Simulation of Cold Roll Forming of Steel Panels

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ABSTRACT

This project uses LS-DYNA to simulate the rolling deformation of a flat steel sheet into a panel of particular shape. The process involves the gradual deformation of the steel sheet by passing it through a series of rollers at a constant speed. Each of these sets of rollers is oriented at a slightly different angle to incrementally increase the deformation of the sheet until the desired geometry is obtained in the panel. Since the sheet could be going through several different sets of rollers at the same time, the deformation process is very complex and highly non-linear. During this process, the sheet metal panel undergoes plastic deformation and develops residual stresses. Some of the problems encountered with these panels include localized buckling, undesirable local deformation at the front (head) of the panel and excessive spring back of the end of the panel (tail). These problems are also observed in the results from the simulation and methods to minimize their effect are investigated. Other issues encountered in the simulation include the contact mechanism between the moving panel and a moving roller, effect of roller size and placement, panel thickness, panel speed and roller friction. An adaptive mesh was used to efficiently mesh the plate and rollers at critical locations. The results obtained should help improve both the simulation process and the actual cold-roll-forming-process especially when new or different metals are being introduced.

INTRODUCTION

Cold forming processes are classified as brake forming or roll forming. Both processes are performed at room temperature with no heating of the material. In the brake forming process, the deformation of the whole panel is accomplished simultaneously in one step (see Figure 1-a), while in the cold roll forming process; the panel is gradually deformed using a piece-wise approach. The cross sections of roll formed panel will not be the same along the length of the panel during the rolling process (see Figure 1-b). A complex pattern of forming may produce considerable residual stresses on the panel. Some of the defects observed are shown in Figure 2. (Halmos, 1997)

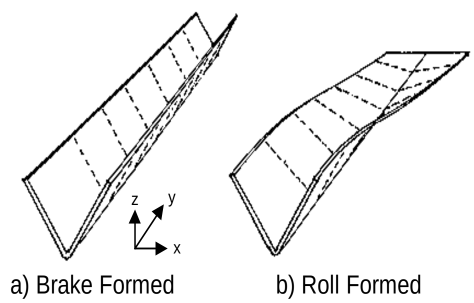

Figure 1. Cross Section Changes in Brake and Roll Formed "V" Section. (Halmos, 1997)

The goal of this project is to simulate and analyze the cold roll forming process using LS-DYNA. The research is focused on investigating the wavy center formed after the cold rolling process by using explicit Finite Element Analysis (FEA) techniques. After the cold rolling process, a sheet metal panel has permanent deformation and residual stresses. It is believed that some of these compressive residual stresses developed are the primary causes of wavy center considered architectural defects. Excessive defects make the panels unacceptable

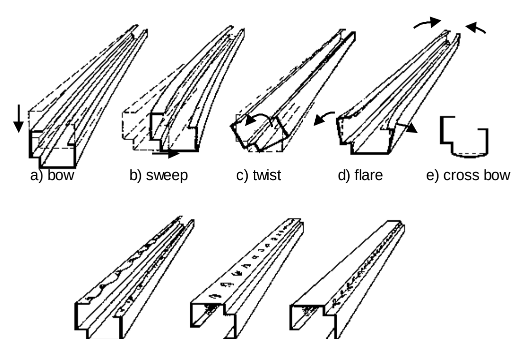

Figure 2. Undesirable effects found in cold roll form sections. (Halmos, 1997)

commercially to manufactures. The wavy effect is generated on the slope surface (as shown in Figure 3). The symmetric setting will be used in the roller setup simulation (as shown in Figure 3).

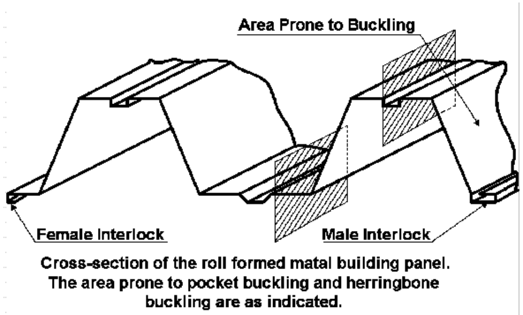

Figure 3. Typical cold roll form sections showing lines of symmetry.

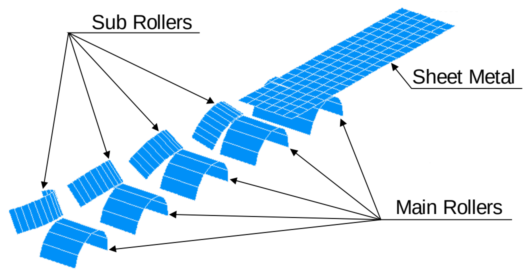

Figure 4. Typical rolling mill setup (upper rollers are not shown for clarity).

BACKGROUND

Donmez (1997) used a mesh of 6x20 elements for the sheet metal panel and the roller setup shown in Figure 4. His results showed that the plate stretches and compresses at both the edges and at the center of the plate during the rolling process. Dong (1998) used a more refined mesh (12×40 elements) and a similar roller setup. His results, showed the stress distribution patterns on the panel including the Von Mises stresses for cases with friction and with a yield point drop. He also showed the locations of the largest residual compressive stress in his report. He recommended that the plate velocity would need further investigation.

TECHNICAL APPROACH

In this project more emphasis was placed on modeling the bending radii (see Figure 6). In roller design, the minimum-bending radius is usually equal to the material thickness for mild steels. The high strength material, low elongation material, can be 4 to 8 times the material thickness. Roll forming is based on permanent deformation at the bend lines of the sheet metal (outside of bending lines are strained, and inside of bending lines are compressed as shown in Figure 5). If the material is not stressed over the yield limit, it will spring back. For the large radii, the permanent deformation may not be reached. Therefore, it is very difficult to roll form metals with the bending radius 10 to 100 times (or more) of the material thickness. (Dobrev & Halmos 1997)

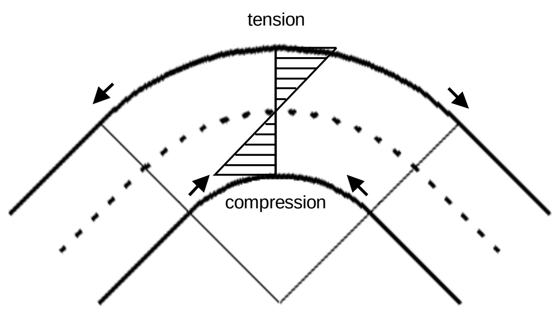

Figure 5. Stress-strain distribution across bending section.

The different bending radii determine the fixed arc length. This helps save on computational effort.

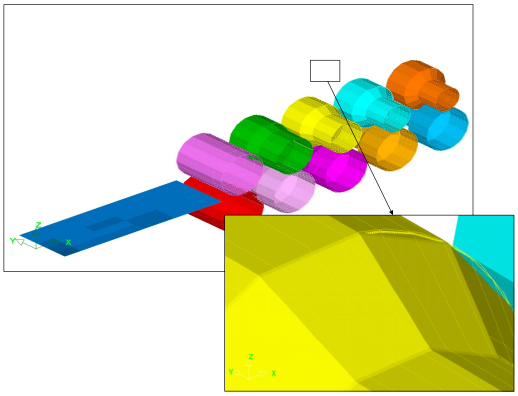

Figure 6. Details of area of changing radii in rollers.

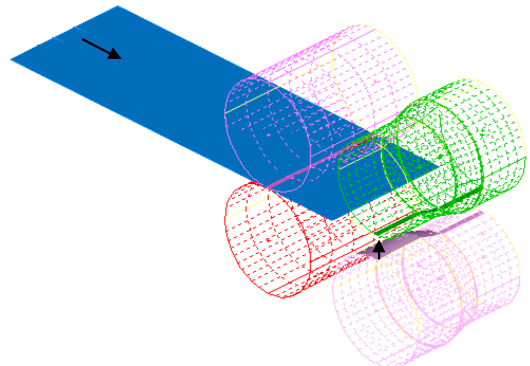

Figure 7. Rolling mill setup used in current project.

The section of the roller that is in contact with the sheet metal panel is modeled as a strip. (see Figure 7). In this simulation, the rollers do not rotate. This also helps save on computational effort without severely affecting the results.

The sheet metal panel is moving with a constant velocity during the rolling process. When the front end of sheet reaches the second set of rollers, the bottom roller is moved up to "meet" the panel and the contact function is turned on. This is called the "birth time." As soon as the rear end of the sheet metal leaves the second set of rollers, the contact function will be turned off and the bottom roller will go back to the original position. This is called the "death time." This use of birth and death time is to save on computational time.

The material properties used for this analysis are shown in Table 1. Two Finite Element Analysis models were made, one based on Donmez (1997) model and the other model based on data from US Steel[3].

Table 1. Material properties.

9705-0768-1A-T1 mild steel			
Plate		Rollers	
MAT_ISOTROPIC_ELASTIC_PLASTIC		MAT_RIGID	
Young's Modulus	1.891×10^5 Mpa	Young's Modulus	1.891×10^5 MPa
Yield Stress	3.659×10^2 Mpa	Material Density	7.83×10^{-9} ton/mm^3
Material Density	7.83×10^{-9} ton/mm^3	Poison Ratio	0.28
Tangent Modulus	5.234×10^2 Mpa		
Shear Modulus	7.387×10^4 Mpa		
Bulk Modulus	1.433×10^5 Mpa		
Thickness	0.5mm	Thickness	0.5mm

[3] US Steel Research Center Monroeville, PA.

Table 2. Geometric properties from Donmez (1997) model. (See Figure 8)

Main Roller Diameter	400 mm		
Velocity of the Plate	1500mm/sec		
Dimension of the Plate	1500mm×500mm×0.5mm		
	Case1	Case 2	Case 3
Center to Center Distance	500mm	400mm	500mm
Displacement of Bottom Roller 1 Applied	90mm	90mm	90.001mm
Static/Dynamic Friction	0/0	0/0	0/0

Table 3: Geometric properties from information from US Steel. (See Figure 8)

Main Roller Diameter	300 mm		
Velocity of the Plate	1500mm/sec		
Dimension of the Plate	1500mm×500mm×0.5mm		
	Case4	Case 5	Case 6
Center to Center Distance	300mm	300mm	300mm
Displacement of Bottom Roller 1 Applied	90.0001mm	90mm	90mm
Static/Dynamic Friction	0/0	0/0	0.002/0.001

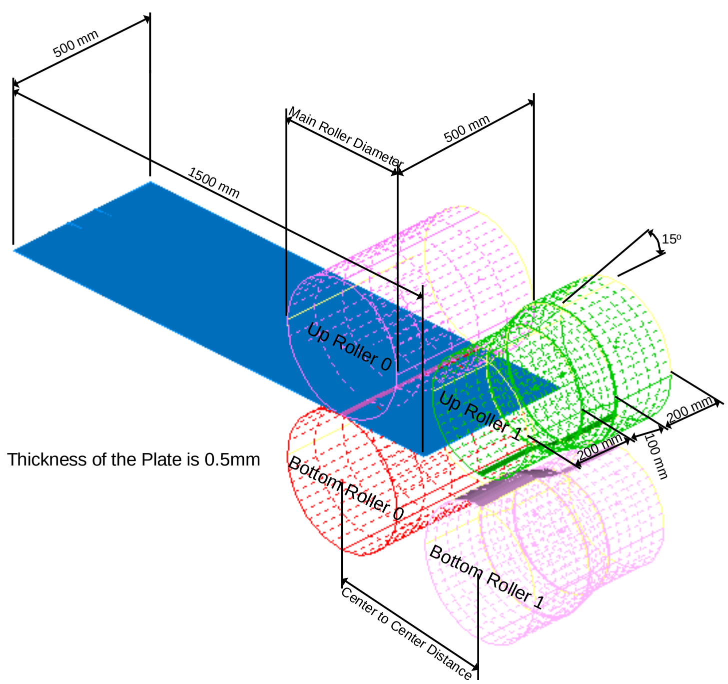

Figure 8. The Model of rolling mill setup.

DISCUSION OF RESULTS

The outs of plane displacements (Y and Z directions) of nodes along the sloped section of the deformed panel are shown in Figure 9 and 10. The data shows the normalized displacements in the Y and Z directions for nodes along the length of the panel (X direction).

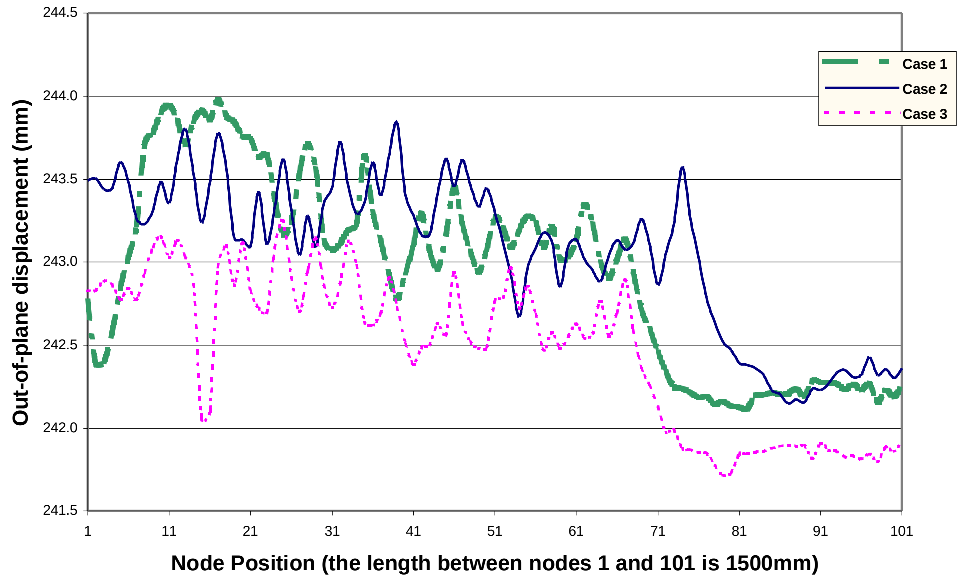

Figure 9. Out of plane displacements from Donmez (1997) model (see Table 2).

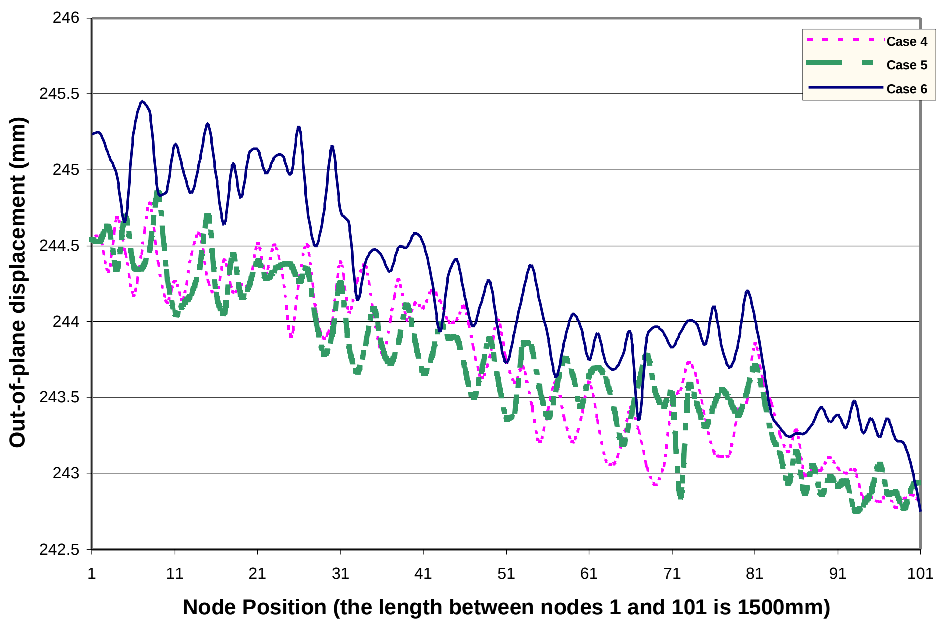

Figure 10. Out of plane displacements from US Steel data (see Table 3).

If the rolling was performed perfectly and there was no springback, the ideal displacements in these plots should be *258mm*. The results from using smaller rollers (Case 4, 5, & 6) are slightly closer to the ideal and these cases also show a smaller variation in amplitudes. These cases show a gradual decline in displacements along the X-axis. This may suggest that if more rollers a used obtaining a more uniform deformation pattern may be possible.

The final σ_{xx} and σ_{yy} stress distributions of the 6 cases are shown in Figures 11 through 22. The stresses (σ_{xx} and σ_{yy}) were larger in magnitude for cases 4, 5 and 6. These cases (4, 5 & 6) also showed a more even stress distribution. The σ_{zz} stresses for these cases also showed a similar pattern. A more uneven residual stress distribution may lead to a more uneven deformation pattern on the finished panel. Of particular concern are area of the panels that show compressive stresses in both the x and y directions (σ_{xx} and σ_{yy}). These areas will be prone to local buckling. All six cases showed areas of significant in-plane compressive stresses. By keeping the panels under a high tensile stress during the rolling process may alleviate this problem.

CONCLUSION

Deformation mechanisms of cold roll formed sections are very complex. This is due to the complicated process that is involved in producing these sections. Based on the above results, the compression and tension stresses in the area of deformation are heavily dependent on the roller setup and configuration used. The same velocity of 1500mm/sec was used for both models. In the real roll forming process, the rotations of upper and bottom rollers are different. This may further complicate the analysis. In this project it was shown that using smaller rollers, placed closer together might produce a panel with fewer defects.

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APPENDIX

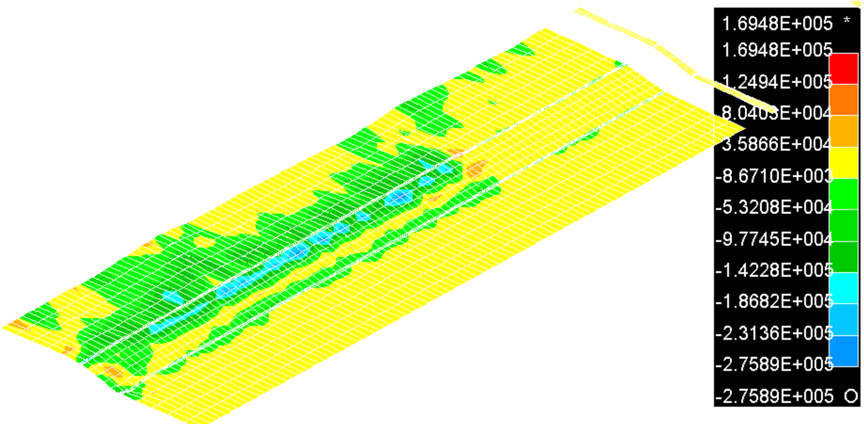

Figure 11. 500mm-0.5mm (Case 1) σ_{xx}.

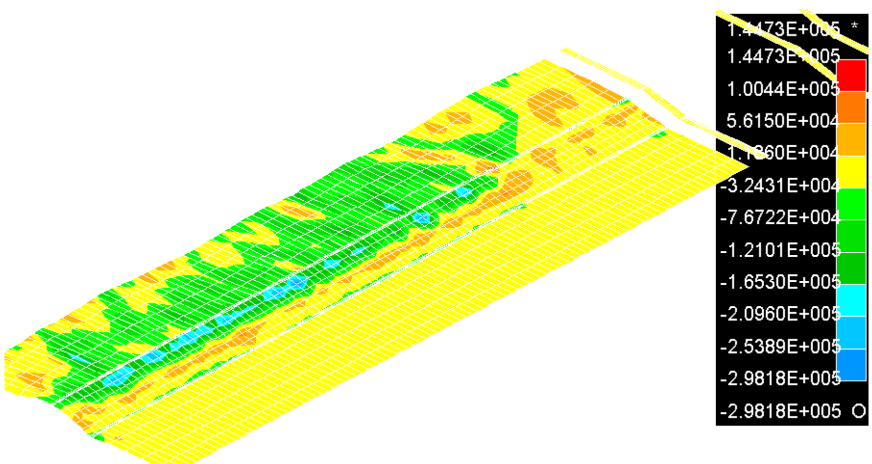

Figure 12. 400mm-0.5mm (Case 2) σ_{xx}

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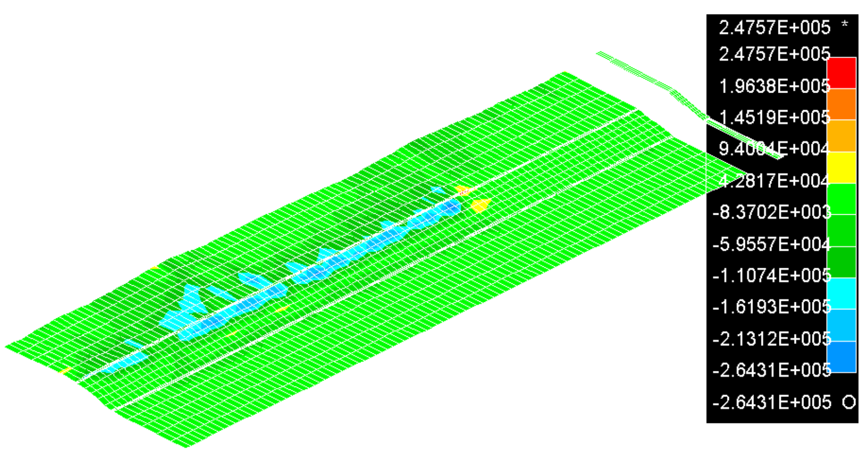

Figure 13. 500mm-0.499mm (Case 3) σ_{xx}.

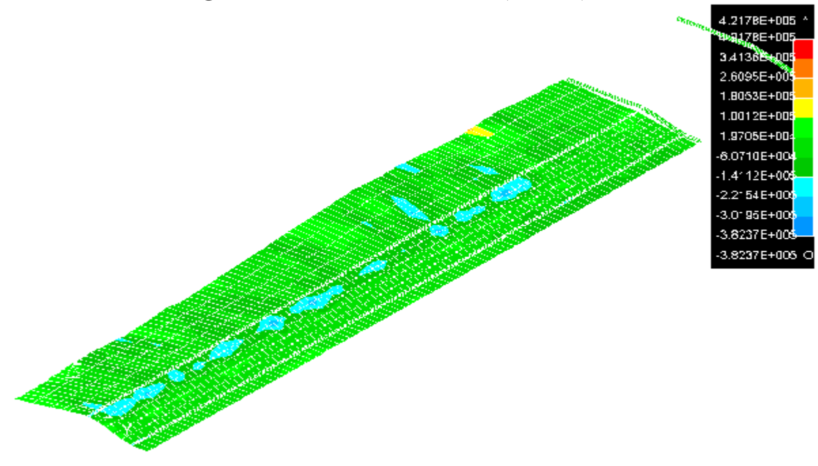

Figure 14. 300mm-0.4999mm (Case 4) σ_{xx}.

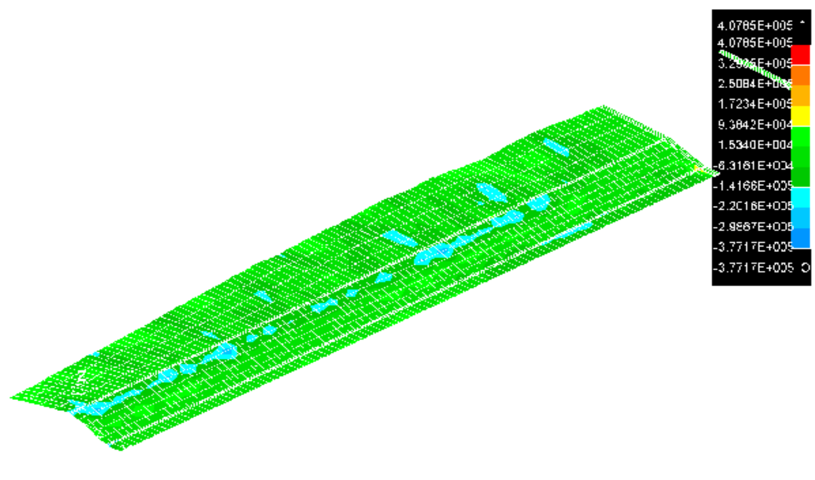

Figure 15. 300mm-0.5mm (Case 5) σ_{xx}.

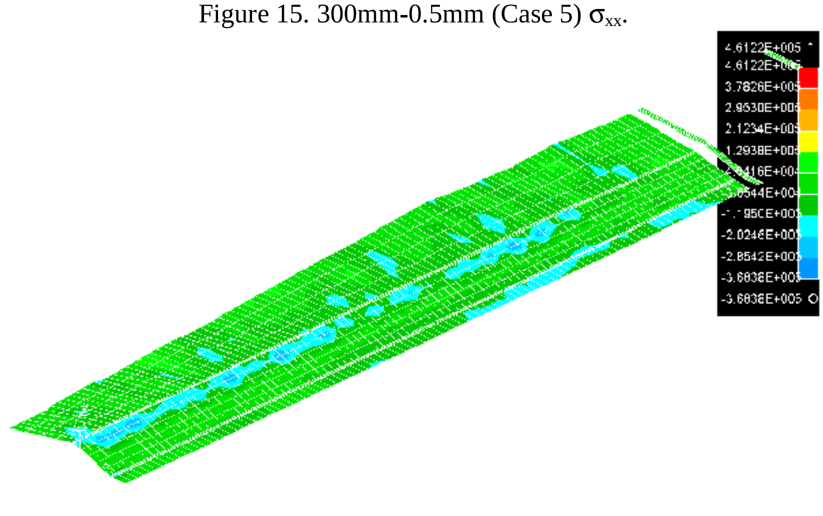

Figure 16. 300mm-0.5mm (Case 6) σ_{xx}. (0.0001/0.0002)

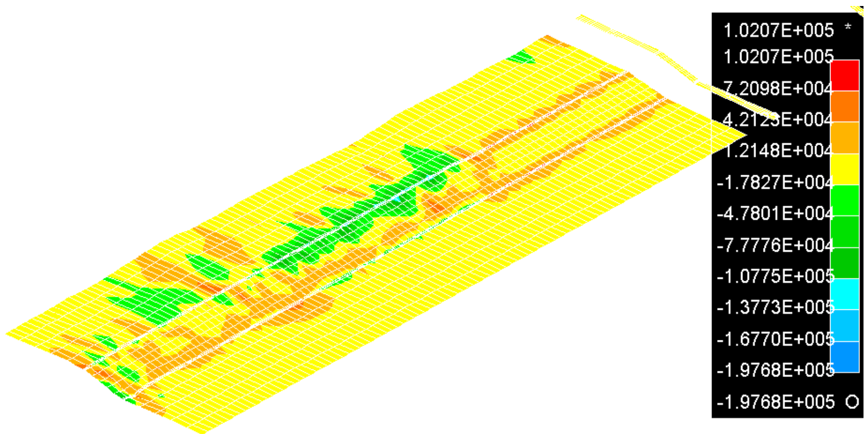

Figure 17. 500mm-0.5mm (Case 1) σ_{yy}.

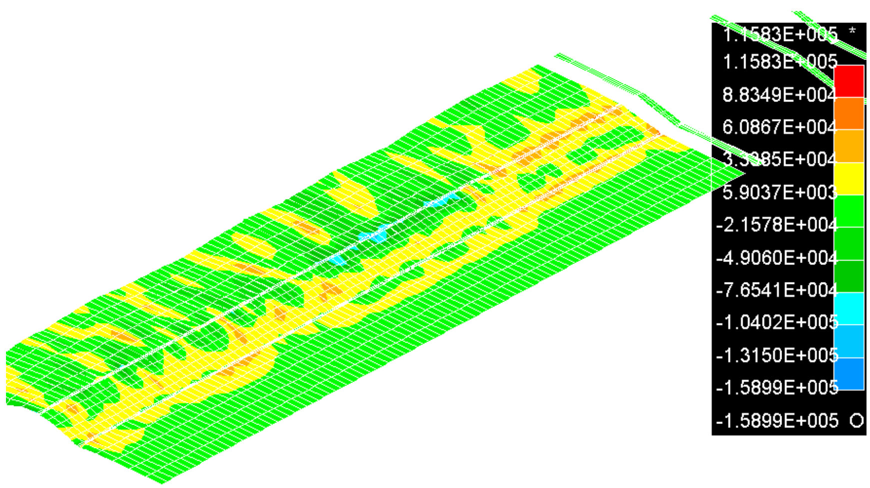

Figure 18. 400mm-0.5mm (Case 2) σ_{yy}.

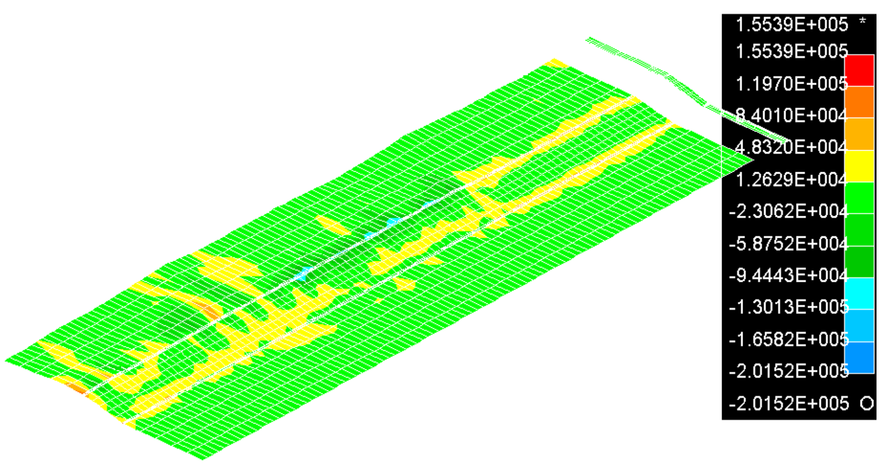

Figure 19. 500mm-0.499mm (Case 3) σ_{yy}.

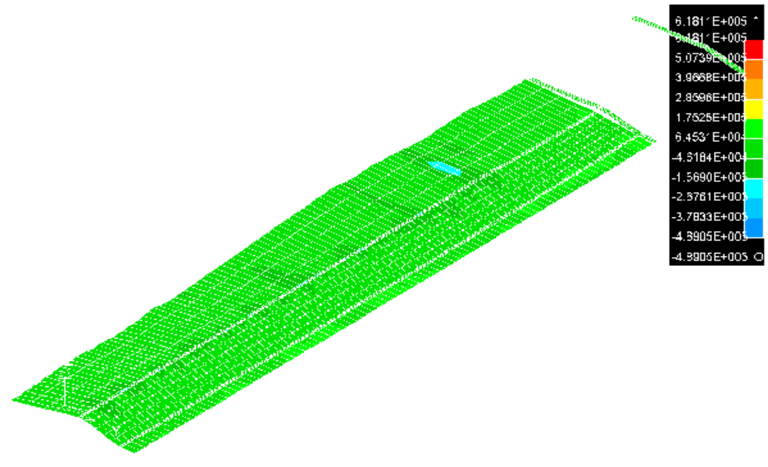

Figure 20. 300mm-0.4999mm (Case 4) σ_{yy}.

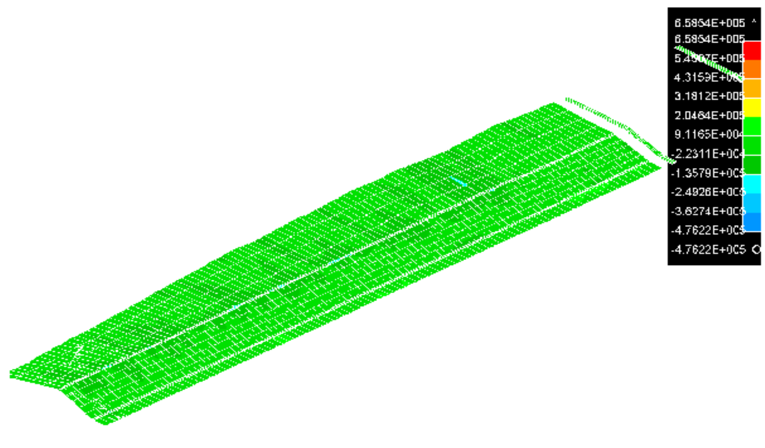

Figure 21. 300mm-0.5mm (Case 5) σ_{yy}.

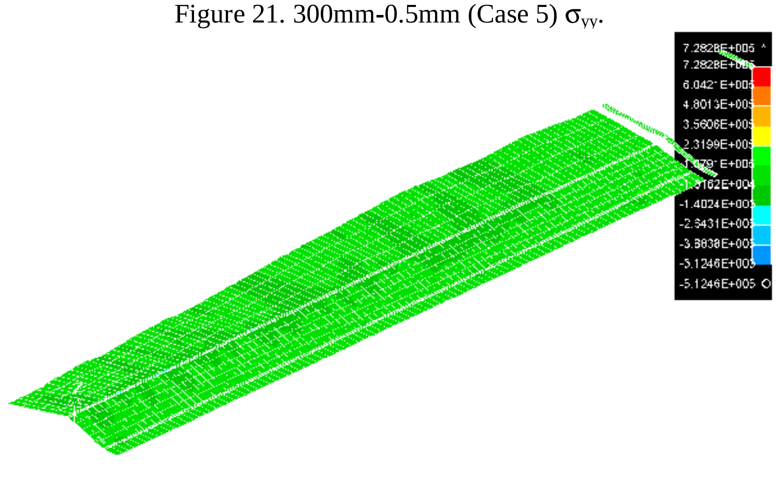

Figure 22. 300mm-0.5mm (Case 6) σ_{yy}. (0.0001/0.0002)