MATHEMATICAL MODELING OF ALUMINIUM REDUCTION CELL POTSHELLS: IMPROVEMENTS AND APPLICATIONS

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In its 2010 TMS conference paper [1], the author presented three types of ANSYS® based thermo-chimio-mechanical potshell models, namely the "empty shell", the "almost empty shell" and the "half empty shell" potshell models. All three types of models take into account the thermal loading coming from the thermal expansion of the potshell steel structure itself considering the thermal gradients present in the steel structure and the internal pressure coming from the cell lining expansion inside the potshell. The model versions presented in [1] were strain forward redevelopment of the work the author presented quite some time ago in [2,3,4 and 5].

Since then, all three kind of models have been improved taking advantage of the contact elements facilities available in ANSYS® 12.0. Those improved model versions will be presented here altogether with two applications. The first application is the test of a potshell retrofit design aiming at eliminating the vertical deflection of monocoque potshells. The second application is the test of the potshell and lining retrofit design the author proposed in [6] to expend potlife of modern high amperage cells using graphitized cathodes blocks up to 3500 days.

Improved "almost empty shell" potshell model

The "almost empty shell" potshell model have been improved by decoupling the 2D potshell mesh from the 3D side lining mesh and by reconnecting the two parts using ANSYS® CONTA174 and TARGE170 contact pair elements. After the decoupling, it is possible to completely refine the 2D potshell mesh, this was not possible before the decoupling. This is important because it was already demonstrated in [7] for the "empty shell" potshell model that the initial thermo-electric model mesh [8,9] is too coarse to carry out accurate thermo-mechanical analysis, hence the possibility to increase the potshell mesh refinement is a significant model improvement.

Figure 1 presents the resulting displacement solution, which is not significantly different from the one presented in [1]. Apart for the possibility to further refine the 2D potshell mesh, a second significant improvement is the added possibility to extract from the solution the pressure that the side lining is applying on the potshell through the contact interface (see figure 2).

Improved "empty shell" potshell model

As discussed in [1], the main weakness of the "empty shell" potshell model type is the fact that the internal pressure load has to be defined by the modeler as a boundary condition and that the modeler can only rely on semi-empirical loading schemes established from measurement campaigns to do so. Now, with the improvement of the "almost empty shell" potshell model, a new possibility has became available, it is now possible to apply as boundary conditions to the "empty shell" model the contact interface pressure distribution extracted from the "almost empty shell" model solution (see figure 3).

As we can see in figure 4, the resulting improved "empty shell" model displacement solution is quite different from the one presented in [1] and is now quite similar to the one presented in figure 1. This clearly demonstrates that the semi-empirical loading scheme that the author knew and used in [1] is quite different from the pressure distribution presented in figure 2.

Testing a new potshell design aiming at eliminating the vertical potshell displacement with the improved "empty shell" model

As discussed in [7,10 and 11], the vertical displacement of very long high amperage cell monocoque potshells has a negative impact on the cell operation. For quite some years now, the author had a potshell retrofit design idea aiming at preventing that vertical potshell displacement, the improved "empty shell" model is the perfect tool to test this potshell retrofit design idea. Figure 5 presents the vertical displacement component of the standard design solution. We can see that for that 300 kA 14 meters long potshell, the floor maximum vertical displacement is about 30 mm. Figure 6 presents the vertical displacement component of the retrofitted potshell clearly showing that there is essentially no vertical displacement component left in the solution.

Testing a new potshell design aiming at eliminating the vertical potshell displacement with the improved "almost empty shell" model

Considering that the "almost empty shell" model is more accurate and hence reliable than the "empty shell" model, the next logical step is to test the retrofitted potshell design idea with the improved "almost empty shell" model. Figure 7 presents the results obtained, which are almost identical to the one obtained with the "empty shell" model confirming the validity of the proposed idea. This also highlight the fact that for a large number of potshell retrofit ideas not affecting the global potshell structure stiffness, the improved "empty shell" model is the most effective analysis tool because it is the fastest tool.

Testing a new potshell and lining design aiming at increasing the cell life of high amperage cells using graphitized cathode blocks with the improved "almost empty shell" model

Of course, when the proposed retrofit is changing the global potshell structure stiffness or when the grade of cathode blocks is changed like it is the case in this second retrofit design proposal, it is not possible to use the "empty shell" potshell model to analyze the proposed design change, this is why the "almost empty shell" model type has to be directly use this time.

In [6], the author presented a cathode panel erosion modeling tool. This type of model can be use to analyze the impact of retrofit design changes affecting the cathode erosion in order to predict the retrofitted cell life expectancy (assuming that the first failure mode is the attach of the collector bar by the metal after that all the carbon above it has been removed by erosion). That model predicted a cell life of 2000 for the standard design based on the usage of 45 cm thick graphitized cathode blocks with 26 cm of carbon above the collector bars (see figure 8 for a full cathode panel solution of that type of erosion model).

In that same paper, the author presented a retrofit design proposal using 55 cm thick graphitized cathode blocks. It is possible to increase the cathode block thickness by 10 cm without reducing the height of the insulation under the blocks or reducing the height of the cell cavity simply by moving the potshell floor 10 cm down. Moving the potshell floor down this way is reducing the height of the cradles web under the floor by 10 cm, which is of course reducing the stiffness of the cradles. In [6], using the cathode panel erosion model, it was demonstrated that combining the usage of 10 cm ticker cathode blocks and the usage of selective rodding would potentially increase the cell life up to 3500 days. It was also speculated that reducing the stiffness of the cradles would not have negative impact on the potshell mechanical behavior because a potshells designed to withstand the 4 to 5% sodium swelling of amorphous cathode blocks have became over-designed now that graphitized blocks with sodium swelling index less than 1% are used.

Unfortunately, the author had no potshell mechanical behavior analysis tools available at the time to test his hypothesis, but this is of course no longer the case. So the proposed potshell and lining design proposed in [6] has been analyzed using the "almost empty shell" potshell model. In that model, one of the key parameter is ε_o the cathode blocks free sodium expansion value (see [1] for more detailed), so far in [1] and in here, that value has been setup to 3%, which is a typical value for 20% semi-graphitic cathode blocks. That parameter must be readjusted in order to match the behavior of graphitized cathode blocks. For that type of cathode blocks, a value of 1% is more typical so 1% was used to carry out the present analysis.

As speculated in [6], results presented in figure 9 confirms that the proposed retrofit design with 55 cm tick graphitized cathode blocks will have a potshell that will deflects less laterally than the standard design using 45 cm thick 20% semi-graphitic cathode blocks even with the cradles web under the potshell floor having 10 cm less height.

Inproved “half empty shell” potshell model

Finally, the “half empty shell” potshell model has also been improved by decoupling the 2D potshell mesh from the 3D lining mesh and by completely refining the 2D potshell mesh. Furthermore, the 3D side lining mesh has been decoupled from the 3D cathode panel mesh as it is assumed that only the cathode panel is affected by sodium swelling. As it was the case for the “almost empty shell” potshell model, contact pair elements are used to reconnect the three decoupled model parts.

The “half empty shell” model has been further improved by also taking into account the cathode panel thermal expansion which was not considered in the model version presented in [1]. When the thermal expansion is one order of magnitude greater than the thermal expansion, it may be justified to neglect the latter in the analysis, but when the sodium chemical expansion is 1% or less, this simplification is no longer acceptable. So in the “half empty shell” model presented here, the pure thermal expansion problem is solved first (see results in figure 10). Then, the transient sodium diffusion and its stress level related expansion is added as presented in [1]. The final predicted potshell and lining displacements are presented in figure 11 for the combined design retrofit case. Figure 12 presents only the lateral displacement confirming the results obtained with the “almost empty shell” potshell model for the second retrofit idea. Figure 13 presents only the vertical displacement confirming the results obtained with the “empty shell” and the “almost empty shell” potshell models for the first retrofit idea. Notice that even if the potshell itself is not deflecting vertically, the cathode panel still does. The gain of cell stability between the standard design presented in [1] and the retrofitted design presented here can be analyzed using MHD-Valdis as demonstrated in [11].

Conclusions

Redeveloped thermo-chimio-mechanical models [2,3,4,and 5] presented at the 2010 TMS conference [1] have been improved adding up to date ANSYS® contact elements technology into them. Furthermore, two innovative retrofit design proposals have been successfully tested using them, demonstrating their ability to be use as efficient design analysis tools. Those models are now available to the hole aluminium industry through GeniSim Inc.

References

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Author

Dr. Marc Dupuis is a consultant specialized in the applications of mathematical modeling for the aluminium industry since 1994, the year when he founded his own consulting company GeniSim Inc (www.genisim.com). Before that, he graduated with a Ph.D. in chemical engineering from Laval University in Quebec City in 1984, and then worked 10 years as a research engineer for Alcan International. His main research interests are the development of mathematical models of the Hall-Héroult cell dealing with the thermo-electric, thermo-mechanic, electro-magnetic and hydrodynamic aspects of the problem. He was also involved in the design of experimental high amperage cells and the retrofit of many existing cell technologies.

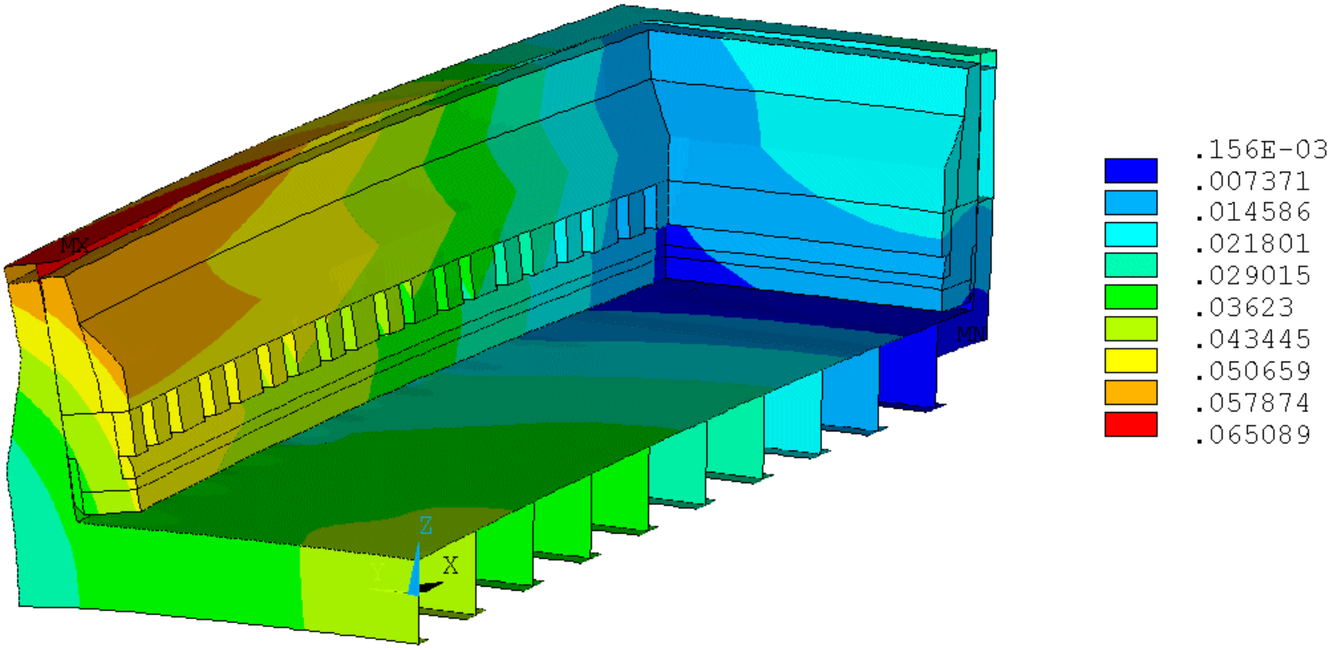

Figure 1: Displacement solution of the improved “almost empty shell” model using the plastic mode (m)

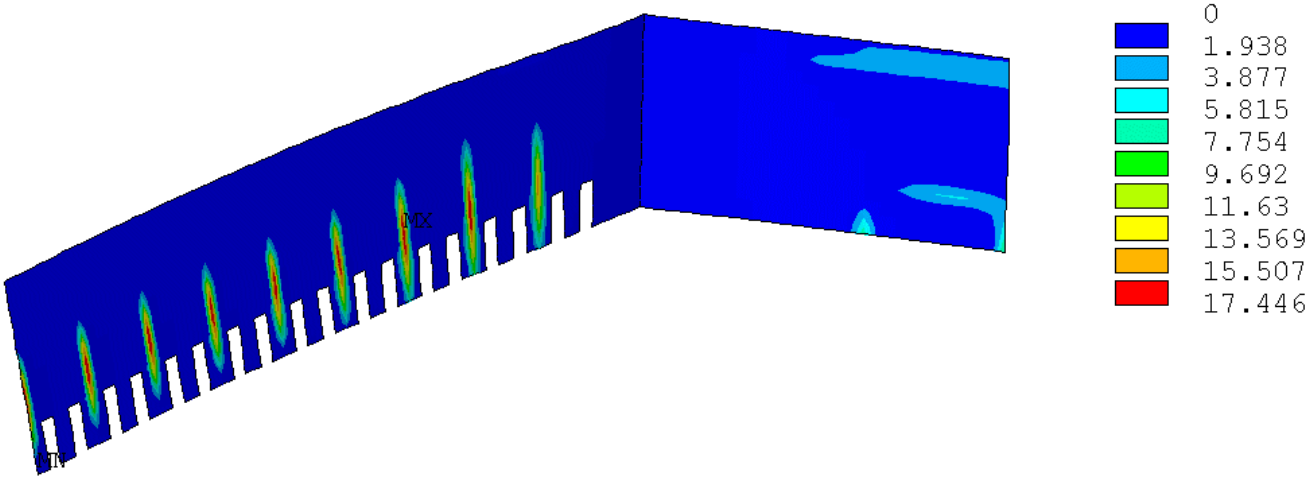

Figure 2: Corresponding pressure applied on the potshell by the side lining (MPa)

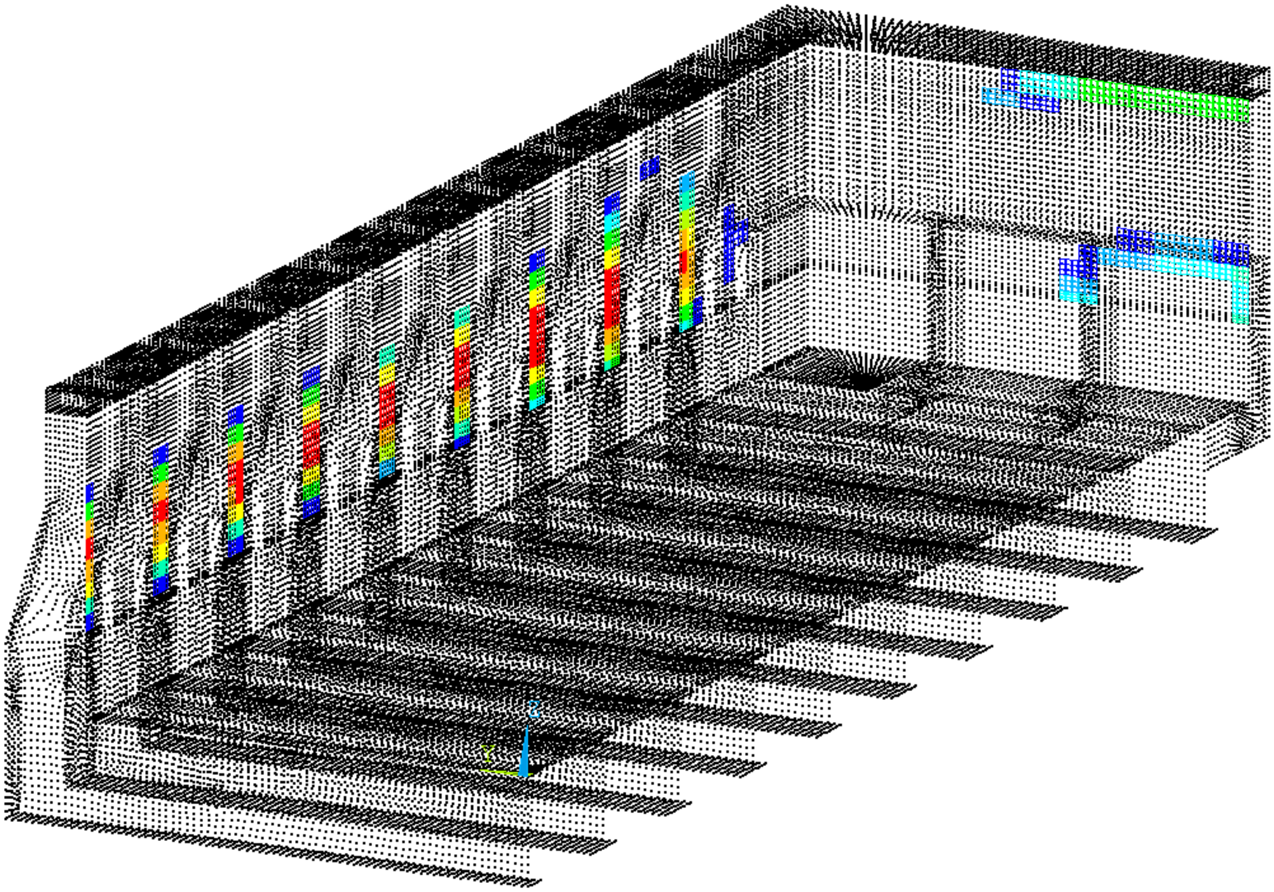

Figure 3: Pressure applied on the “empty shell” model potshell structure as boundary condition

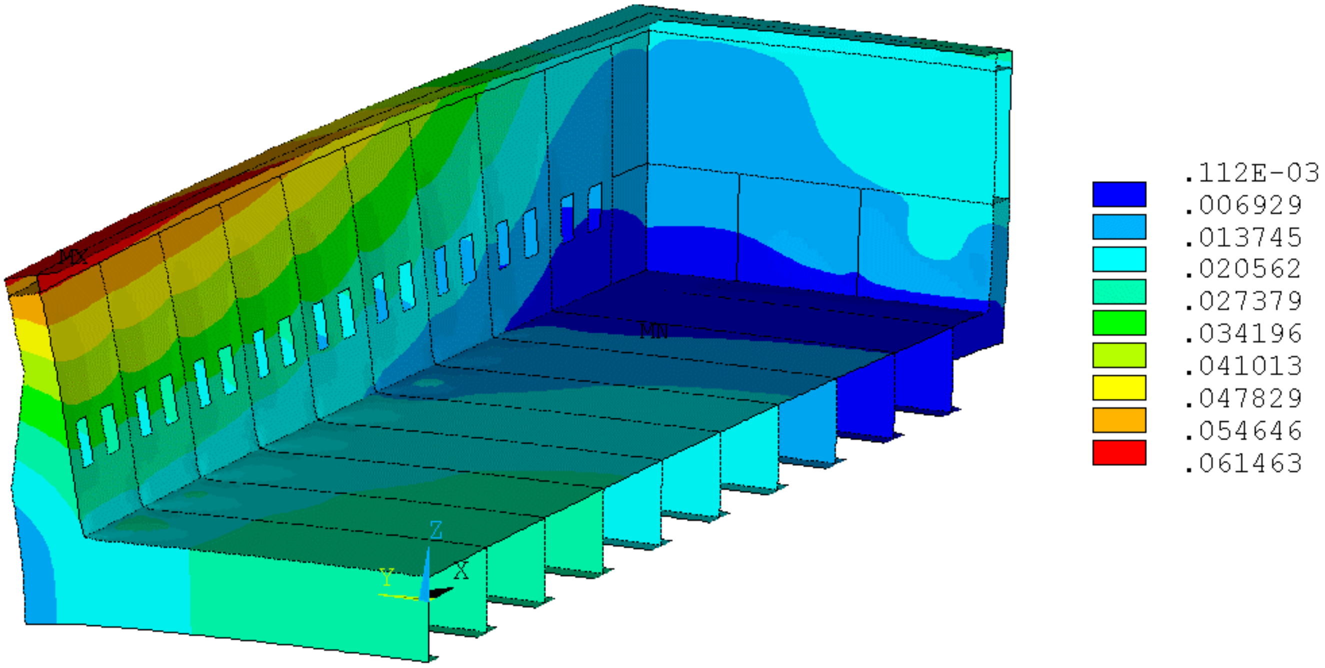

Figure 4: Displacement solution of the improved “empty shell” model using the plastic mode (m)

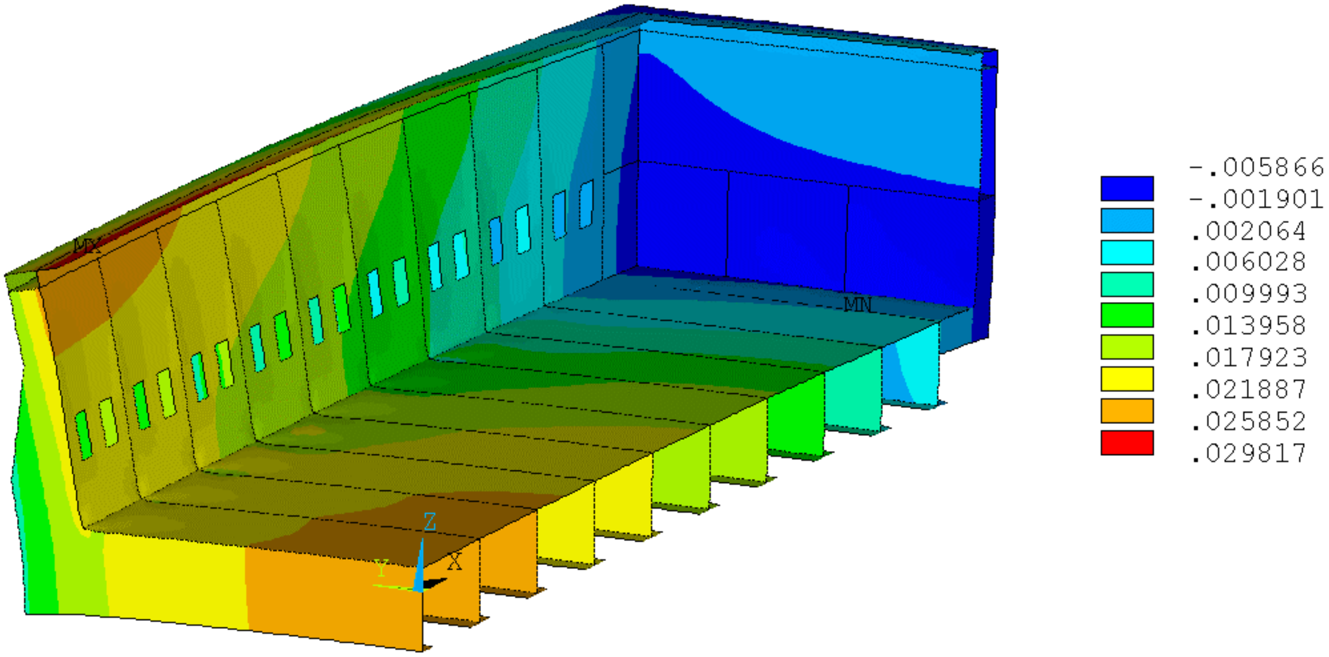

Figure 5: Vertical displacement solution of the improved “empty shell” model for the standard potshell design using the plastic mode (m)

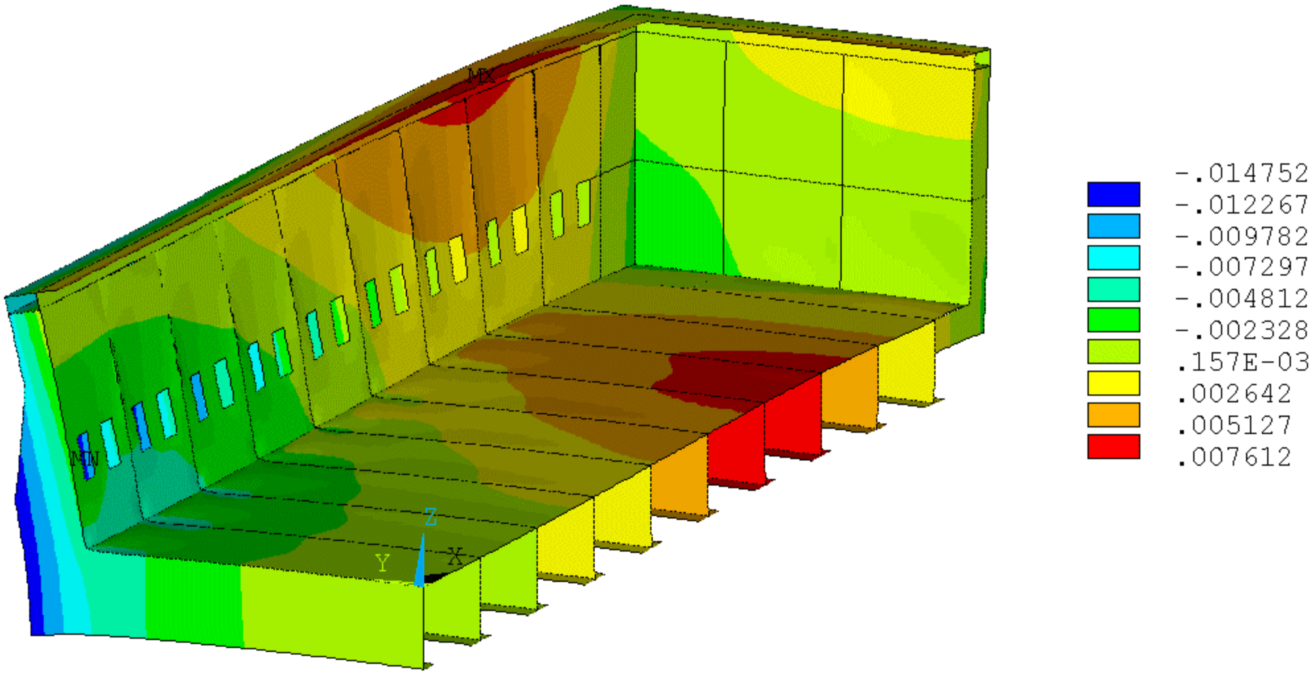

Figure 6: Vertical displacement solution of the improved “empty shell” model for the retrofitted potshell design using the plastic mode (m)

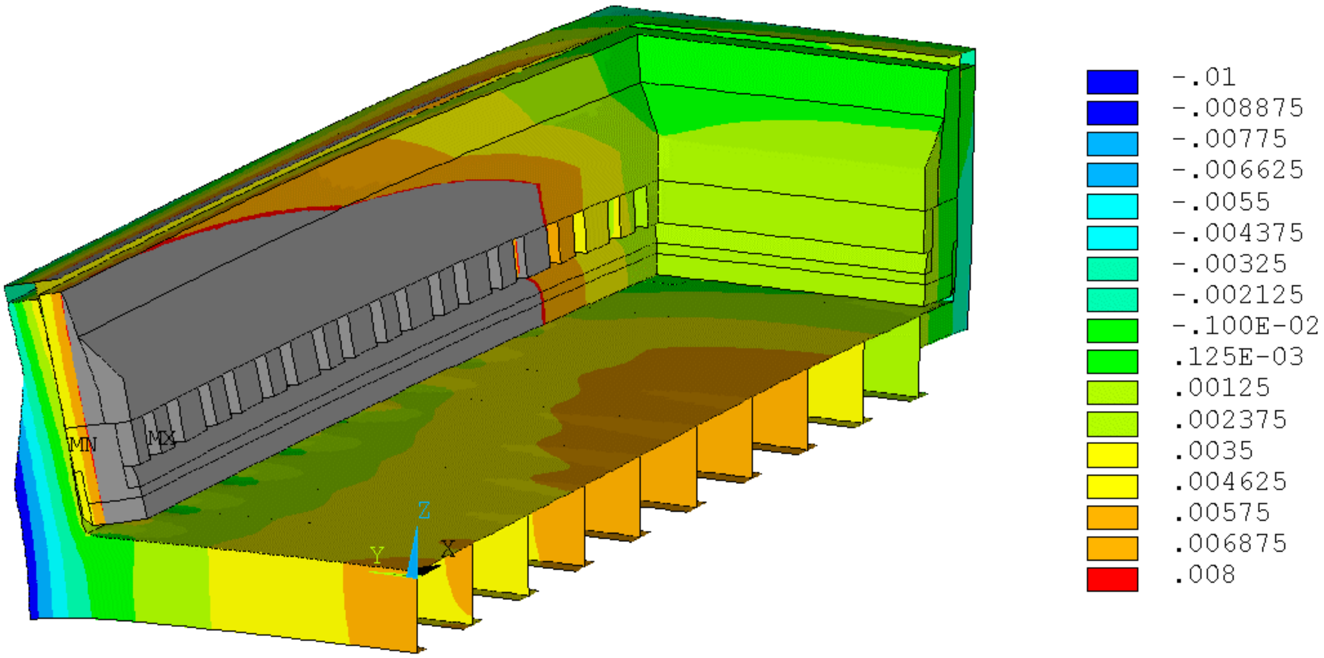

Figure 7: Vertical displacement solution of the improved “almost empty shell” model for the retrofitted potshell design using the plastic mode (m)

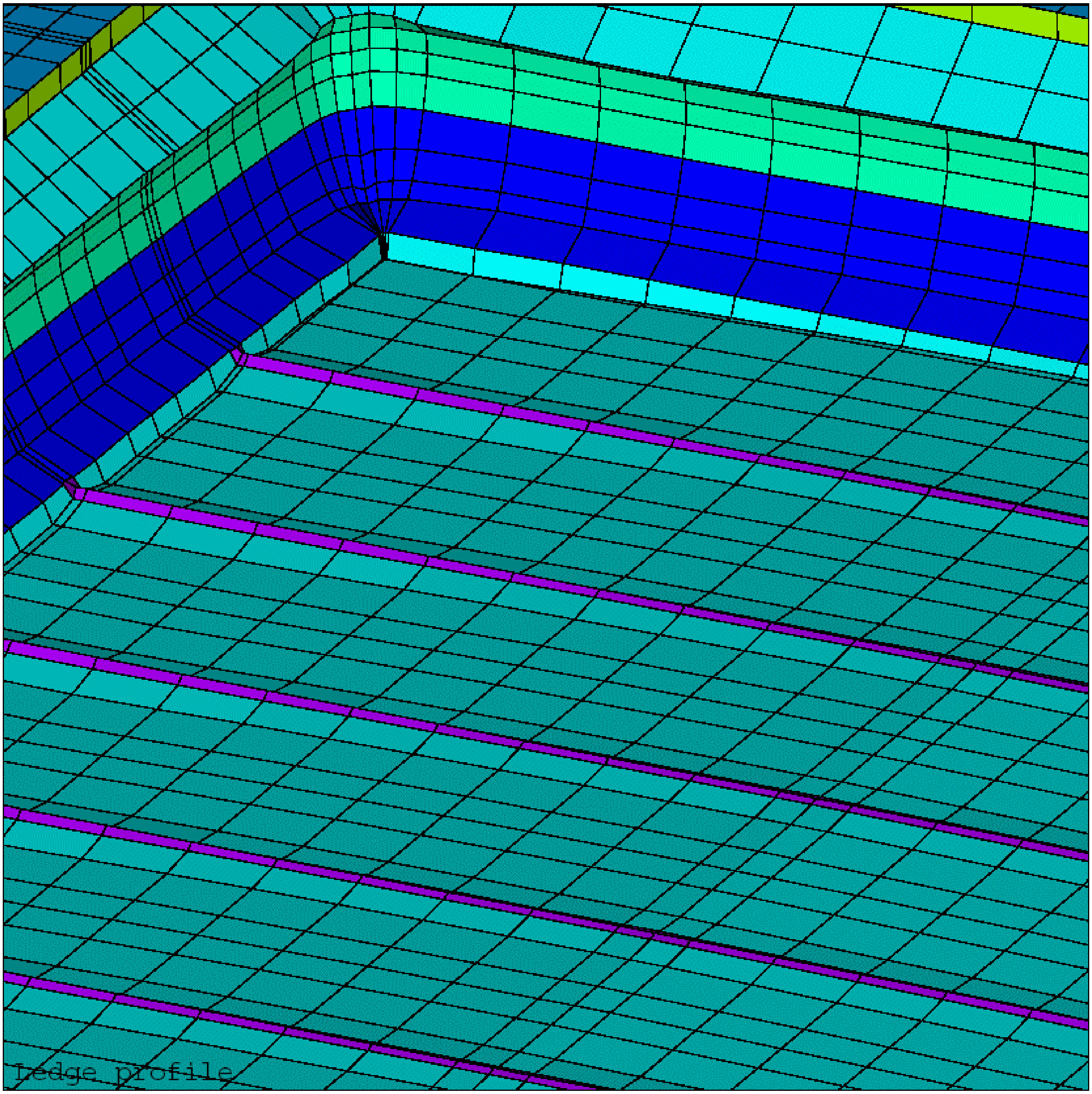

Figure 8: Cathode panel erosion profile obtained using the full cathode panel erosion model

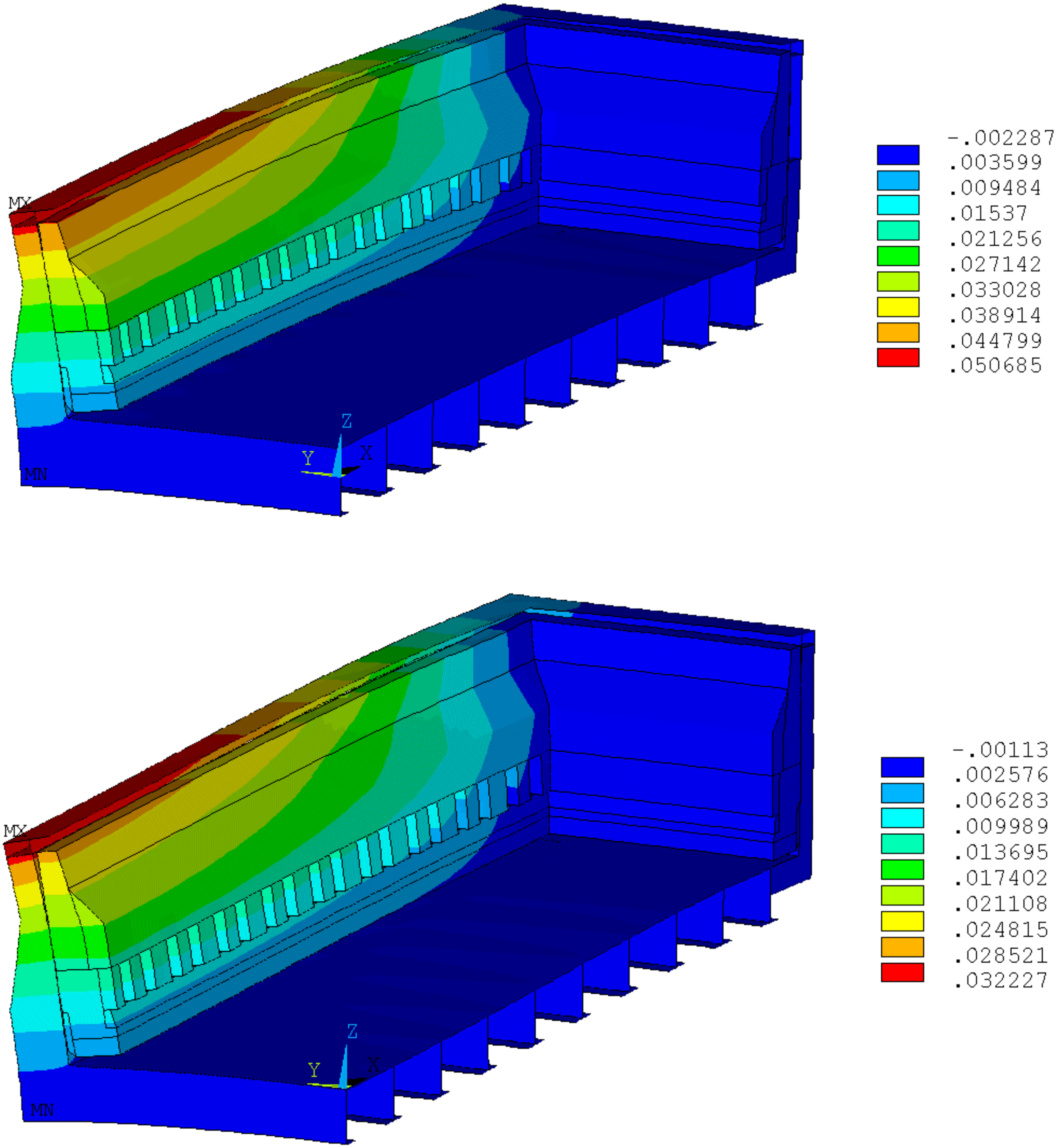

Figure 9: Lateral displacement solution of the improved "almost empty shell" using the plastic mode (m)

Top: standard potshell and lining design, bottom: retrofitted potshell and lining design

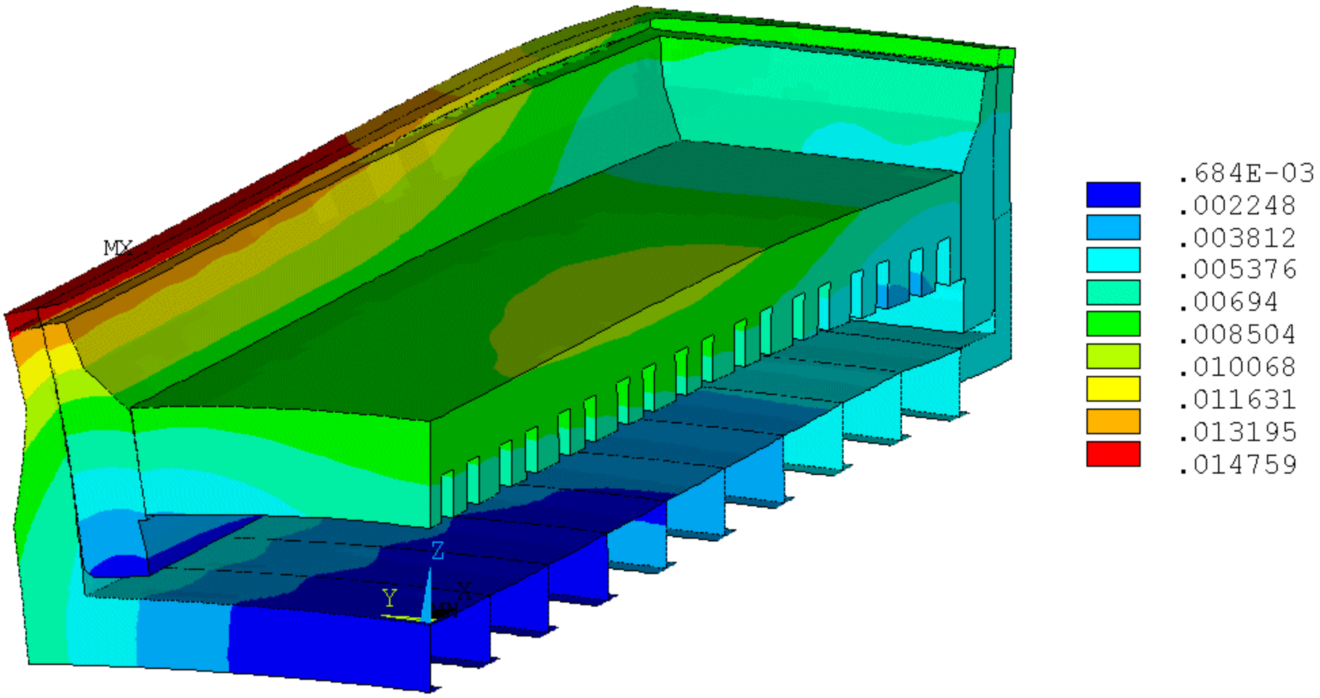

Figure 10: Temperature only displacement solution of the improved “half empty shell” model using the plastic mode (m)

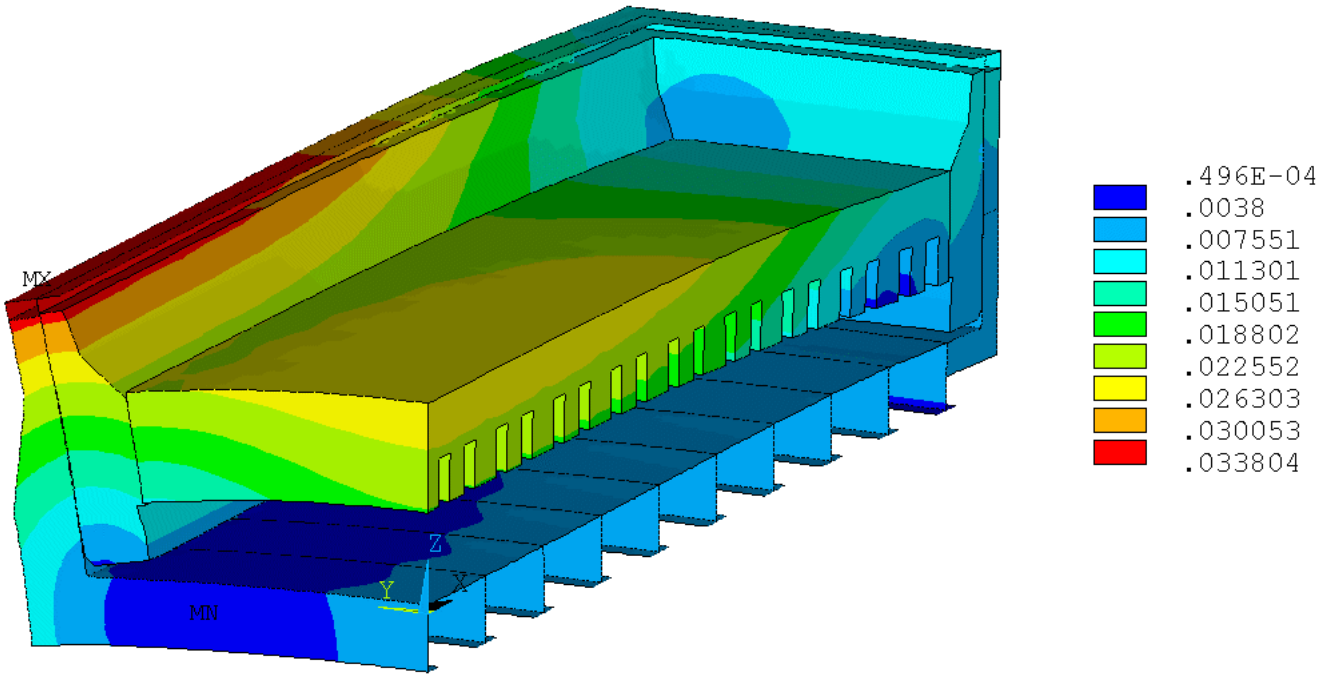

Figure 11: Final displacement solution of the improved “half empty shell” model using the plastic mode (m)

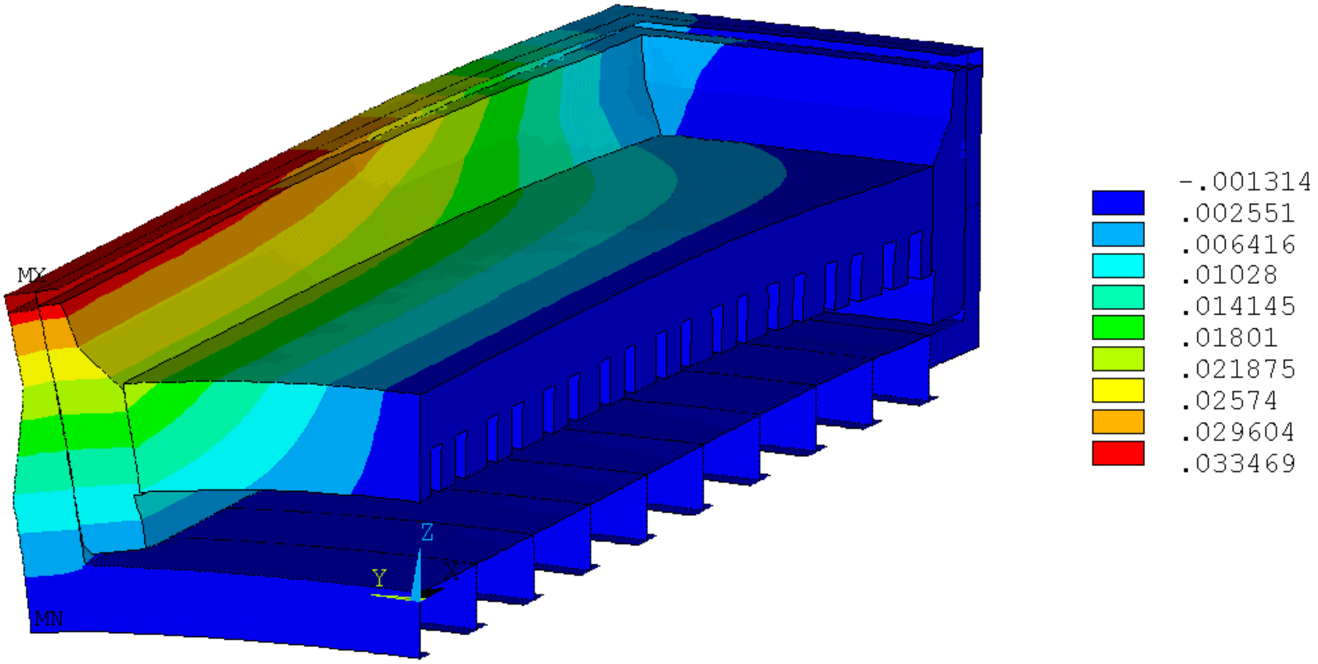

Figure 12: Final lateral displacement solution of the improved “half empty shell” model using the plastic mode (m)

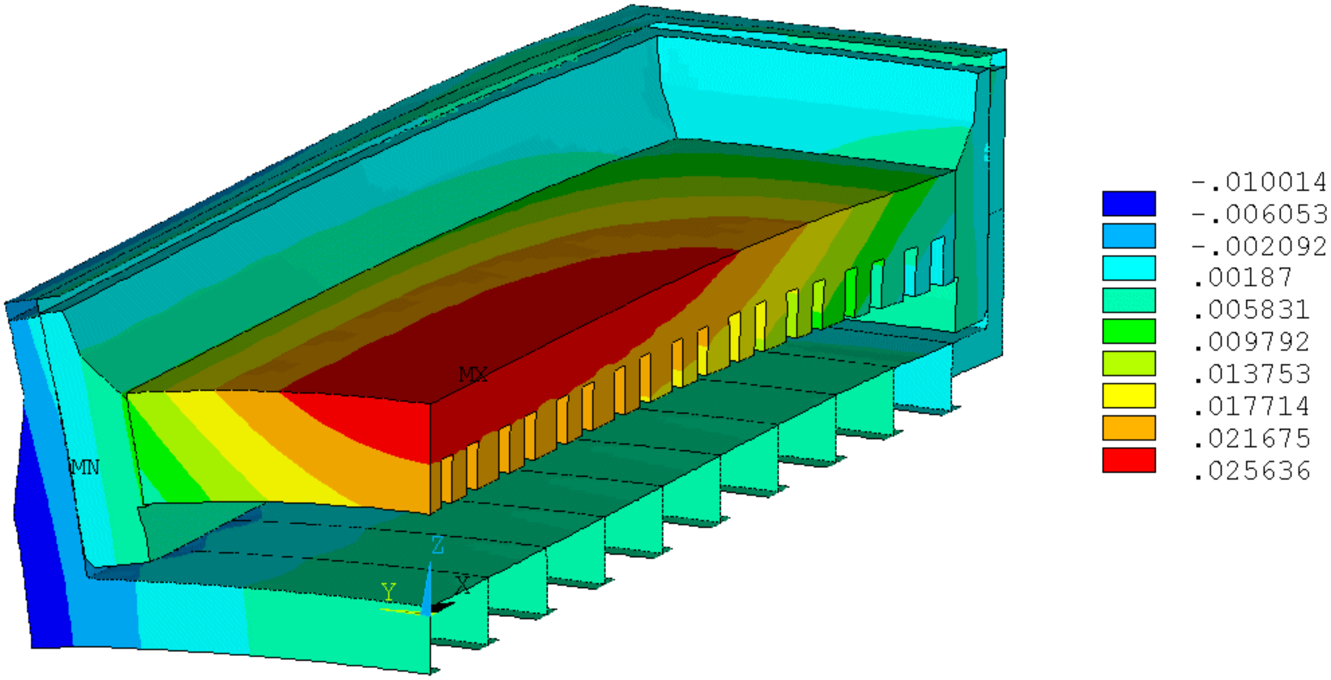

Figure 13: Final vertical displacement solution of the improved “half empty shell” model using the plastic mode (m)