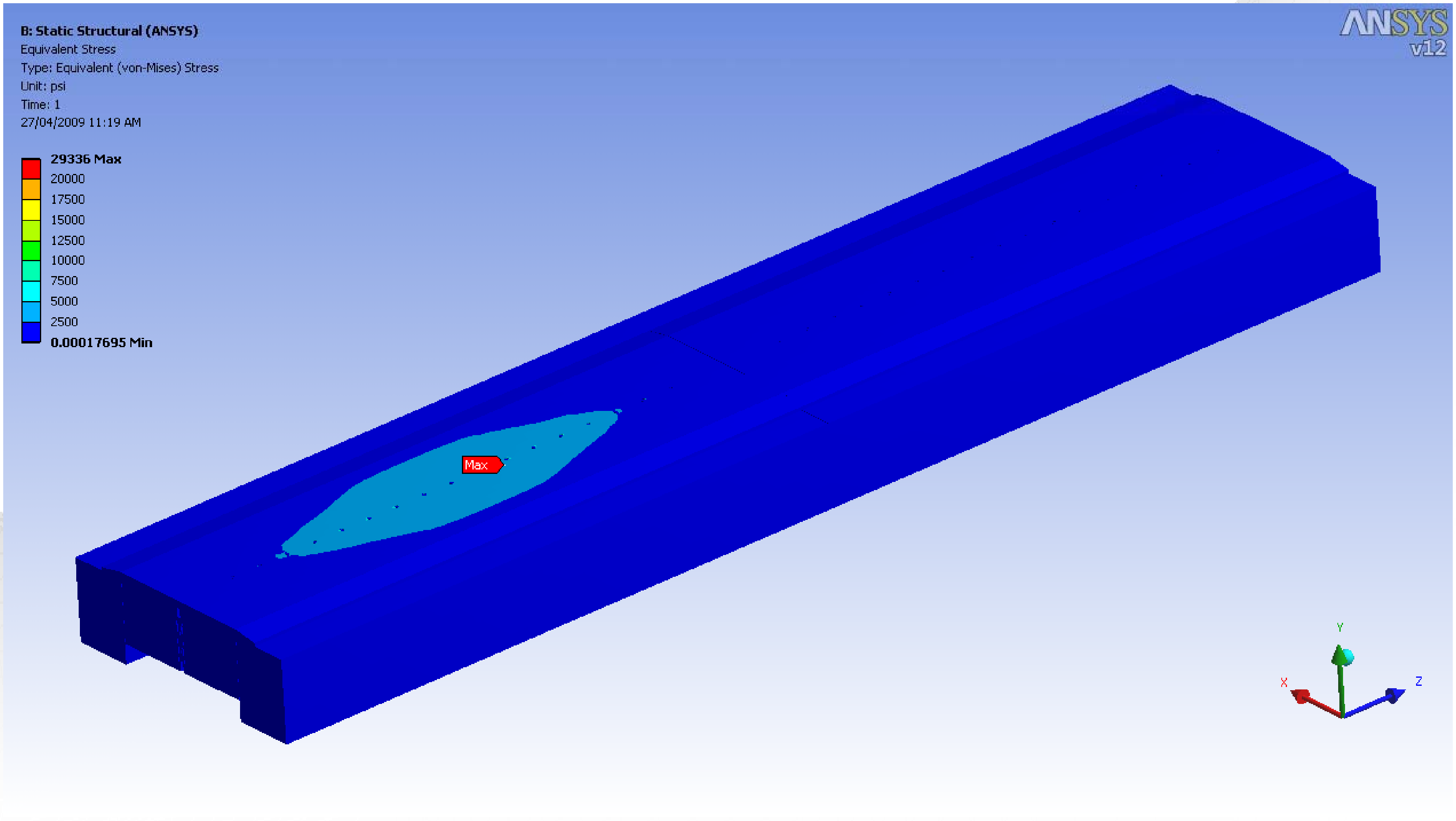


Figure 7. von Mises Equivalent Stress Contours, Complete Assembly.

Results (cont.)

Time = 2.0

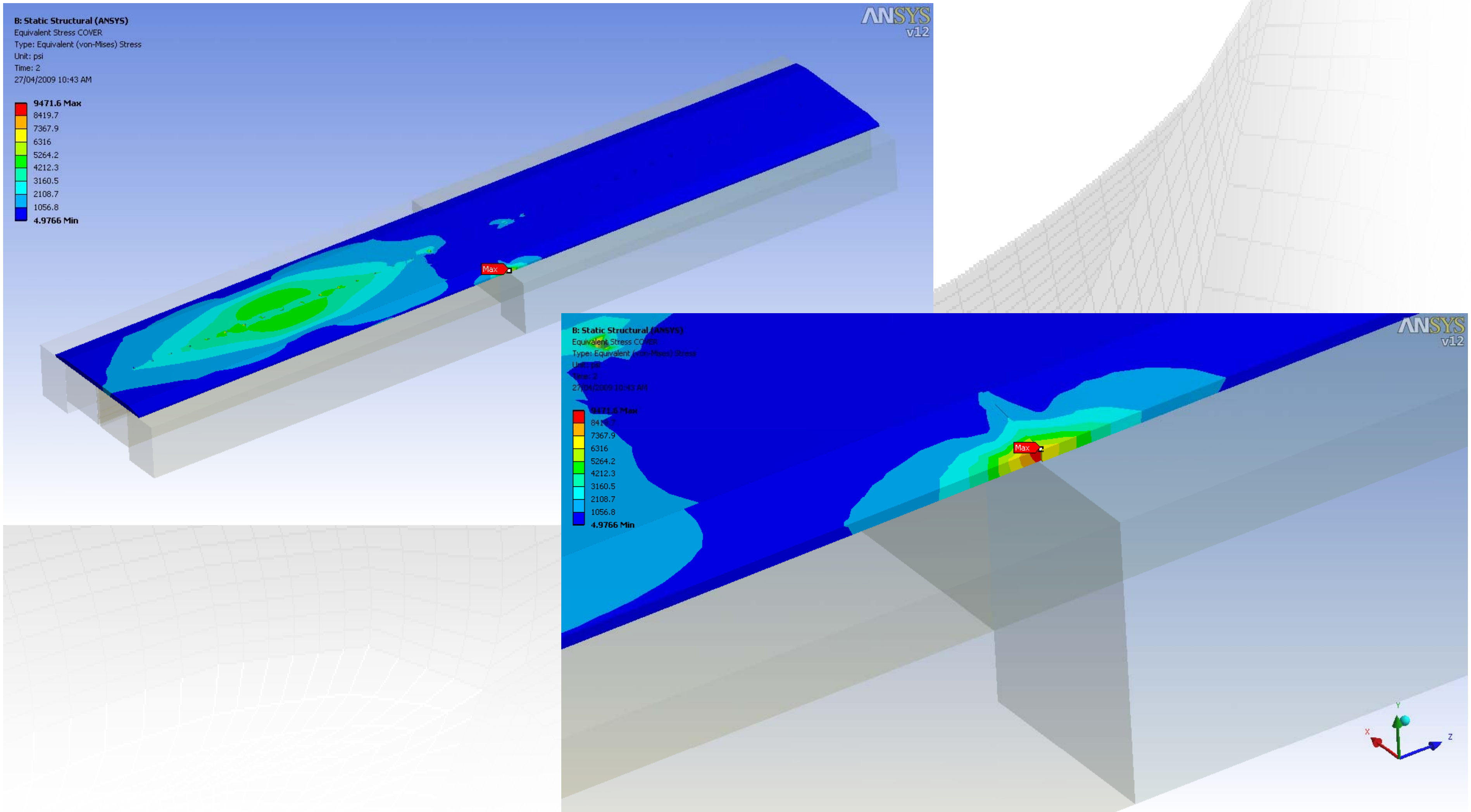


Figure 8. von Mises Equivalent Stress Contours, Cover Plate.

Results (cont.)

Time = 1.4155

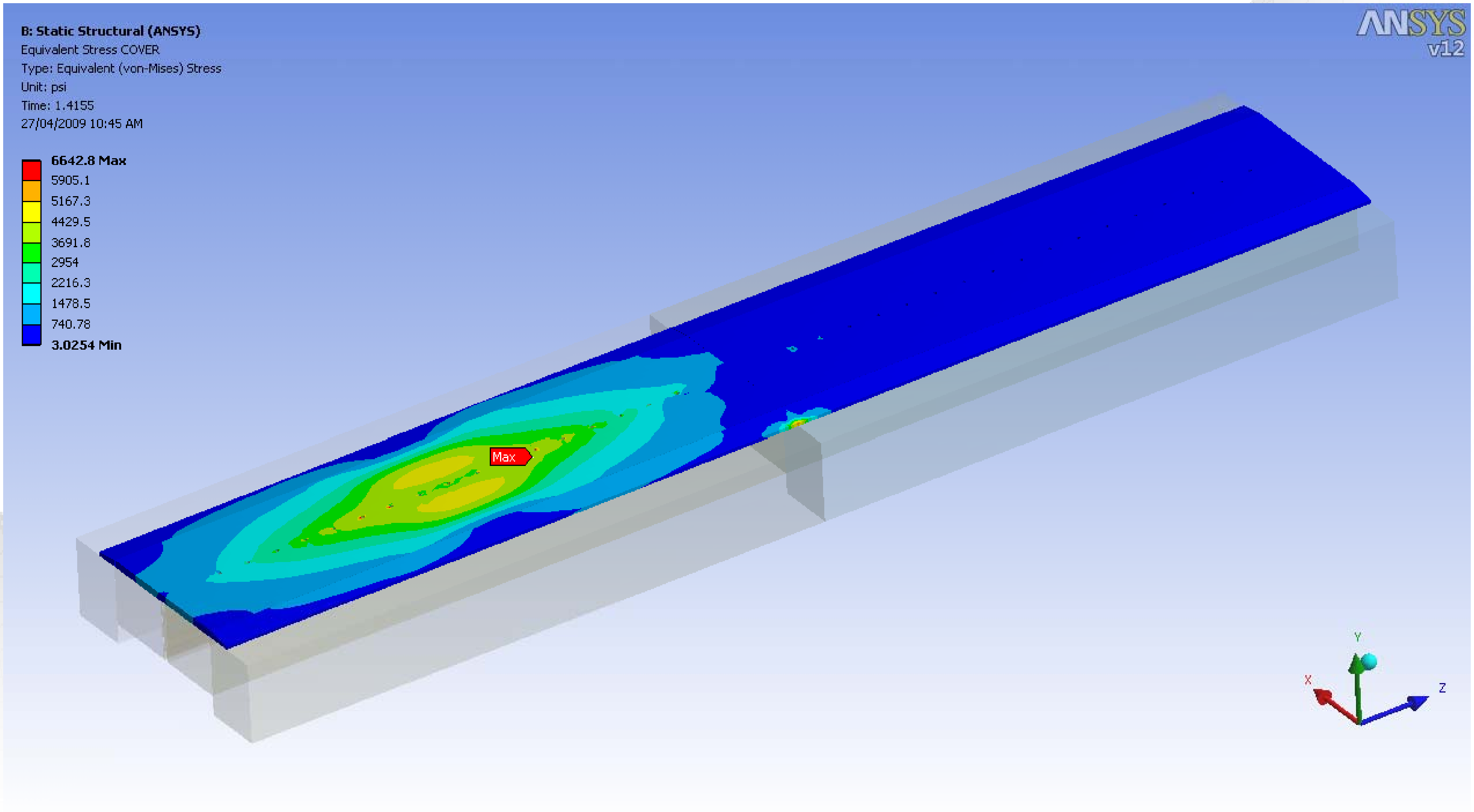


Figure 9. von Mises Equivalent Stress Contours, Cover Plate.

Results (cont.)

Time = 1.0

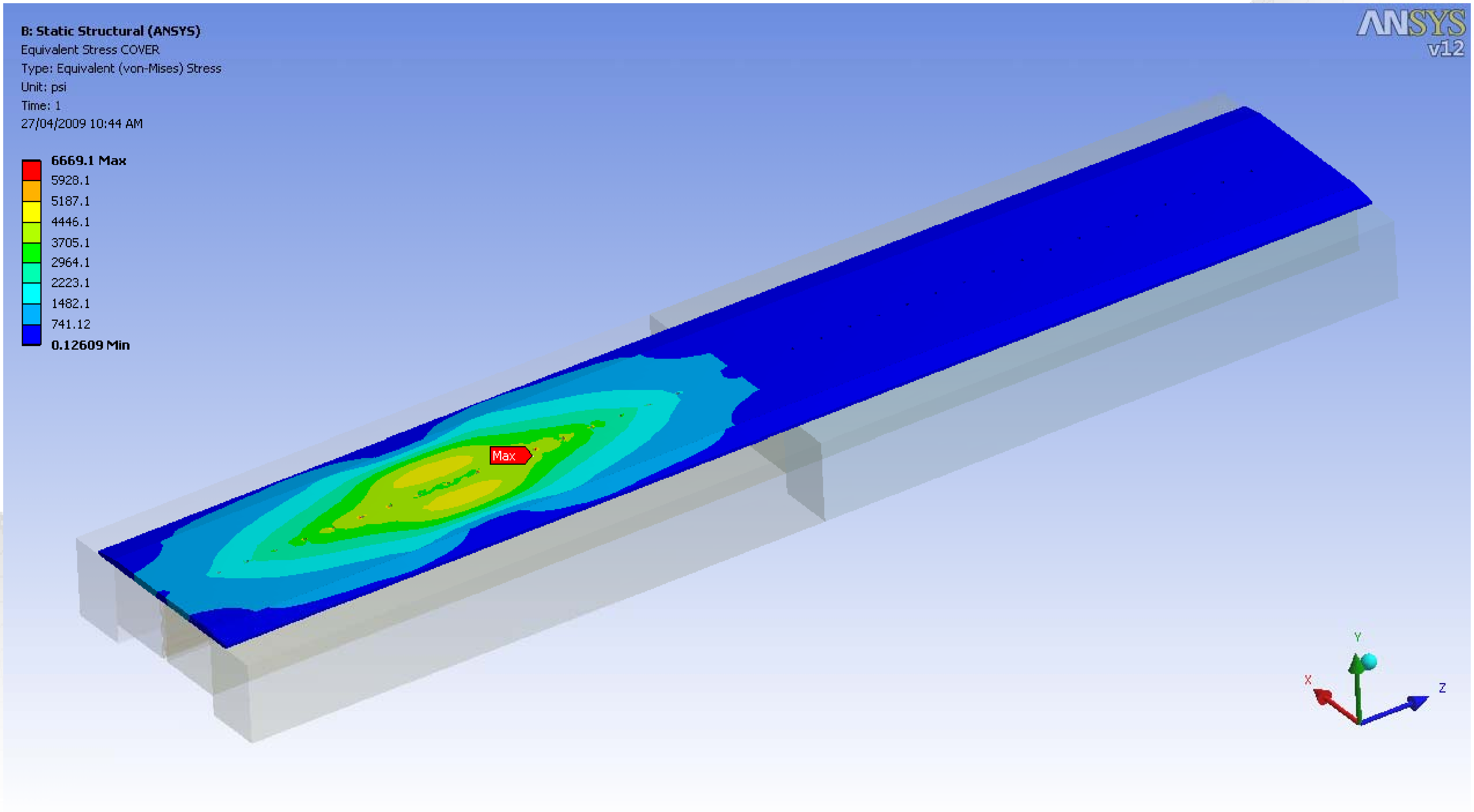


Figure 10. von Mises Equivalent Stress Contours, Cover Plate.

Results (cont.)

Time = 2.0

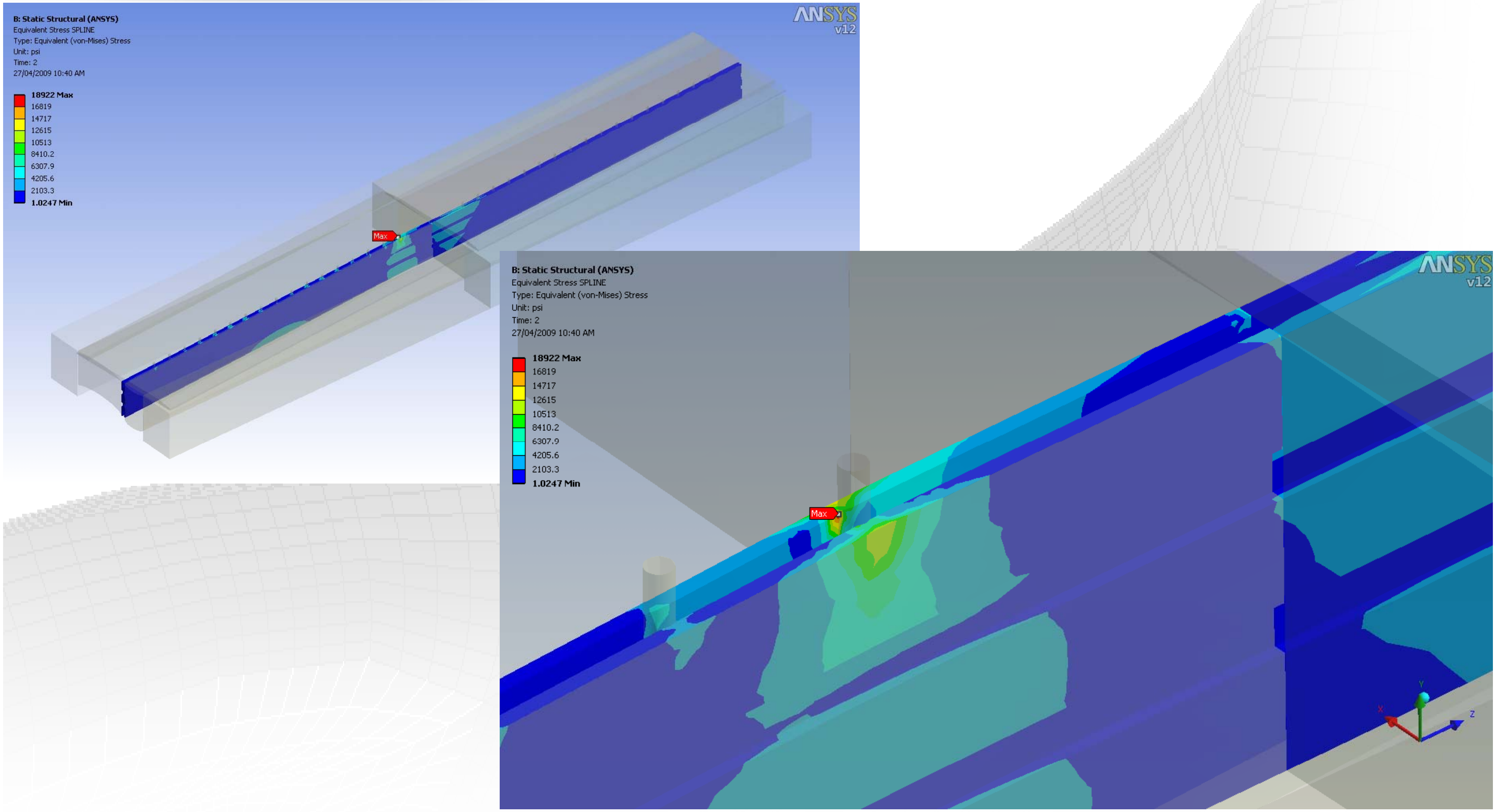


Figure 11. von Mises Equivalent Stress Contours, Spline.

Results (cont.)

Time = 1.4155

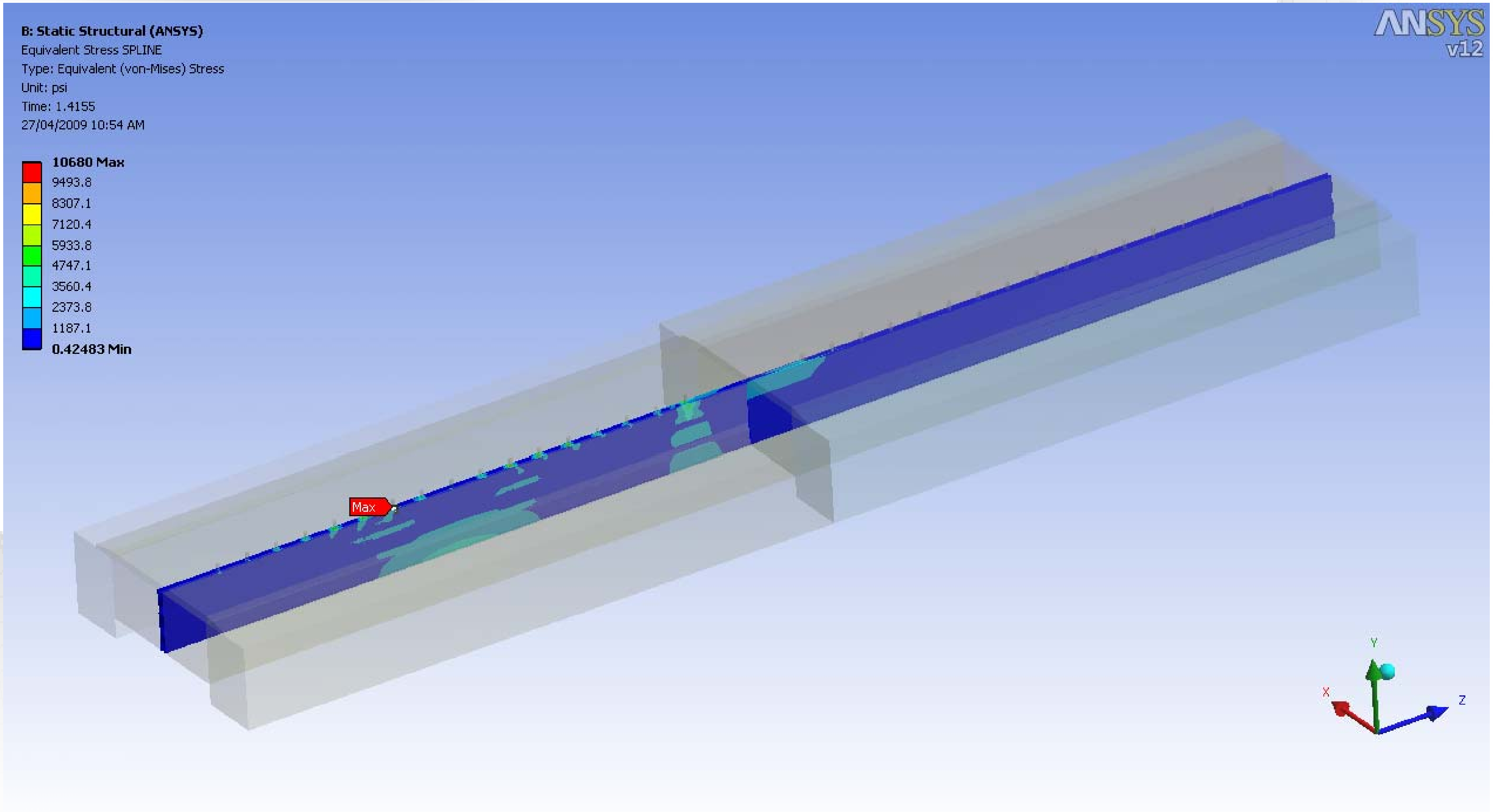


Figure 12. von Mises Equivalent Stress Contours, Spline.

Results (cont.)

Time = 1.0

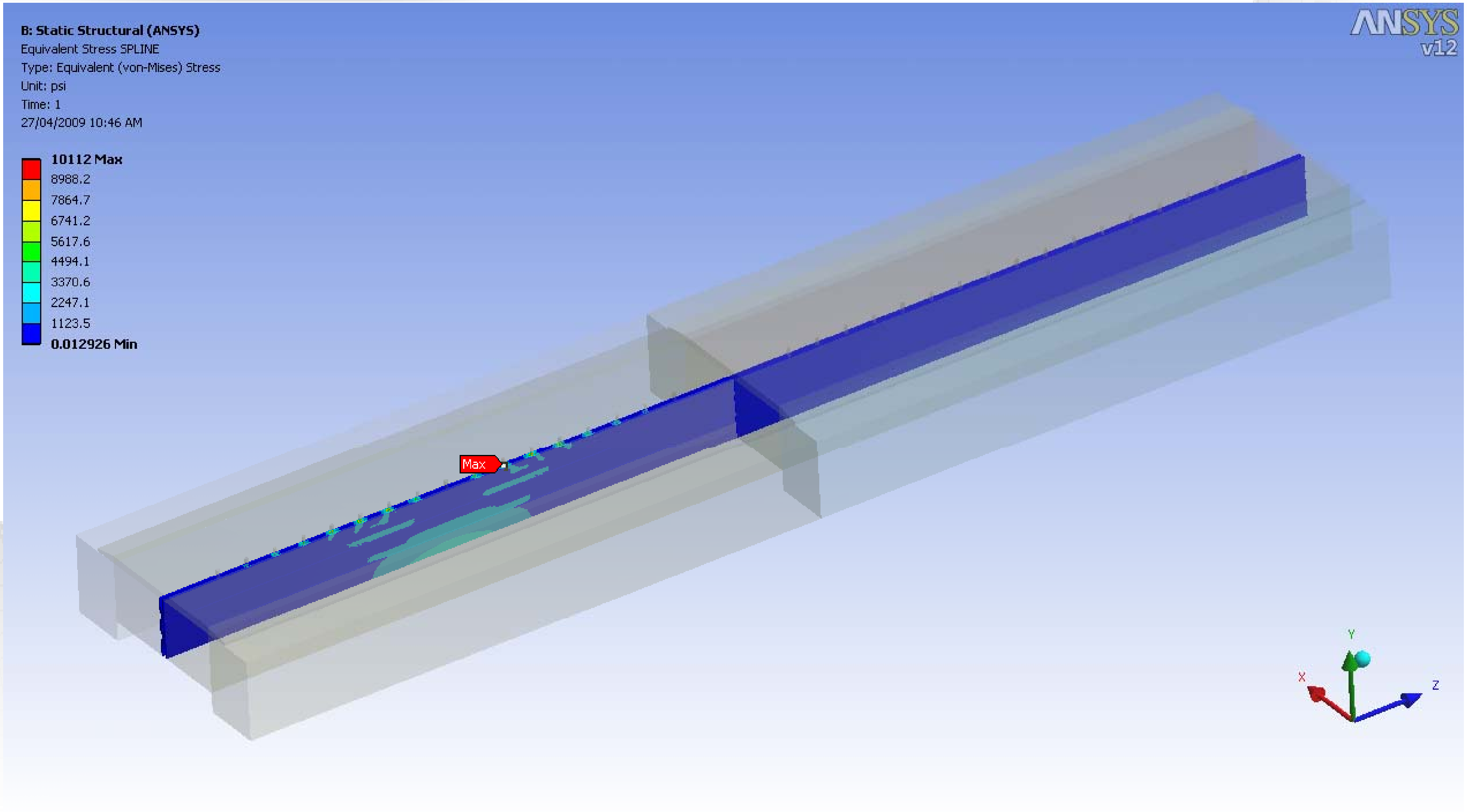
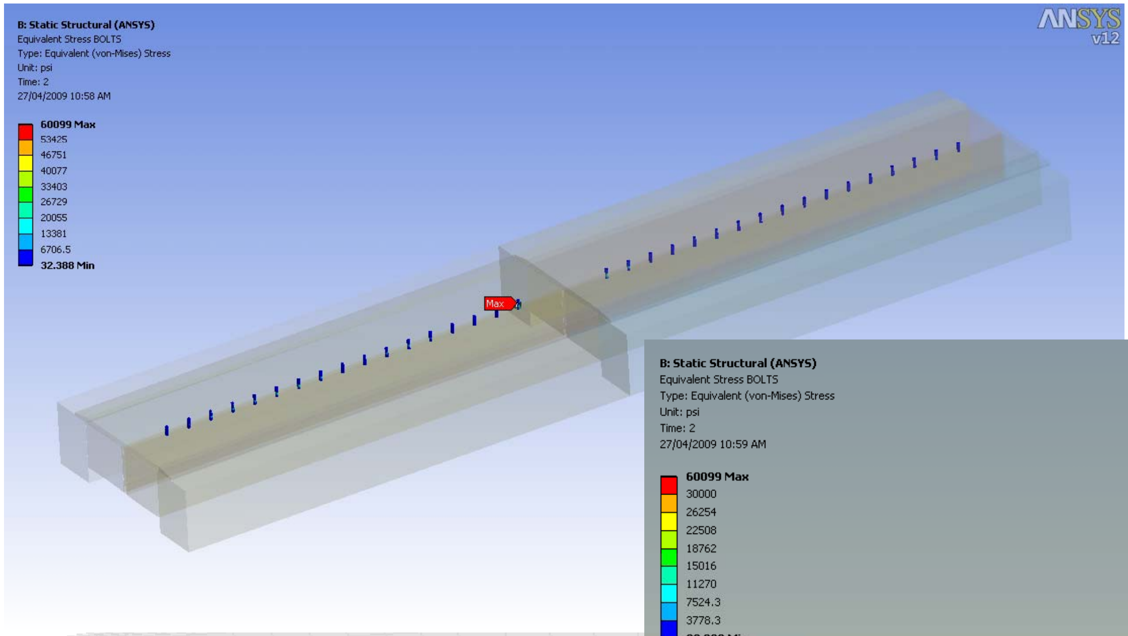


Figure 13. von Mises Equivalent Stress Contours, Spline.

Results (cont.)

Time = 2.0



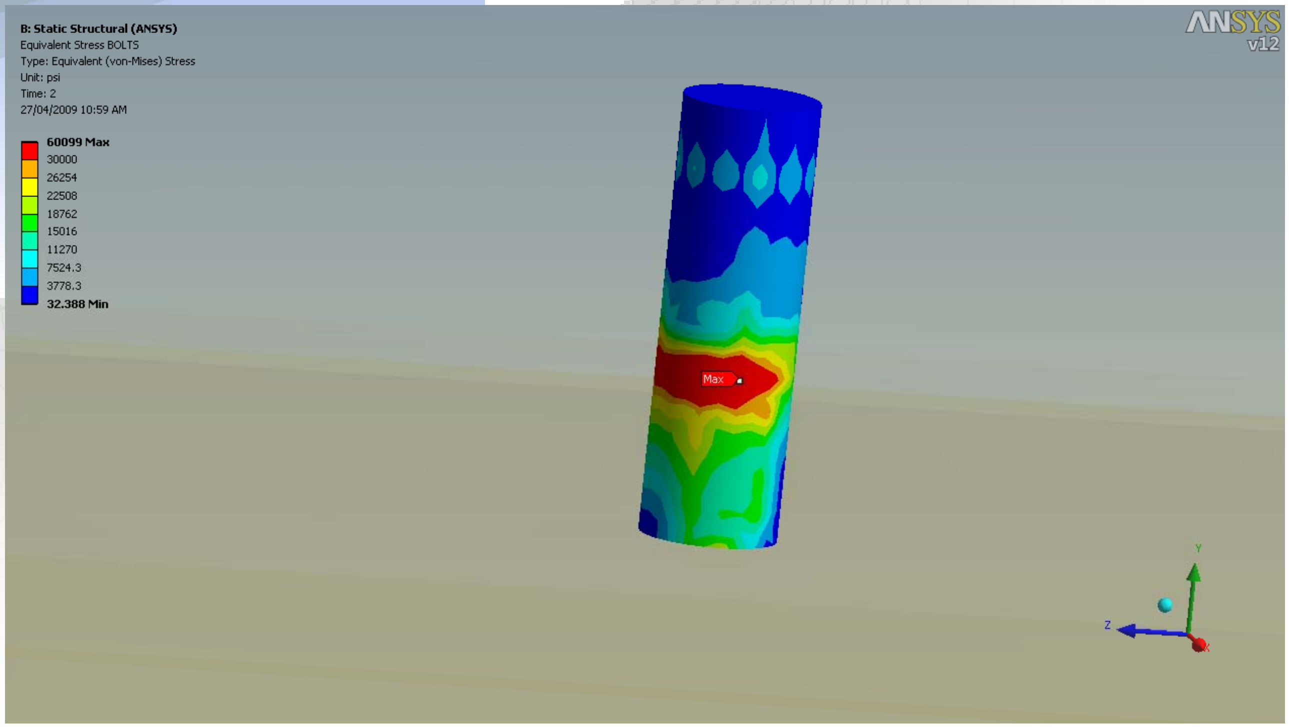
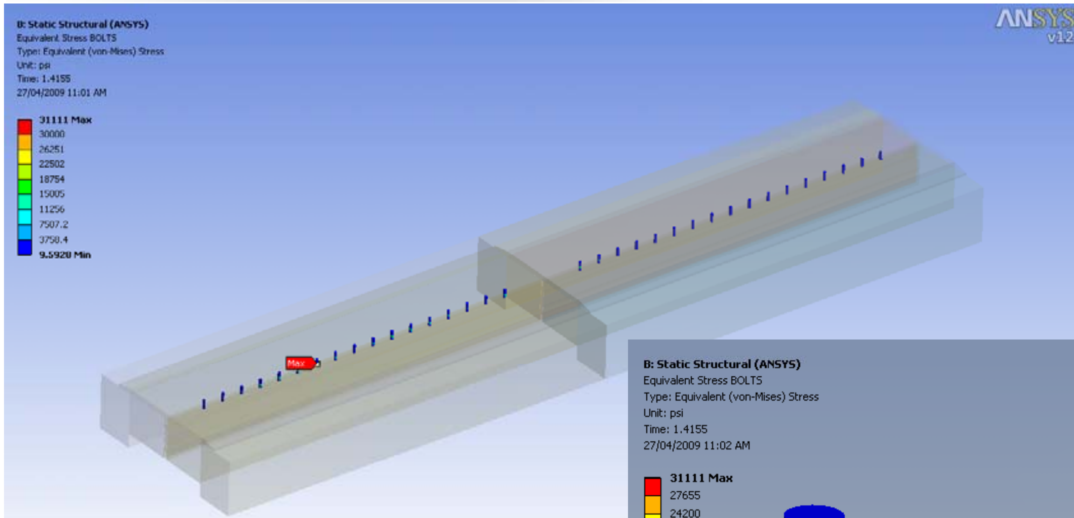


Figure 14. von Mises Equivalent Stress Contours, Bolts.

Results (cont.)

Time = 1.4155



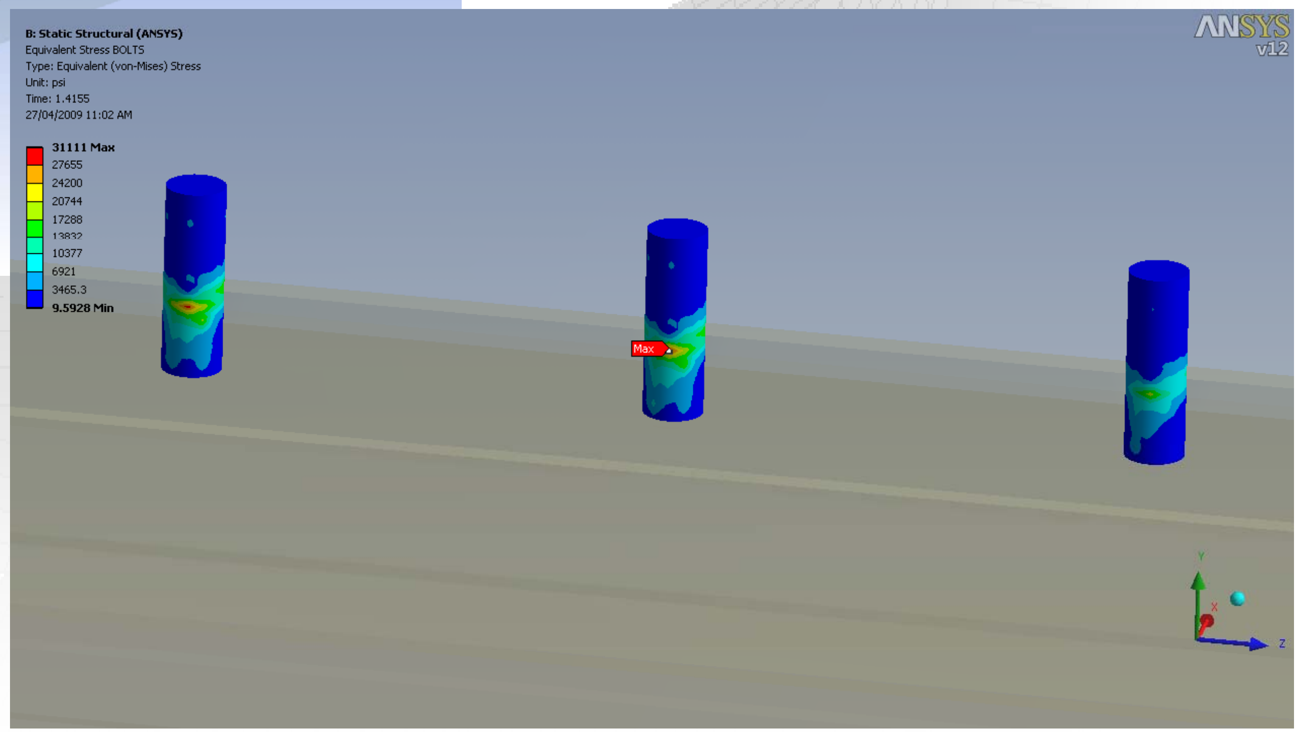


Figure 15. von Mises Equivalent Stress Contours, Bolts.

Results (cont.)

Time = 1.0

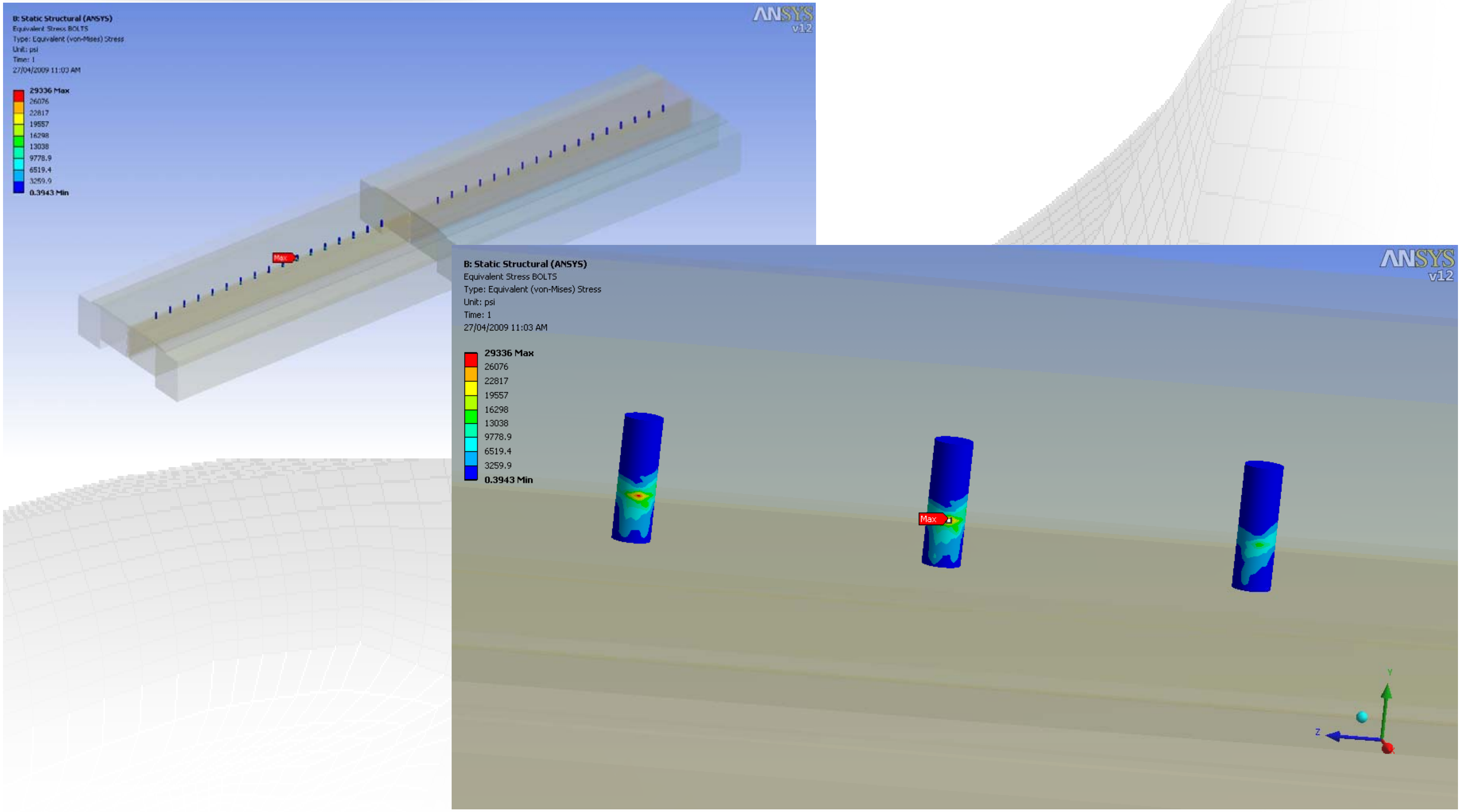


Figure 16. von Mises Equivalent Stress Contours, Bolts.

Results (cont.)

Time = 2.0

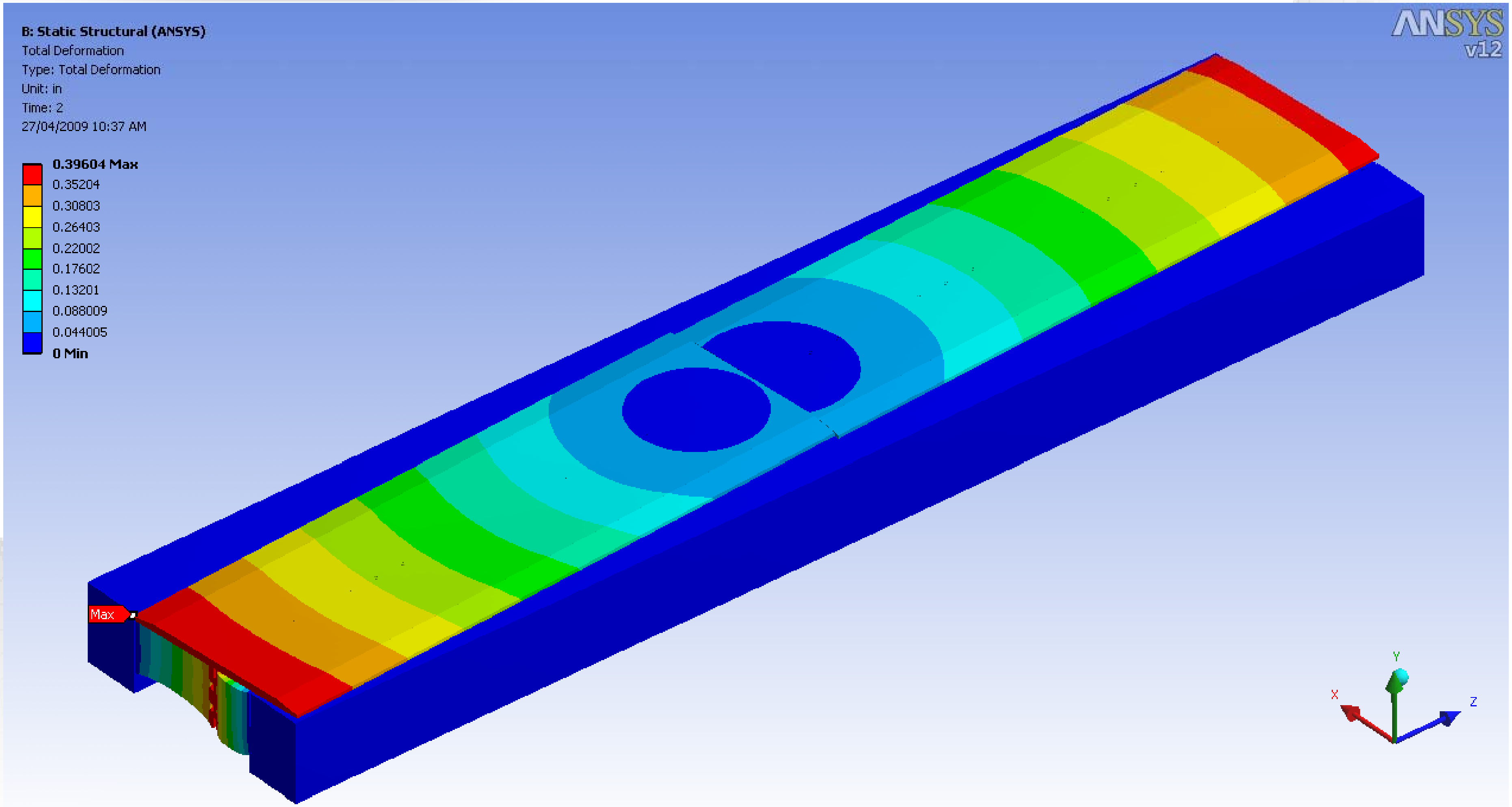


Figure 17. Deflection Contours, Assembly.

Results (cont.)

Time = 1.4155

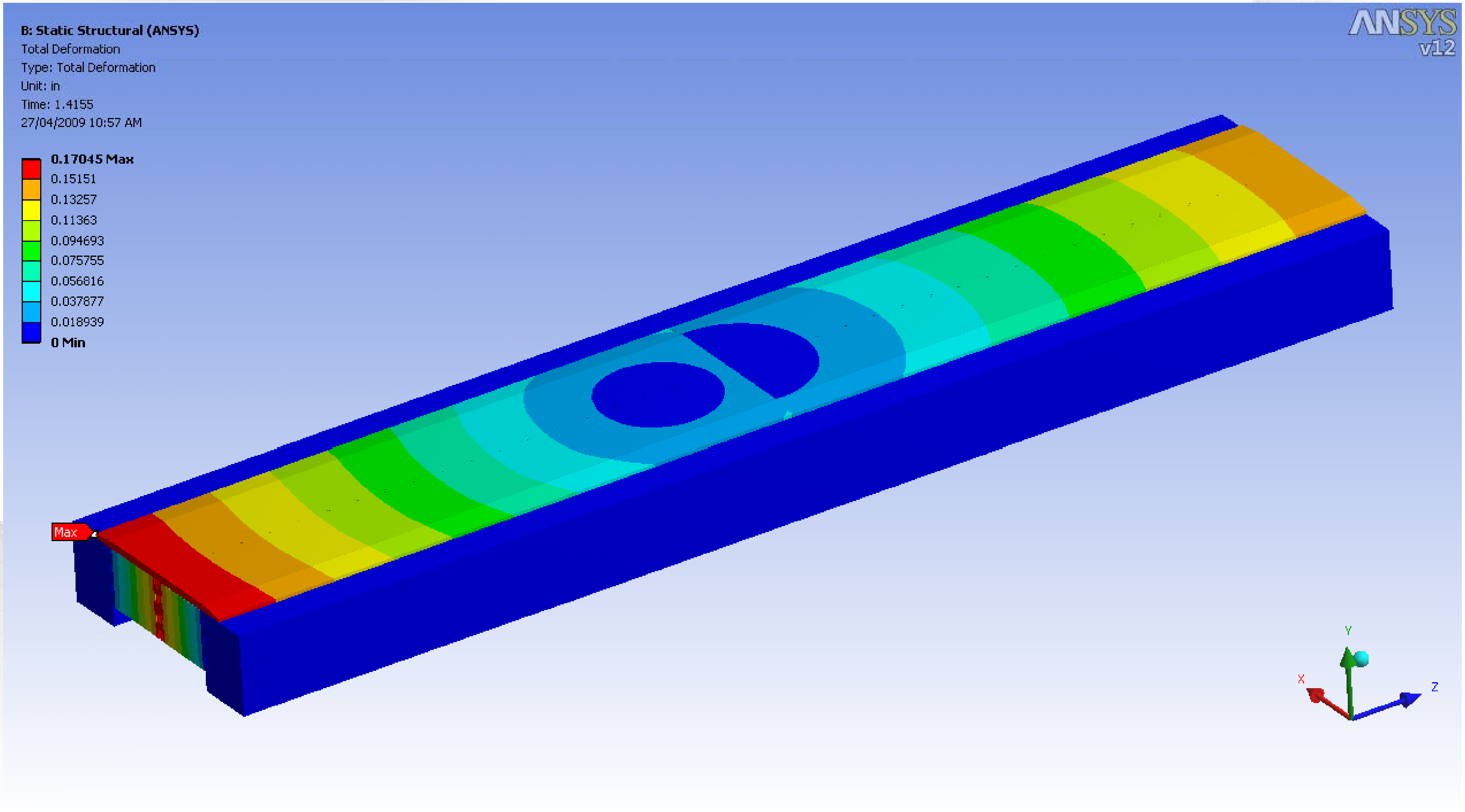


Figure 18. Deflection Contours, Assembly.

Results (cont.)

Time = 1.0

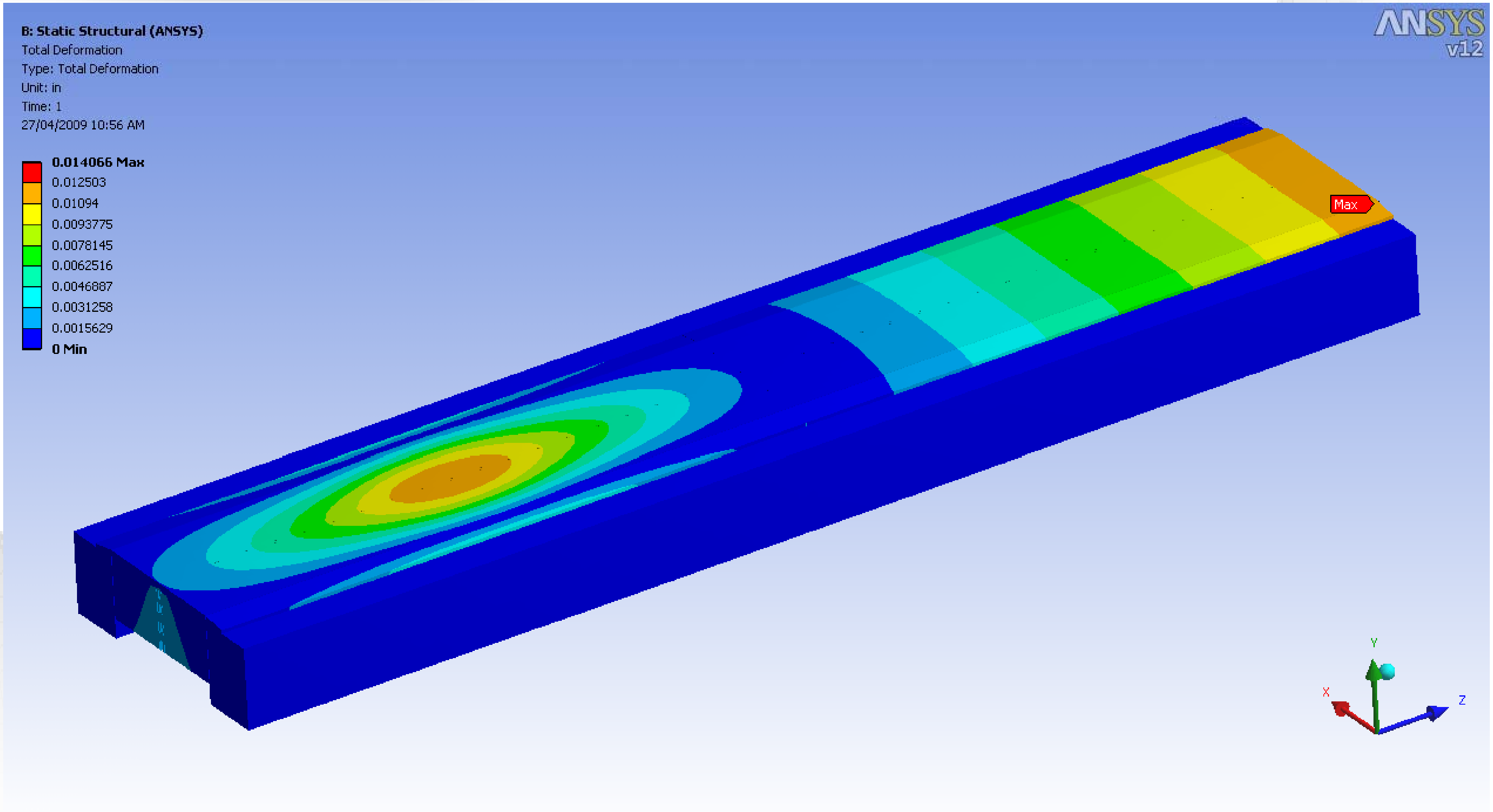


Figure 19. Deflection Contours, Assembly.

Results (cont.)

Time = 2.0

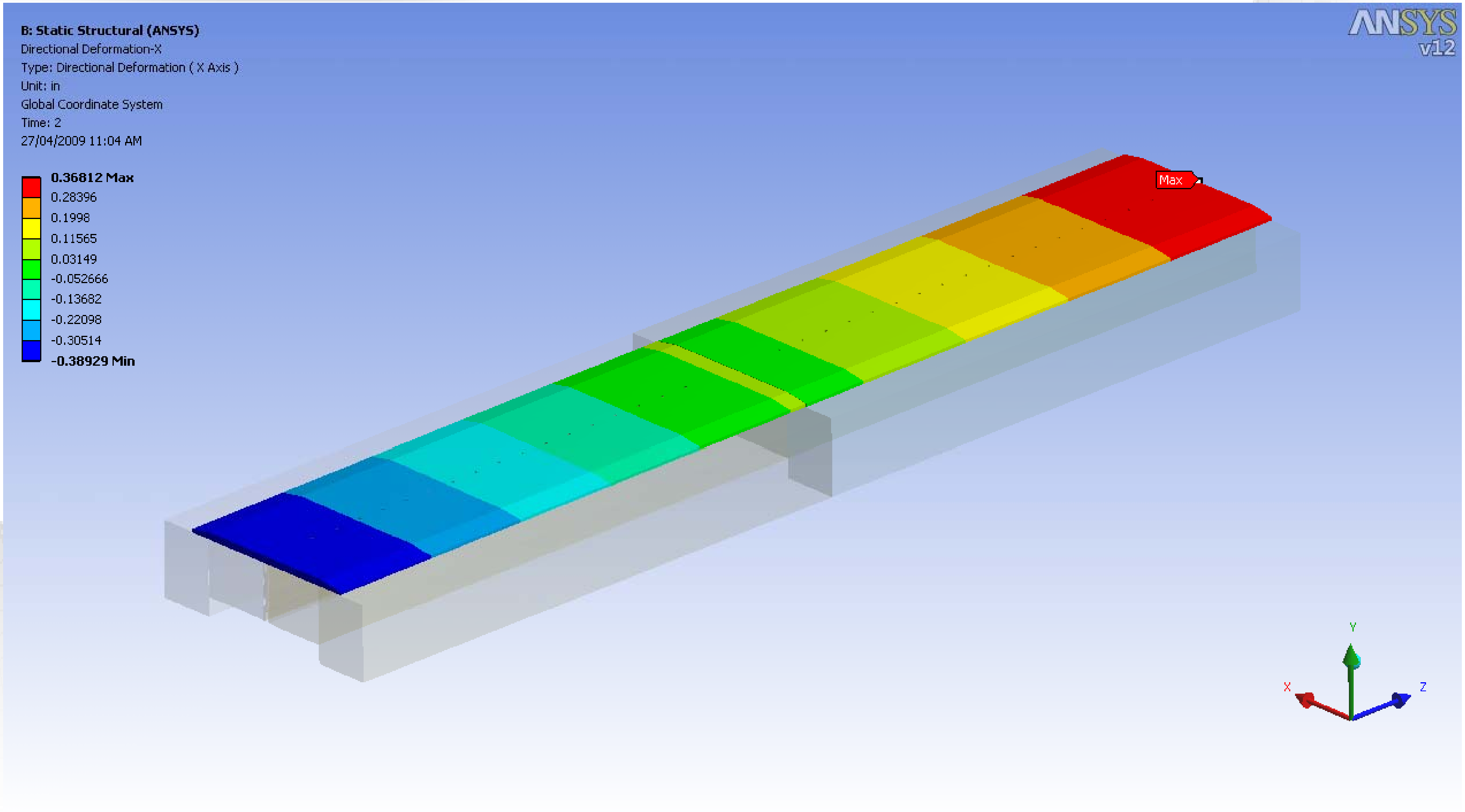


Figure 20. Deflections, Global X Direction.

Results (cont.)

Time = 1.4155

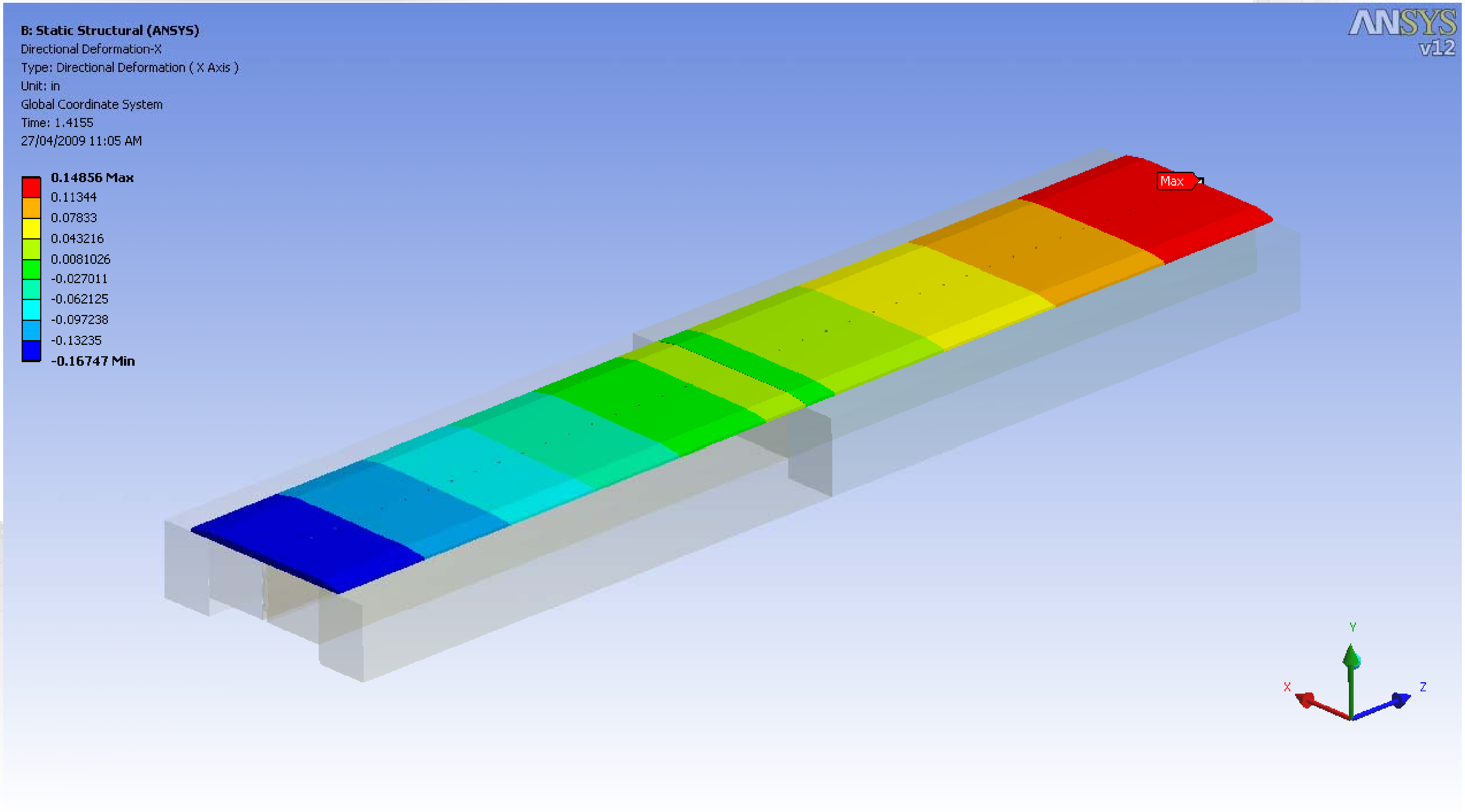


Figure 21. Deflections, Global X Direction.

Results (cont.)

Time = 1.0

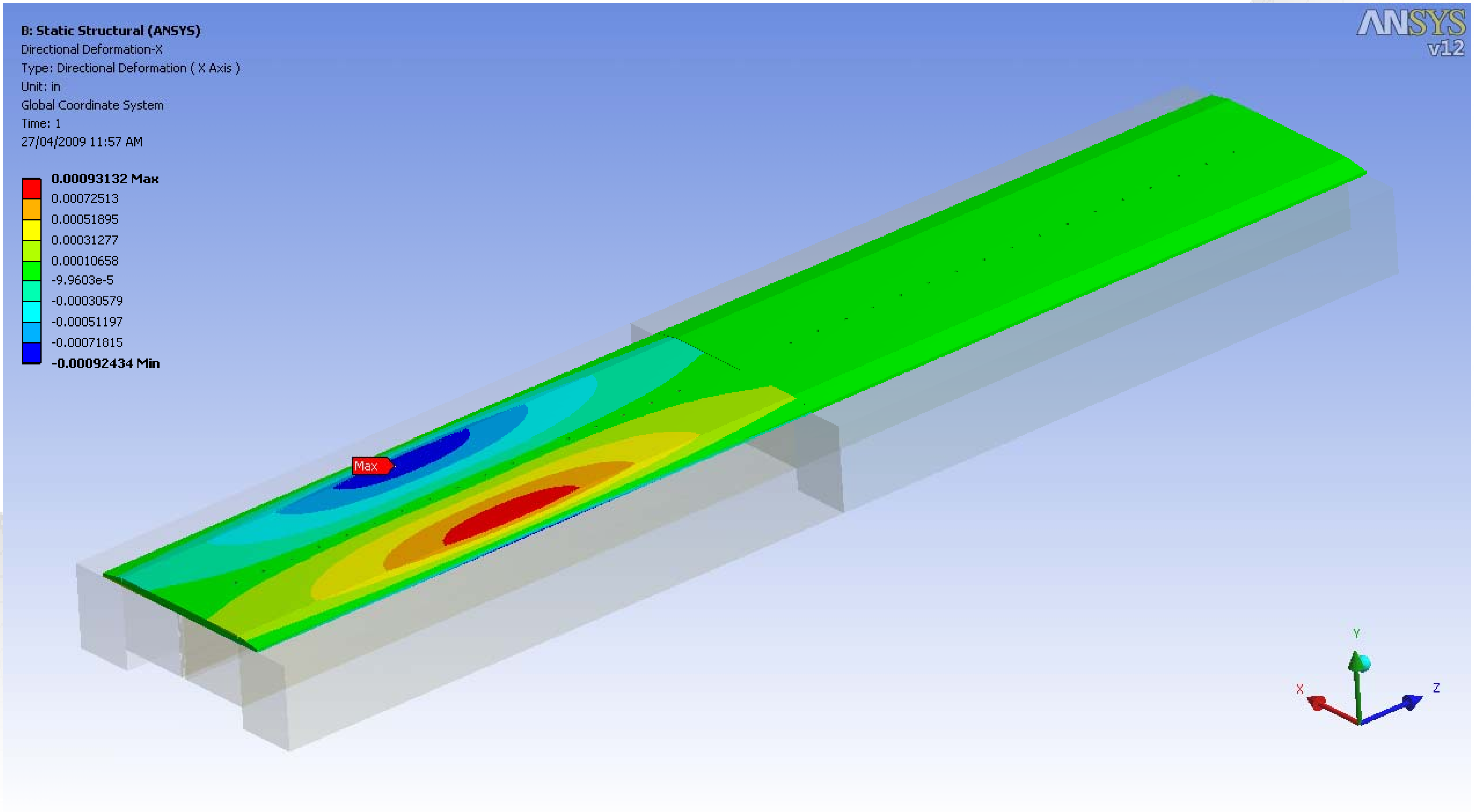


Figure 22. Deflections, Global X Direction.

Results (cont.)

Time = 2.0

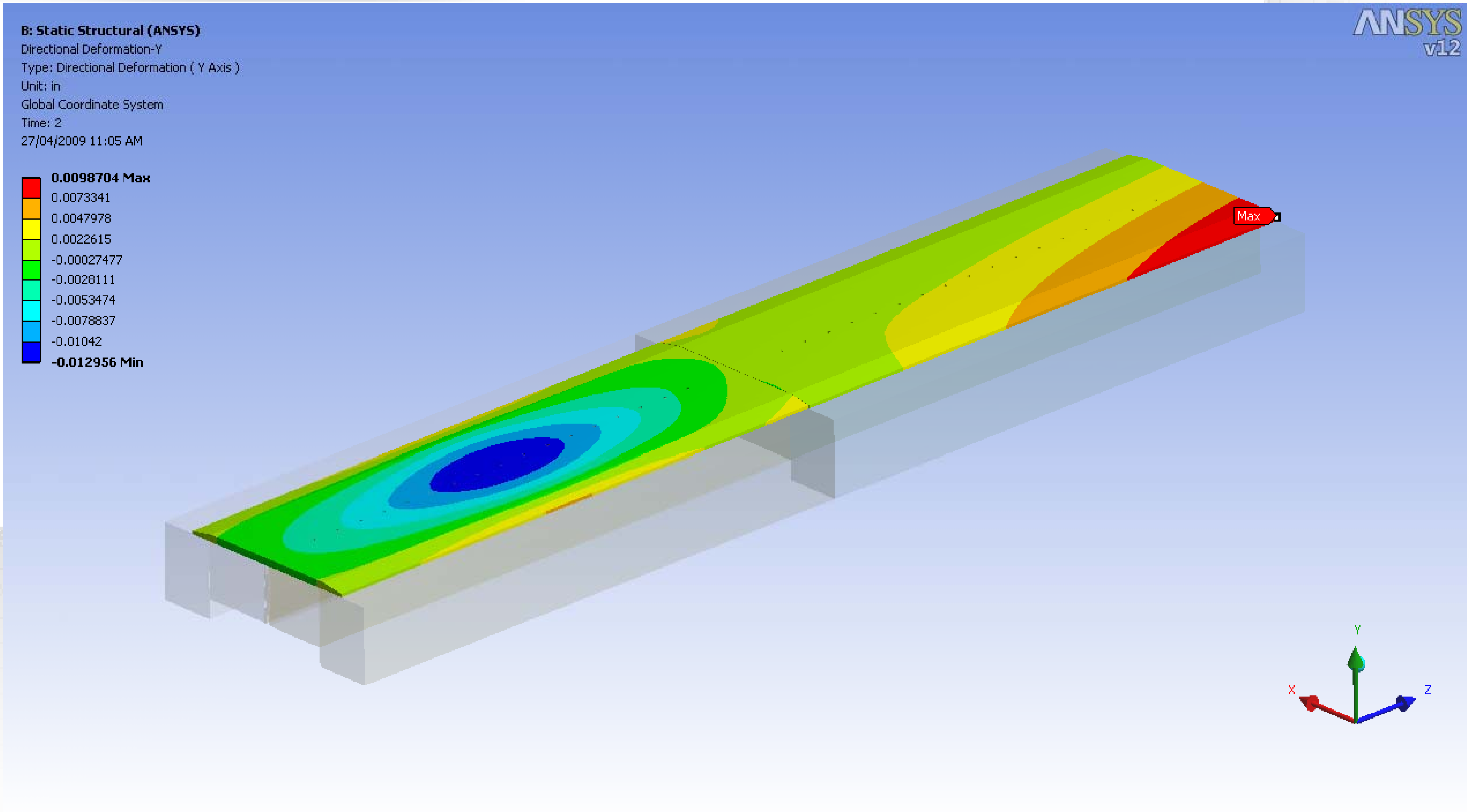


Figure 23. Deflections, Global Y Direction.

Results (cont.)

Time = 1.4155

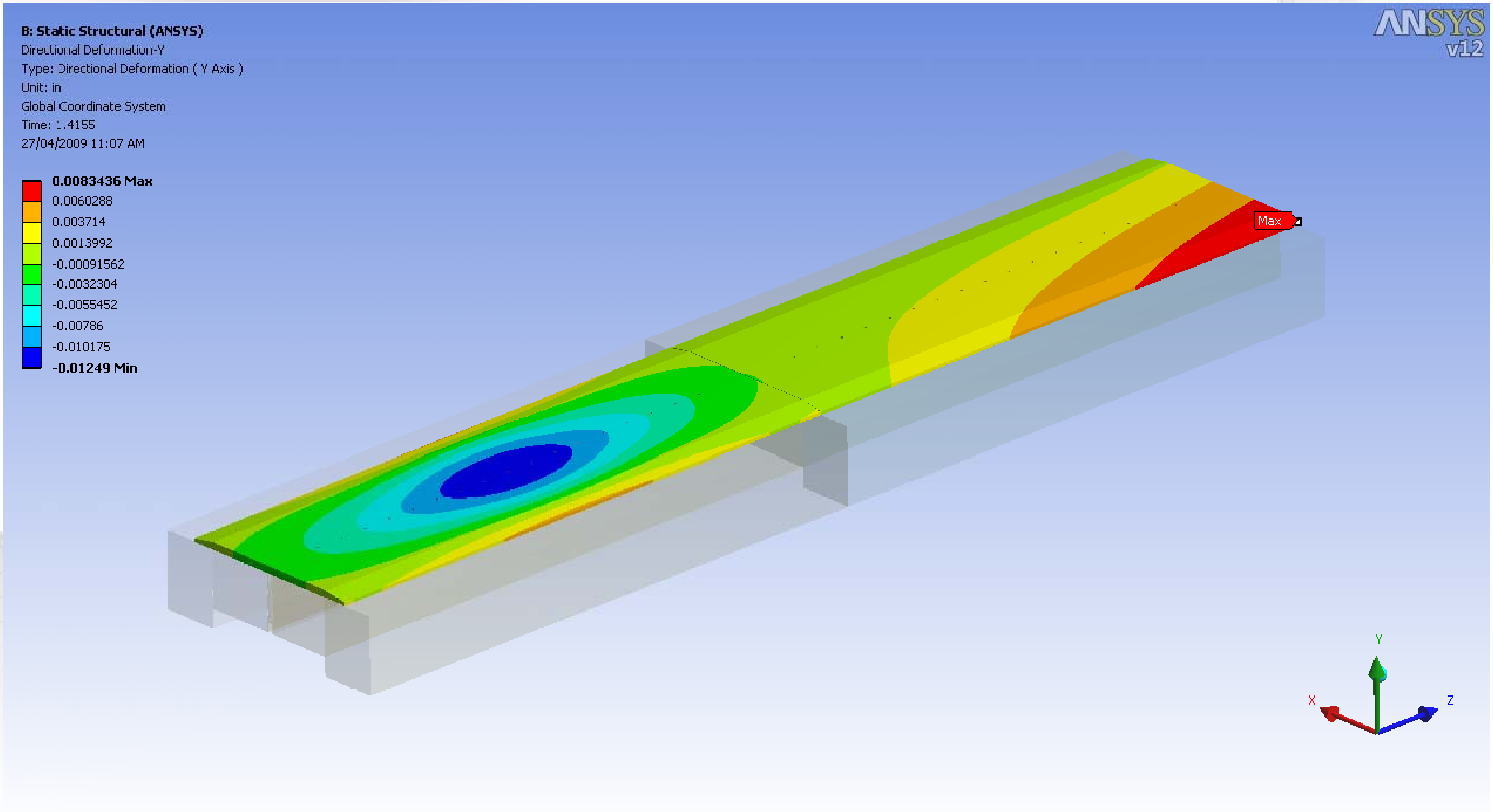


Figure 24. Deflections, Global Y Direction.

Results (cont.)

Time = 1.0

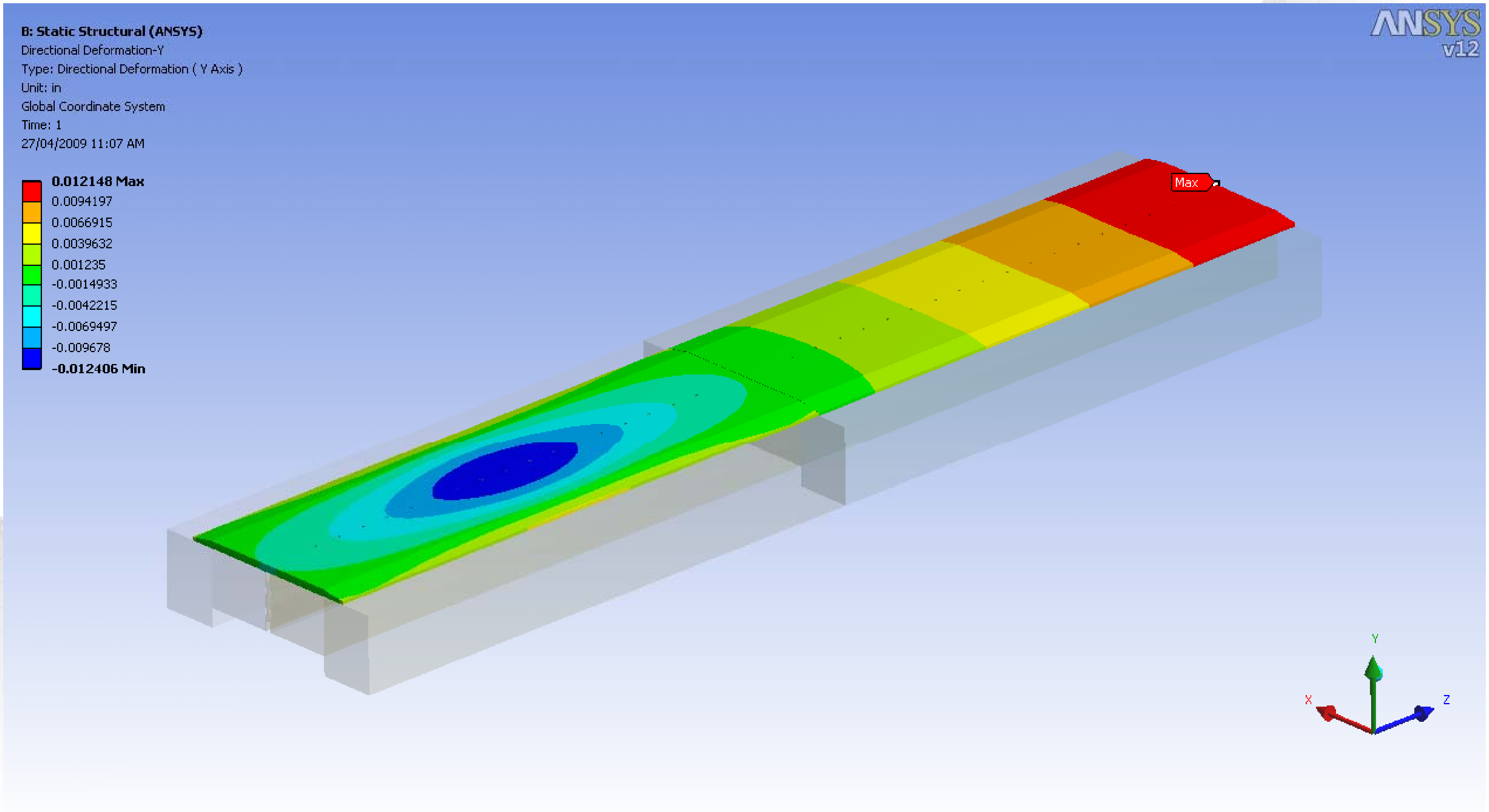


Figure 25. Deflections, Global Y Direction.

Results (cont.)

- Table 1 is a summary of maximum computed stresses for the SJS configuration analyzed.
- The maximum stress computed occurs at the bonded contact regions that represent the base connection of the screw to the spline (see Figure 14). The value is 60,099 lbf/in.^{2}
- This peek stress is highly concentrated and may not be a representative physical stress. The average stress at this location is closer to 30,000 lbf/in.^{2}
- The maximum stress computed in the cover plate is 9,472 lbf/in.^{2} (see Figure 8).
- The maximum stress computed in the spline is 18,922 lbf/in.^{2} and is at a screw location (see Figure 11).
- The maximum upward deflection is 0.012 in. and occurs when there is vertical load only (Time = 1.0, see Figure 25).
- The maximum downward deflection is 0.013 in. and occurs when maximum torque is applied with the vertical load (Time = 2.0, see Figure 23).
- The maximum lateral deflection is 0.389 in. at Time = 2.0 (see Figure 20).

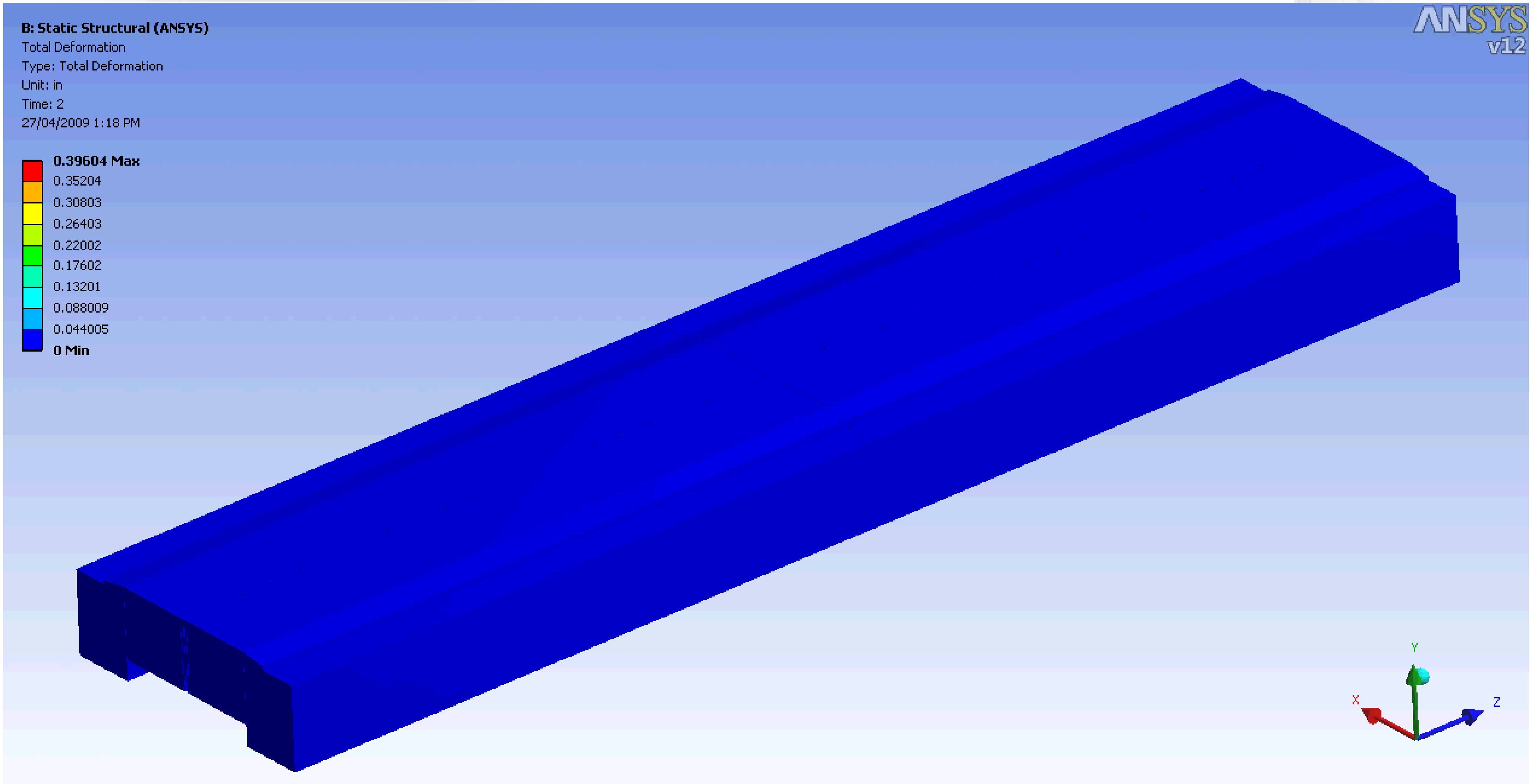
Results (cont.)

	Time = 1.0 8,000 lbf only	Time = 1.4155 8,000 lbf plus 12,800 lbf-in. torque	Time = 2.0 8,000 lbf plus 30,800 lbf-in. torque
Max. Stress 304 SS Plate ($lbf/in.^2$)	6,669	6,643	9,472
Max. Stress Spline ($lbf/in.^2$)	10,112	10,680	18,922
Max. Stress Bolts ($lbf/in.^2$)	29,336	31,111	60,099
Max. Upward Deflection (in.)	0.0121	0.0008	0.01
Max. Downward Deflection (in.)	0.0124	0.0125	0.013
Max. Lateral Deflection (in.)	0.0009	0.167	0.389

Table 1. Summary of Maximum Stress and Deflections.

Results (cont.)

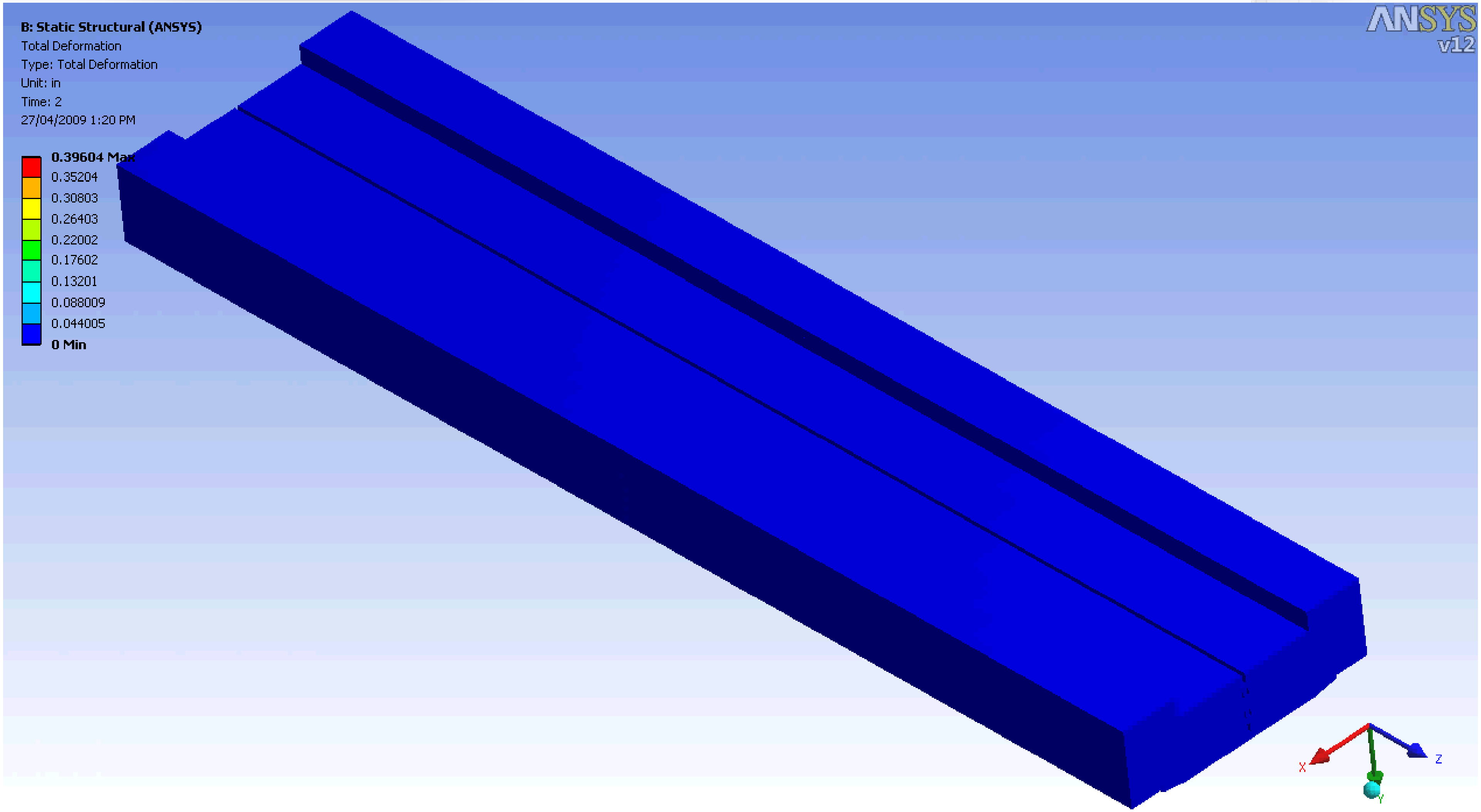
Animation Files



Exaggerated Scale (x10)

Results (cont.)

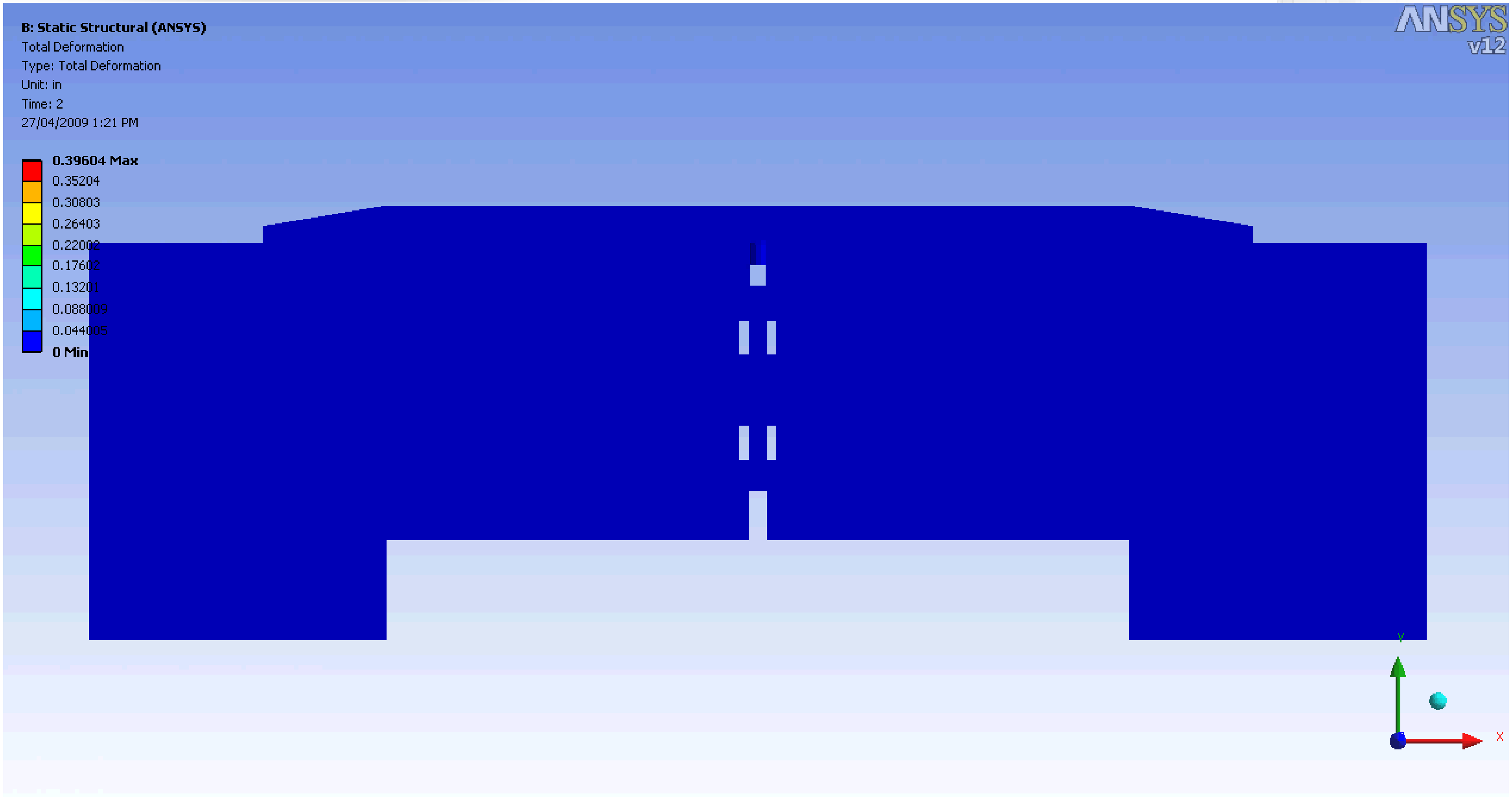
Animation Files



Exaggerated Scale (x10)

Results (cont.)

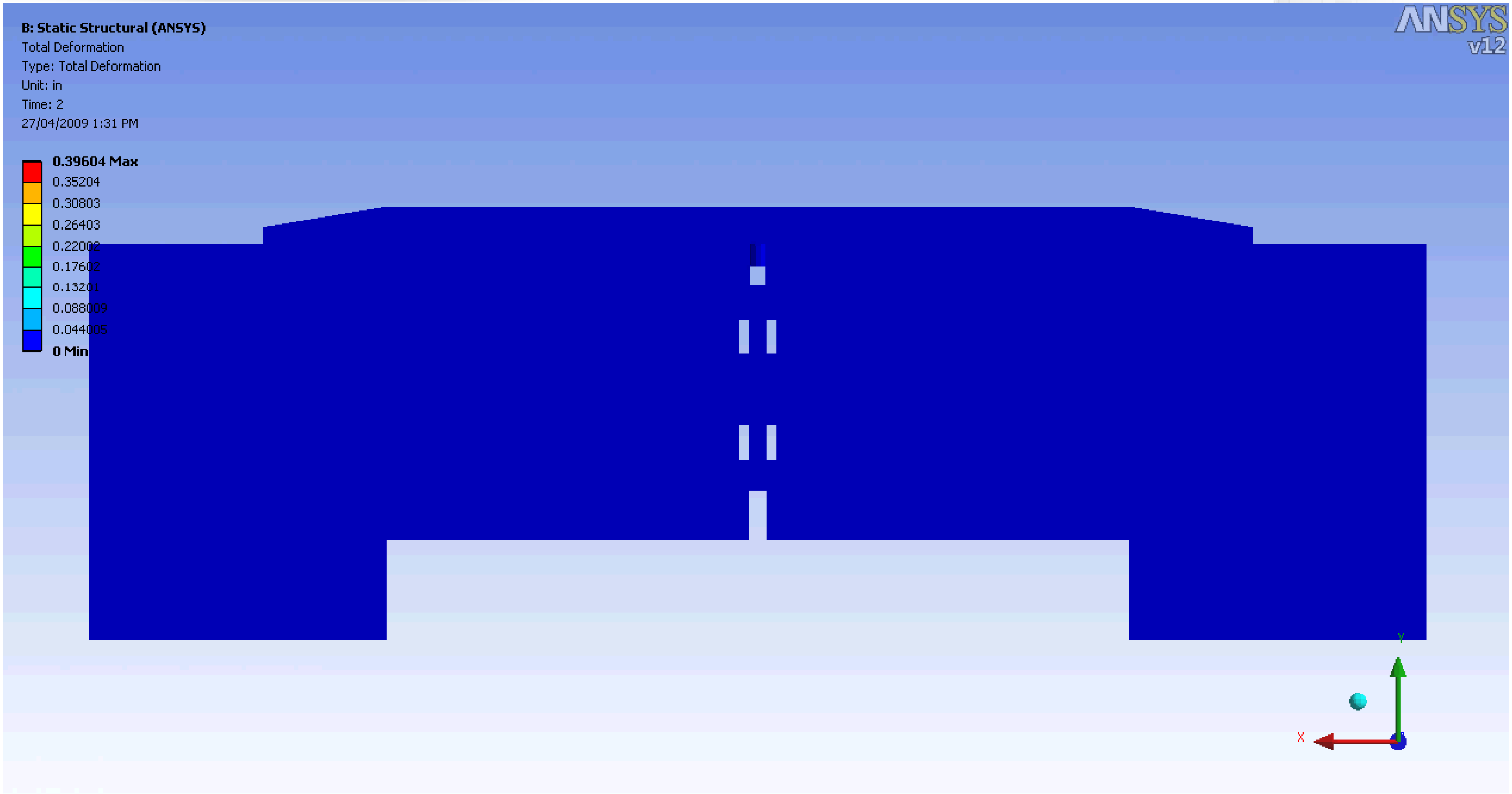
Animation Files



Exaggerated Scale (x10)

Results (cont.)

Animation Files



Exaggerated Scale (x10)

Comments

•The maximum stresses computed are at the fastening locations. These absolute peak stress magnitudes computed should not be viewed as quantitative. However, the peak stresses are likely to occur at the fastener locations therefore the fastening method should be reviewed to ensure safety after many application of loads.

•The stresses in the cover plate are acceptable and well below the yield and fatigue allowable for this material.

•The peak stress computed in the spline is at a fastener location and is also concentrated (see Figure 11). This should not be a concern accept for long term repeated loads and the possibility of a fastener loosening.

•As mentioned in the introduction an SJS configuration with keyways bonded to the cover plate was also analyzed. The intention for the keyways was to transfer the torque through the spline, foam and finally to the pavement. Since the keyways will have a clearance tolerance, the fasteners will initially react all the torque and the keyways will contact the spline after some deformation is allowed by the fasteners.

Comments (cont.)

- The efficiency of the keyways to transfer the torque on the cover plate for the SJS configuration with 9 fasteners and 10 keyways was not demonstrated from the FE analysis results as most of the load went through the fasteners.

- Removal of the keyways and replacing with fasteners will give a more efficient structure to transfer the torque and some redundancy in the number of fasteners for long term safety.