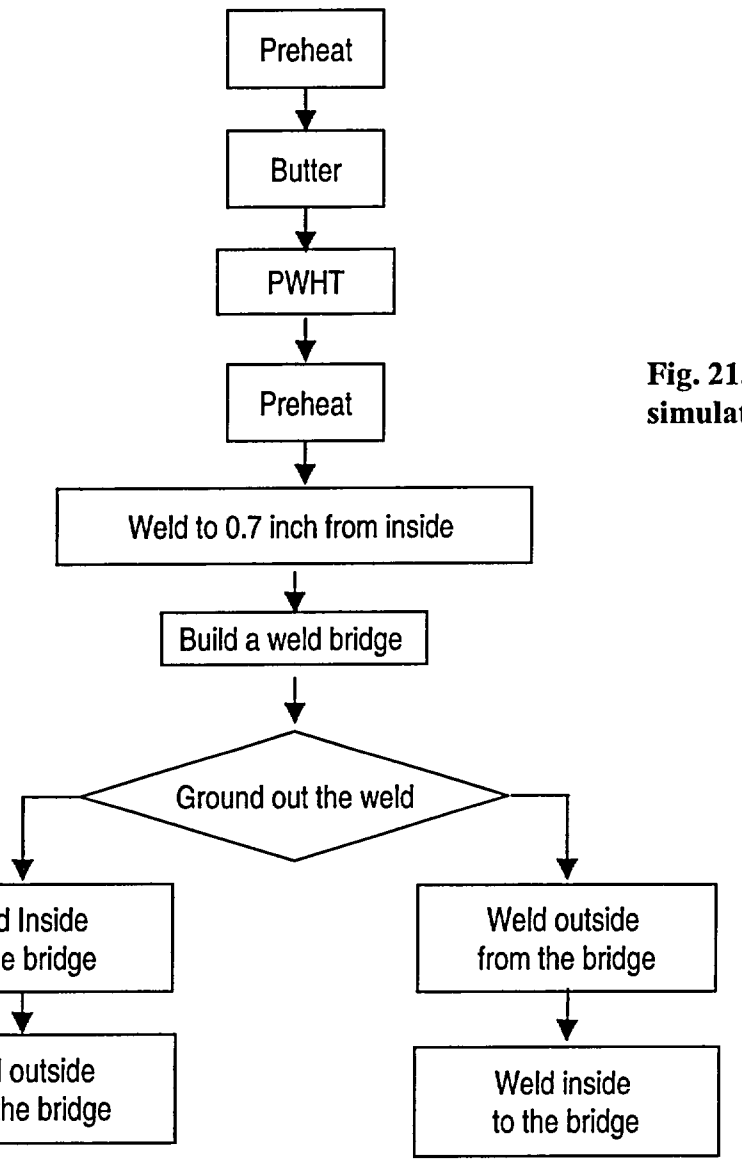


Fig. 21. Welding process simulated on hot leg.

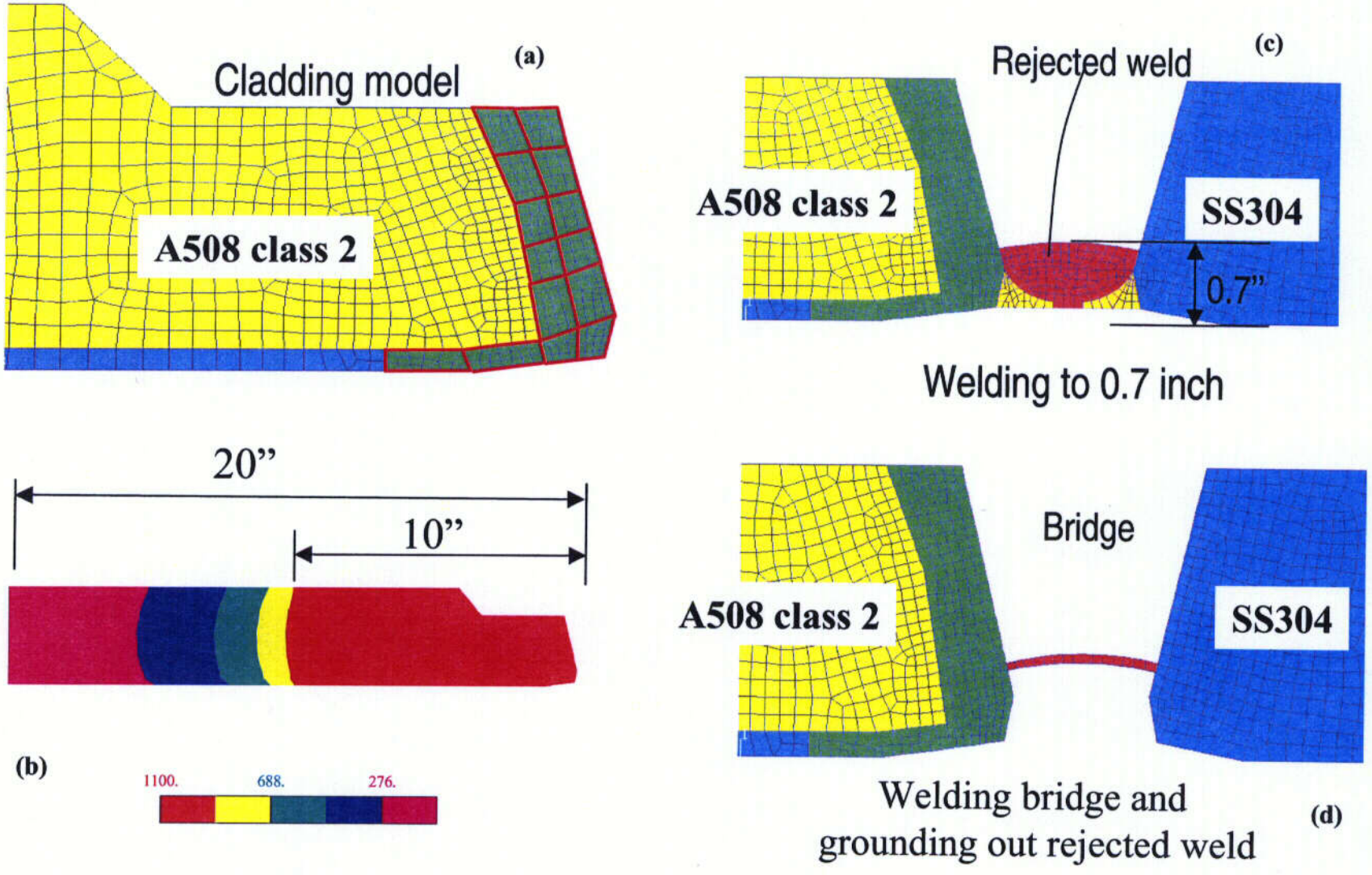


Figure 22. Cladding (Butter) and Rejected Weld Model.

C01

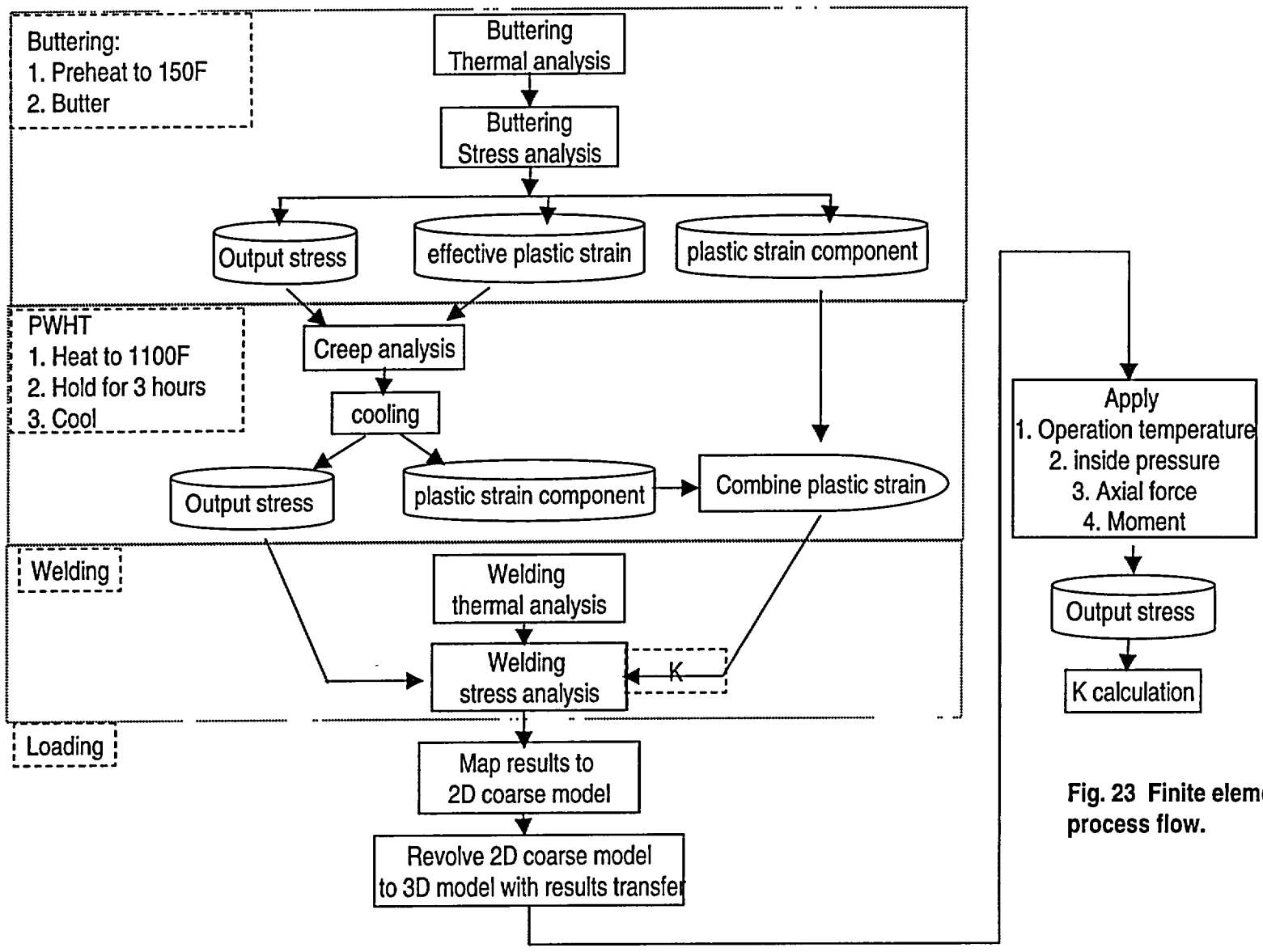


Fig. 23 Finite element analysis process flow.

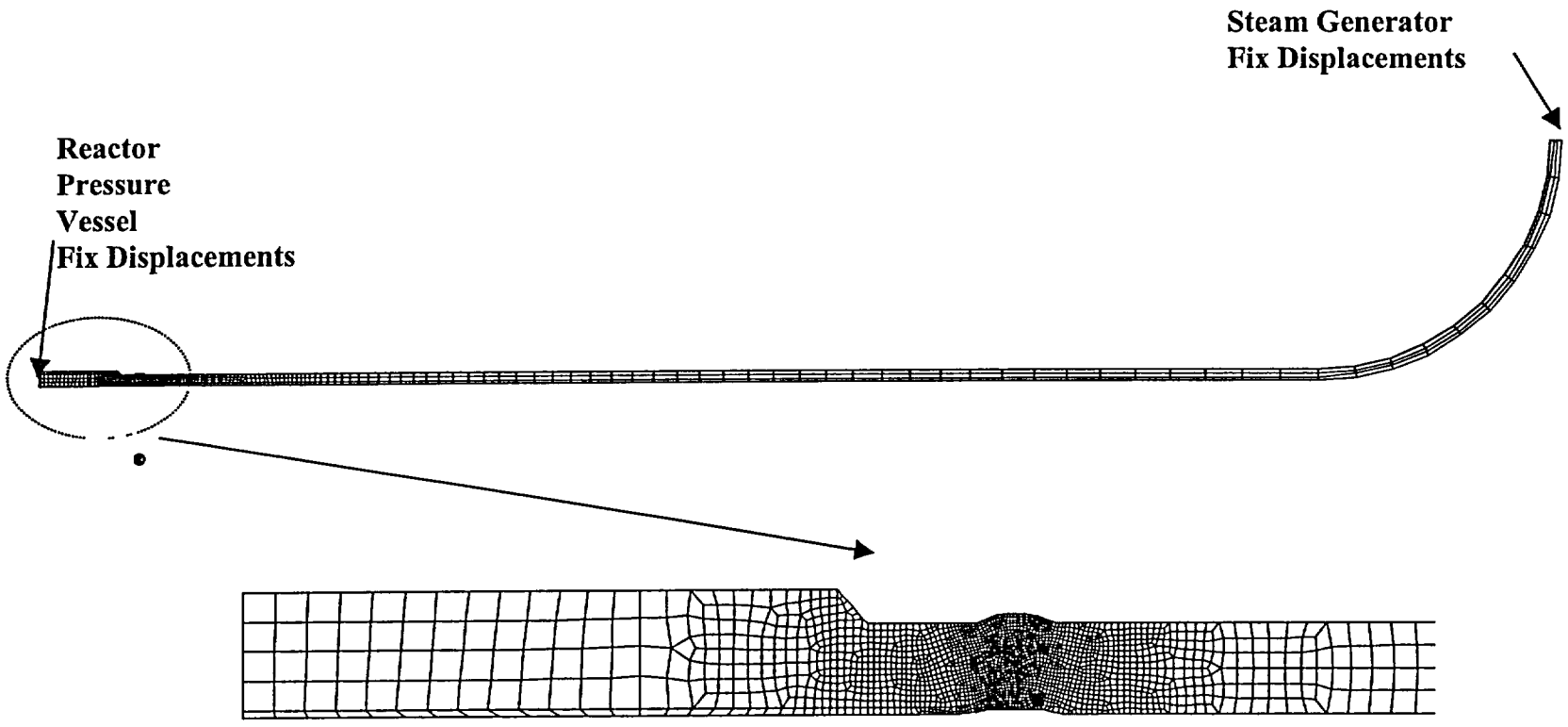


Figure 24. Full Finite Element Model.

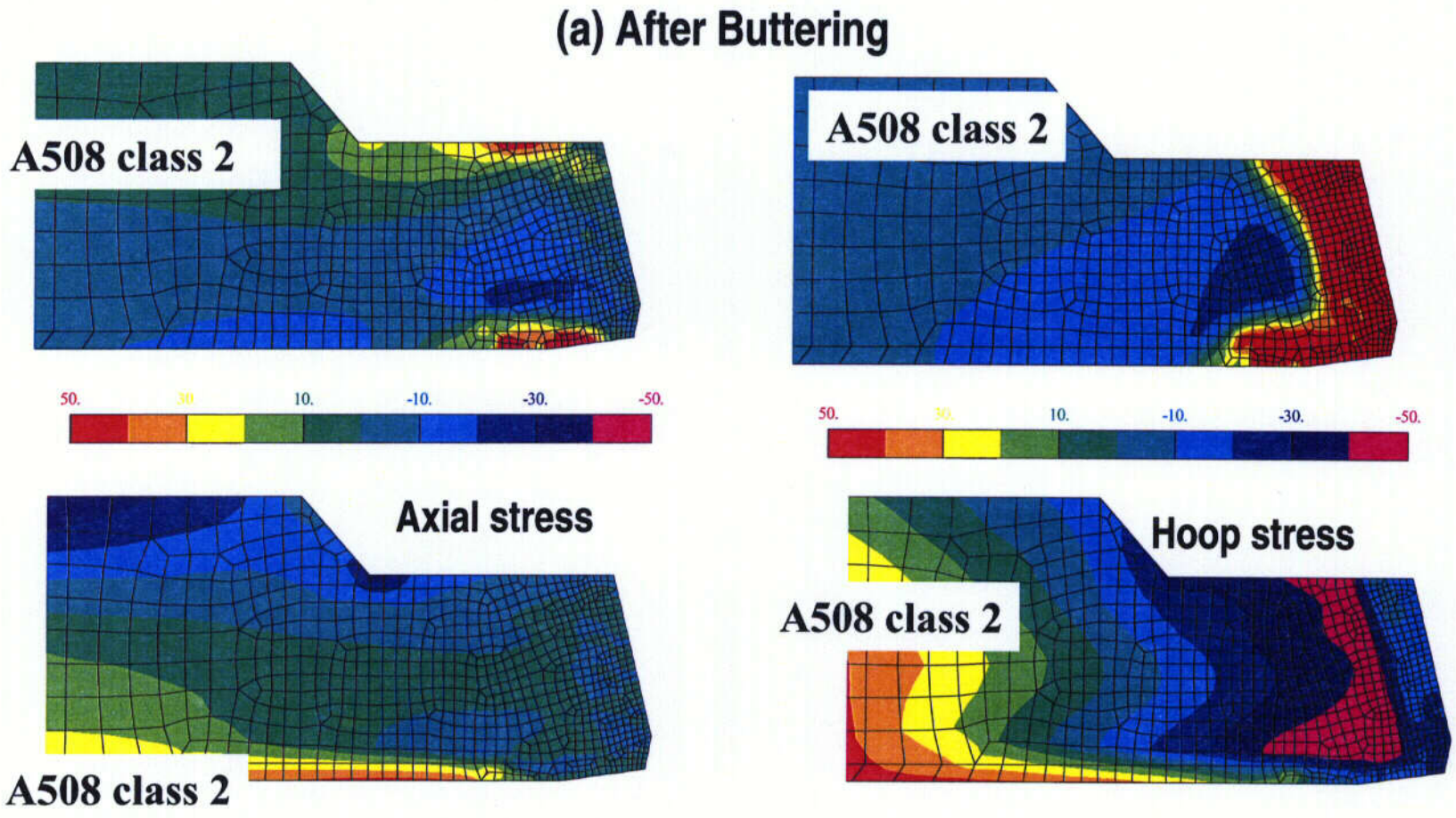
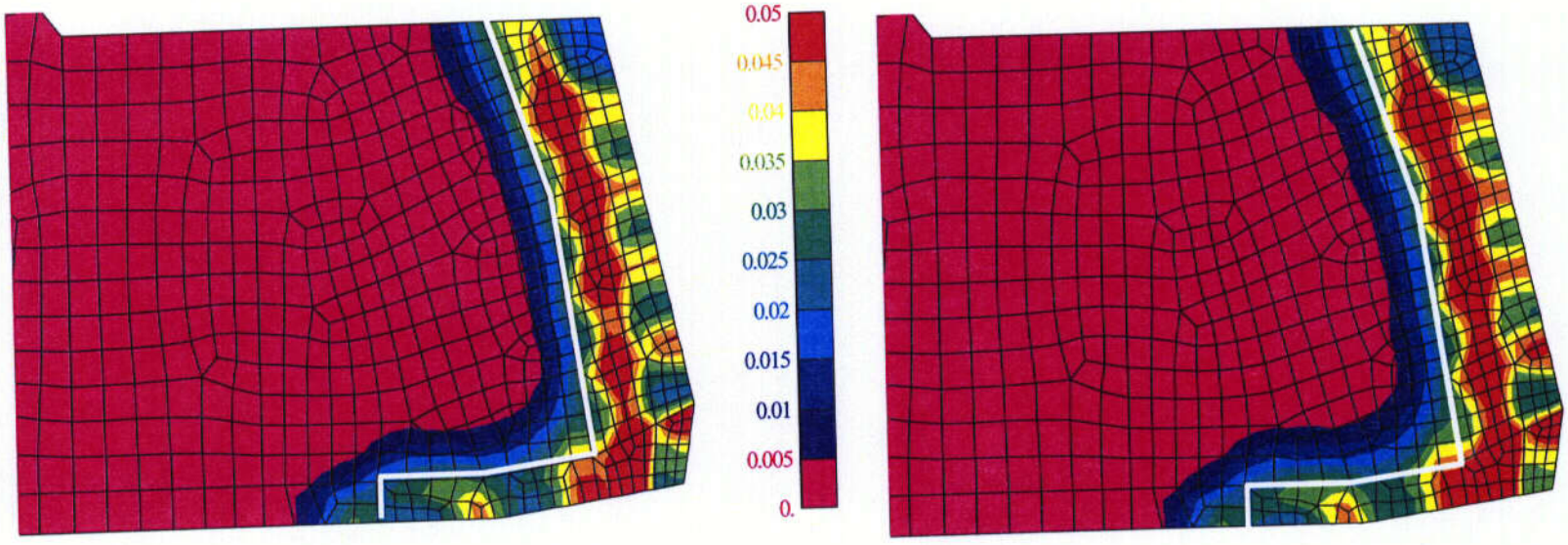


Figure 25. Cladding Simulation Stresses (after cooling to room temperature).

C02



(a) End of Cladding

(b) End of Post cladding heat treatment

Figure 26. Cladding Simulation – Effective Plastic Strains.

C03

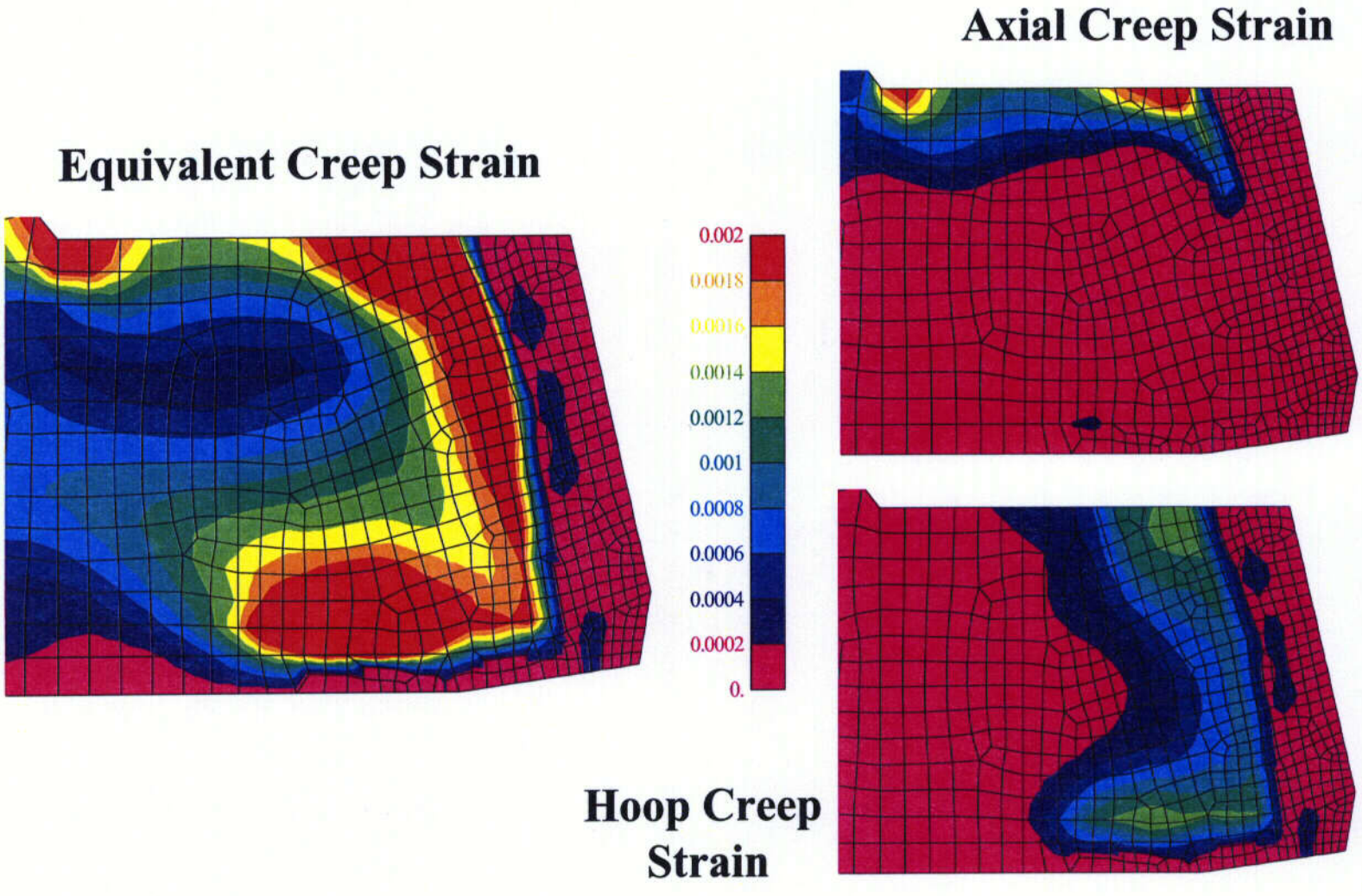


Figure 27. Post Cladding Heat Treatment Simulation – Creep Strains.

C04

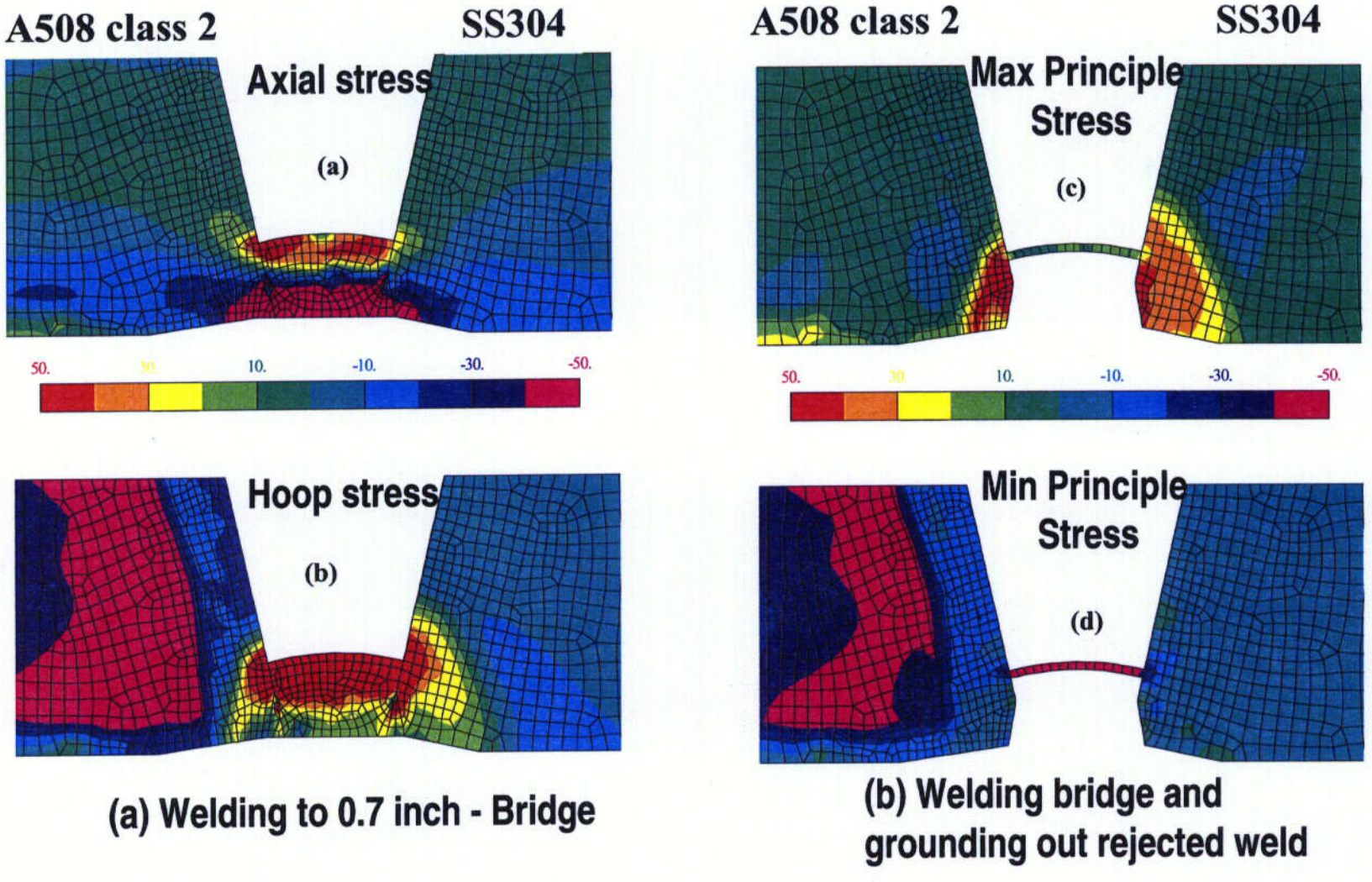


Figure 28. Rejected Weld and Bridge Simulation.

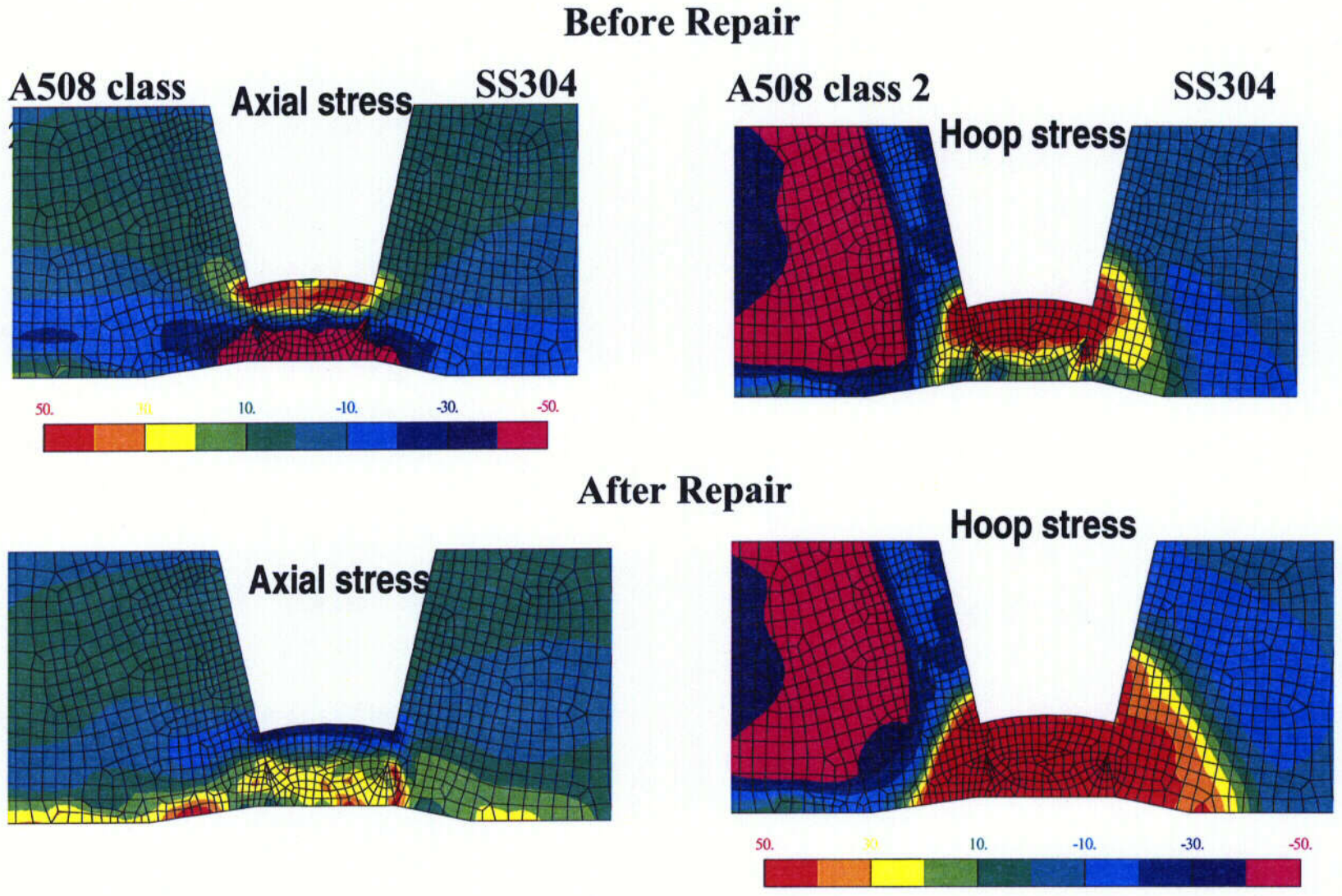


Figure 29. Comparison of Rejected Weld and Bridge Simulation.

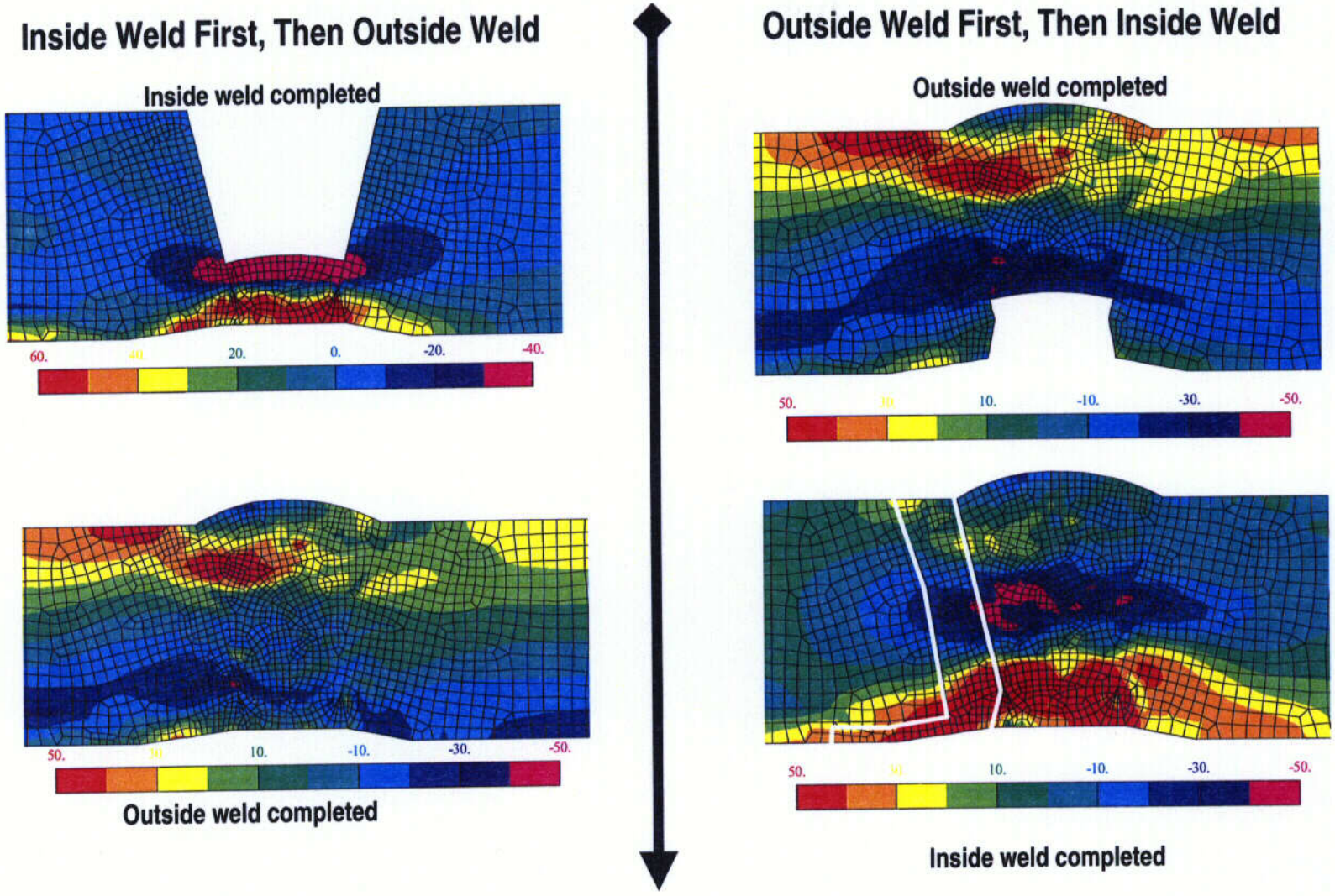


Figure 30. Axial Stress Comparison Between Two Sequences.

C07

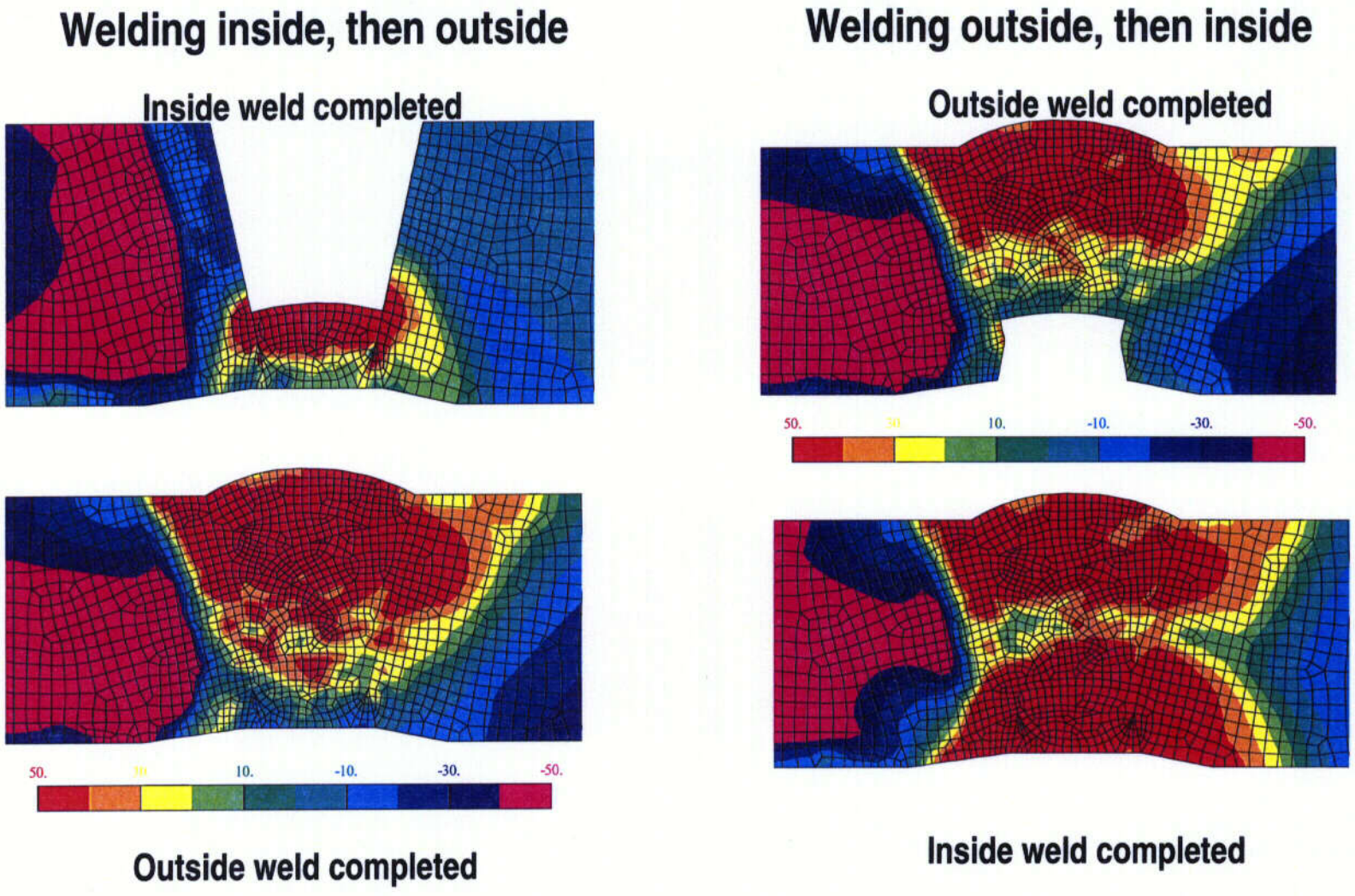
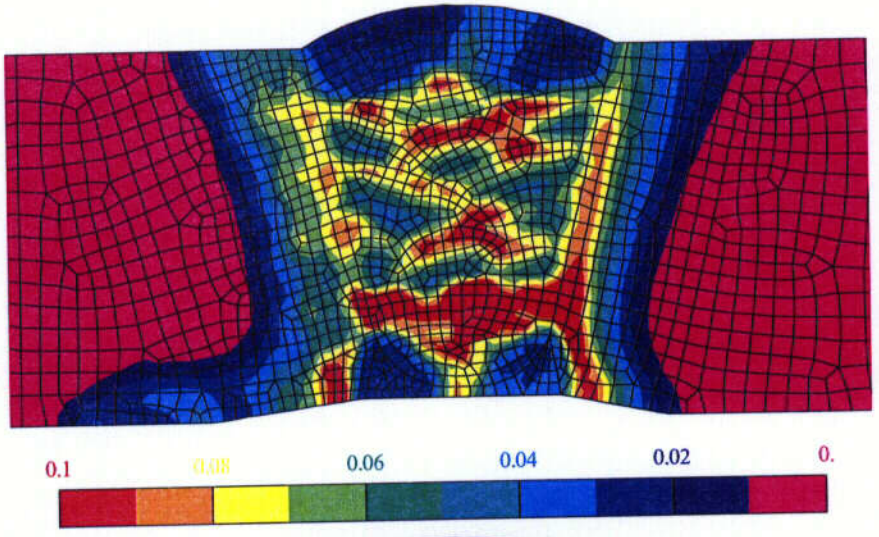


Figure 31. Hoop Stress Comparison Between Two Sequences.

Welding inside, then outside



Welding outside, then inside

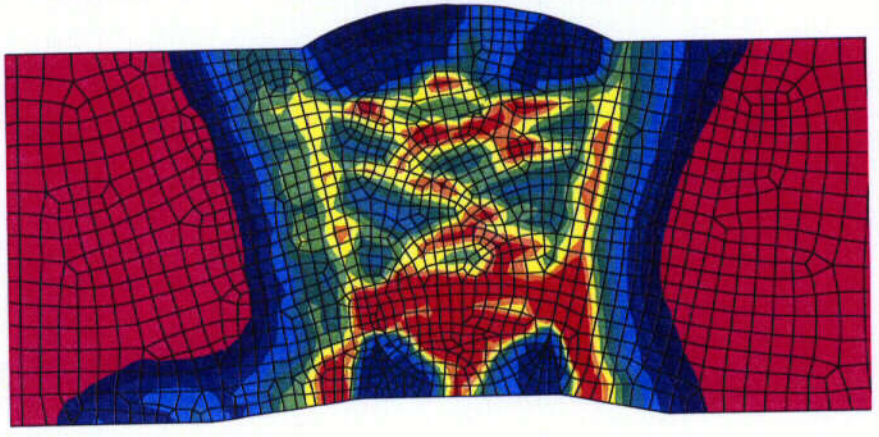


Figure 32. Effective Plastic Strain Comparison Between Two Sequences.

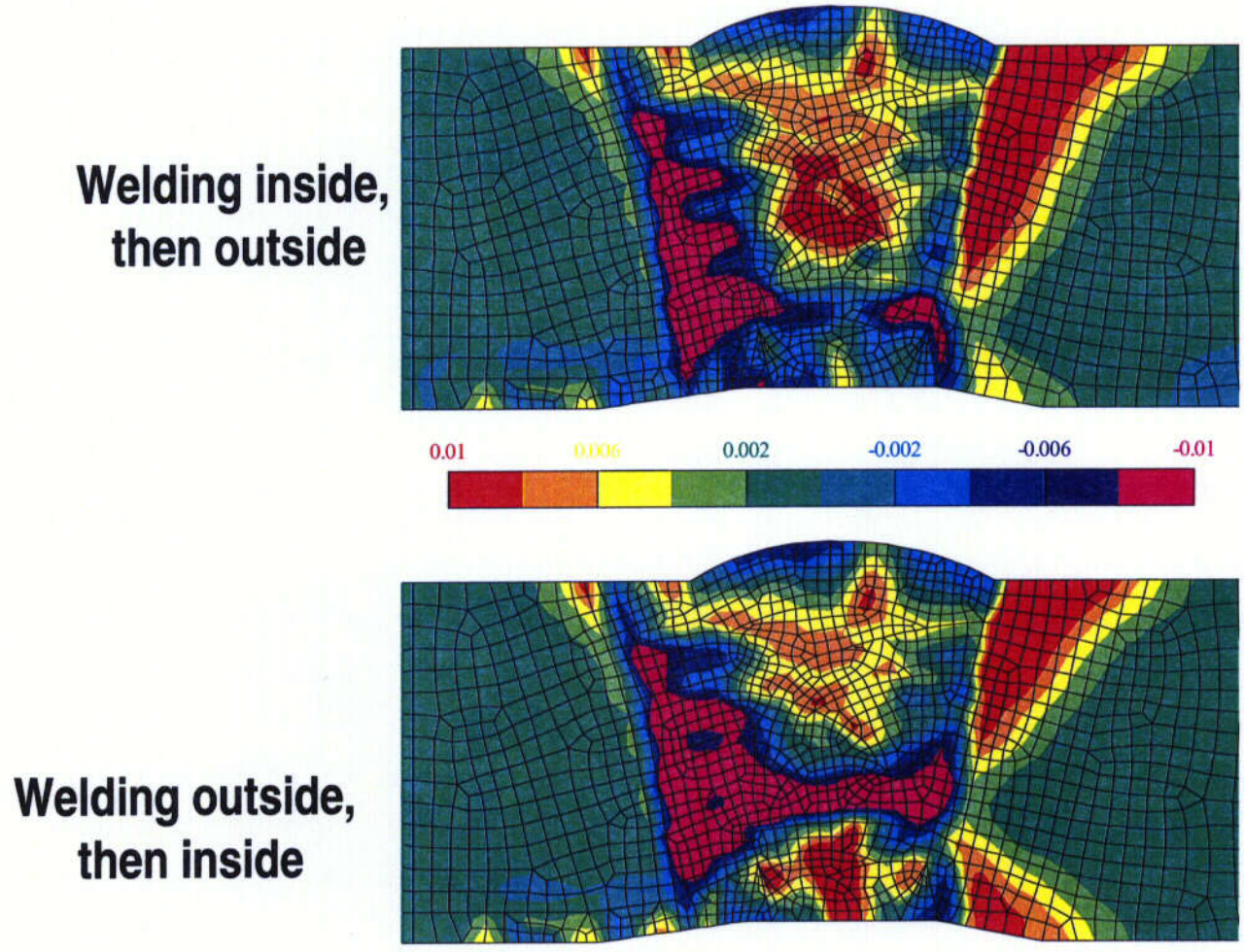


Figure 33. Axial Plastic Strain Comparison Between Two Sequences.

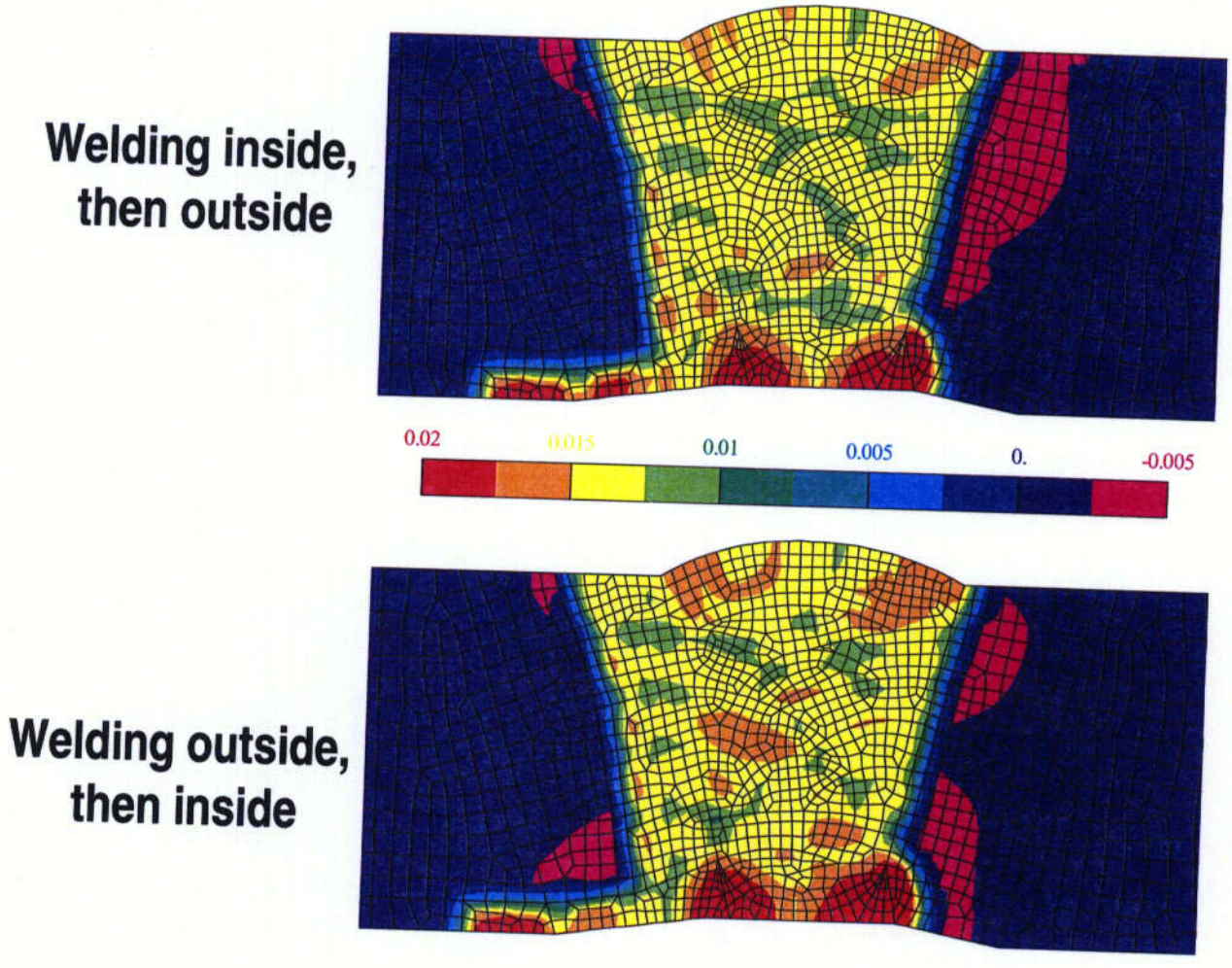
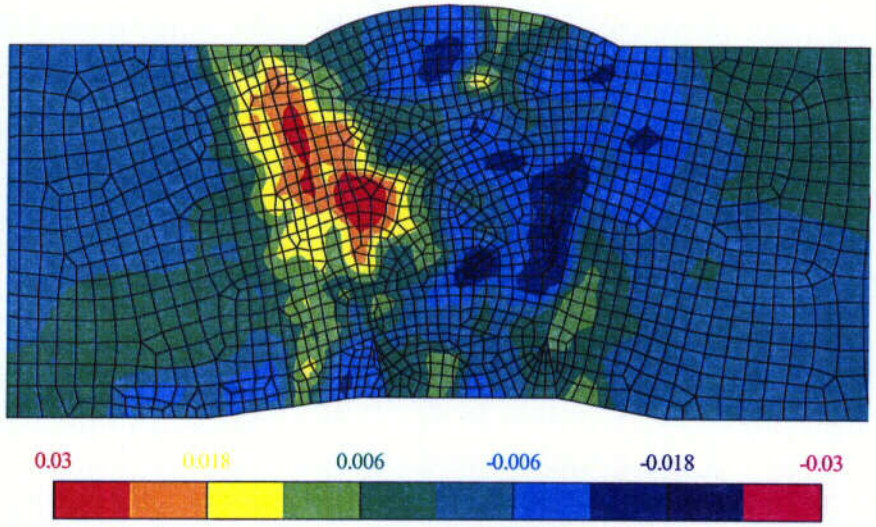


Figure 34. Hoop Plastic Strain Comparison Between Two Sequences.

Welding inside, then outside



Welding outside, then inside

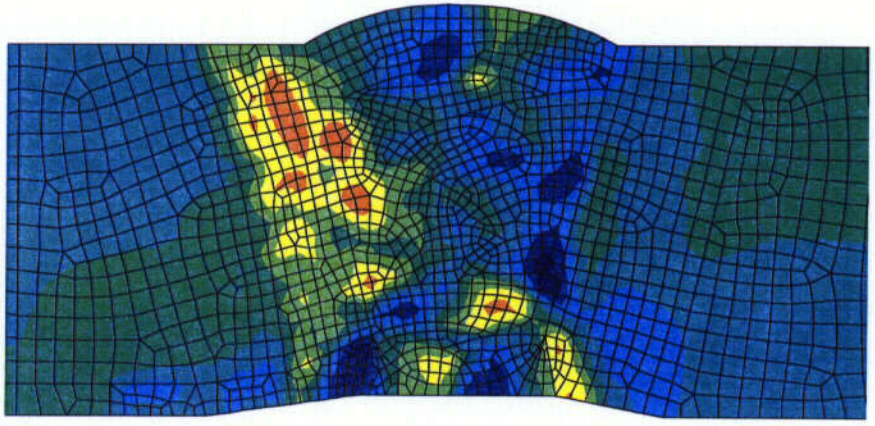


Figure 35. Shear Plastic Strain Comparison Between Two Sequences.

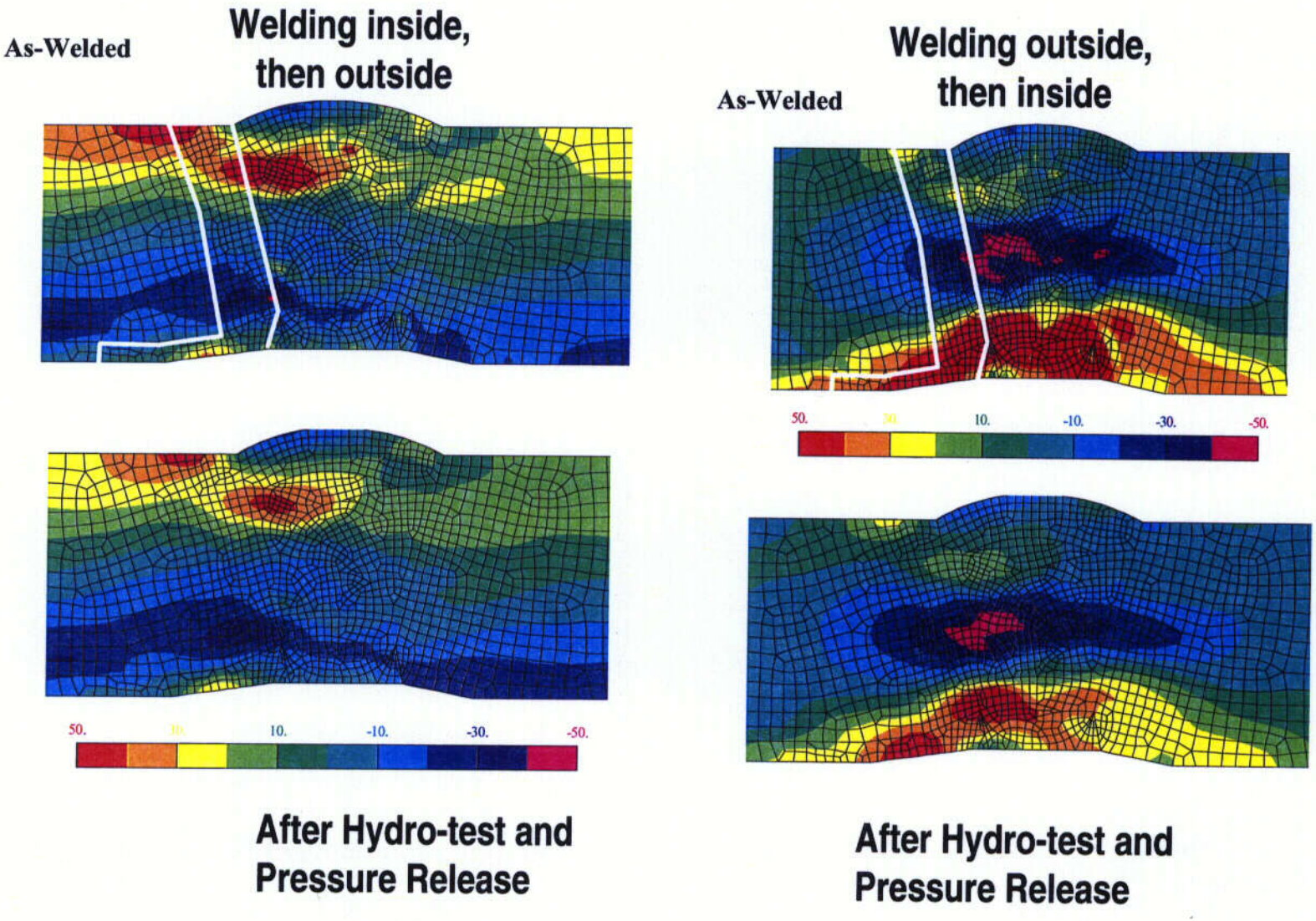


Figure 36. Effect of Hydro-test – Axial Stresses (Pressure = 3.125 ksi, then unload).

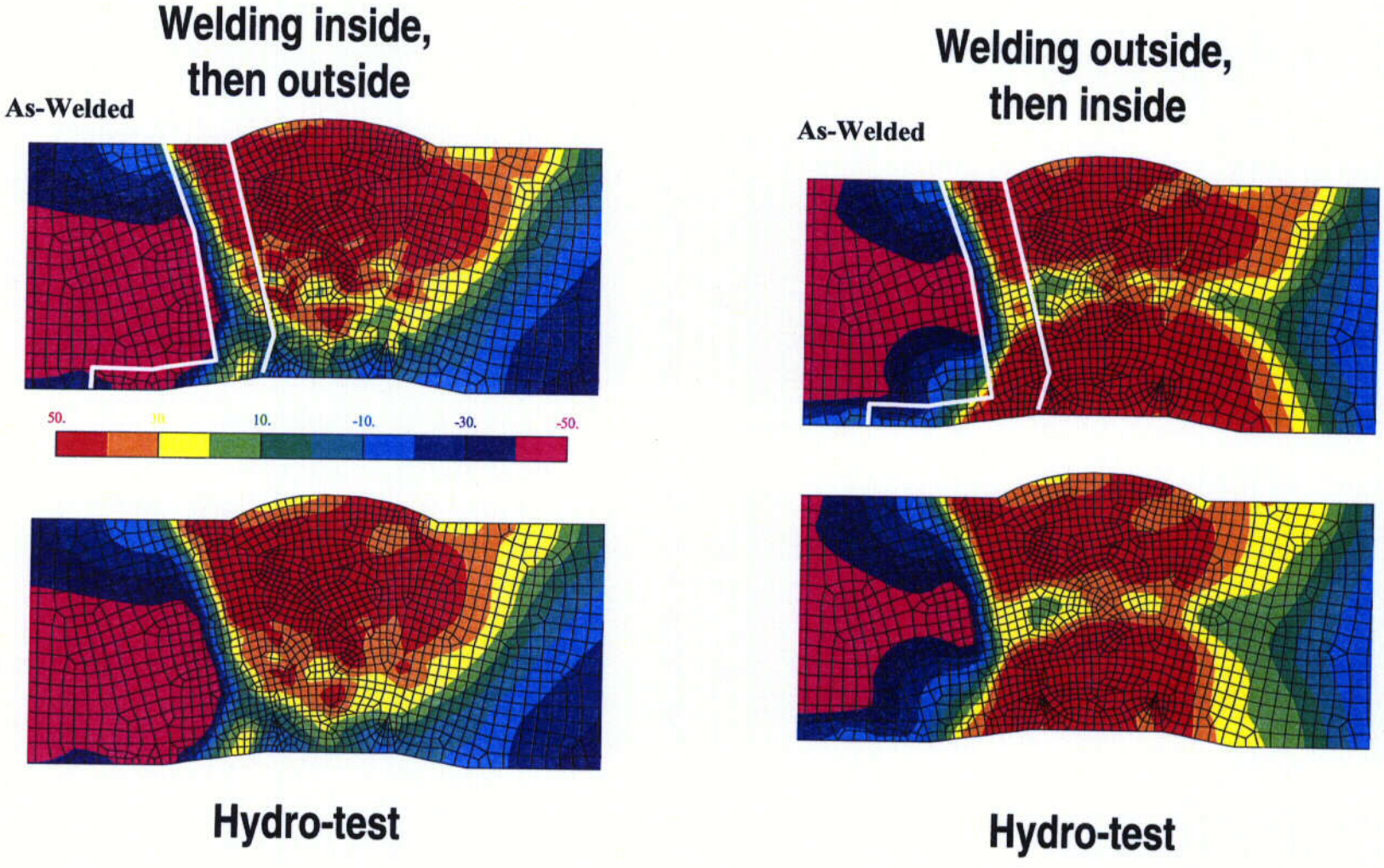


Figure 37. Effect of Hydro-Test – Hoop Stresses.
(Pressure = 3.125 ksi, then unload at Room Temperature)

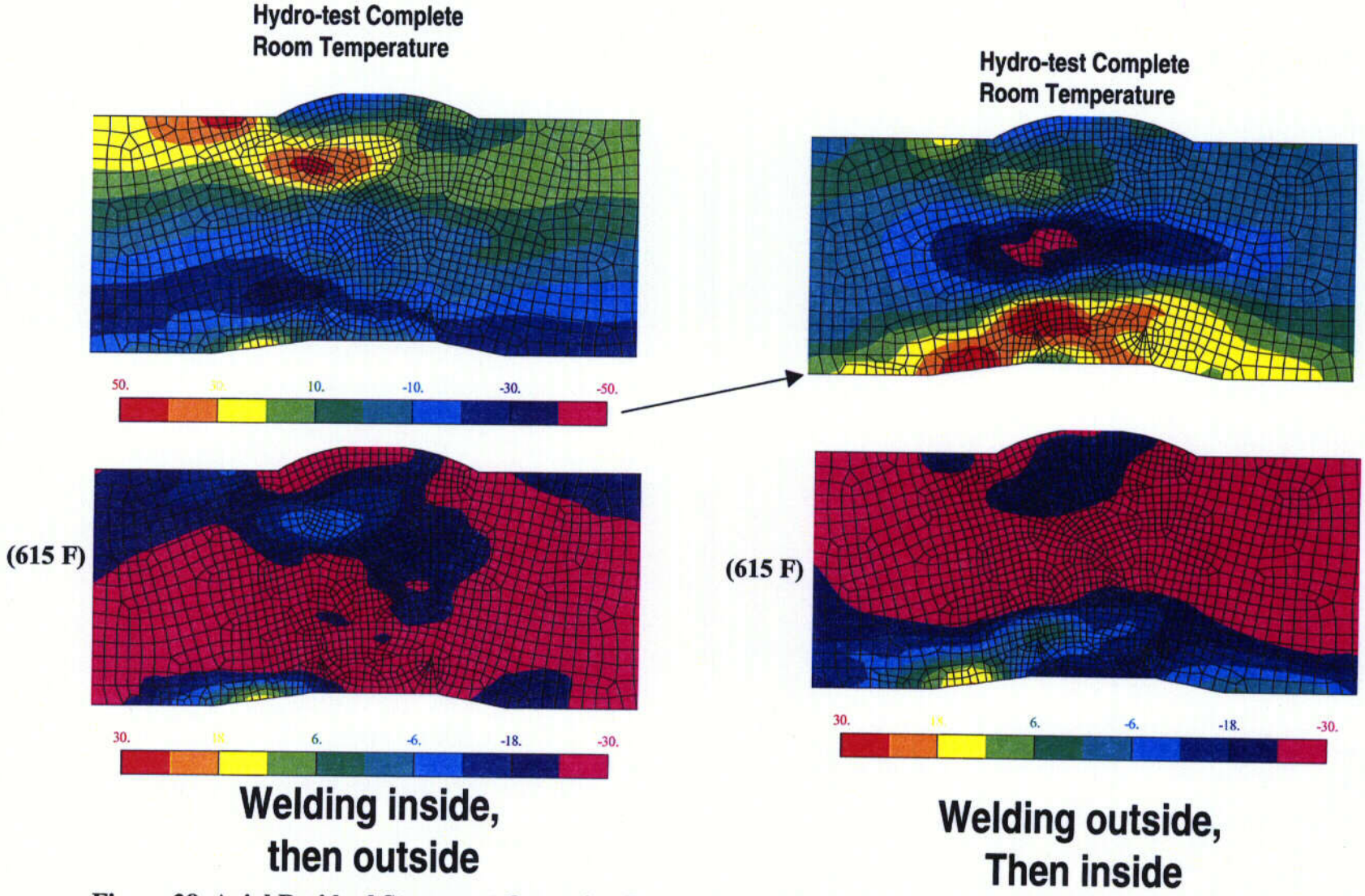


Figure 38. Axial Residual Stresses at Operating Temperature (after all welding and hydro-test). Top: Room Temperature Before Heat Up to 615 F; Bottom: After Heat Up.

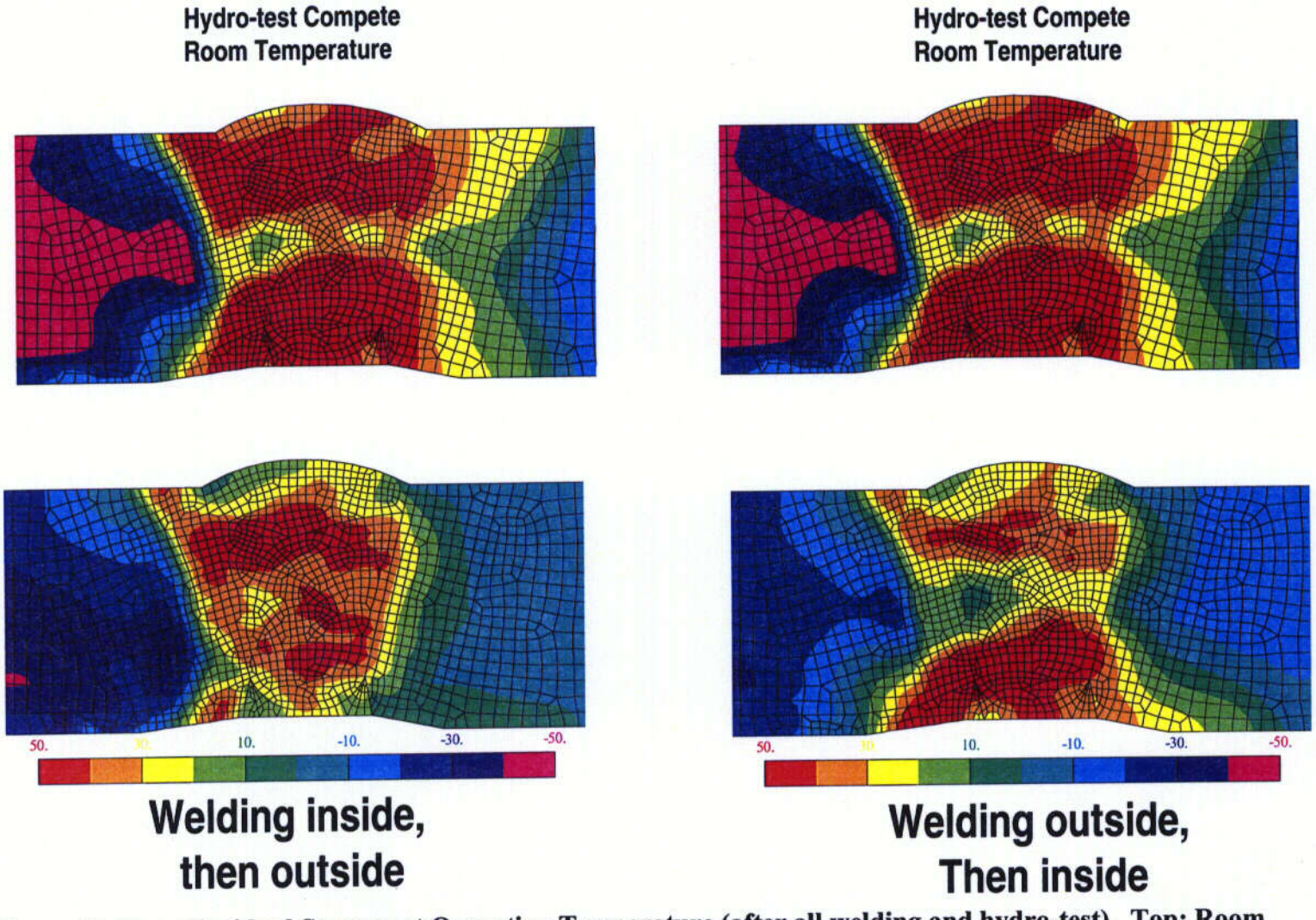


Figure 39. Hoop Residual Stresses at Operating Temperature (after all welding and hydro-test). Top: Room Temperature Before Heat Up to 615 F; Bottom: After Heat Up.

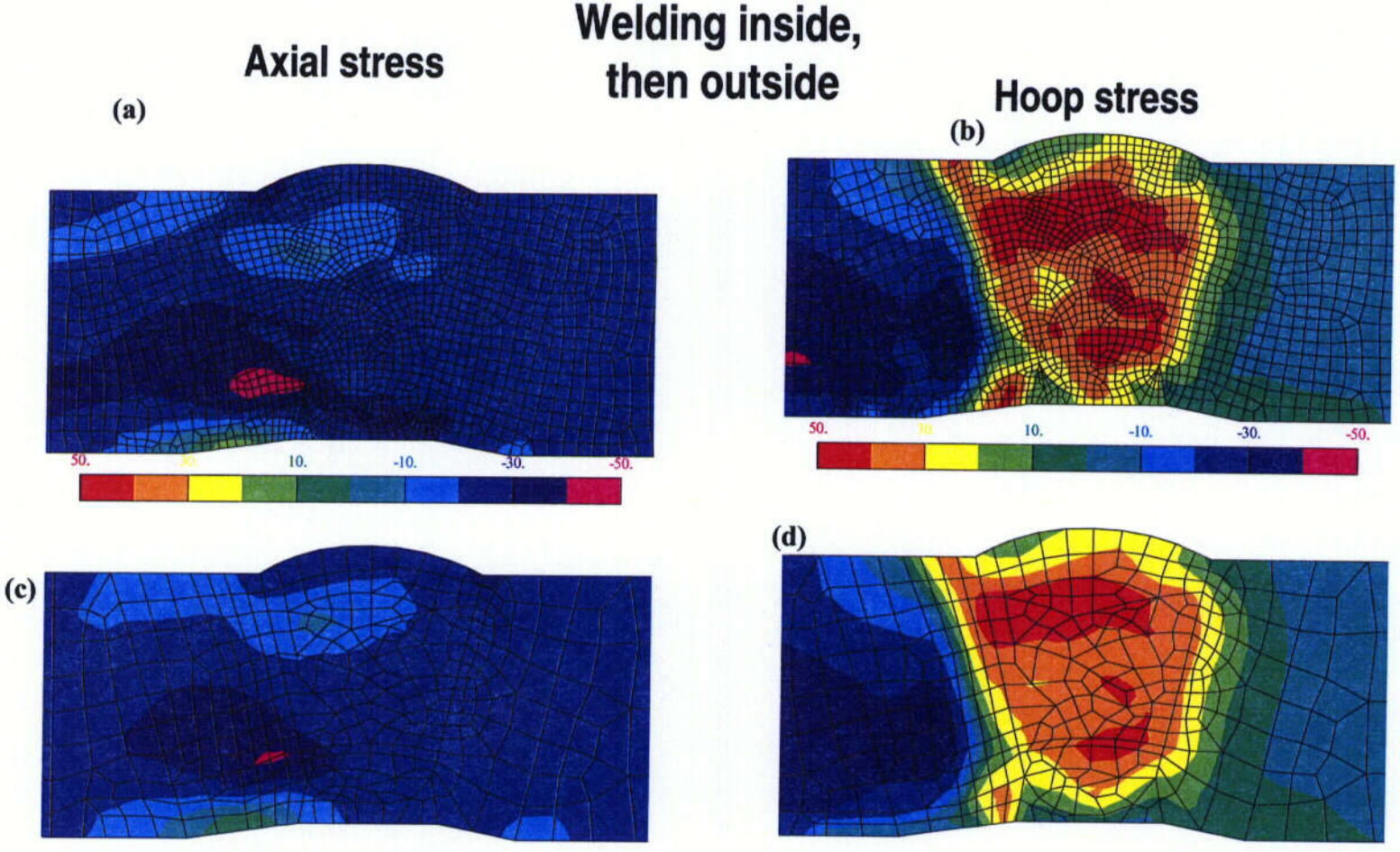


Figure 40. Operation Residual Stresses (615 F – No Loading) for Inside First Weld (a) and (b). (c) and (d) Mapped Residual Stresses at Operating Temperature from Fine to Coarse Mesh. These Stresses Are Then Mapped to a Three Dimensional Mesh (inside weld first, then outside weld).

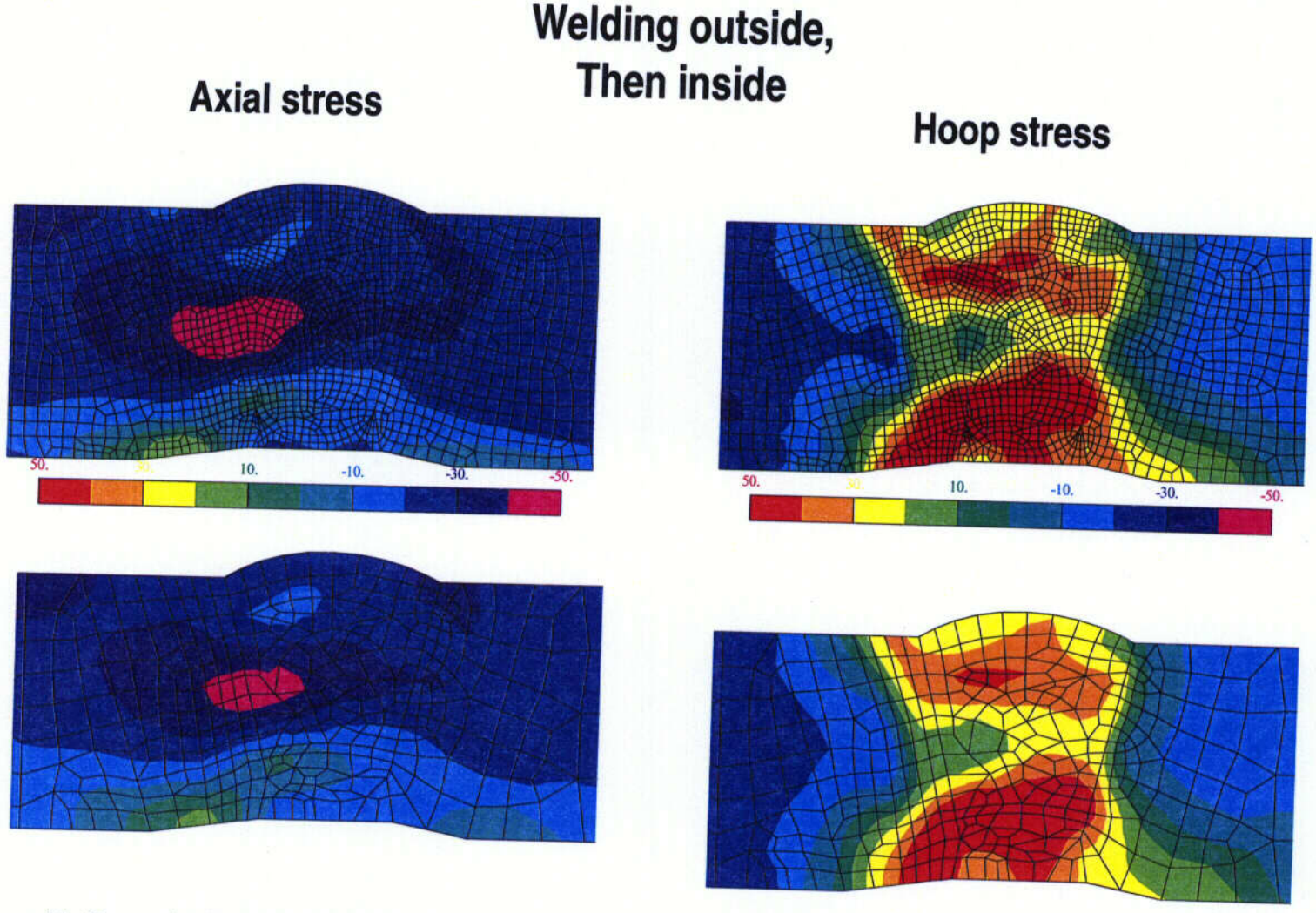


Figure 41. Operation Residual Stresses (615 F – No Loading) for Outside First Weld (a) and (b). (c) and (d) Mapped Residual Stresses at Operating Temperature from Fine to Coarse Mesh. These Stresses Are Then Mapped to a Three Dimensional Mesh (Outside weld first, then inside weld).

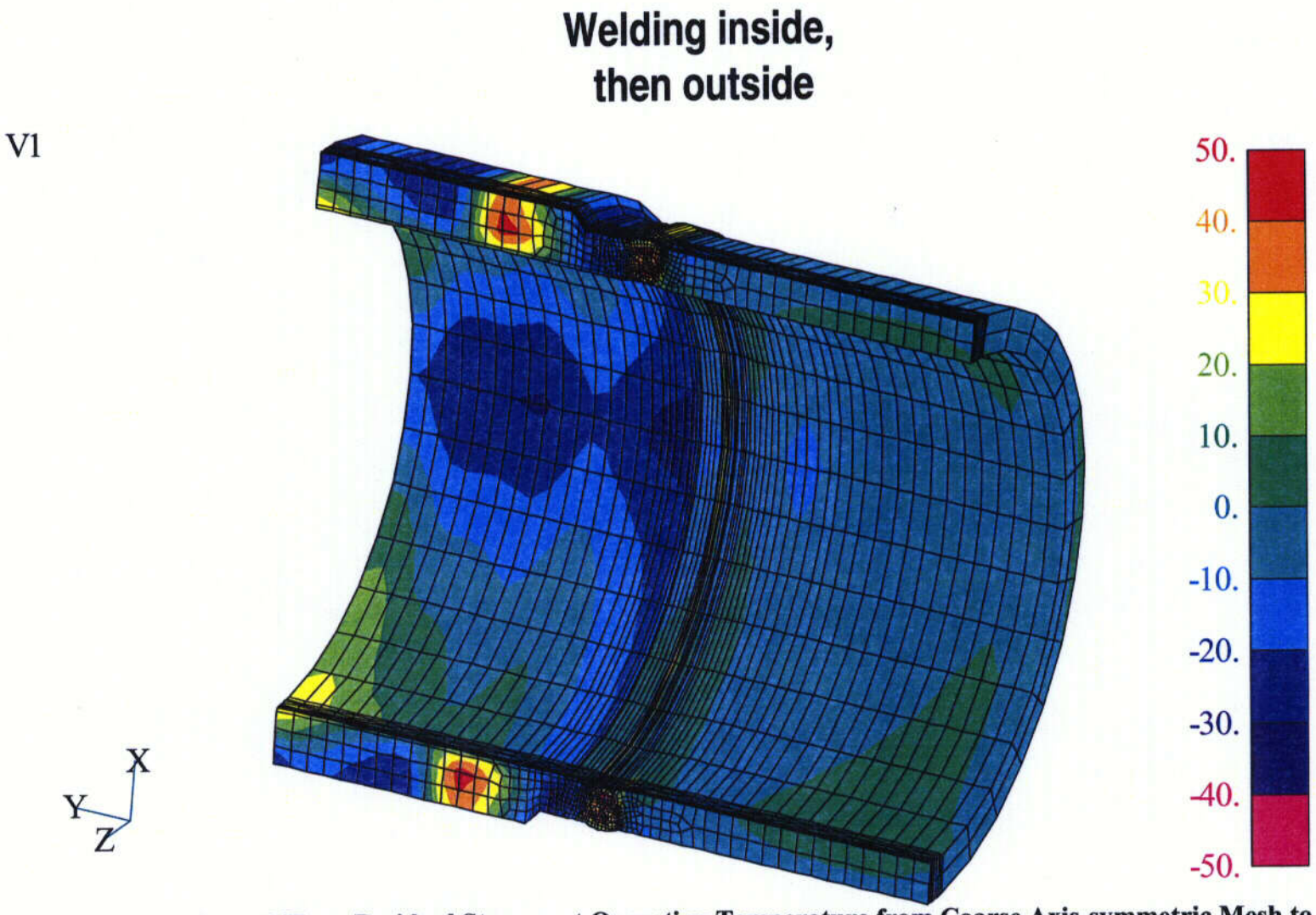


Figure 42. Mapped Hoop Residual Stresses at Operating Temperature from Coarse Axis-symmetric Mesh to 3D Mesh (inside weld first, then outside weld). (This 3D model is then used to obtain stress intensity factors via the finite element alternating method).

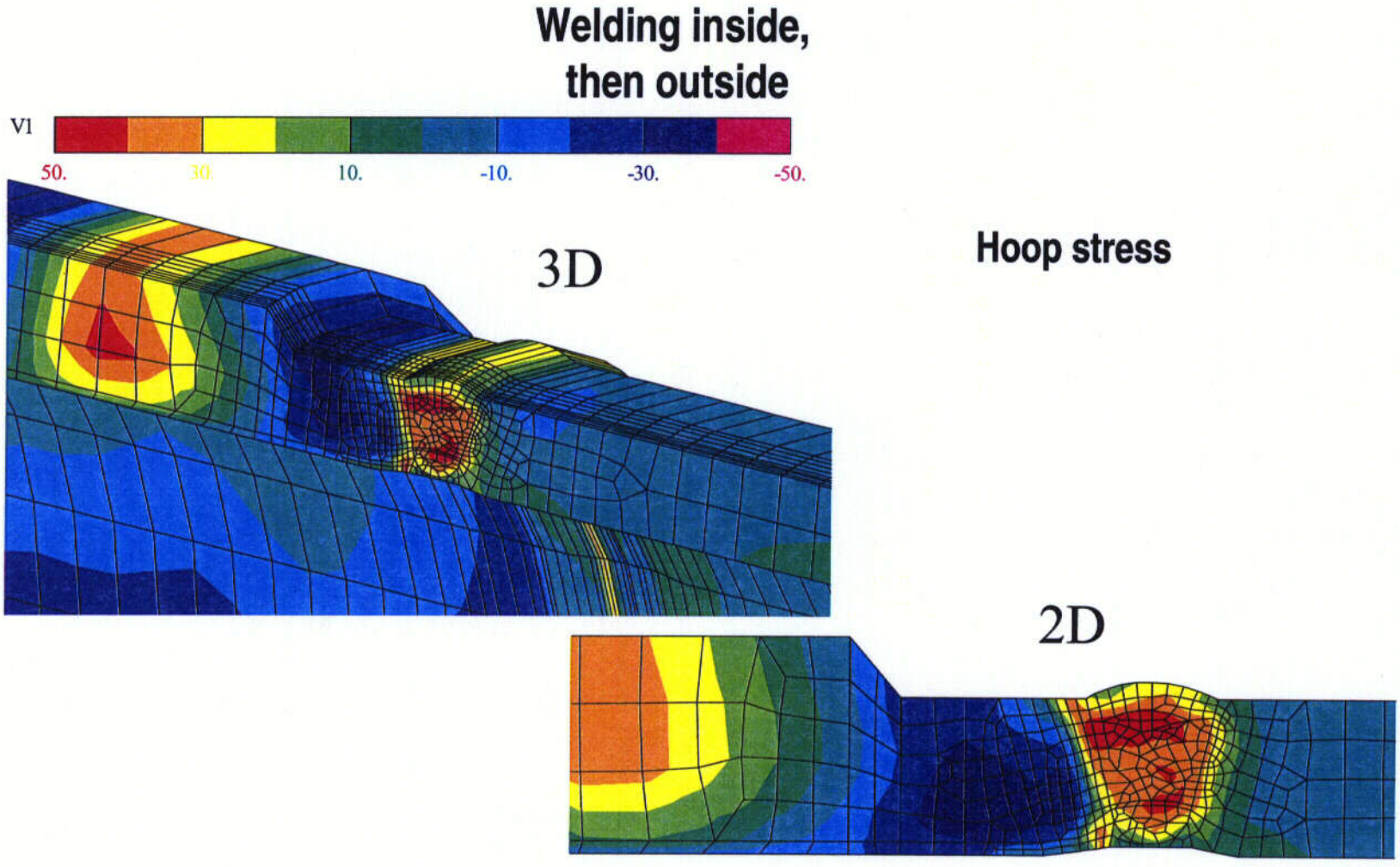


Figure 43. Comparison of Mapped Hoop Residual Stresses at Operating Temperature from Coarse Axis-symmetric Mesh to 3D Mesh (inside weld first, then outside weld).

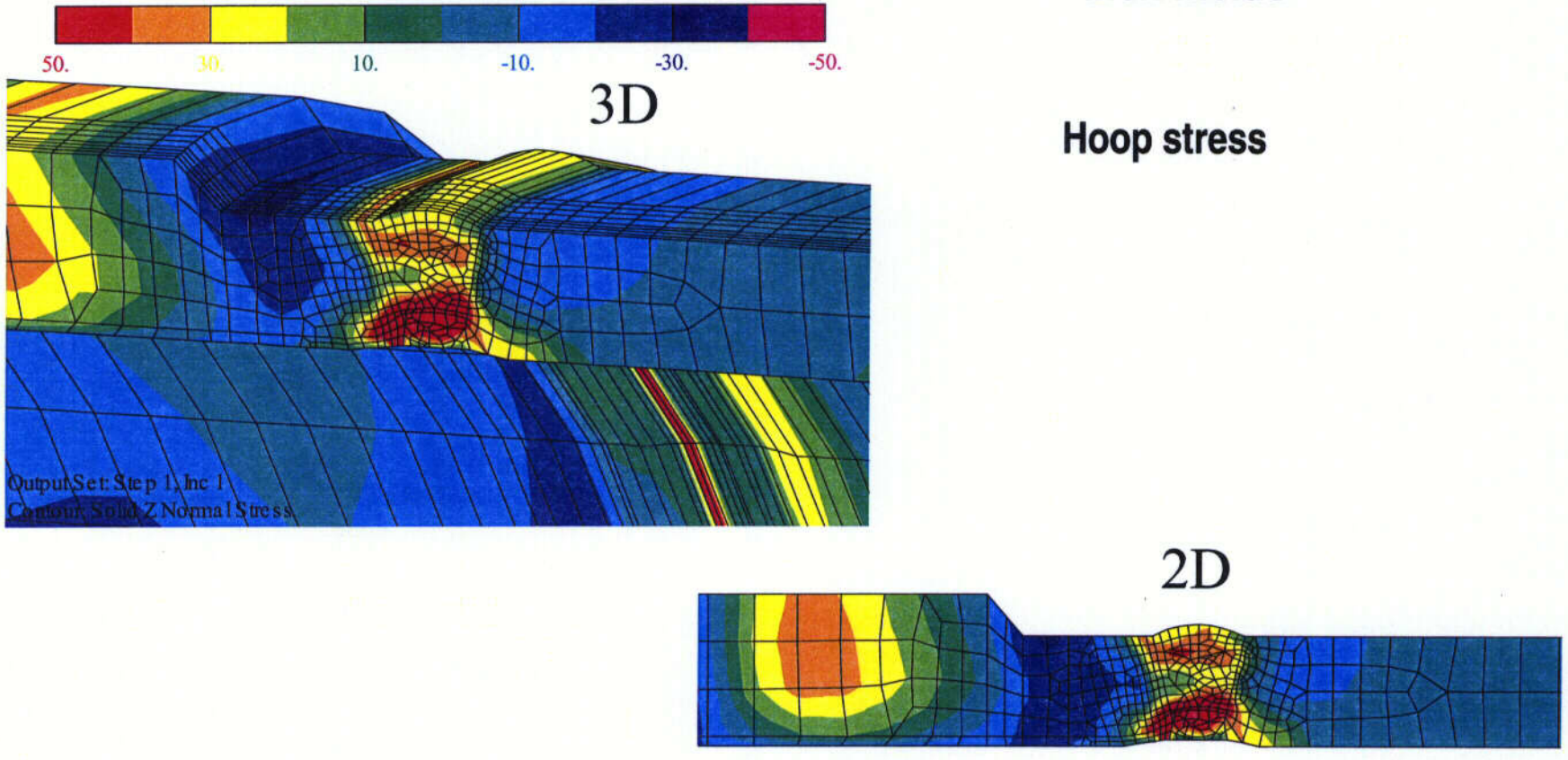


Figure 44. Comparison of Mapped Hoop Residual Stresses at Operating Temperature from Coarse Axis-symmetric Mesh to 3D Mesh (Outside weld first, then inside weld).

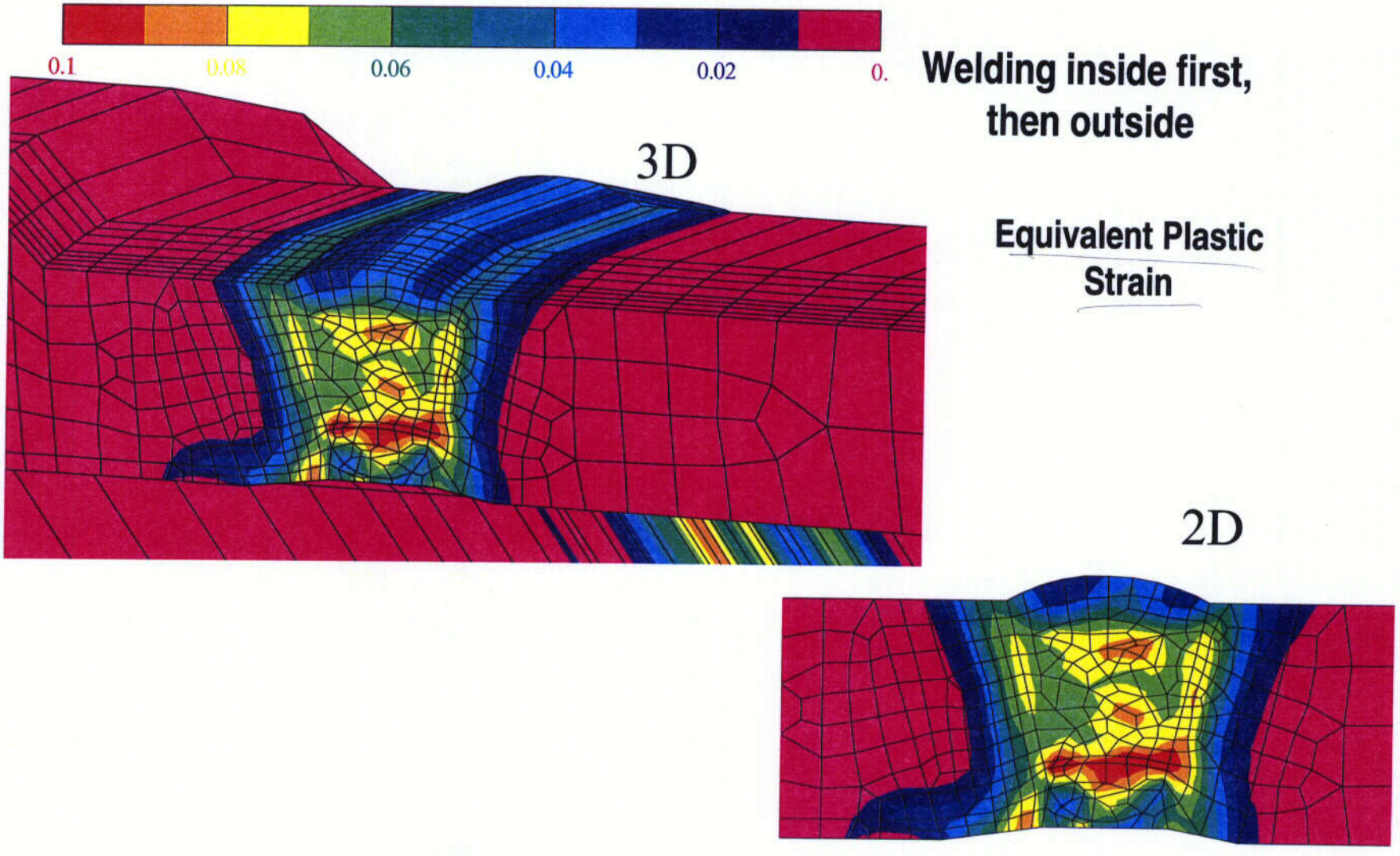
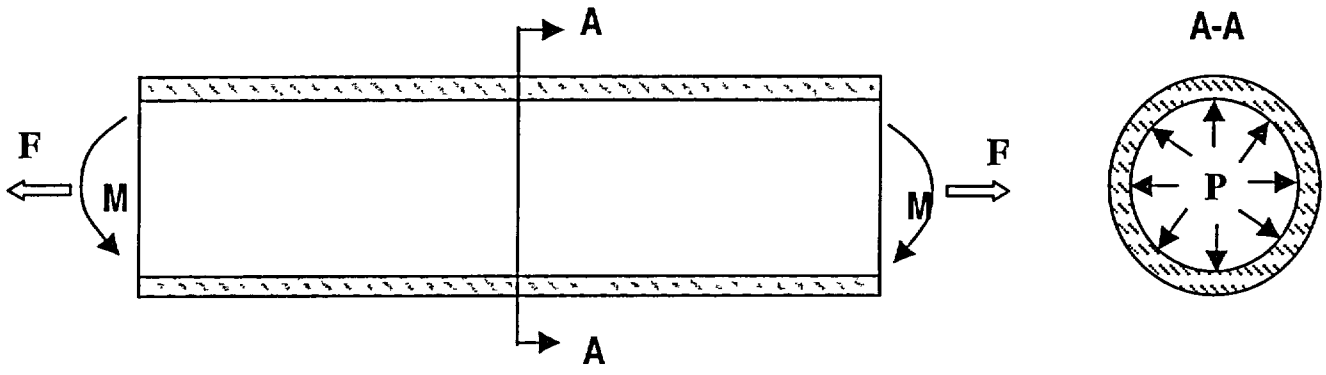


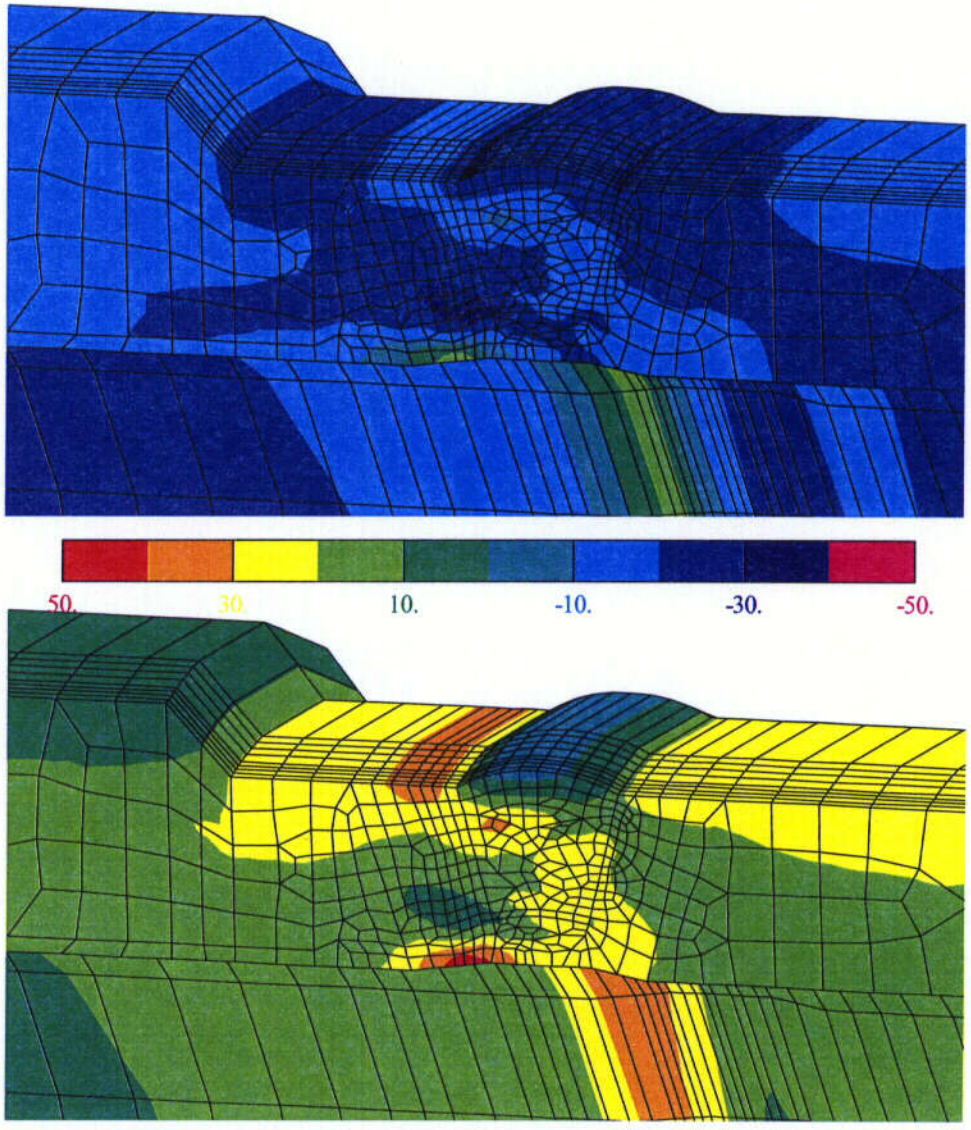
Figure 45. Comparison of Mapped Equivalent Plastic Strains at Operating Temperature from Coarse Axis-symmetric Mesh to 3D Mesh (inside weld first, then outside weld).



P-pressure: 2.25 (ksi)
F-force: 1476 kips (including the force due to the pressure)
M-bending moment: 22052 in-kips

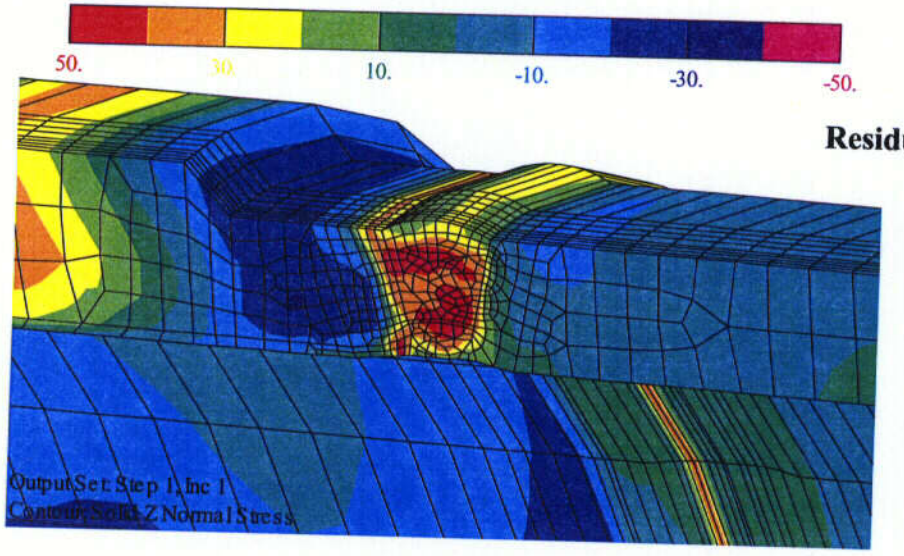
Figure 46. Normal Operating Loads Applied on Hot Leg.

Residual Stress Only:
615F



Residual Stress Plus:
615F
Normal Operating
Loads

Figure 47. Axial Stresses – Used for FEAM Analyses:
Inside Weld First then Outside Weld.



Residual Stress Only:
615F

Residual Stress Plus:
615F
Normal Operating
Loads

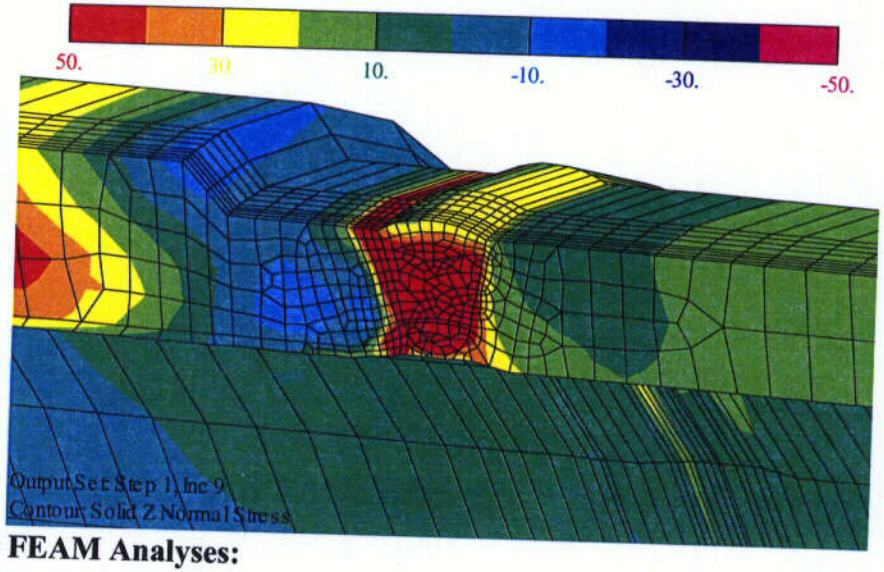
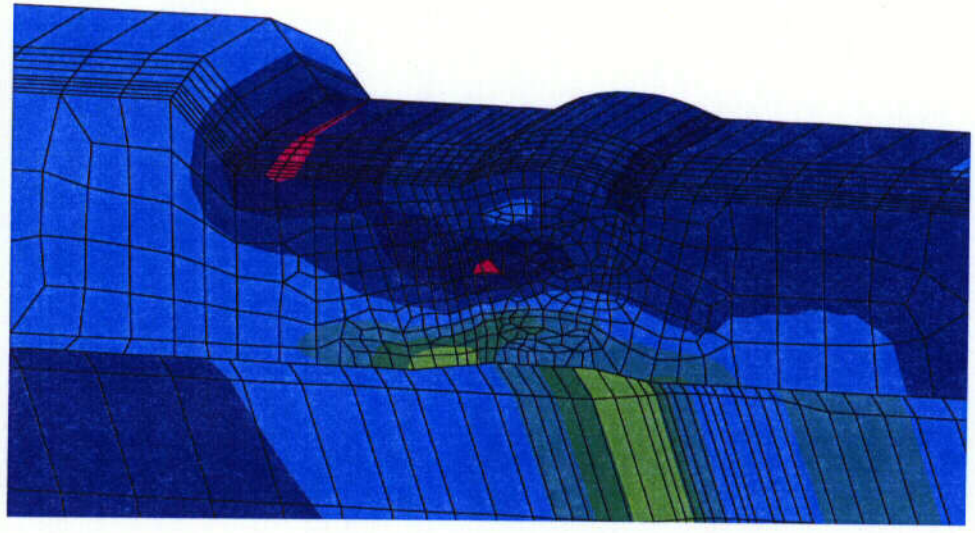
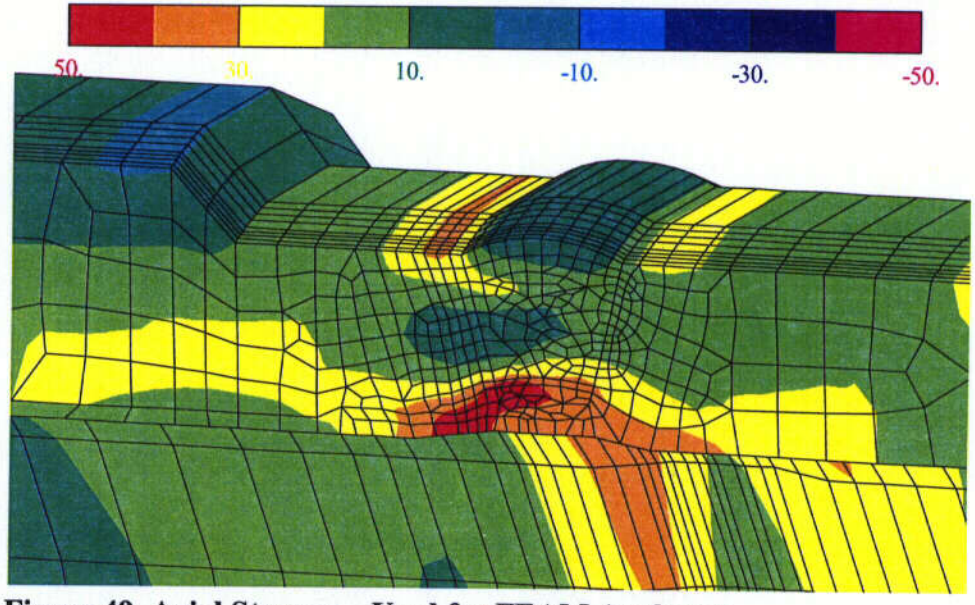


Figure 48. Hoop Stresses – Used for FEAM Analyses: Inside Weld First then Outside Weld.

Residual Stress Only:
615F

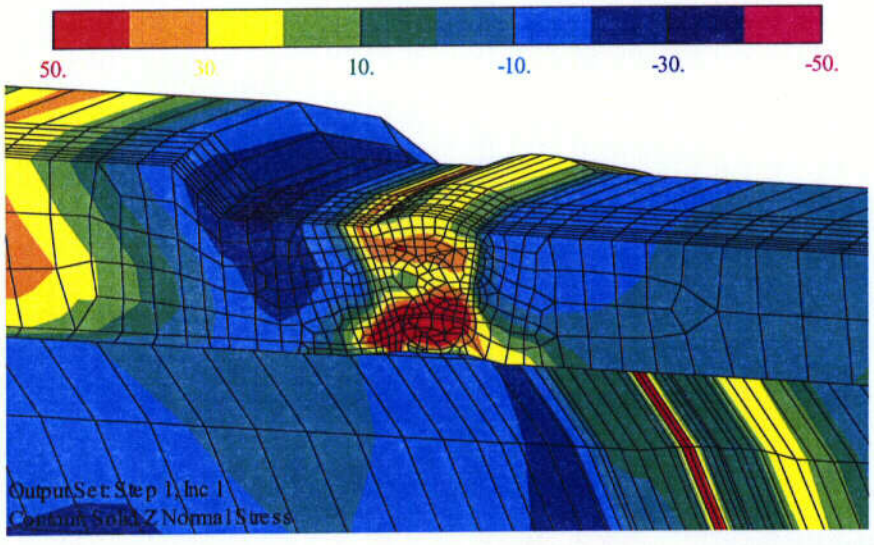




Residual Stress Plus:
615F
Normal Operating
Loads

Figure 49. Axial Stresses – Used for FEAM Analyses:
Outside Weld First then Inside Weld.

Residual Stress Only:
615F



Residual Stress Plus:
615F
Normal Operating
Loads

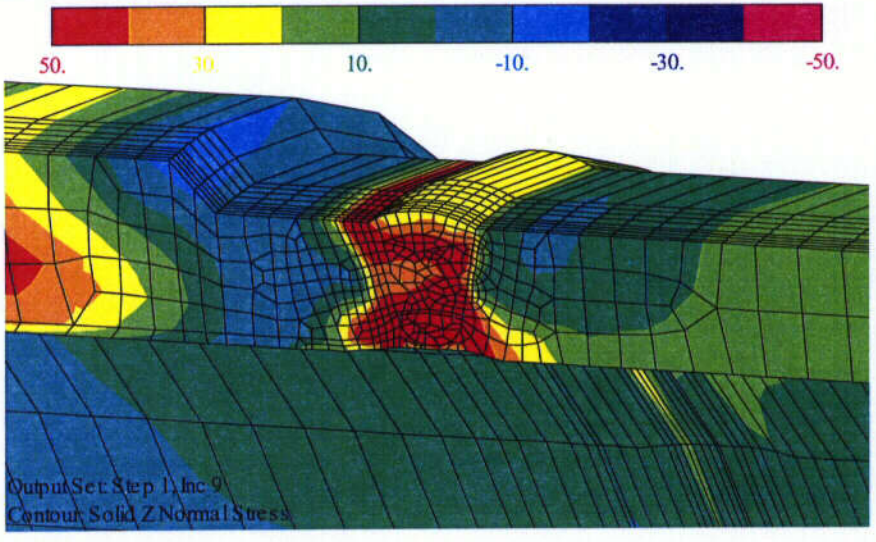


Figure 50. Hoop Stresses – Used for FEAM Analyses:
Outside Weld First then Inside Weld.

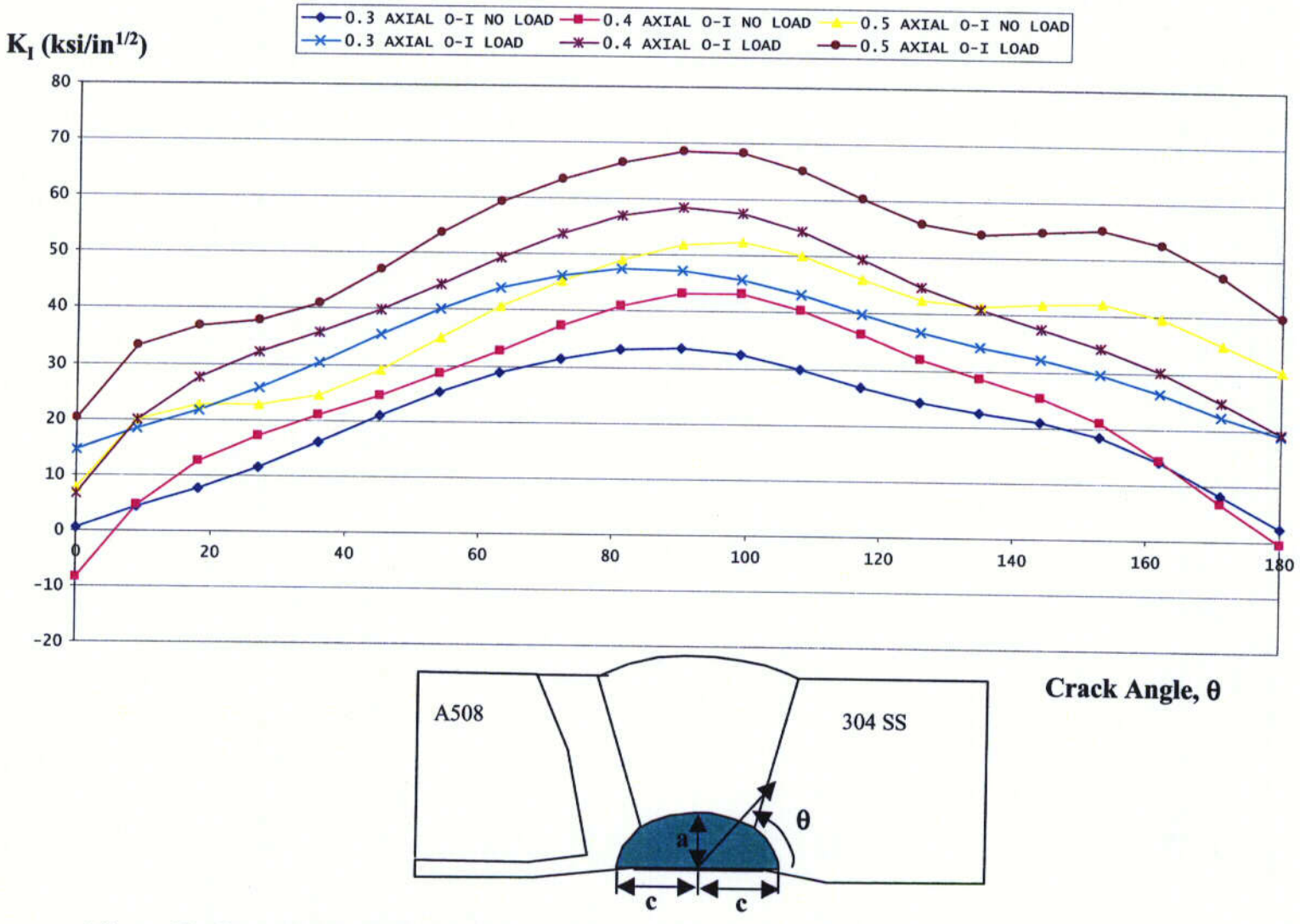


Figure 51. Stress Intensity Factors; a = 0.3, 0.4, 0.5; c/a = 1.5. 'NO LOAD' = 'Residual Stress Only', 'LOAD' = 'Residual Stress Plus Normal Operating Load'.

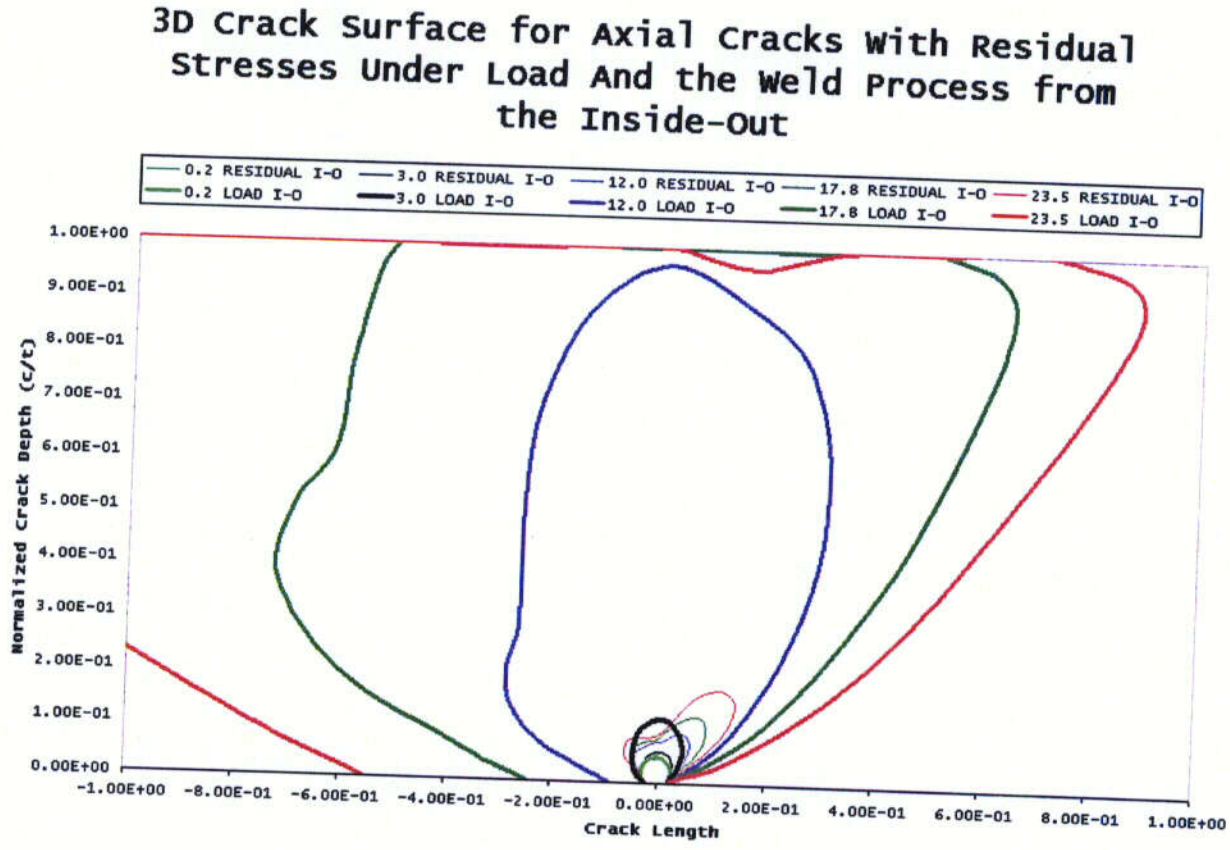


Figure 52a. Axial Crack Growth for the Inside-Out Weld Process.

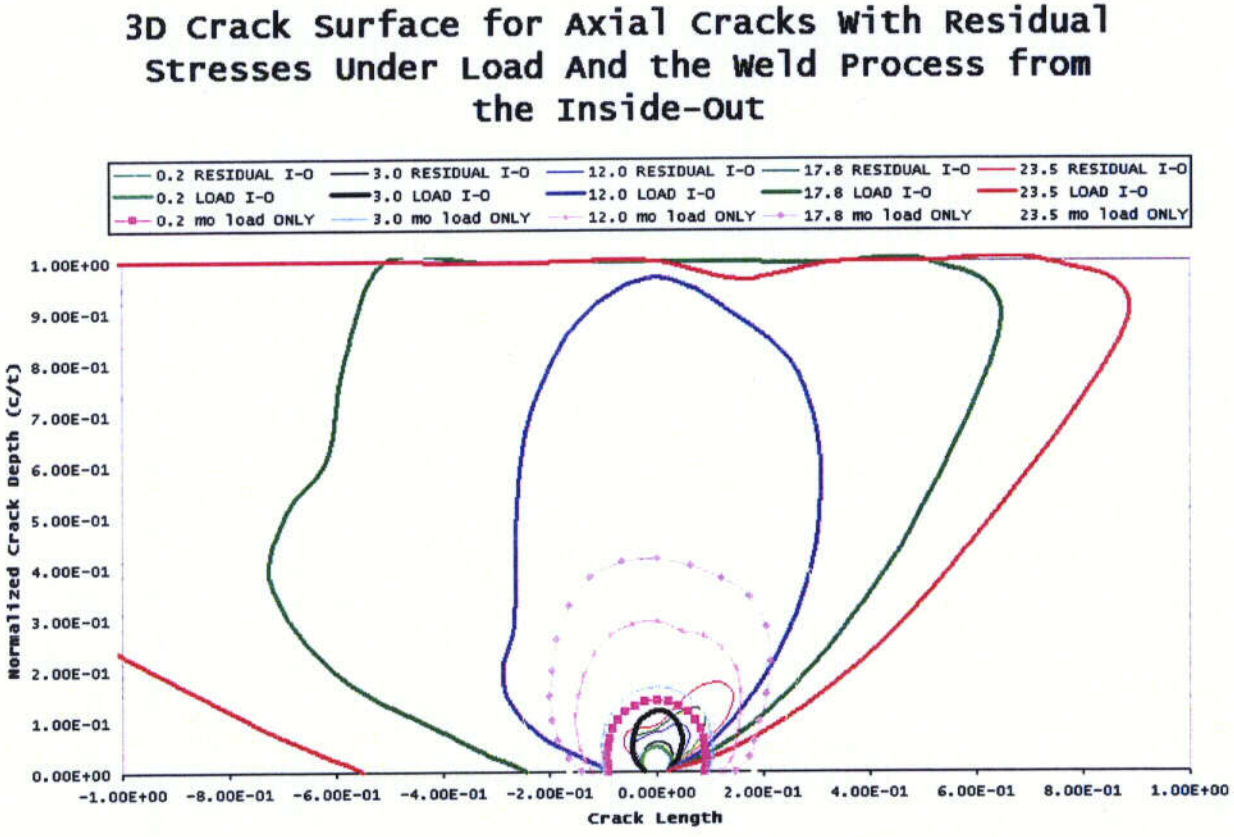


Figure 52b. Approximation for the Impact of the Residual Stress Field on the Crack Size and Shape

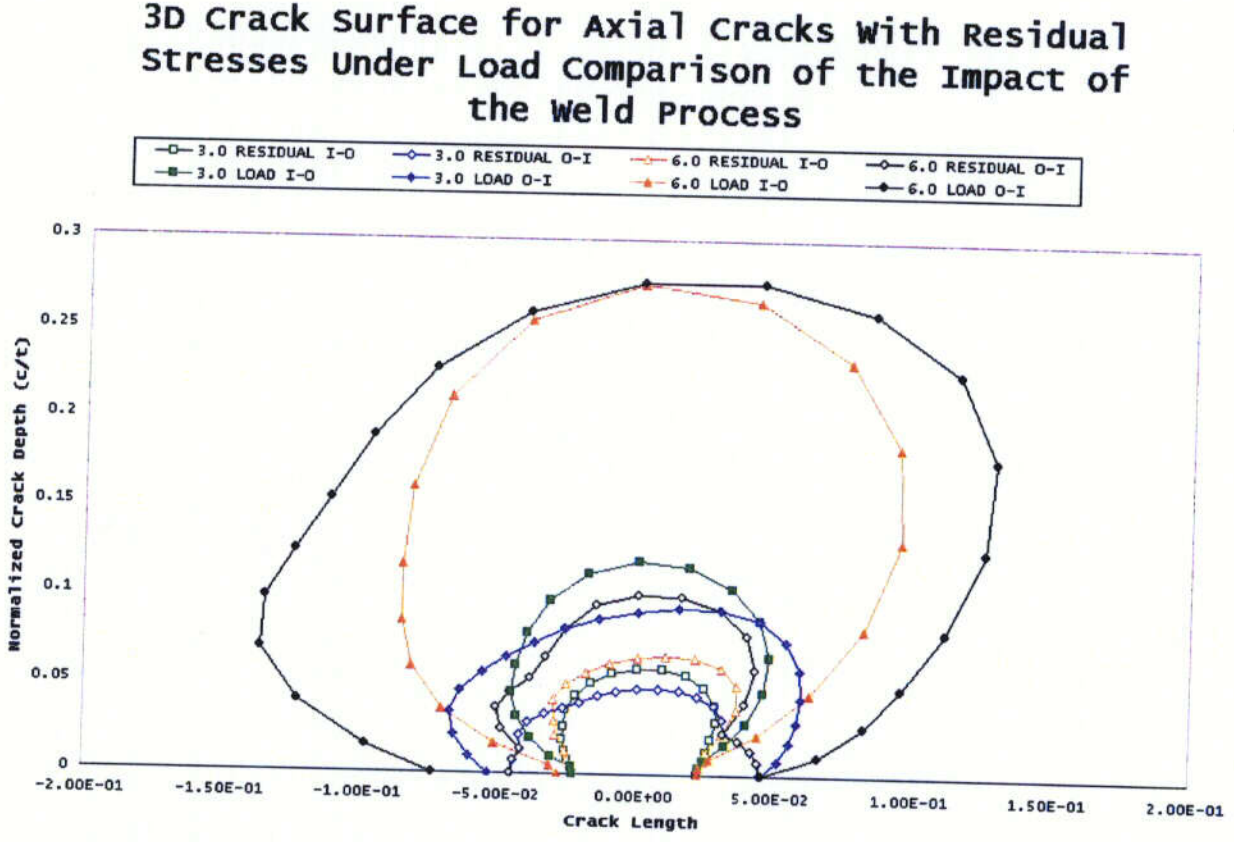


Figure 52c. Three and Six Month Crack Growth Shapes.

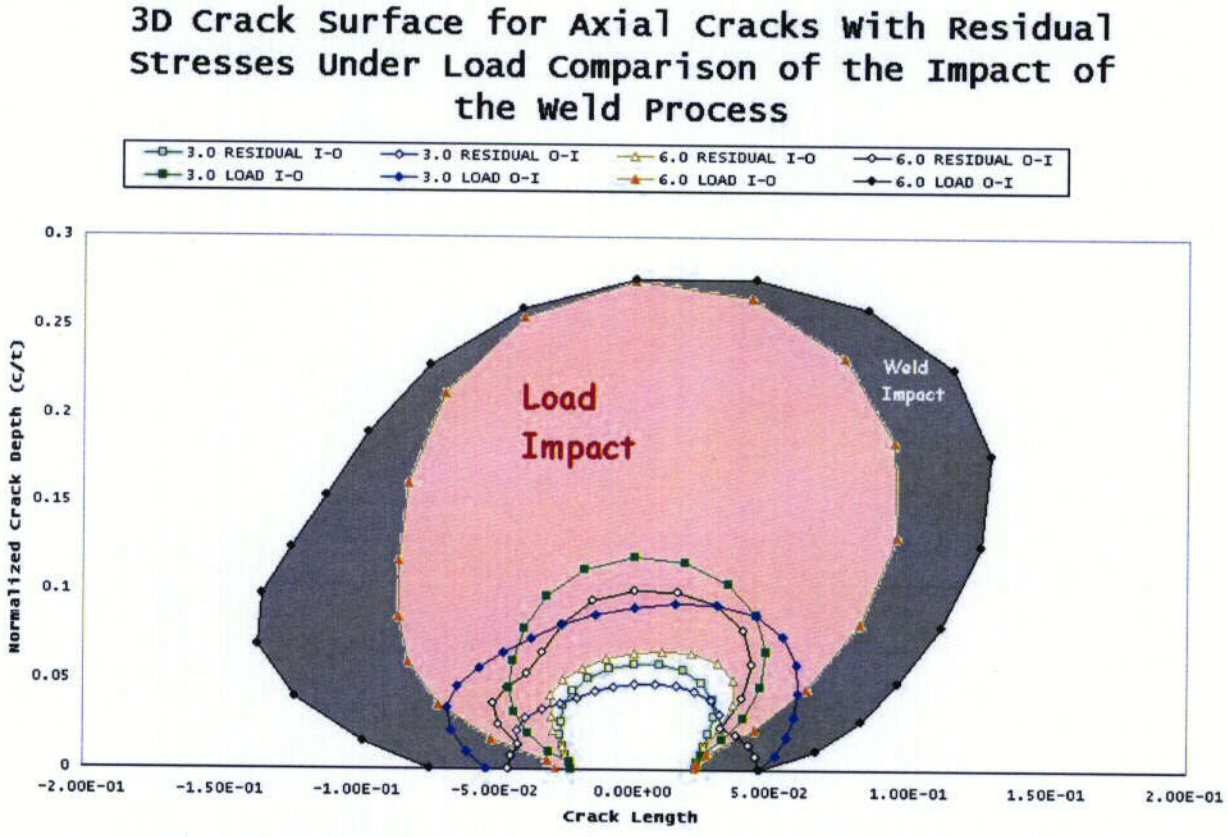


Figure 53. Approximation for the Impact of the Residual Stress Field on the Crack Size and Shape. The 'red' shape represents the crack shape for the case of loading and residual stresses (for the I-O case) and the 'white' shape is the crack shape for the residual stress only case after 6 months of PWSCC growth. The 'red' curve (I-O case) can be compared to the 'gray' (O-I case) curve for a comparison of the weld sequence effect.

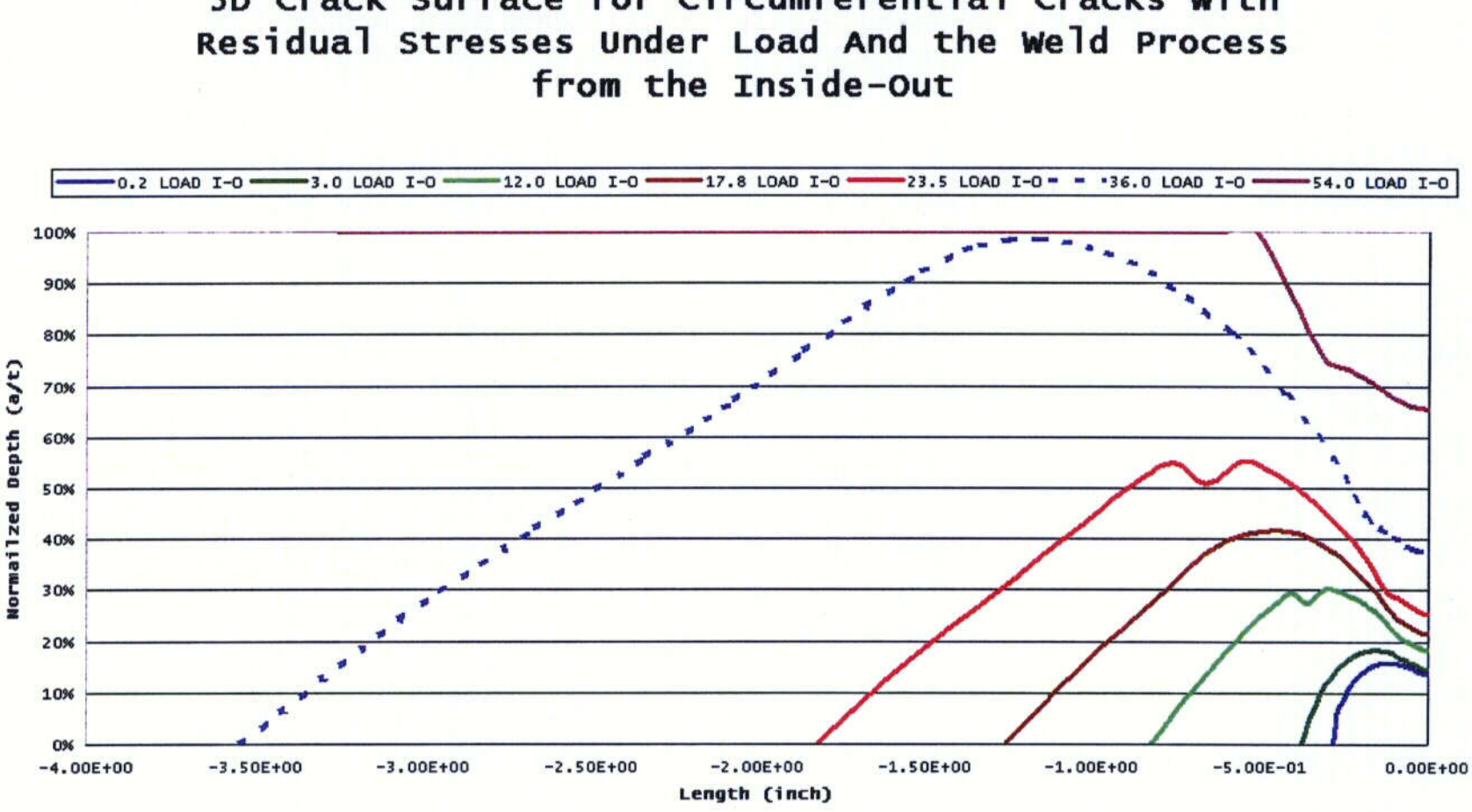


Figure 54a. Circumferential PWSCC growth – Inside Weld First Case.

C32

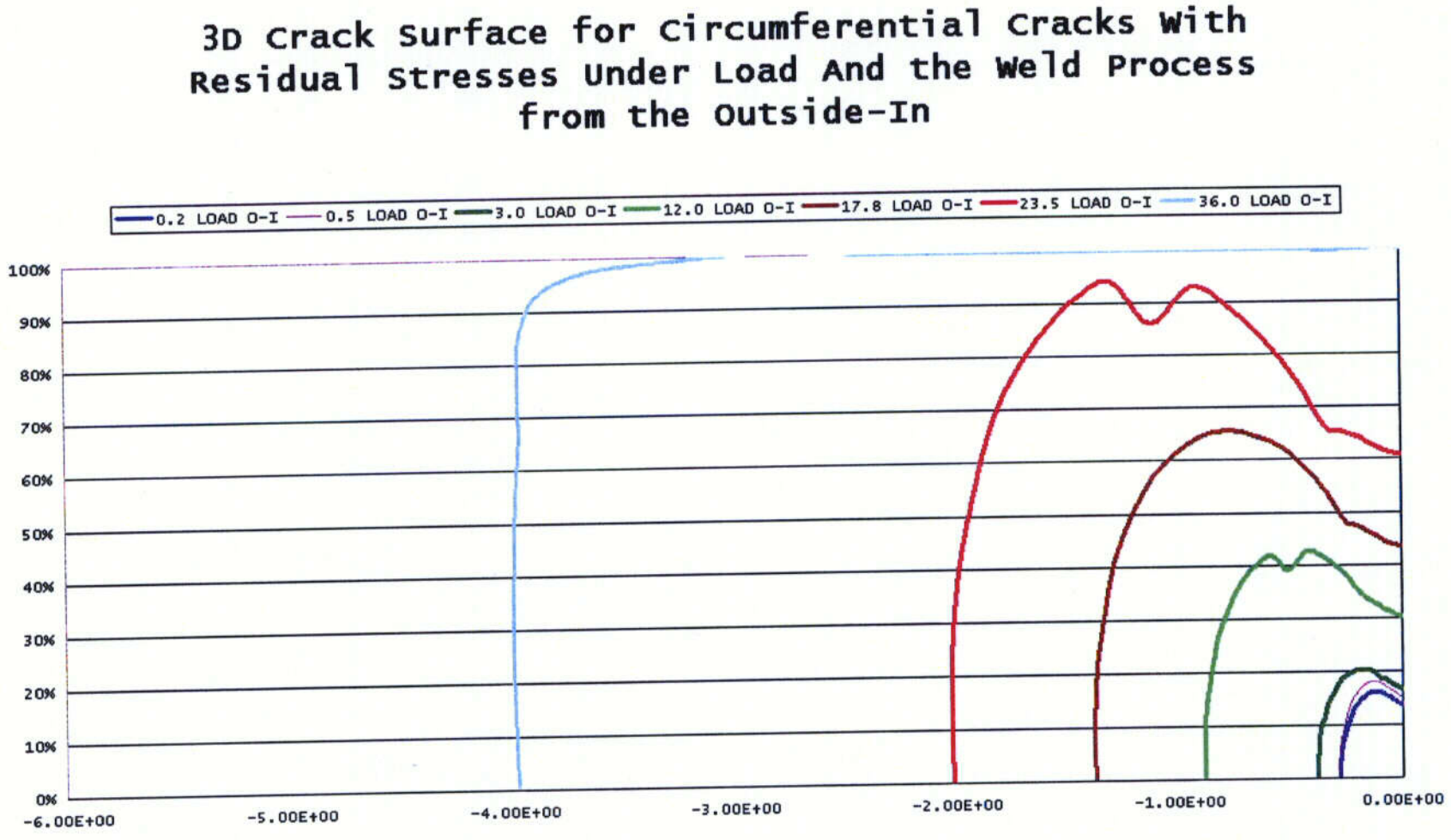


Figure 54b. Circumferential PWSCC growth – Outside Weld First Case.

The Impact of Conservative Stress-Corrosion Cracking Models on 3D Surface Crack Predictions for Axial Cracks With Residual Stresses Under Load for the Inside-Out Weld Process

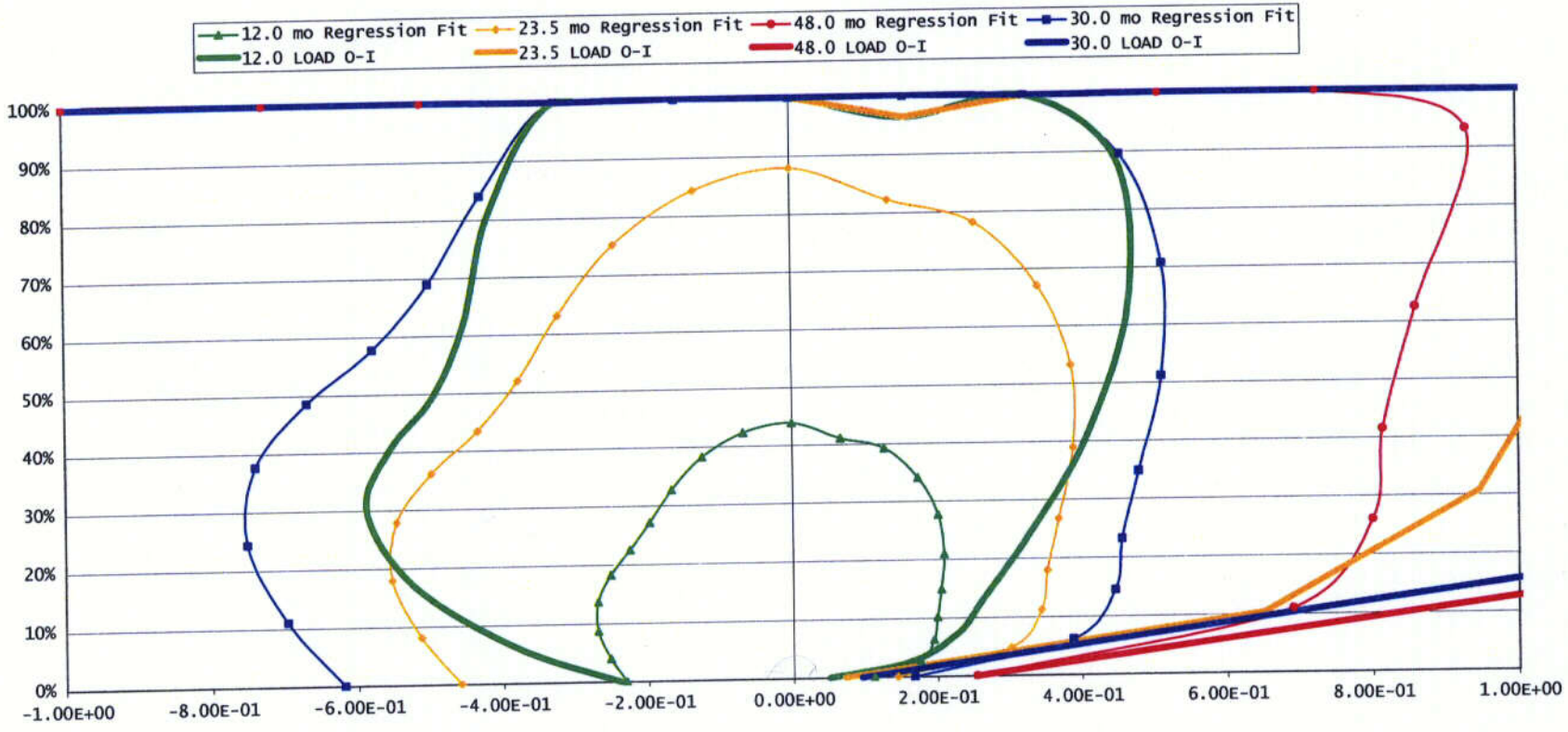


Figure 55a. The Impact of Using a Conservative PWSCC Law on Crack Growth – Axial Crack.

C34

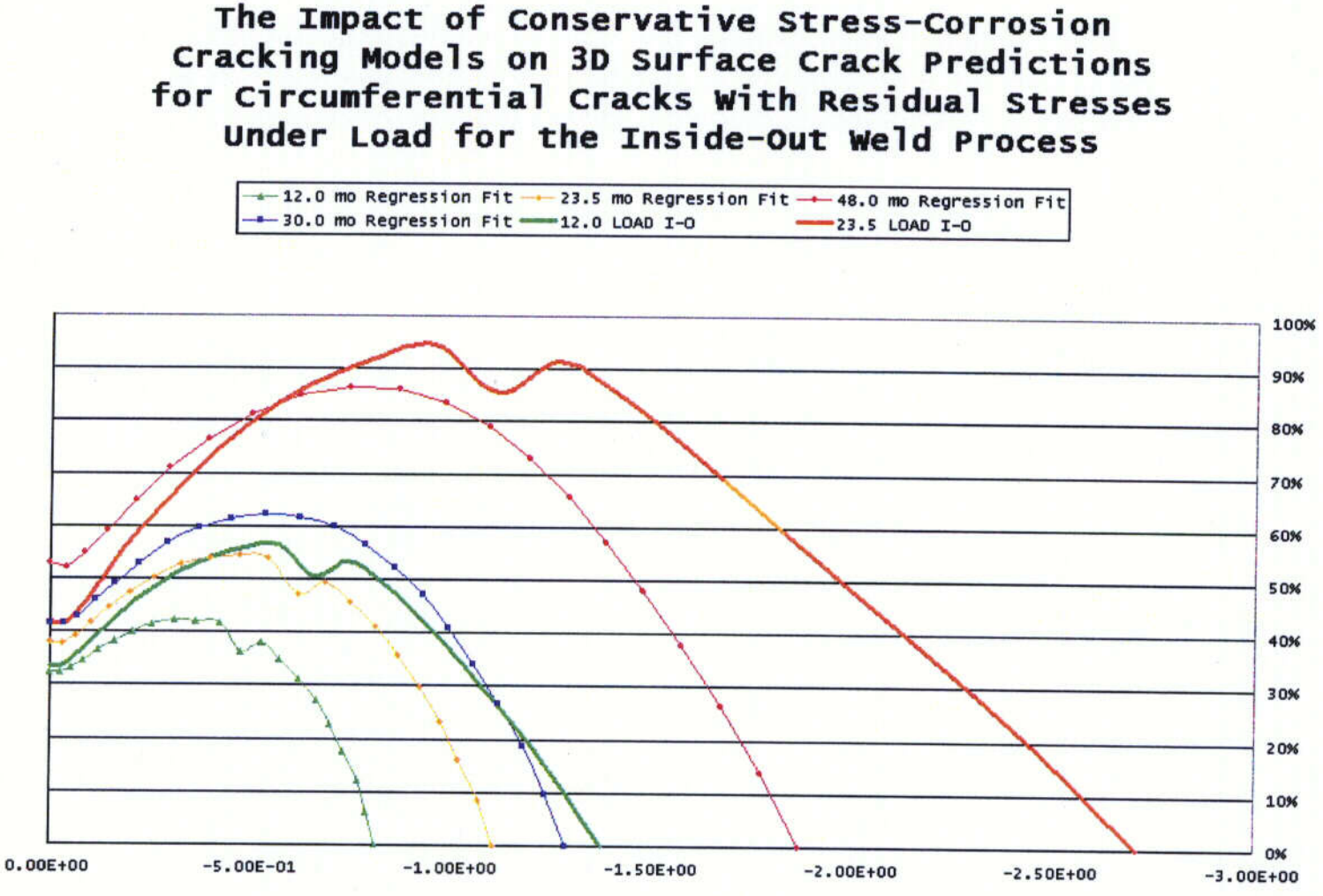


Figure 55b. The Impact of Using a Conservative PWSCC Law on Crack Growth – Circumferential Crack.

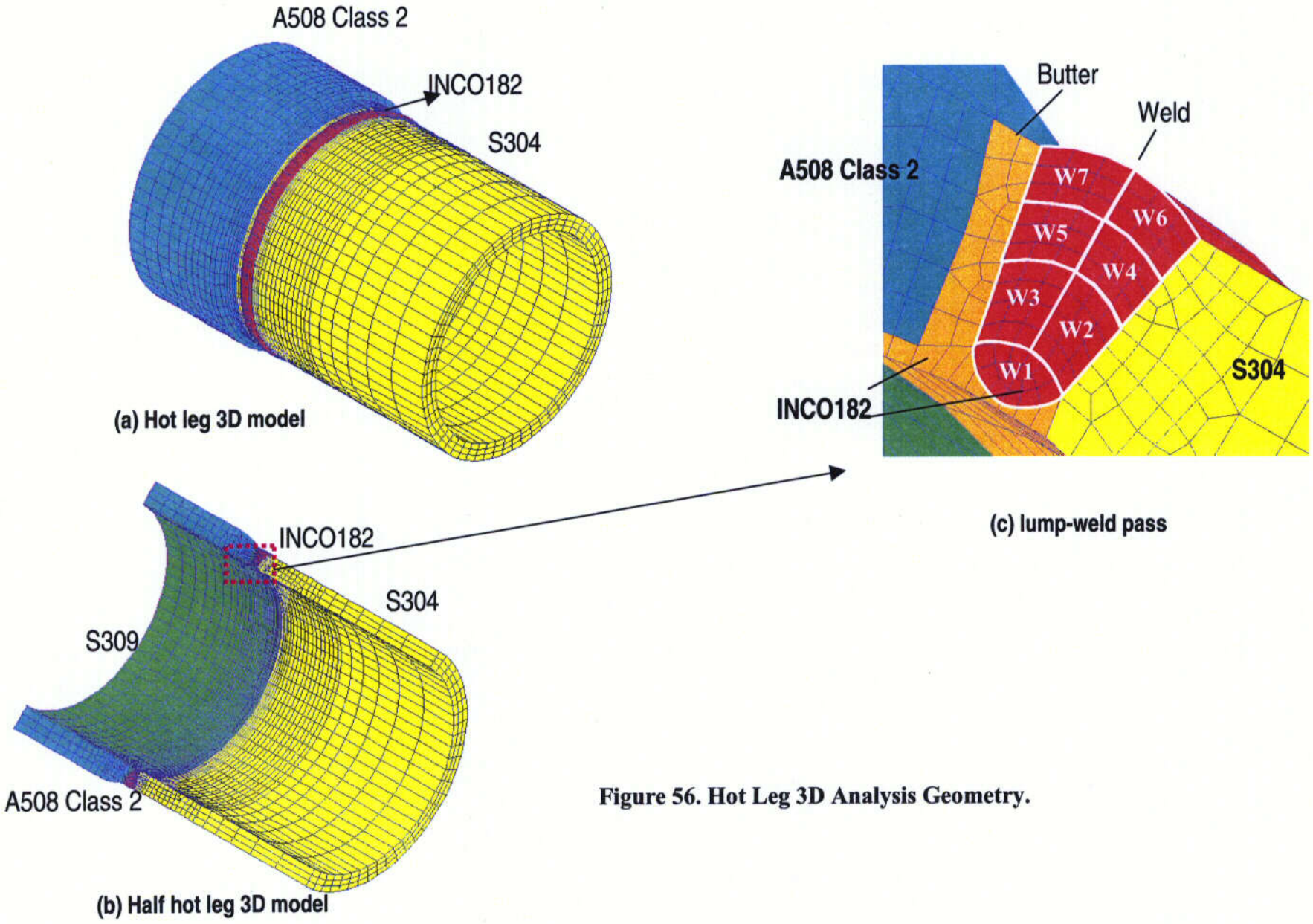


Figure 56. Hot Leg 3D Analysis Geometry.

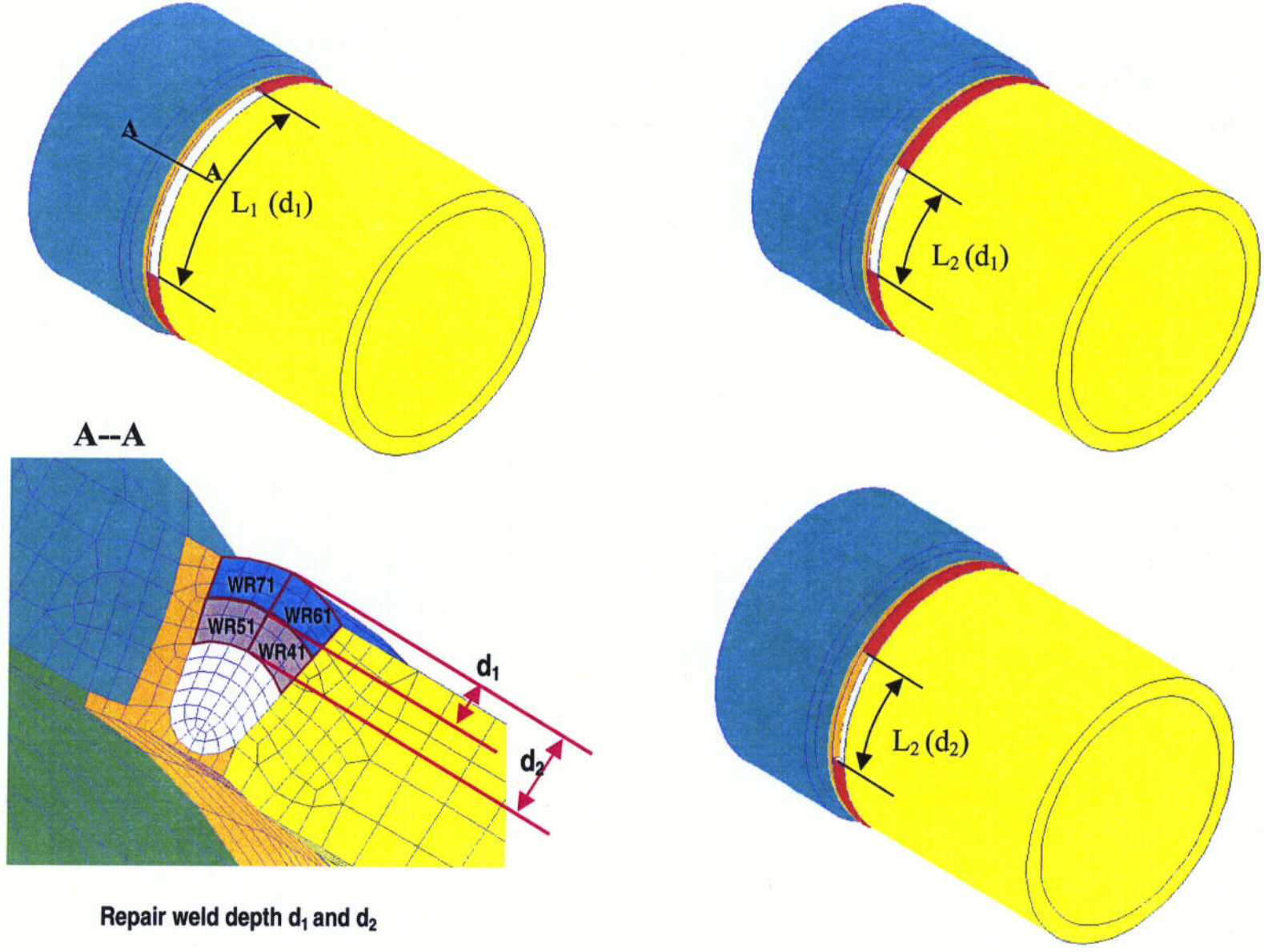
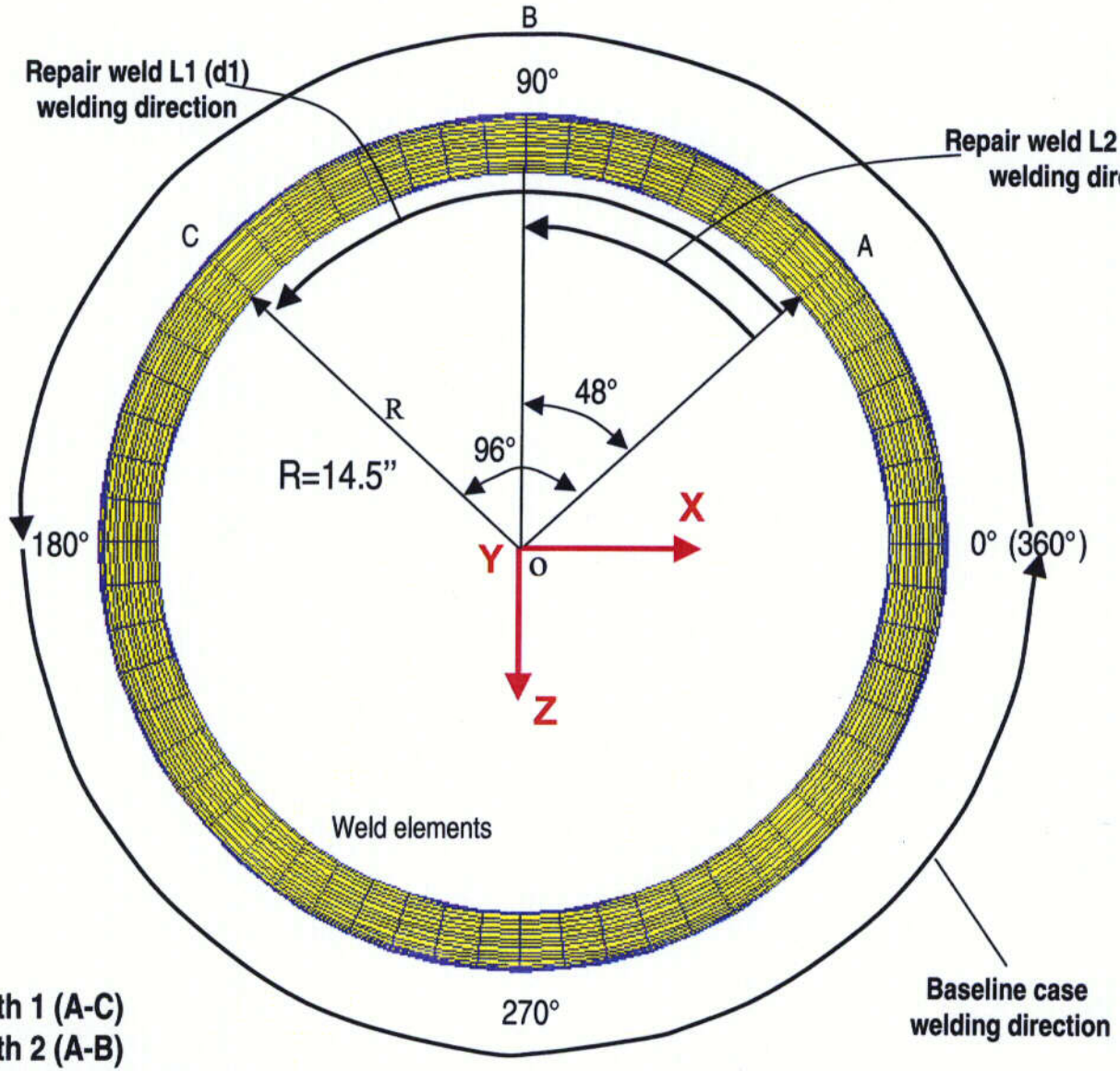


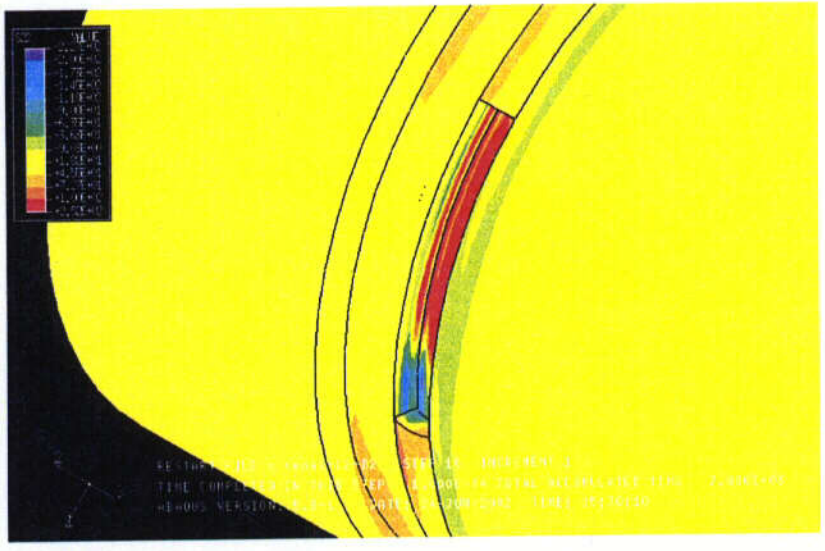
Figure 57. Two-length and two-depth Repair Analyses.

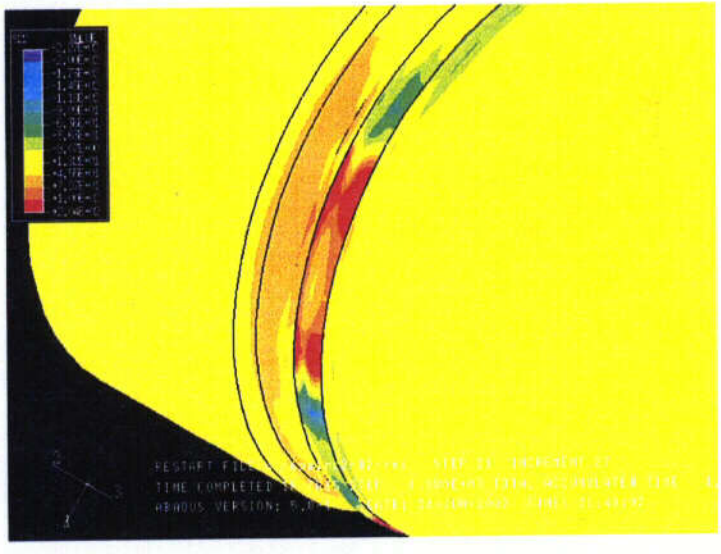


L1-Repair weld length 1 (A-C)
L2-Repair weld length 2 (A-B)
D1-Repair weld depth 1 (A-B or A-C)
D2-Repair weld depth 2 (A-B)

Figure 58. Weld directions.

Ground out





After repair

Repair length
L2-D2

Figure 59. An Example of the Grinding and Weld Repair Model During Analysis.

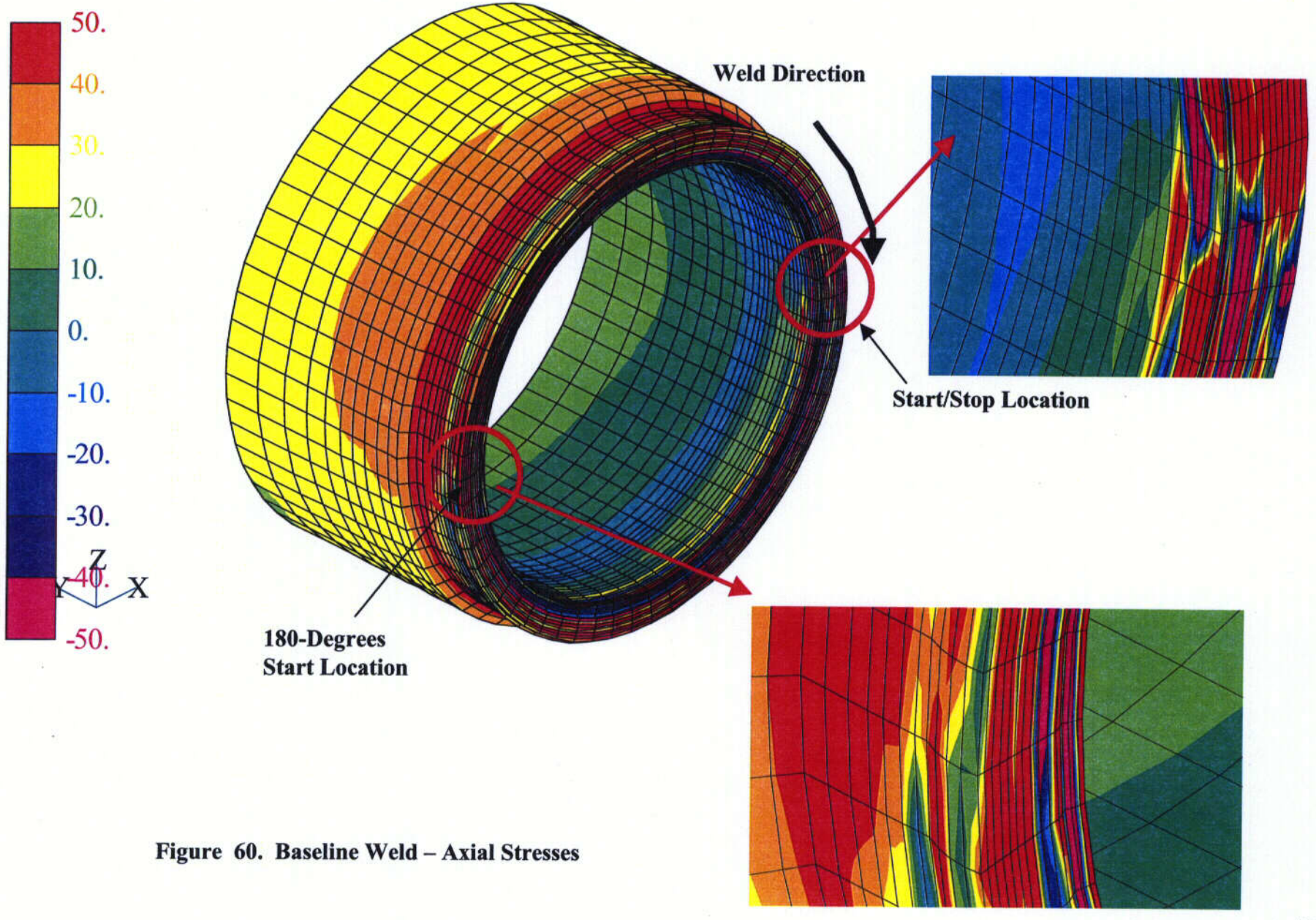


Figure 60. Baseline Weld – Axial Stresses

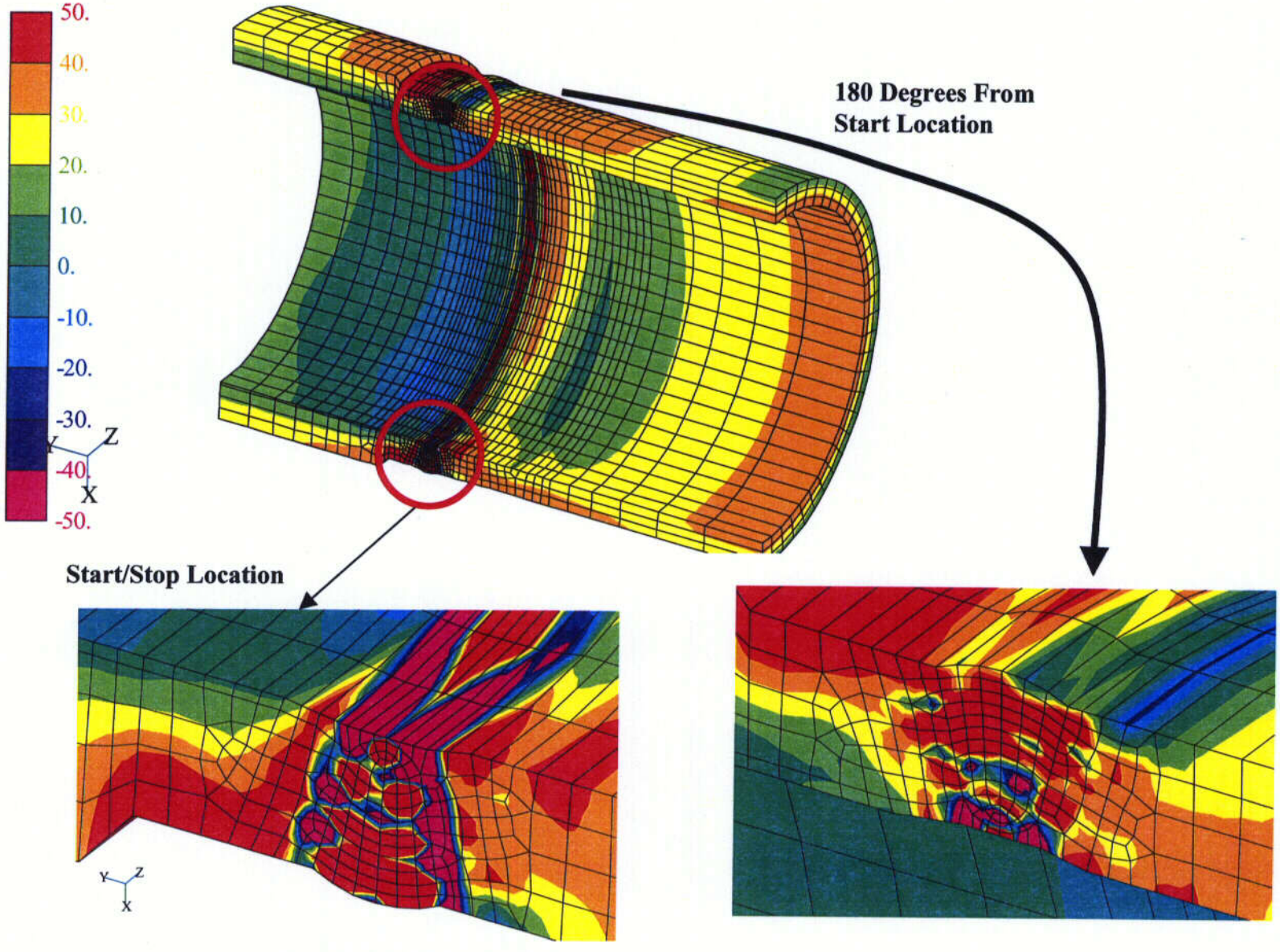


Figure 61. Baseline Weld – Axial Stresses

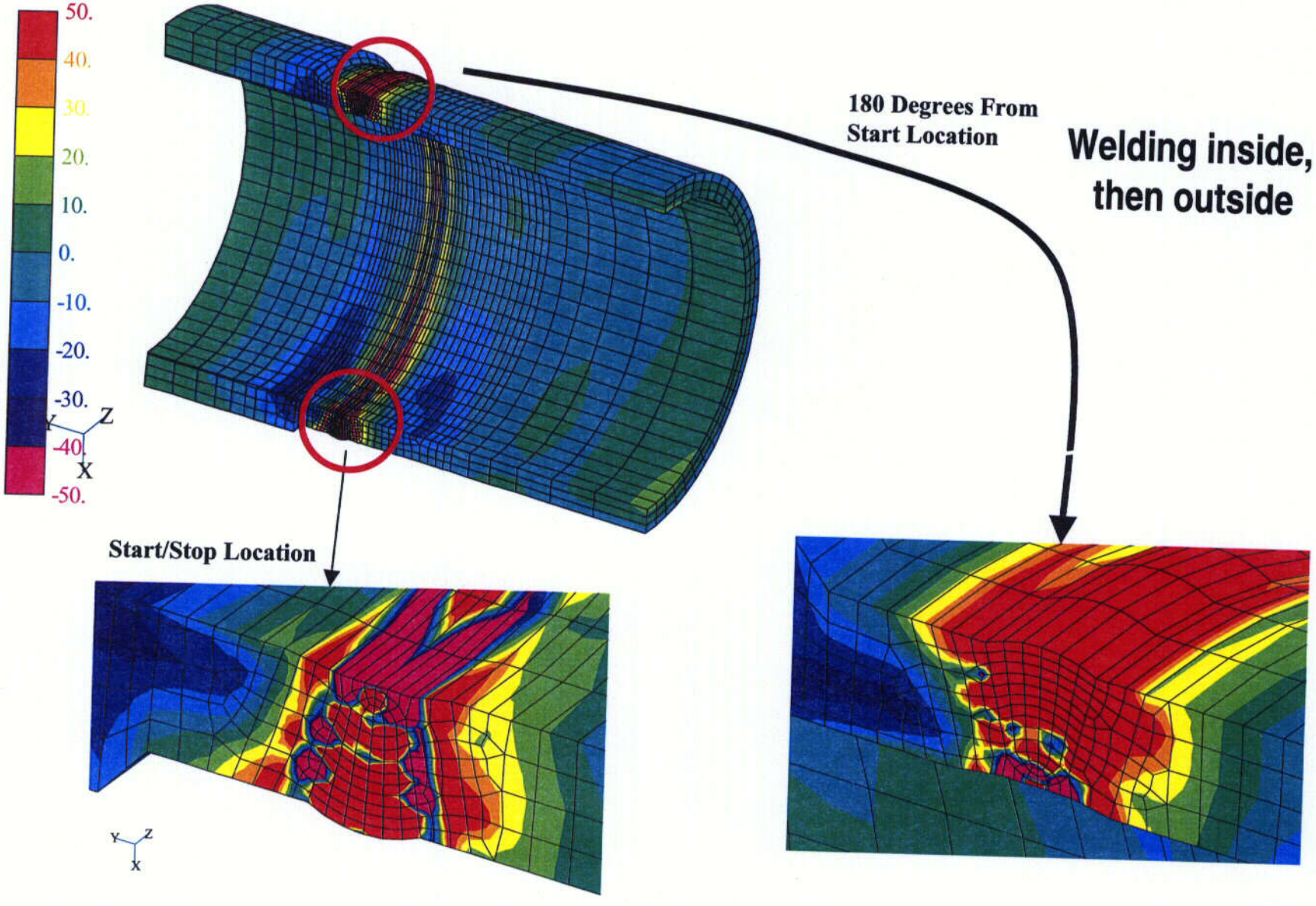


Figure 62. Baseline Weld – Z-Component Stresses (These Represent Hoop Stresses on the Cut Planes)

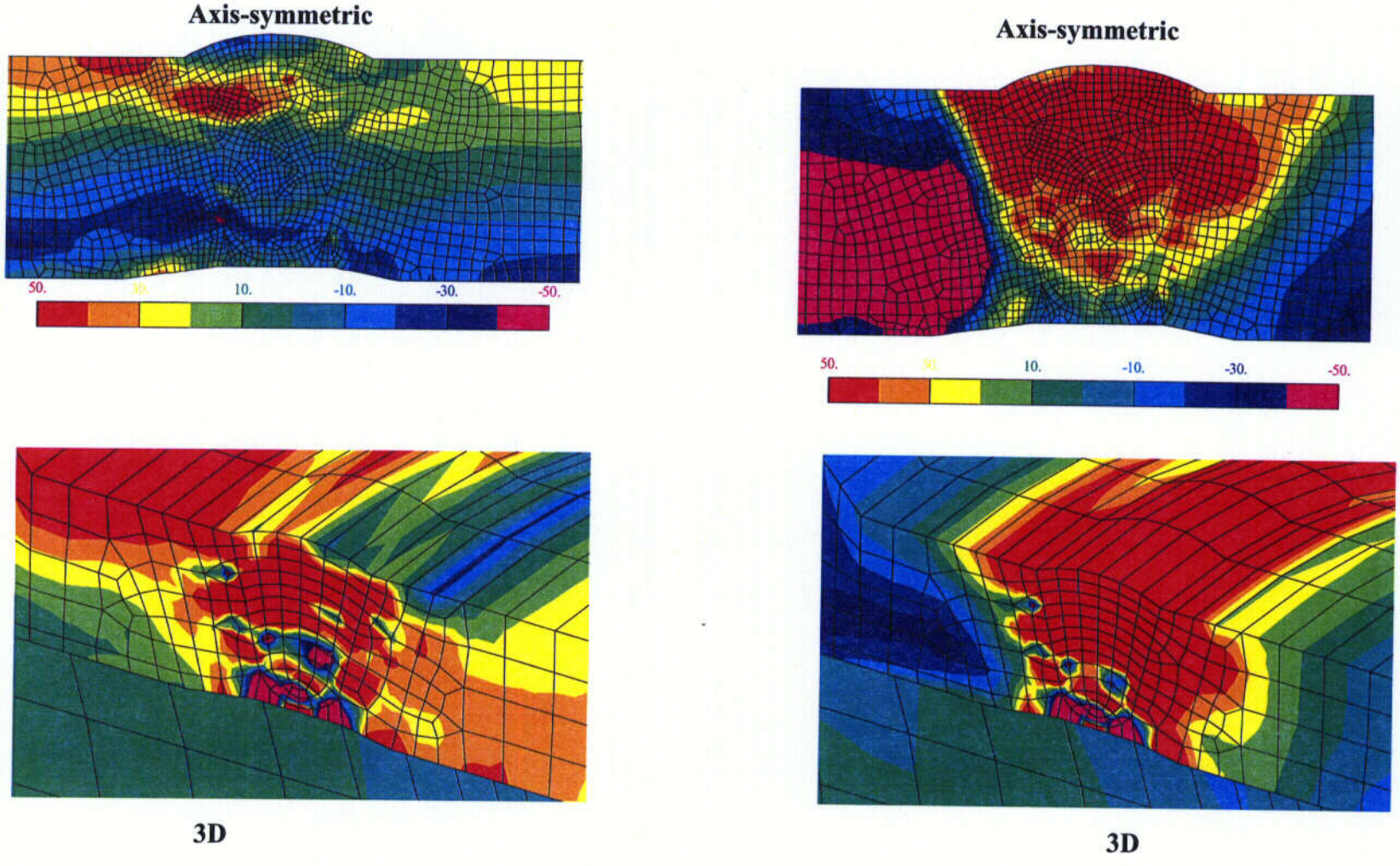


Figure 63. Comparison of Axial and Hoop Stresses Between the axis-symmetric and 3D Solutions.

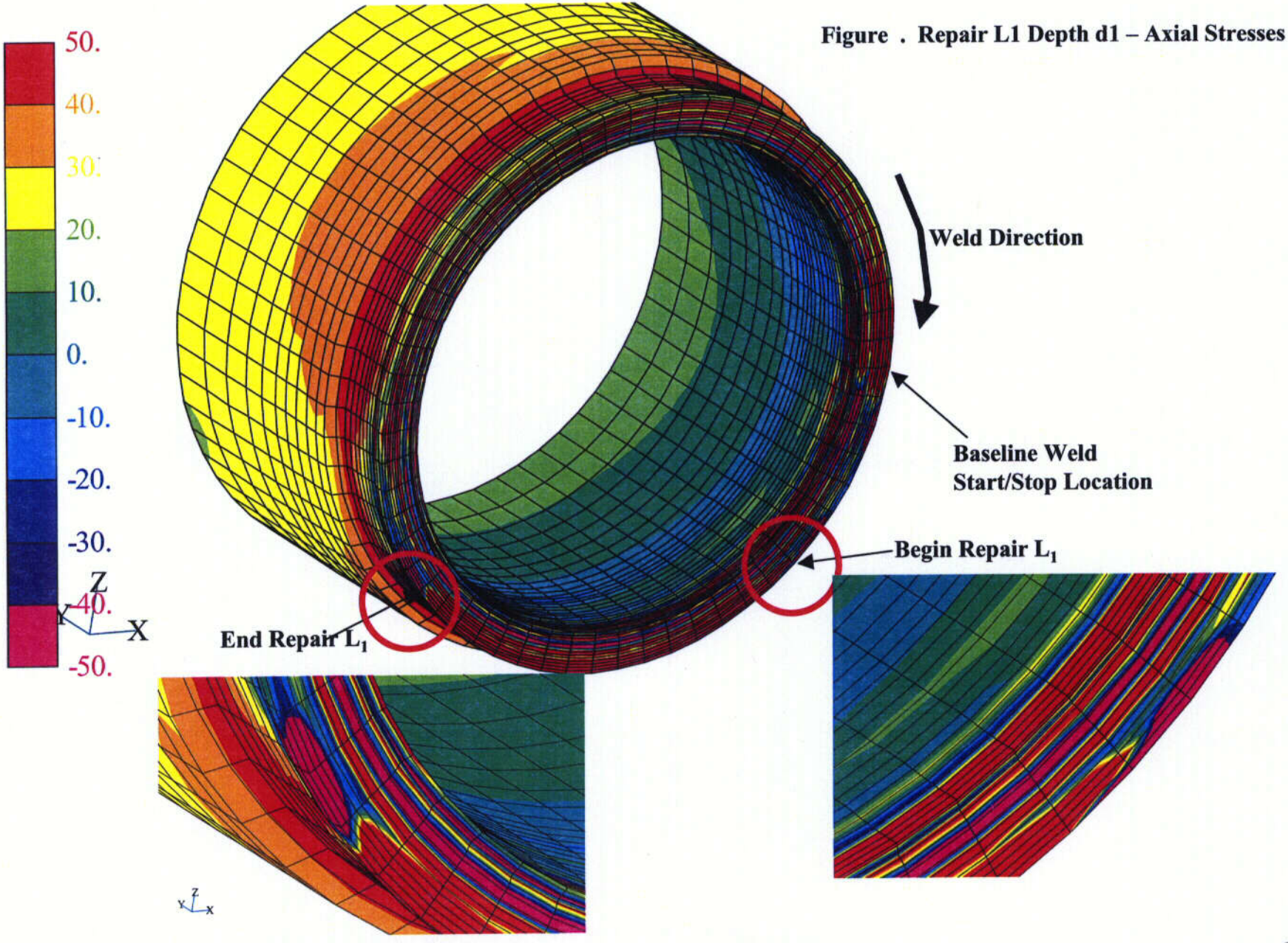


Figure 64. Comparison of Axial Stresses for Repair Case Number 1.

C44

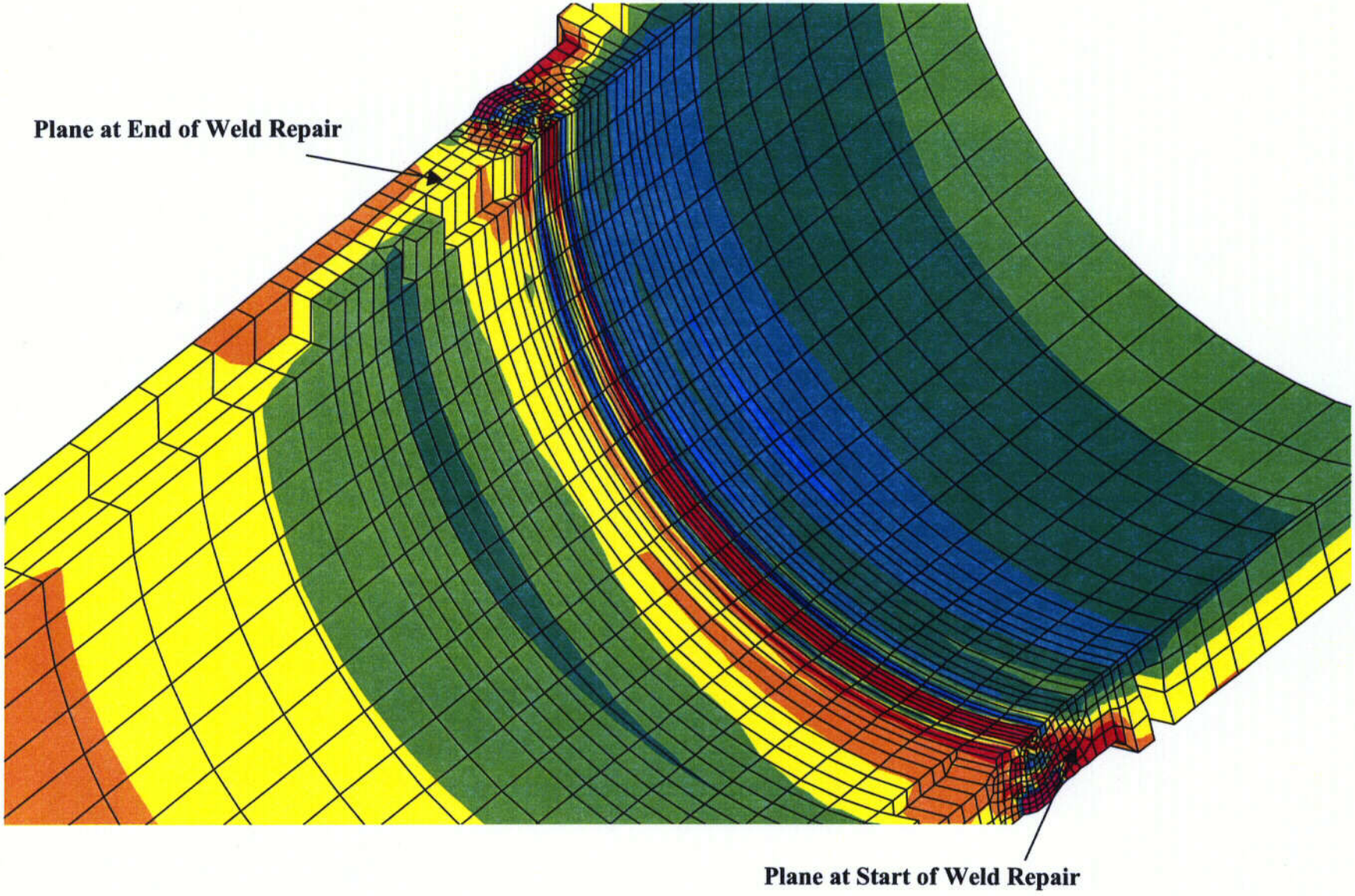


Figure 65. Comparison of Axial Stresses for Repair Case Number 1.

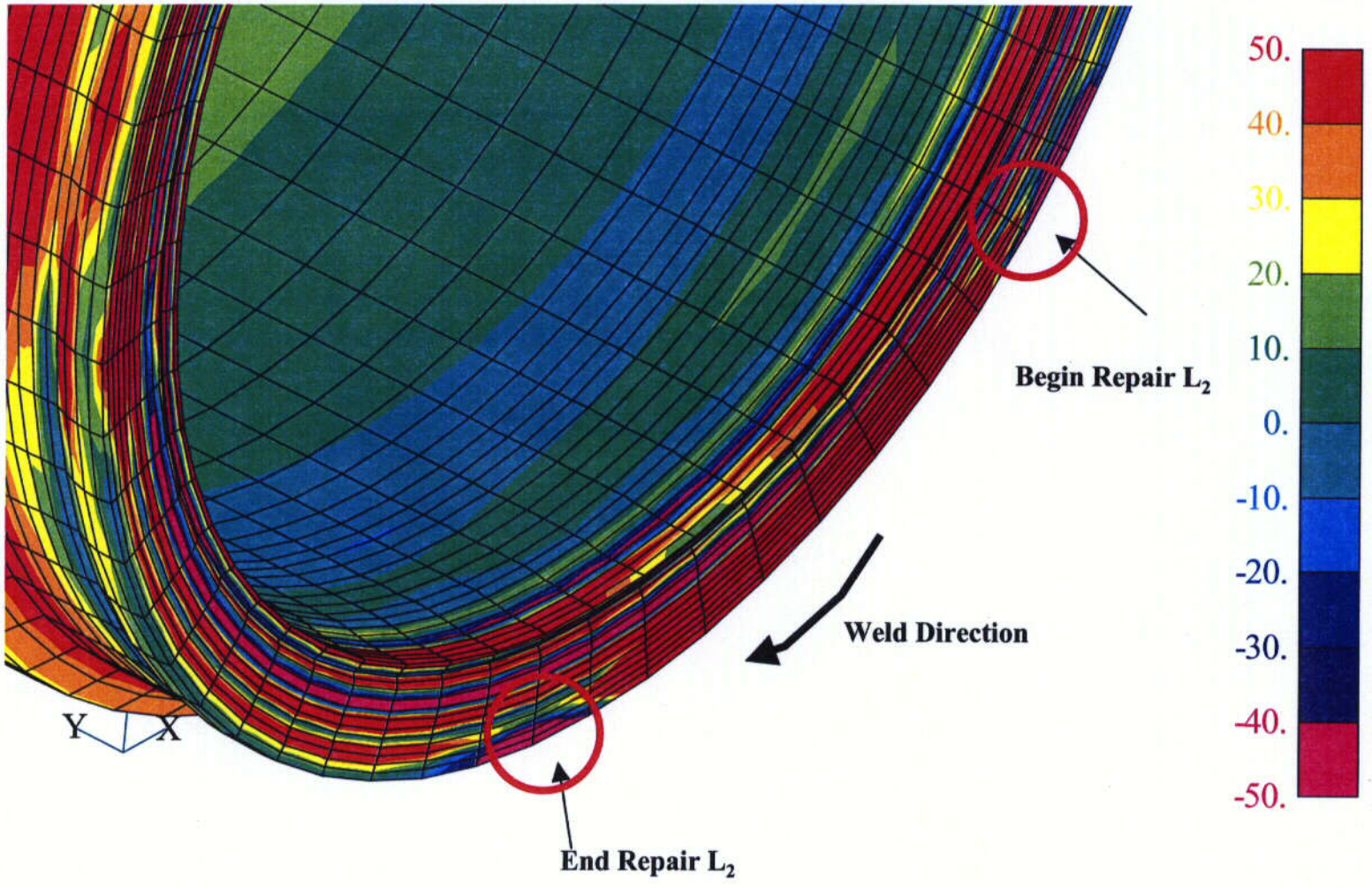


Figure 66. Repair L2 Depth d1 – Axial Stresses

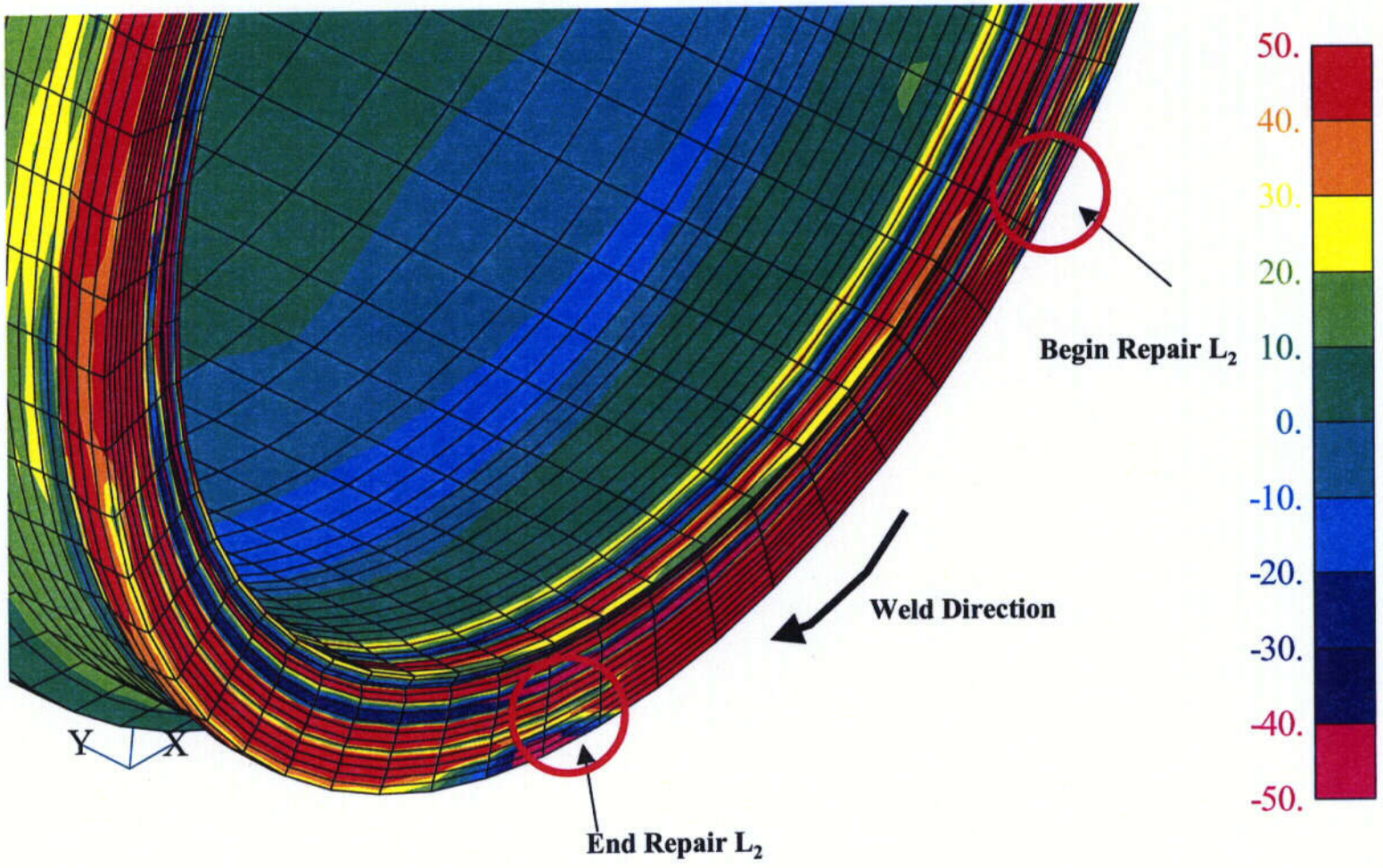


Figure 67. Repair L2 Depth d1 – Mean Stress ($\sigma_{kk}/3$)

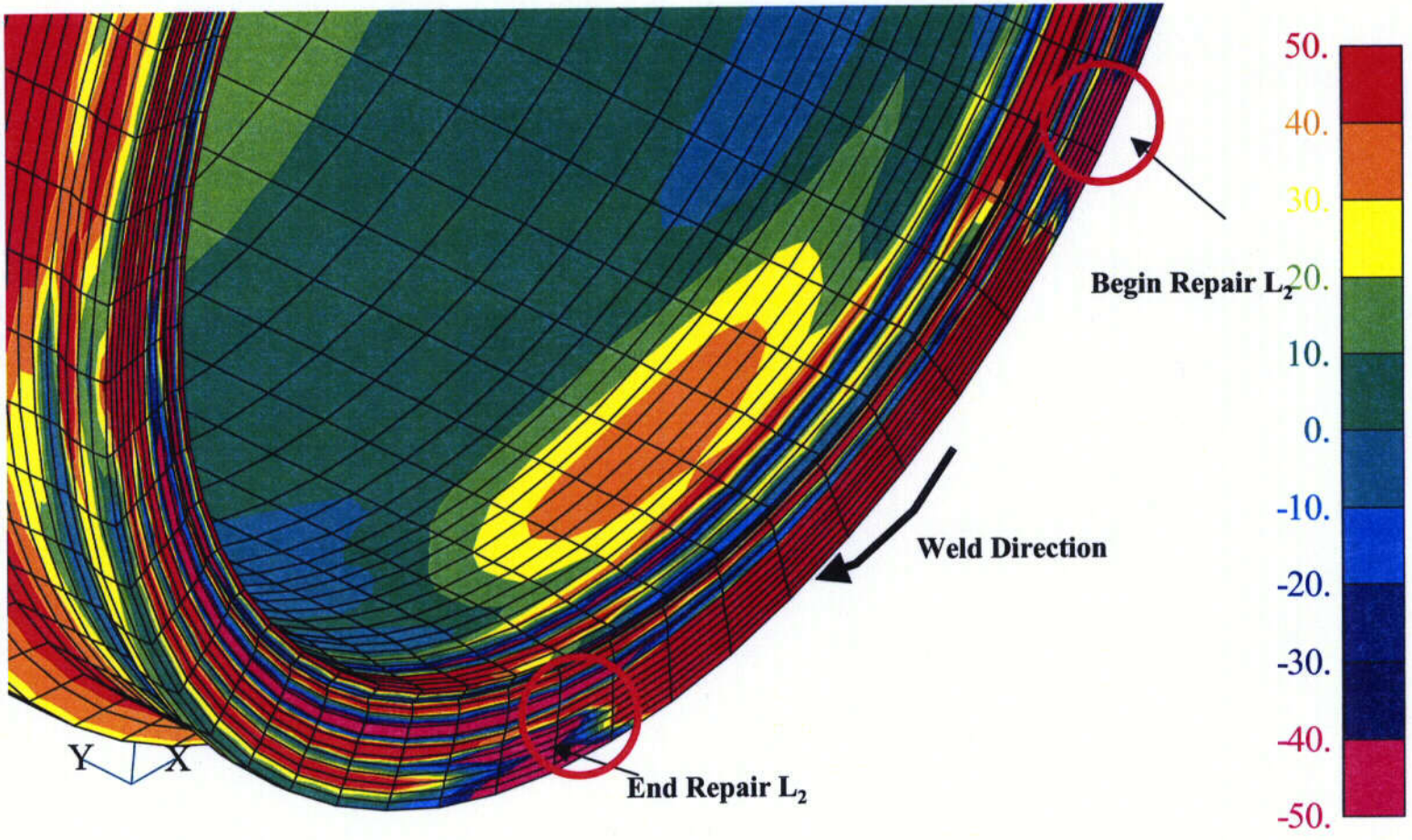


Figure 68. Repair L2 Depth d1 – Axial Stresses

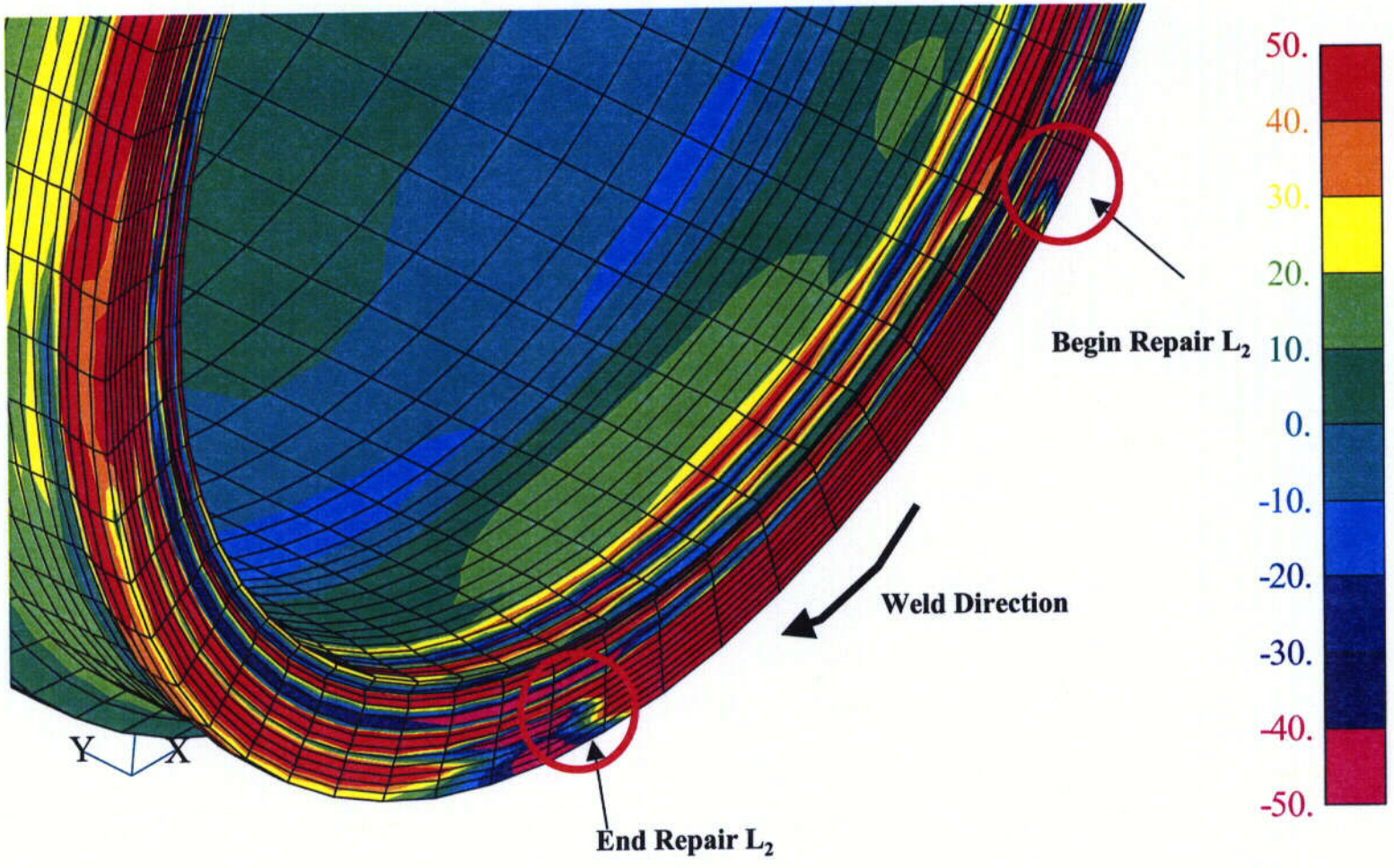


Figure 69. Repair L2 Depth d2 – Mean Stress ($\sigma_{kk}/3$)

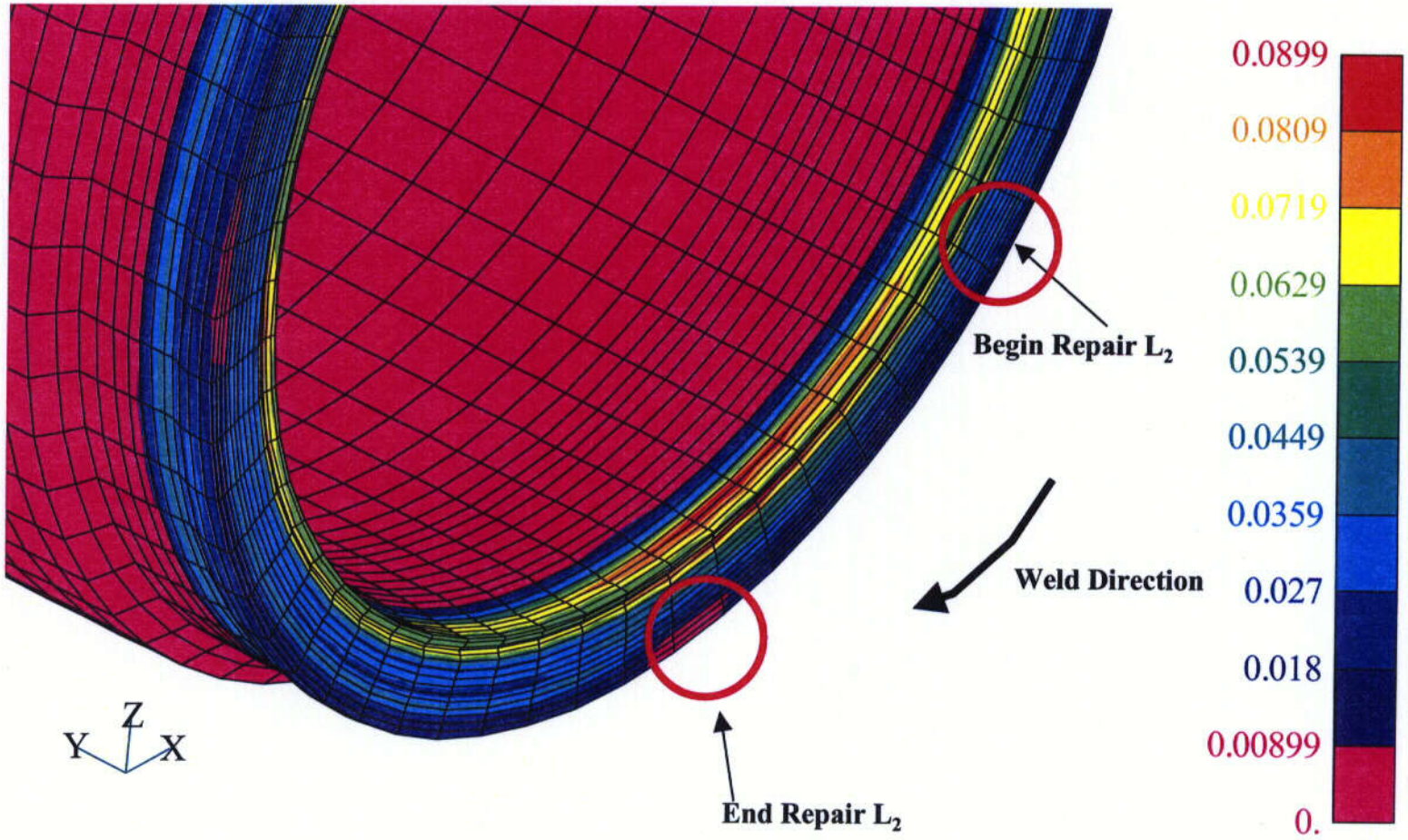


Figure 70. Repair L2 Depth d2 – Equivalent Plastic Strain