Analysis of a Seismic Joint System

for

EMSEAL Corporation

Prepared by

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Contents

Introduction

•EMSEAL Corporation requested ROI Engineering Inc. (ROIE) to analyze a Seismic Joint System (SJS).

•Static linear and non-linear material analyses were completed and summary reports prepared dated 27-May-2008 and 06-June-2008 respectively.

•The purpose of the current analysis is to extend the investigation, as reported in the 06-June-2008 report, for an SJS system with 18” cover plates and a 15” span between the concrete supports.

•The FE model used with loading and boundary conditions for this investigation is similar to that used for the SJS configuration presented in the report dated 06-June-2008.

•The geometry of the quarter 3-D model developed for the FE analysis is shown in Figure 1. The cover plate is 18” in width and 3/8” in thickness.

Introduction (cont.)

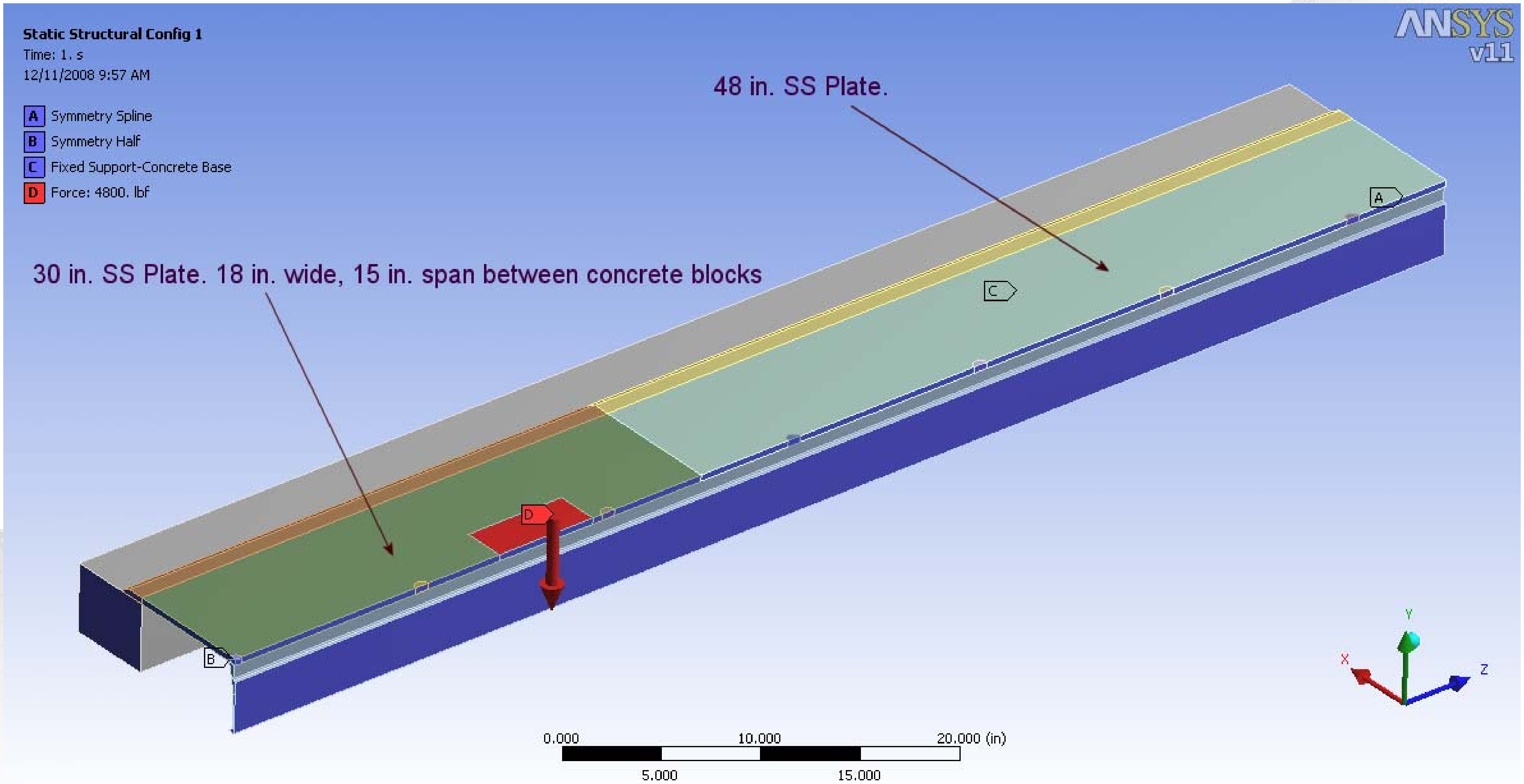


Figure 1. Quarter CAD Geometry for the SJS Configuration.

Introduction (cont.)

•The boundary conditions used at the symmetry plane represents Configuration-1 referred to in the report dated 27-May-2008.

•The fatigue analysis will be done using the standard S-N approach for which the S-N curve will be developed from the commonly used values for endurance limit at 10^3 and 10^6 cycles.

•For steels with ultimate strength (S_u) less than 200,000 lbf/in.^{2} and Brinell hardness number (BHN) less than 400 the accepted values for endurance limit S_e for 10^3 and 10^6 cycles are: (see Figure 2)

- •($0.9 \times S_u$) for 10^3 cycles and
- •($0.5 \times S_u$) or ($0.25 \times$ BHN)x1000 in lbf/in.^{2}, whichever is less, for 10^6 cycles

•Miner’s linear damage formula will be used for assessing the spectrum of loads for fatigue if required.

•Miner’s formula states fatigue failure occurs if the cummulative damage index $D_i = \sum(n_i/N_i) \geq 1$ where n_i are the number of cycles at an operating stress and N_i are the allowable stress cycles from the S-N curve at this operating stress.

Introduction (cont.)

- The load spectrum specified for the SJS by EMSeal for 10^6 cycles is as follows:
    - 20% of loads at 3,200 lbf (fully loaded) or 200,000 cycles
    - 30% of loads at 2,500 lbf or 300,000 cycles
    - 50% of loads at 1,800 lbf (unloaded) or 500,000 cycles
- In Figure 2 the upper curve (blue) represents endurance versus cycles from the un-factored values of S_u and BHN whereas the lower curve (black) represents the same curve with some typical factors for confidence level, size, environment, surface finish, loading, etc.
- The lower curve in Figure 2 will be used to assess the fatigue life of the SJS.

Introduction (cont.)

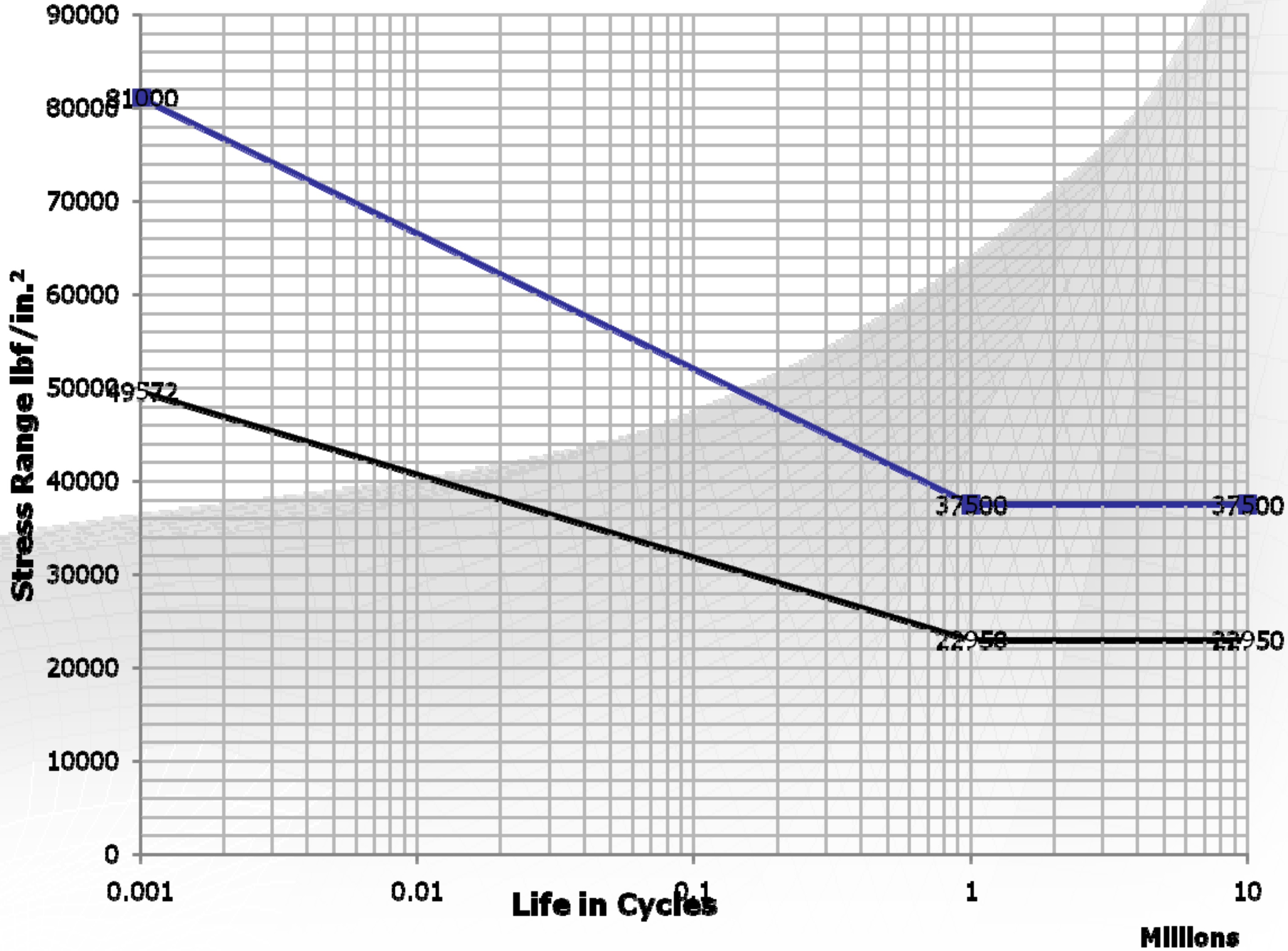
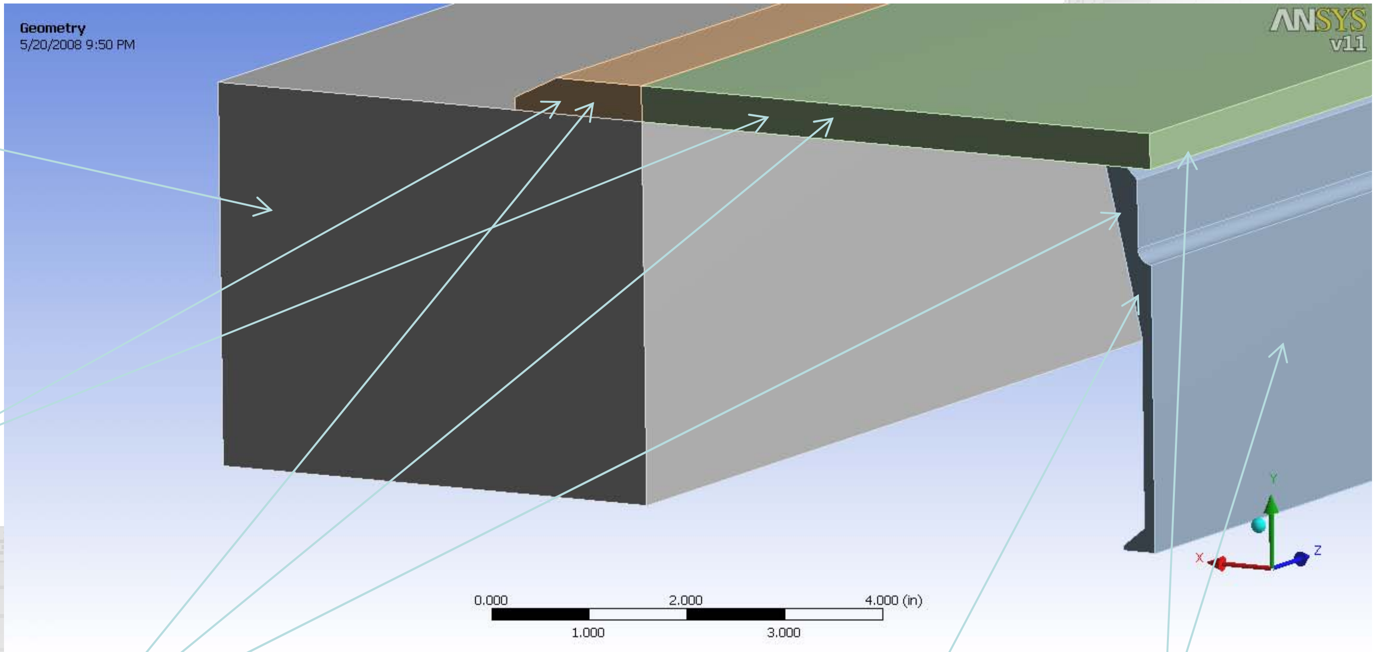


Figure 2. S-N Curve for 304 SS.

Introduction (cont.)

Symmetry Plane
Common to all
Configurations

Symmetry Plane
Configuration 1



Symmetry Plane
Configuration 2

Symmetry Plane
Configuration 3

Symmetry Plane
Common to all
Configurations

Figure 3. Symmetry Boundary Conditions.

Finite Element Model

- High order hexahedra (ss plates, dummy concrete) and tetrahedra (spline) used for the FE mesh, three degrees of freedom (dof) at each node.
- Bonded contact between the ss plate and aluminum spline at patches representing the screw locations.
- Non-linear frictionless contact between the ss plate and concrete support.
- Symmetry boundary conditions at cut planes to represent Configuration-1 as defined in the report dated 27-May-2008 (see Figure 3).
- The base of the concrete block restrained against movement in all global X, Y and Z directions.
- 6 in. by 5 in. area (see Figure 4) to represent the contact patch between forklift tyre and ss plate. Load per tyre to be applied is 9,600 lbf for ultimate stress qualification and 3,200 lbf for fatigue evaluation.
- Figure 4 shows Configuration-1 with applied load and boundary conditions.

Finite Element Model (cont.)

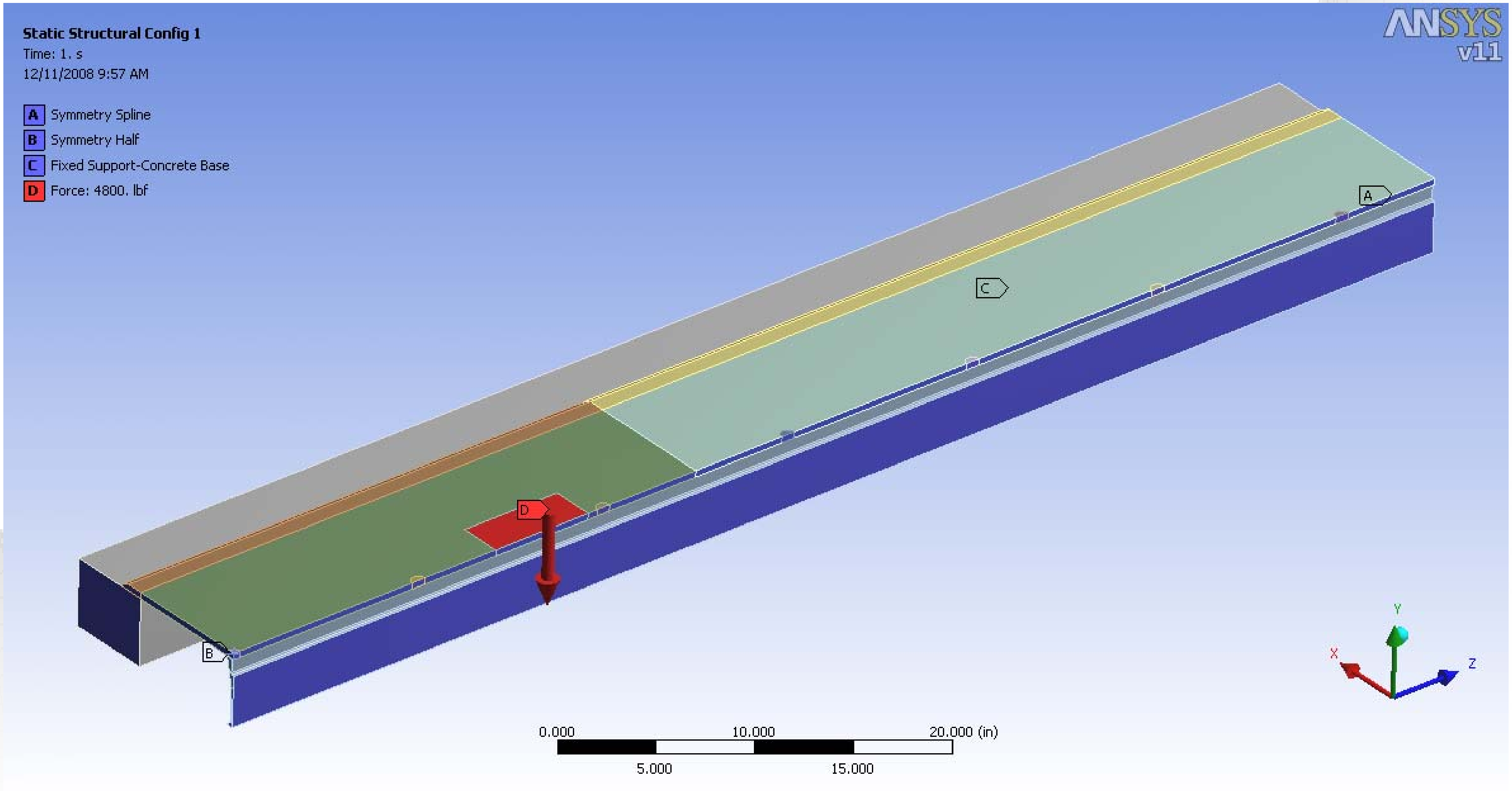


Figure 4. Boundary Conditions and Loading for Configuration 1.

Finite Element Model (cont.)

•The overall FE mesh is shown in Figure 5.

•A close-up view of the FE mesh is shown in Figure 6.

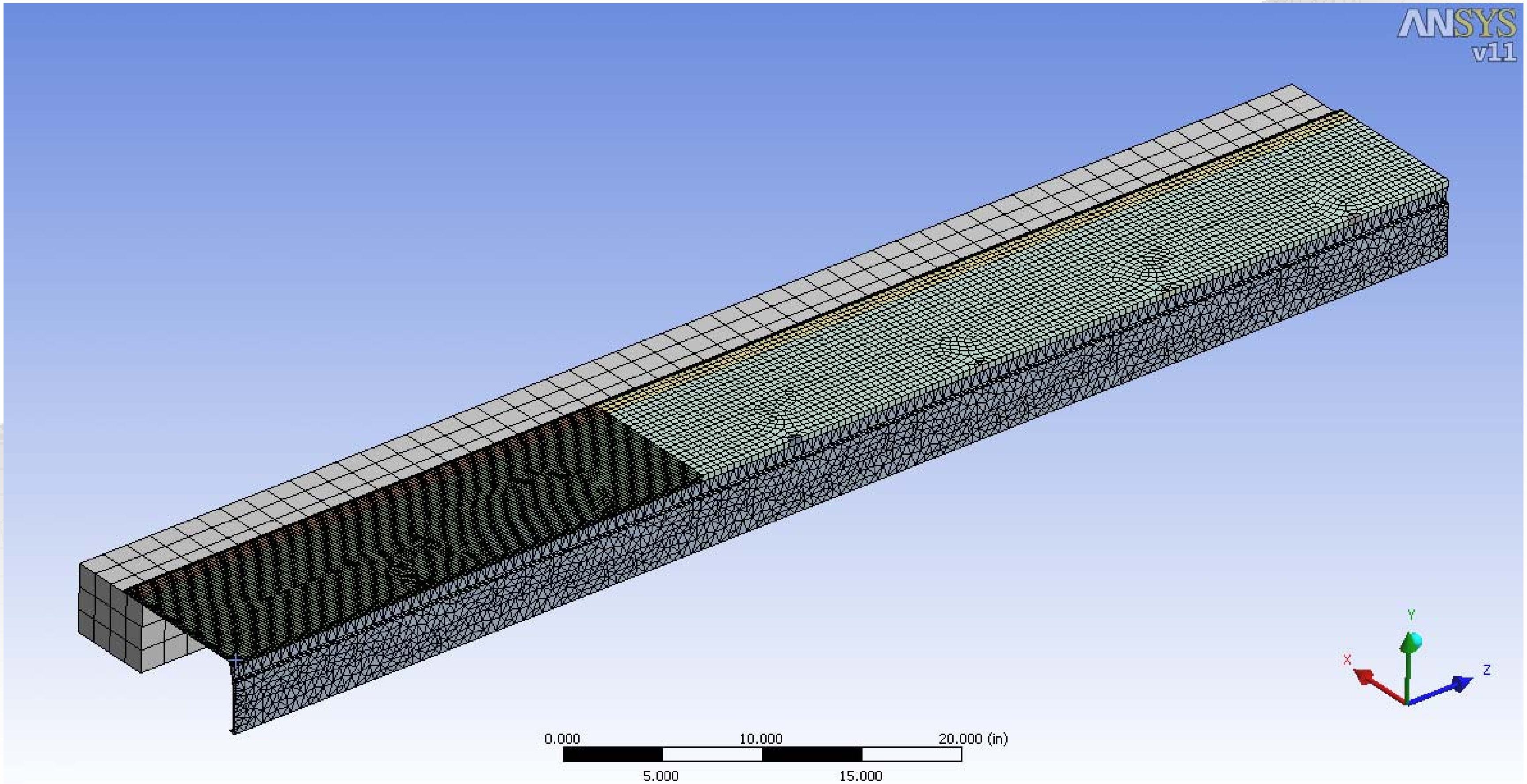


Figure 5. Overall FE Mesh.

Finite Element Model (cont.)

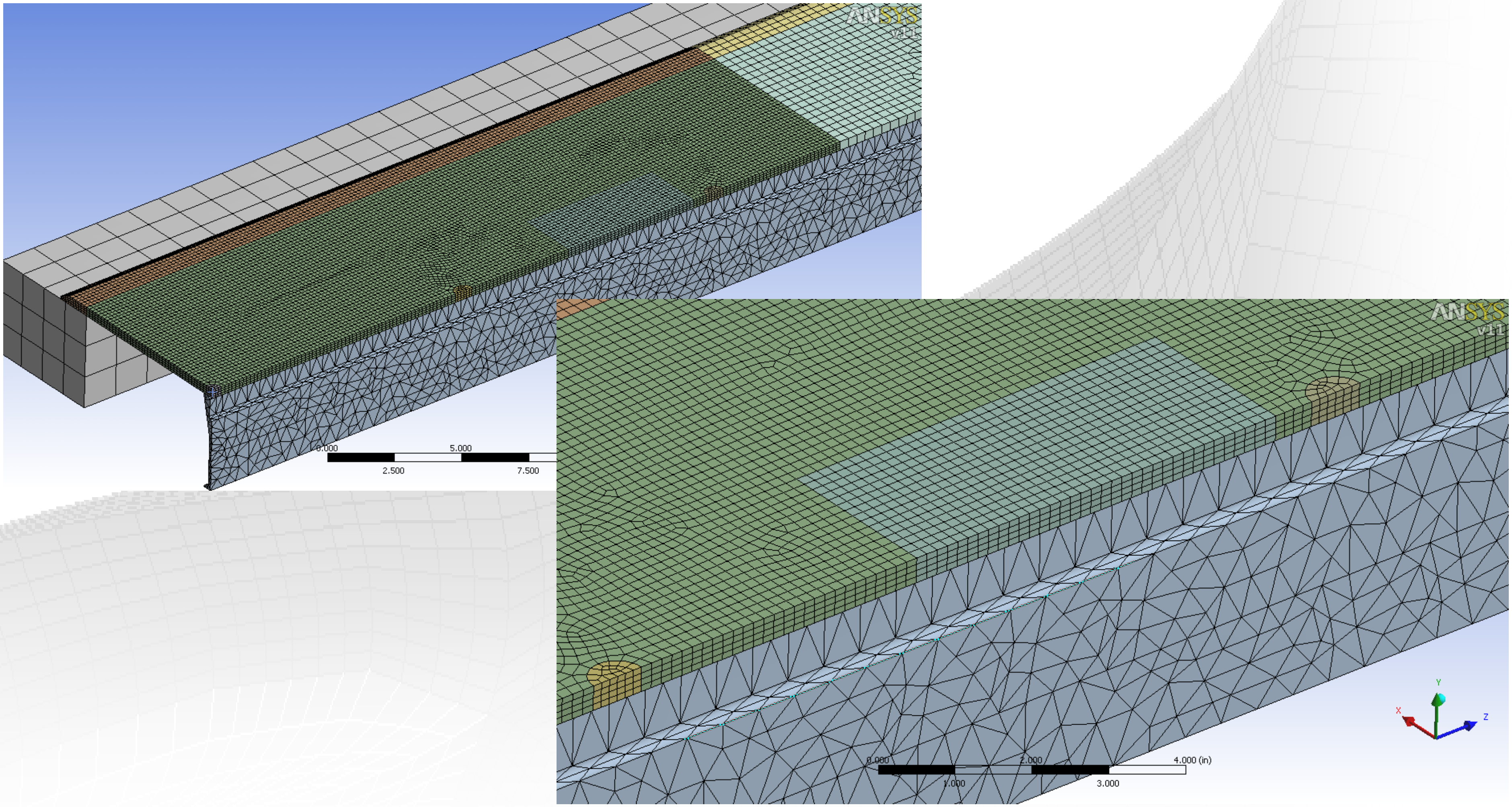


Figure 6. Close-Up View of FE Mesh.

Finite Element Model (cont.)

- A total of 223,491 nodes, 670,473 dof used for the FE model.
- Large deflection analysis used (non-linear geometry) to account for stress state due to deflected geometric shape.
- Non-linear material properties used for the 304 ss plate (bi-linear isotropic hardening):
  - Modulus of Elasticity E = 28 x 10^6 lbf/in.^{2}
  - Poisson's ratio v = 0.3
  - Yield stress 42,000 lbf/in.^{2}
  - Ultimate stress 90,000 lbf/in.^{2}
  - Tangent modulus 280,000 lbf/in.^{2} (1% of E, this represents a nearly perfect plastic material past the yield stress which is more conservative than actual behavior since the purpose of this study is to observe load shedding and plastic strains past the yield stress).
  - Elongation at ultimate stress 50%

Finite Element Model (cont.)

- For the spline 6061 aluminium:
  - Modulus of Elasticity E = 10 x 10^6 lbf/in.^{2}
  - Poisson's ratio v = 0.33
- For the dummy concrete (stiff representation):
  - Modulus of Elasticity E = 28 x 10^6 lbf/in.^{2}
  - Poisson's ratio v = 0.3

Results

•A series of plots showing the von Mises equivalent stress and equivalent plastic strain contours as well as displacement contours are presented in Figures 7 to 9 for the material non-linear analysis of Configuration-1.

•Results are also extracted from this analysis at the appropriate time step increment to represent loads of 1,800 lbf, 2,500 lbf and 3,200 lbf for the fatigue analysis calculations, these are shown in Figures 10 to 12.

•An extra run was made for Configuration-1 with the spline suppressed to represent a situation that no structural contribution is included from the spline. These are shown in Figures 13 to 17.

Results (cont.)

Configuration 1 – 9,600 lbf Load

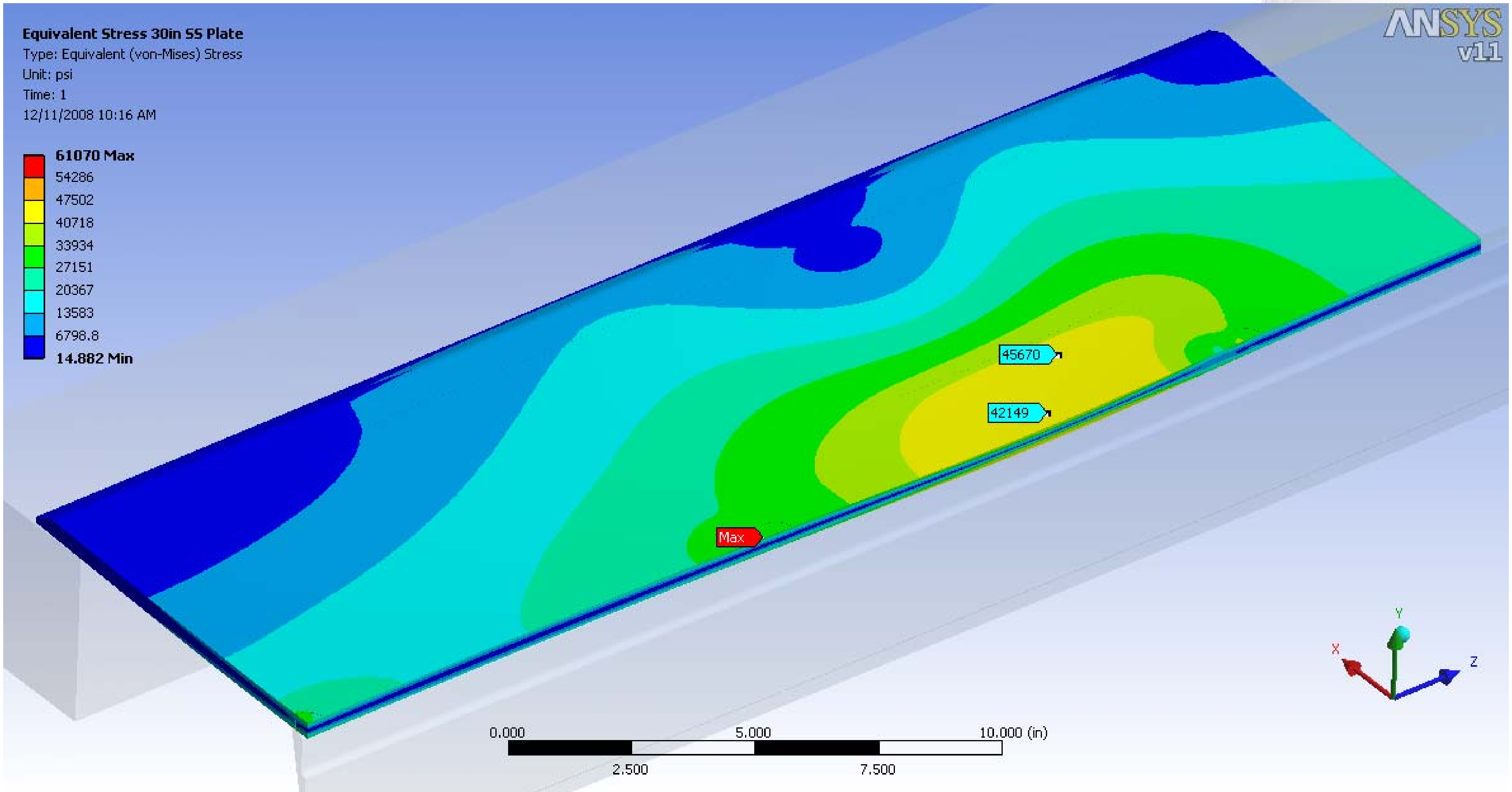


Figure 7. von Mises Equivalent Stress Contours, Configuration-1.

Results (cont.)

Configuration 1 – 9,600 lbf Load

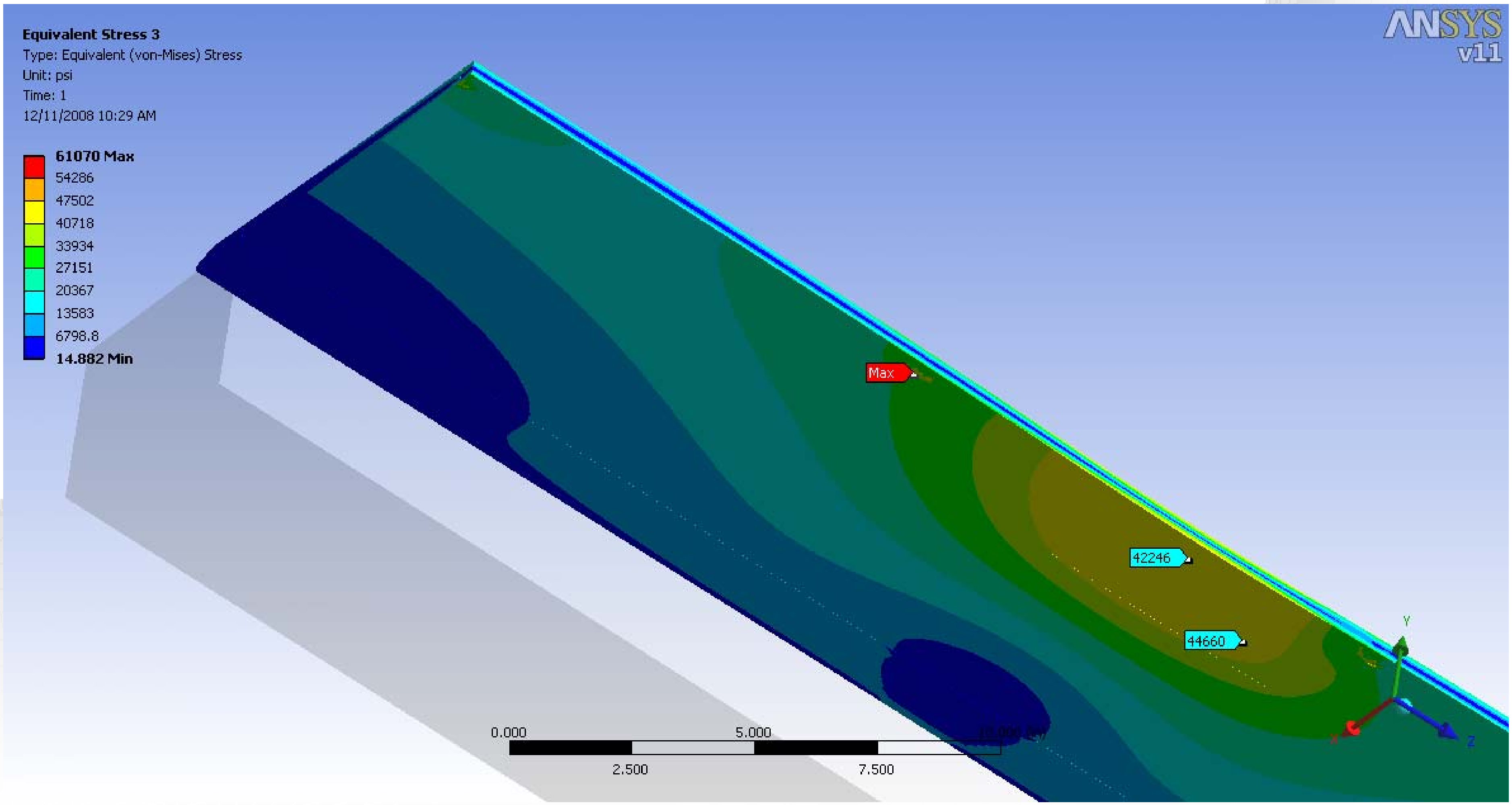


Figure 7a. von Mises Equivalent Stress Contours, Configuration-1.

Results (cont.)

Configuration 1 – 9,600 lbf Load

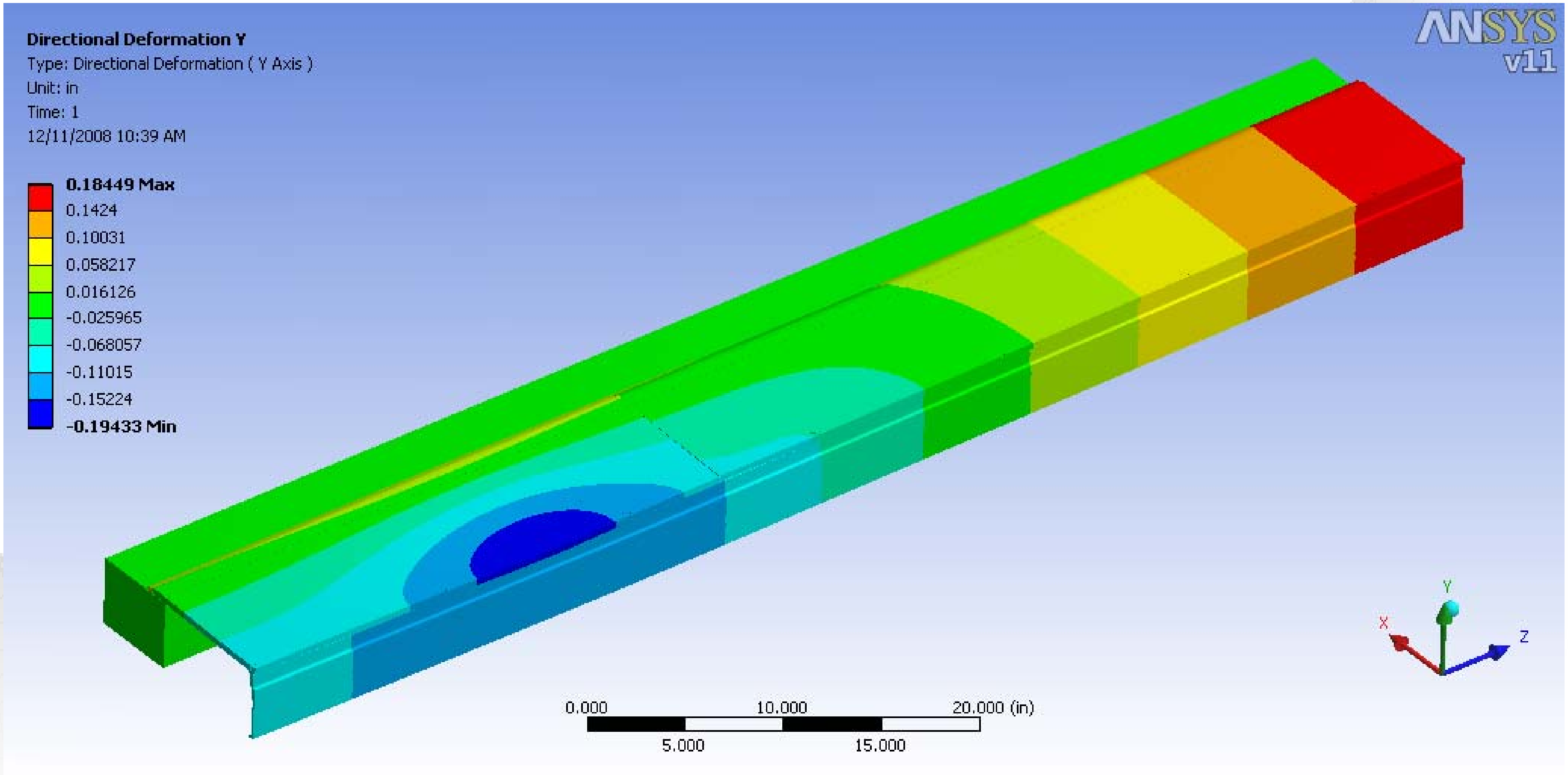


Figure 8. Deflection Contours Global Y-Direction, Configuration-1.

Results (cont.)

Configuration 1 - 9,600 lbf Load

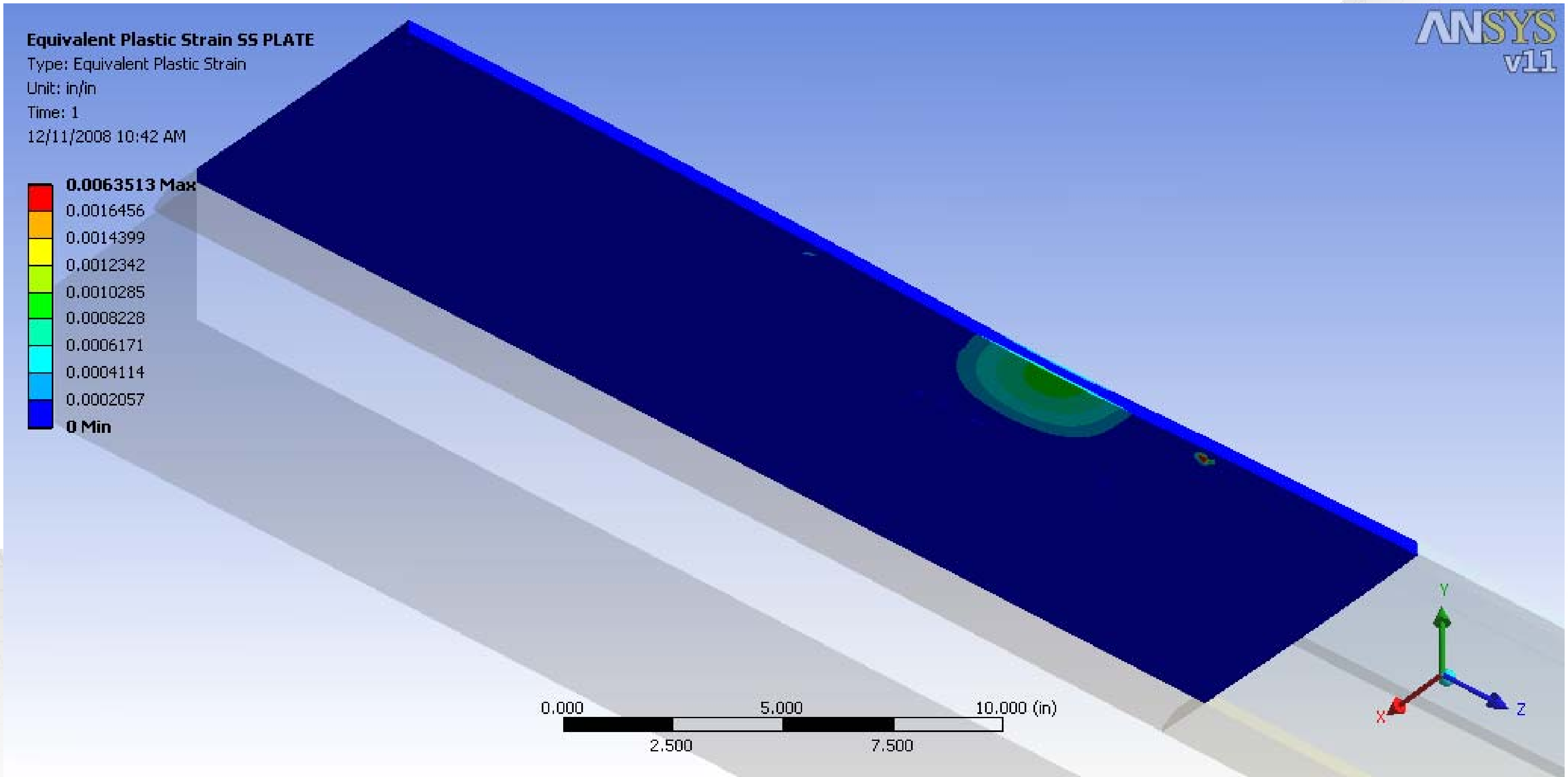


Figure 9. Equivalent Plastic Strain Contours, Configuration-1.

Results (cont.)

Configuration 1- 3,200 lbf Load

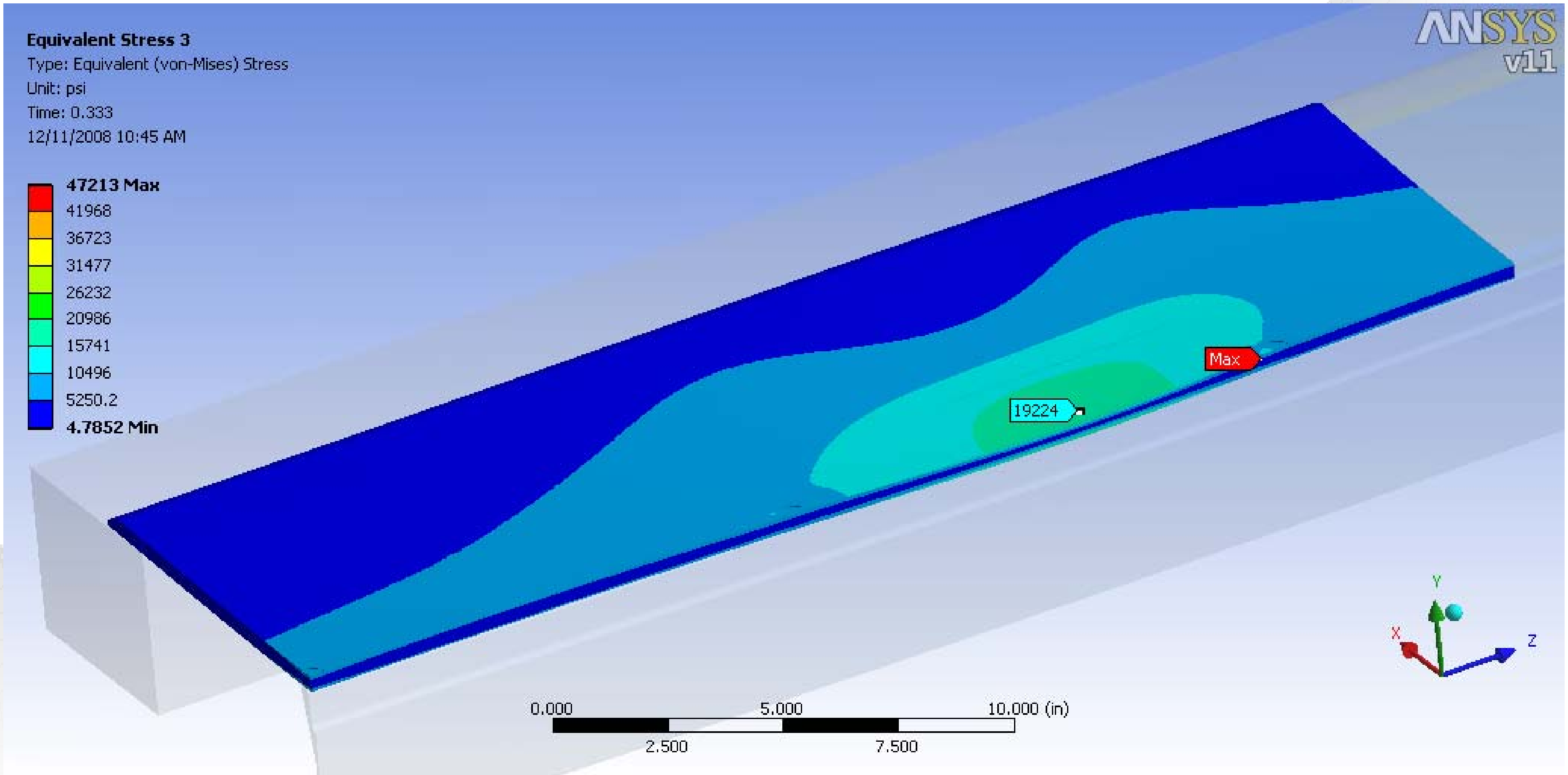


Figure 10. von Mises Equivalent Stress Contours, Configuration-1, 3,200 lbf.

Results (cont.)

Configuration 1- 2,500 lbf Load

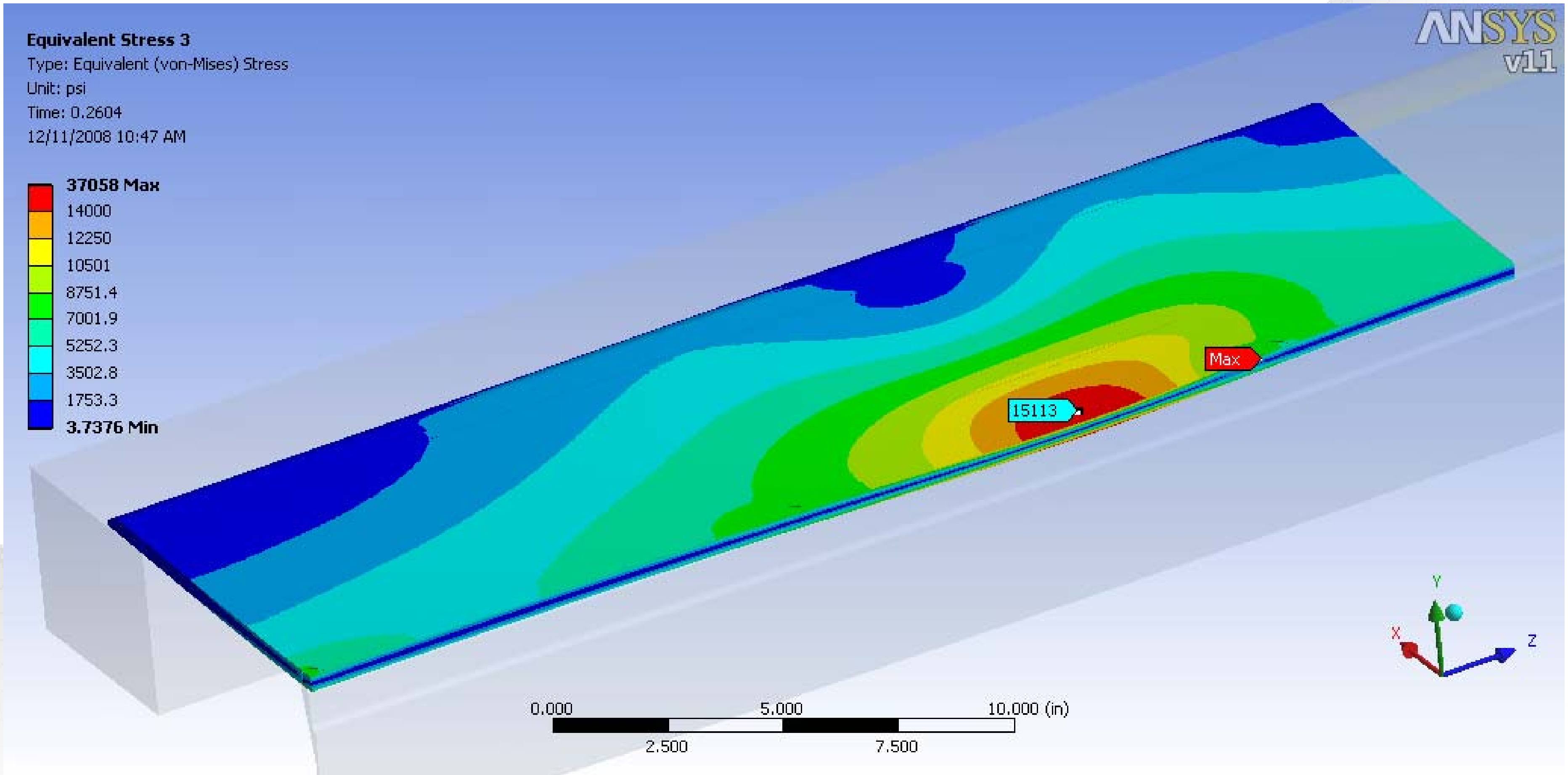


Figure 11. von Mises Equivalent Stress Contours, Configuration-1, 2,500 lbf.

Results (cont.)

Configuration 1- 1,800 lbf Load

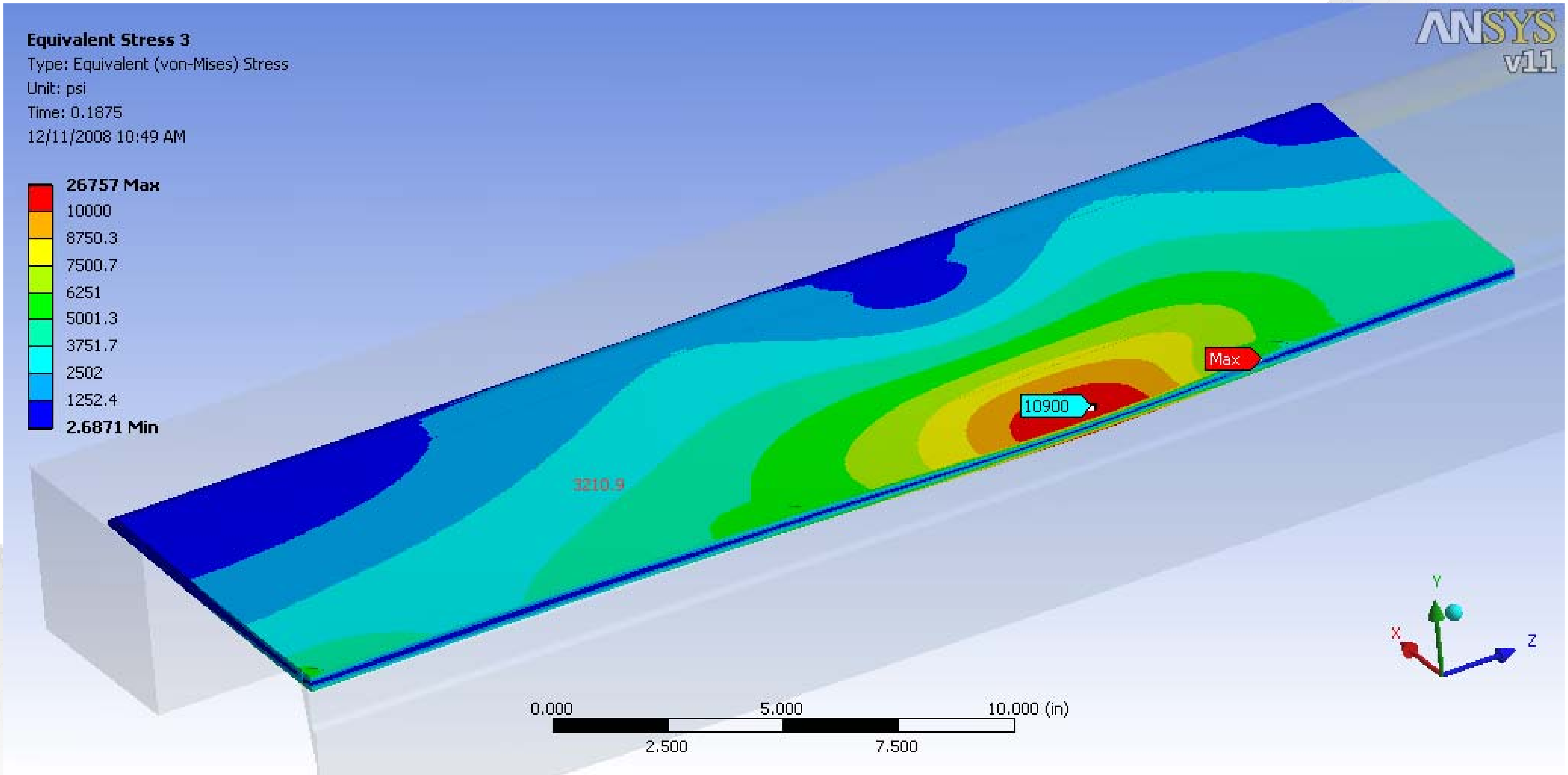


Figure 12. von Mises Equivalent Stress Contours, Configuration-1, 1,800 lbf.

Results (cont.)

Configuration 1- 9,600 lbf, No Spline

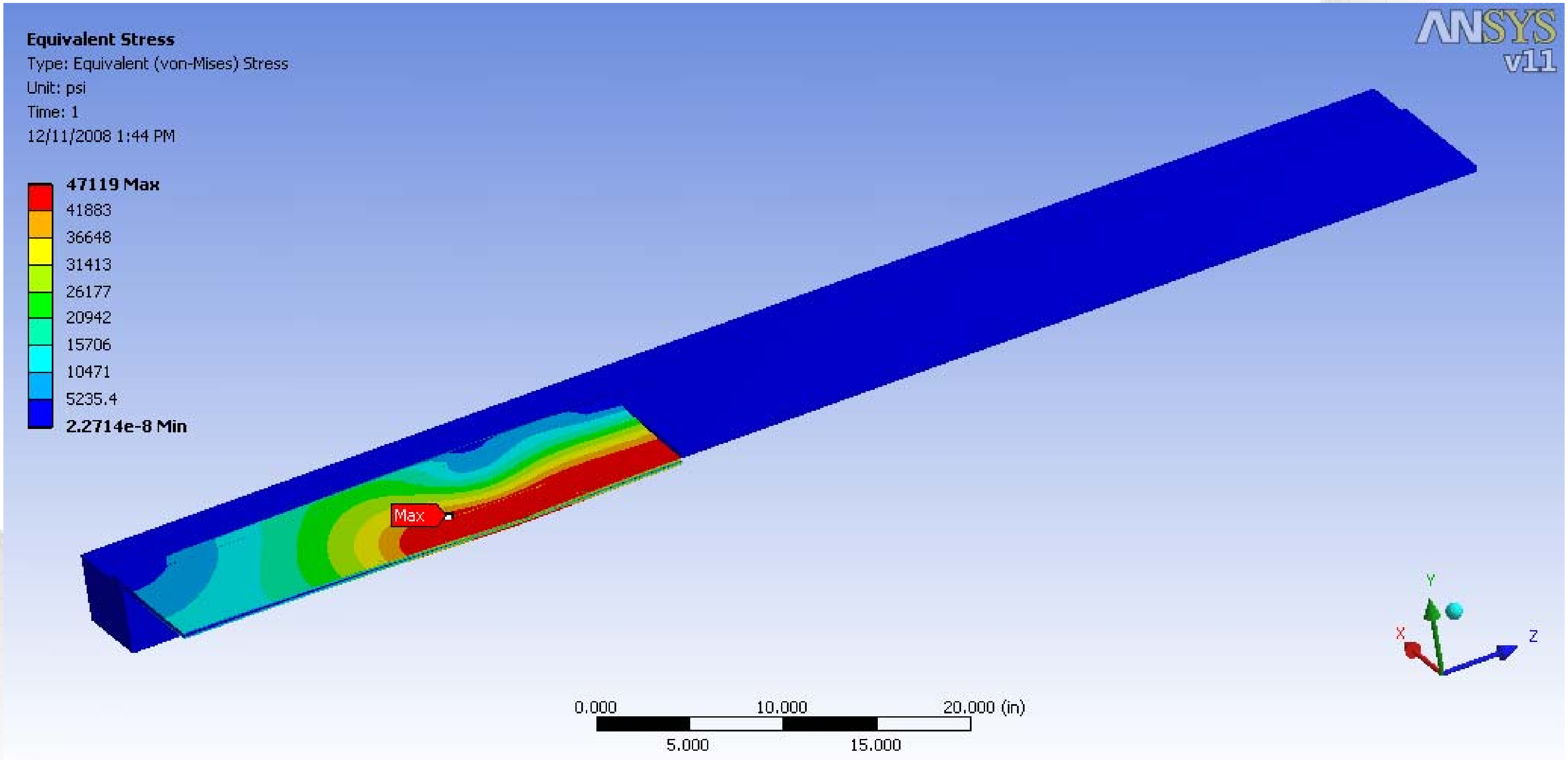


Figure 13. von Mises Stress Contours, Configuration-1, No Spline

Results (cont.)

Configuration 1- 9,600 lbf, No Spline

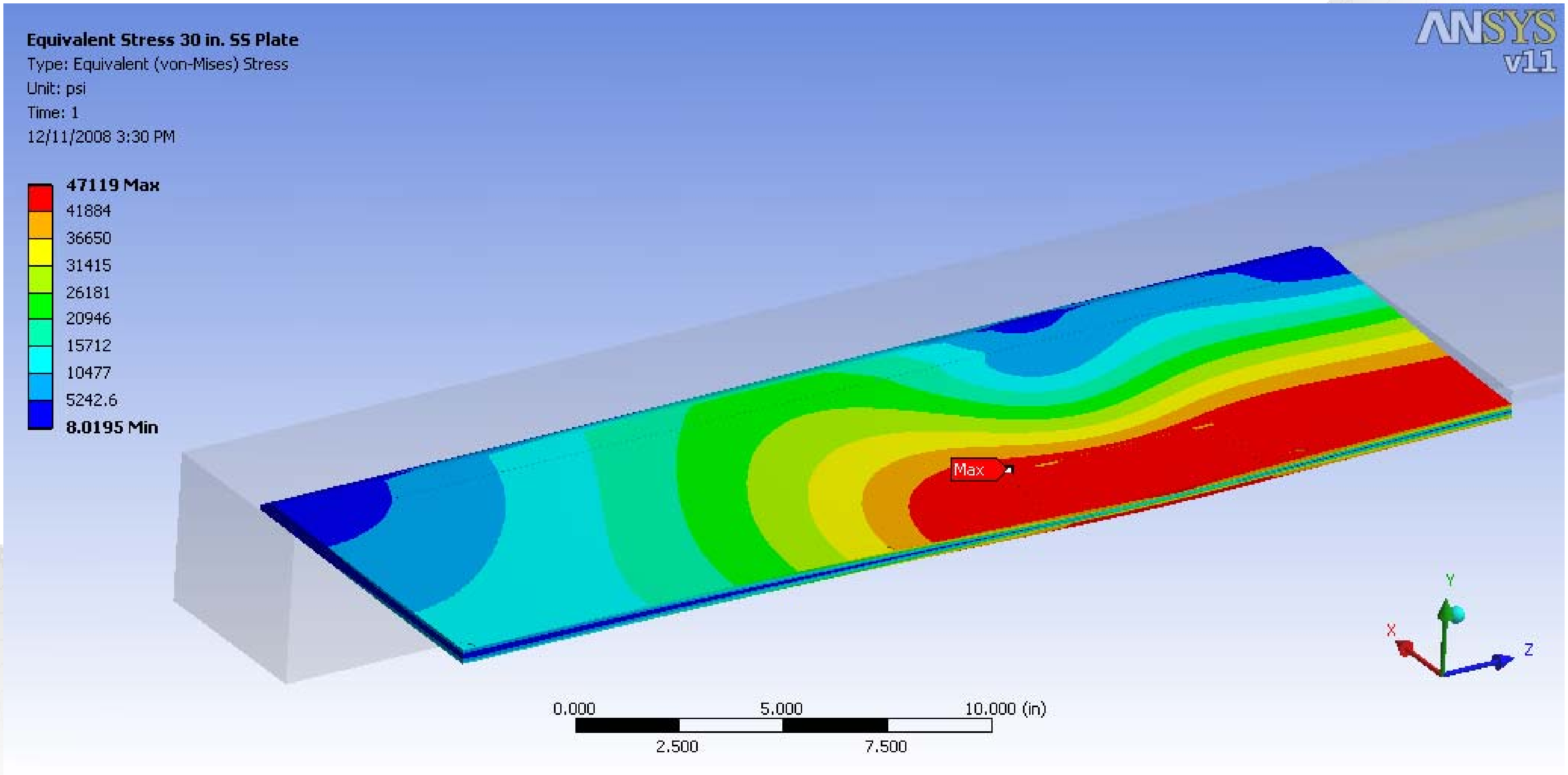


Figure 14. von Mises Stress Contours, Configuration-1, No Spline

Results (cont.)

Configuration 1- 9,600 lbf, No Spline

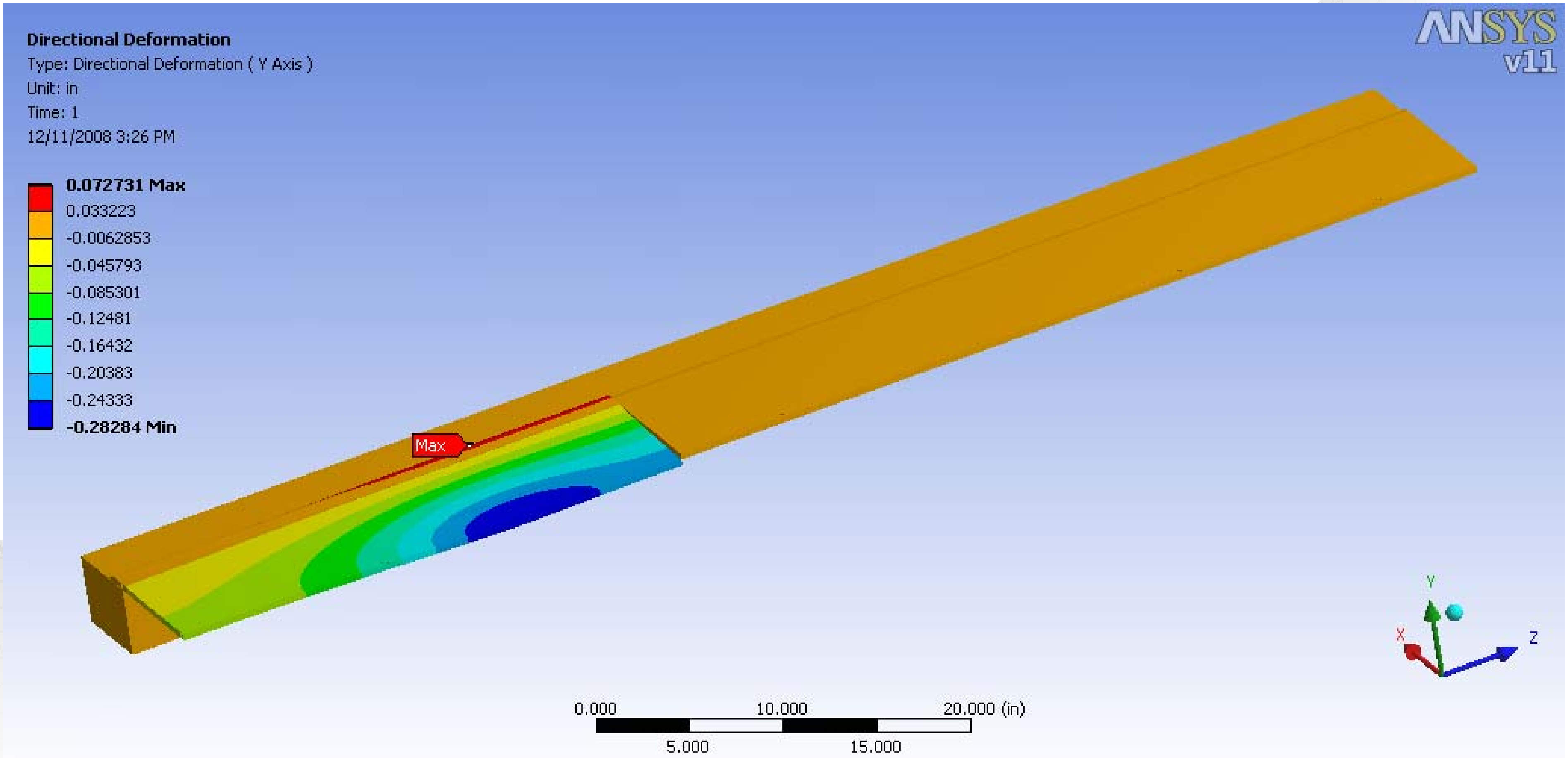


Figure 15. Global Y-Direction Displacement Contours, Configuration-1, No Spline

Results (cont.)

Configuration 1- 9,600 lbf, No Spline

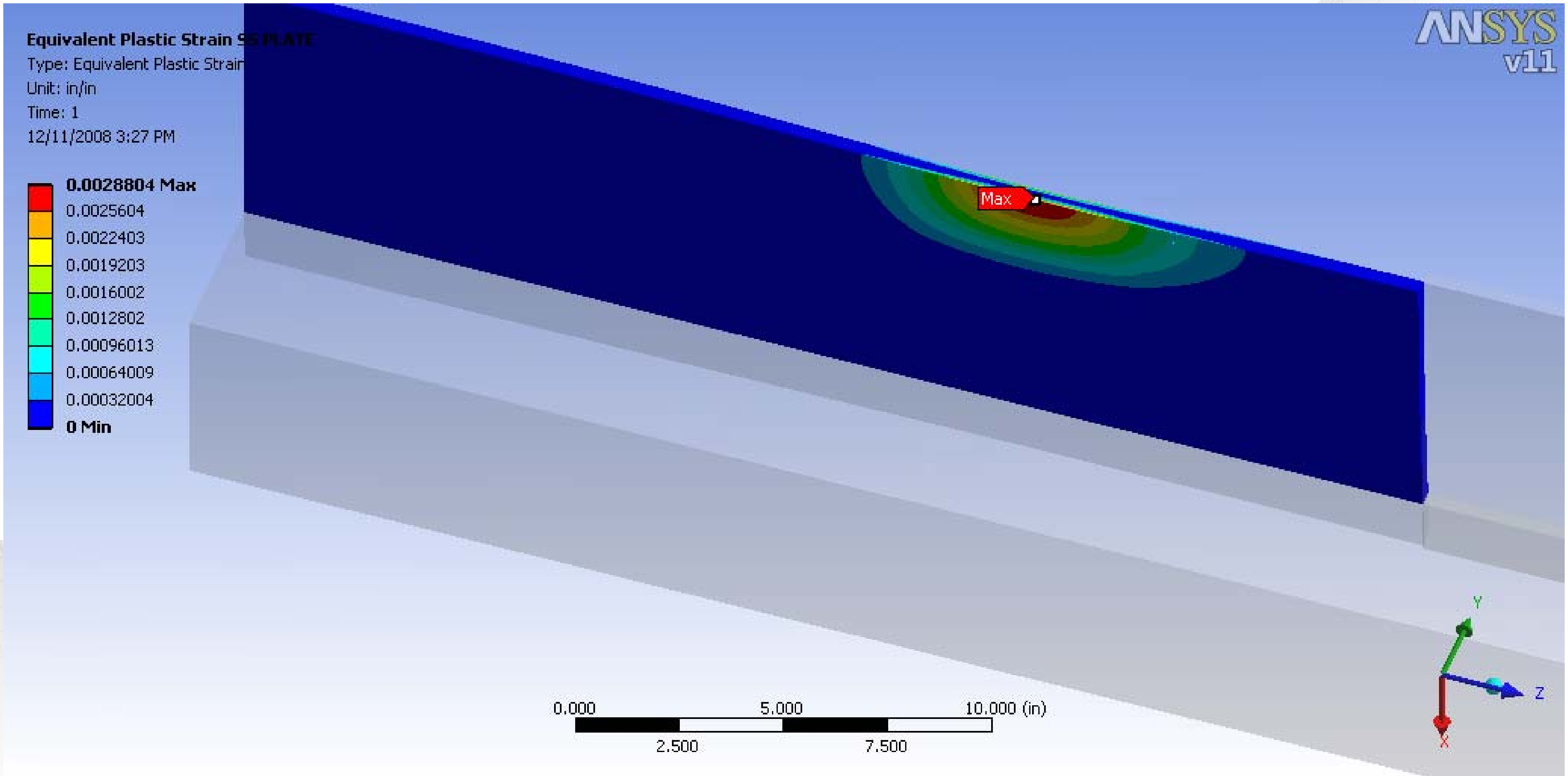


Figure 16. Plastic Strain Contours, Configuration-1, No Spline

Results (cont.)

Configuration 1- 3,200 lbf, No Spline

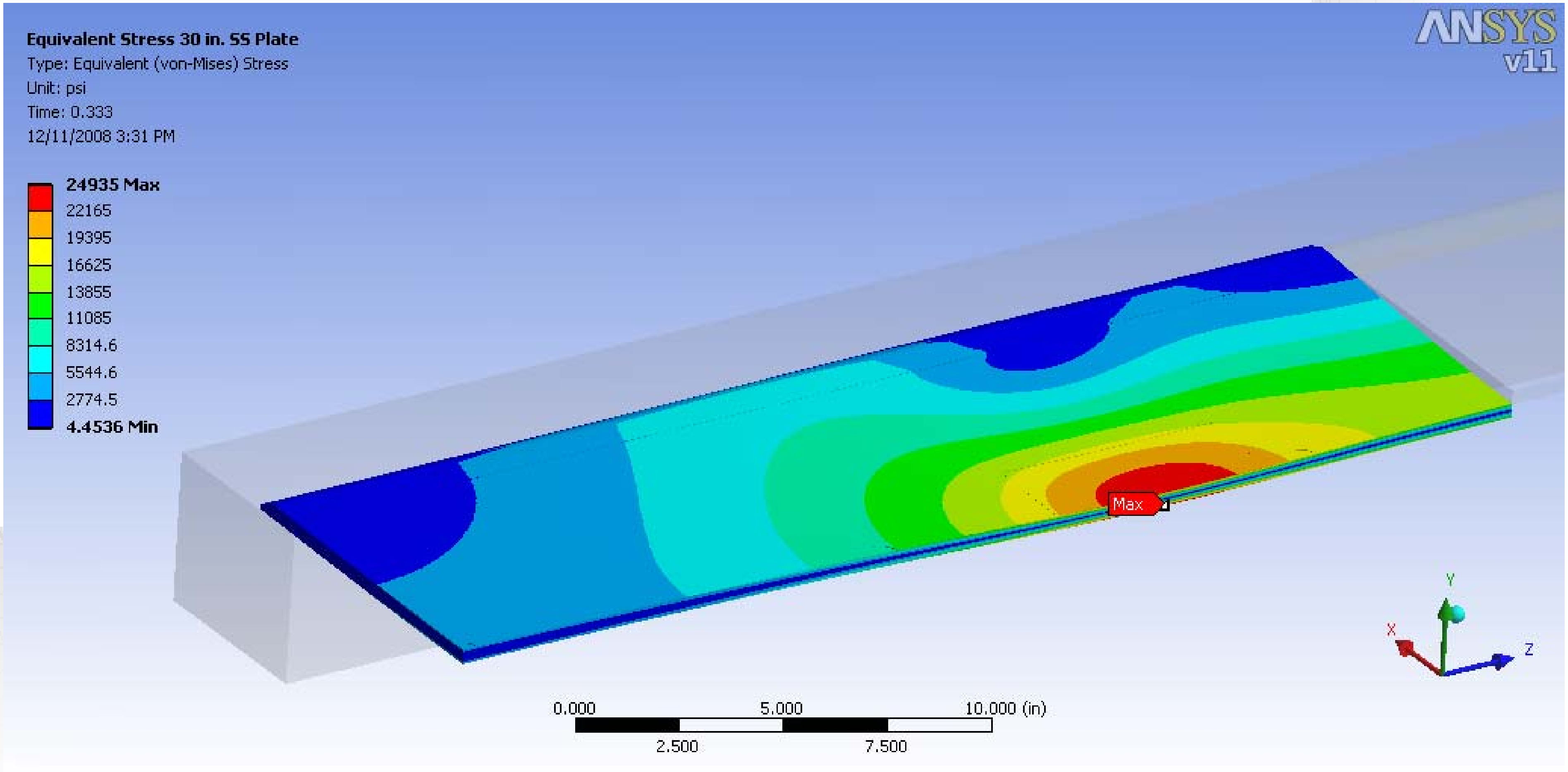


Figure 17. von-Mises Stress Contours, Configuration-1, No Spline

Results (cont.)

- From Figures 7, 7a and 9 the peak stress computed for a load of 9,600 lbf is 61,070 lbf/in.^{2} at a fastener location and the maximum plastic strain in the body of the 304 ss plate is 0.6%. Note that the maximum stress in the body of the ss plate is just over 45,000 lbf/in.^{2} (see Figure 7).
- From Figures 10, 11 and 12 the maximum stress in the body of the 304 ss plate is 19,250 lbf/in.^{2} (3,200 lbf), 15,200 lbf/in.^{2} (2,500 lbf) and 10,900 lbf/in.^{2} (1,800 lbf) respectively.
- The maximum stress in the body of the 304 ss plate for 9,600 lbf wheel load without any structural contribution from the spline is 47,719 lbf/in.^{2}
- The Goodman formula is used to assess the effects of mean stress on fatigue life.
- The Goodman formula states:
  - $(\sigma_a/S_e) + (\sigma_m/S_u) = 1$ where
  - $\Delta\sigma = \sigma_{max} - \sigma_{min}$ = stress range
  - $\sigma_a = (\sigma_{max} - \sigma_{min})/2$ = stress amplitude
  - $\sigma_m = (\sigma_{max} + \sigma_{min})/2$ = mean stress
  - S_e is the endurance limit and S_u is the ultimate stress

Results (cont.)

- For the case at 3,200 lbf, σ_{max} = 19,250 lbf/in.^{2} and σ_{min} = 0 lbf/in.^{2}
- Therefore σ_a = 9,625 lbf/in.^{2} and σ_m = 9,625 lbf/in.^{2}
- And S_e = 10,778 lbf/in.^{2} from the Goodman formula.
- It can be seen from Figure 2 that for an alternating stress range of 10,778 lbf/in.^{2} an infinite number of cycles are allowed.
- The same will be the case for the alternating stress range at 2,500 lbf and 1,800 lbf wheel loads.

Comments

- The maximum stress computed for a wheel load of 9,600 lbf is close to 46,000 lbf/in.^{2} in the body of the 304 ss plate.
- The associated plastic strain at this stress level is 0.6%.
- The maximum stress in the 304 ss plate without the spline for a load of 9,600 lbf is 47,119 lbf/in.^{2} which is slightly over the material yield allowable of 42,000 lbf/in.^{2}
- No failure is predicted in the body of the 304 ss plate for a load three times (9,600 lbf) the normal maximum operating load (3,200 lbf). A very small amount of plastic straining is predicted, less than 1%, which when compared to the elongation allowed at ultimate of 50% indicates an adequate load shedding capability of the SJS configuration.
- The fatigue analysis also indicates an infinite life capability (>10^6 cycles) for the SJS 304 ss plate even when the maximum load is considered for all the cycles.