Mathematical Modeling of Aluminium Reduction Cell Potshells: Improvements and Applications

Marc Dupuis

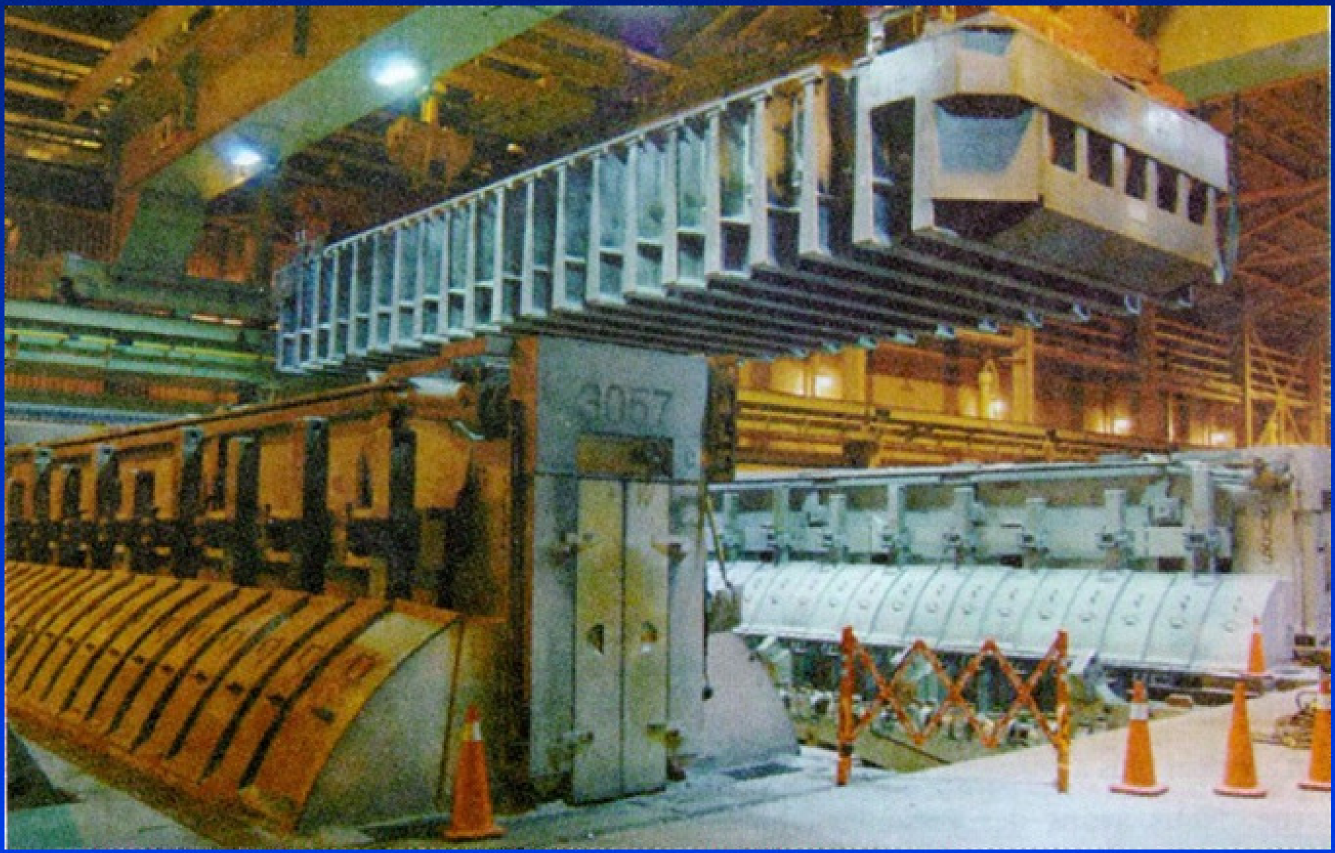
GENISIM

GENISIM

Plan of the Presentation

- Introduction
- Improved "Almost Empty Shell" Potshell Model
- Improved "Empty Shell" Potshell Model
- Testing a New Potshell Design with the Improved "Empty Shell" Model
- Testing a New Potshell Design with the Improved "Almost Empty Shell" Model
- Testing a second New Potshell Design with the Improved "Almost Empty Shell" Model
- Improved "Half Empty Shell" Potshell Model
- Testing the two New Potshell Design Proposals with the Improved "Half Empty Shell" Model
- Conclusions

Introduction



The 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 been improved taking advantage of the contact elements facilities available in ANSYS® 12.0.

They then have been used to test two new designs, the first aiming at eliminating the vertical deflection of monocoque potshells and the second aiming at expending potlife by lowering the potshell floor.

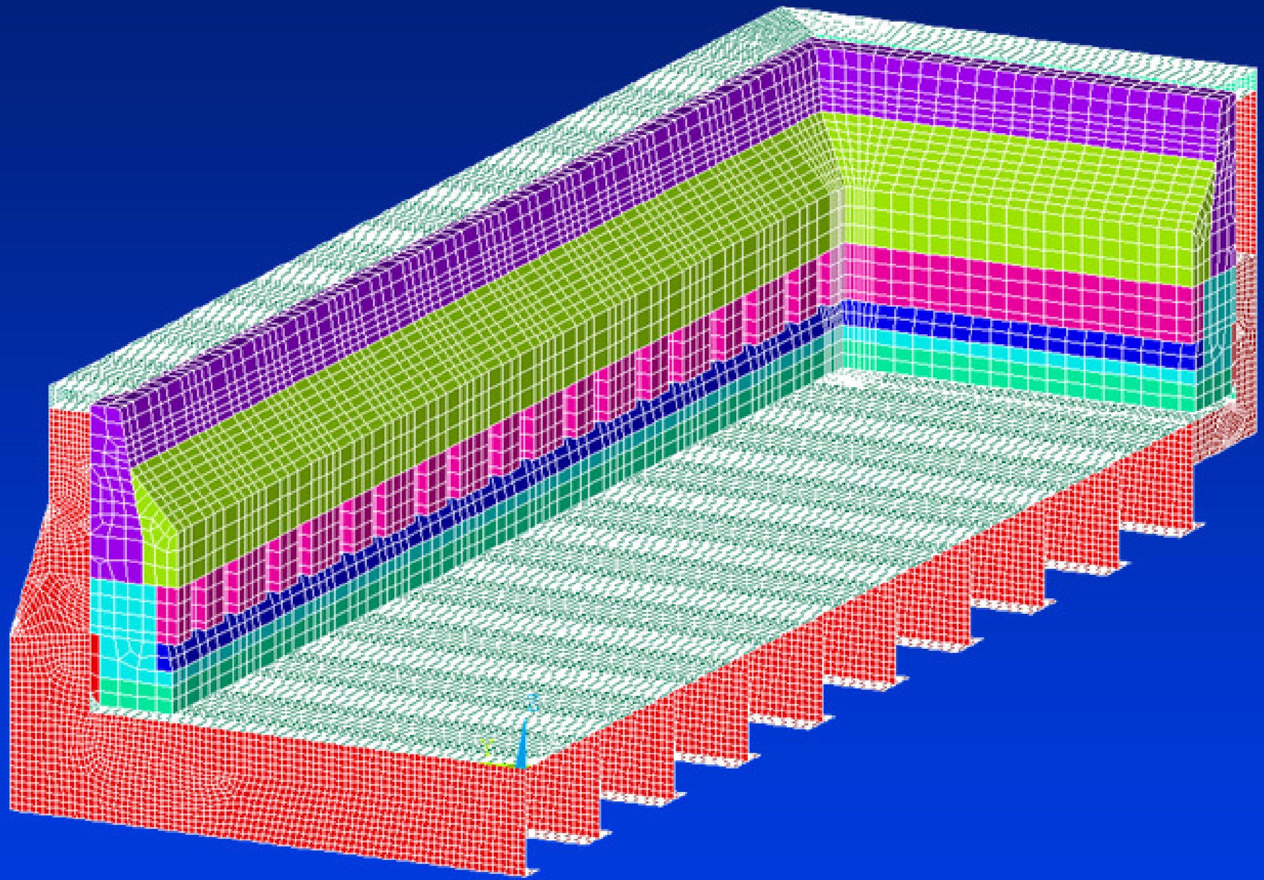
GENISIM

“Almost Empty Shell” Potshell Model

- Based on the usage of the quadrilateral Finite Strain shell element (SHELL181) in the commercial code ANSYS®.
- Temperature distribution obtained from the full cell quarter thermo-electric model applied as a body load to the entire potshell structure.
- Adding the lining geometry between the potshell walls and the cathode blocks all around the potshell and applying a pressure loading as boundary condition at the carbon block/side lining interface that is lying on the Dewing strain-stress relationship.
- Elastic mode: solving the mechanical problem only by considering only the elastic properties of the potshell steel.
- Plastic mode: solving the temperature dependent isotropic hardening von Mises plasticity behavior of the potshell steel structure using the MISO non-linear hardening option in ANSYS®.

GENISIM

Improved "Almost Empty Shell" Potshell Model

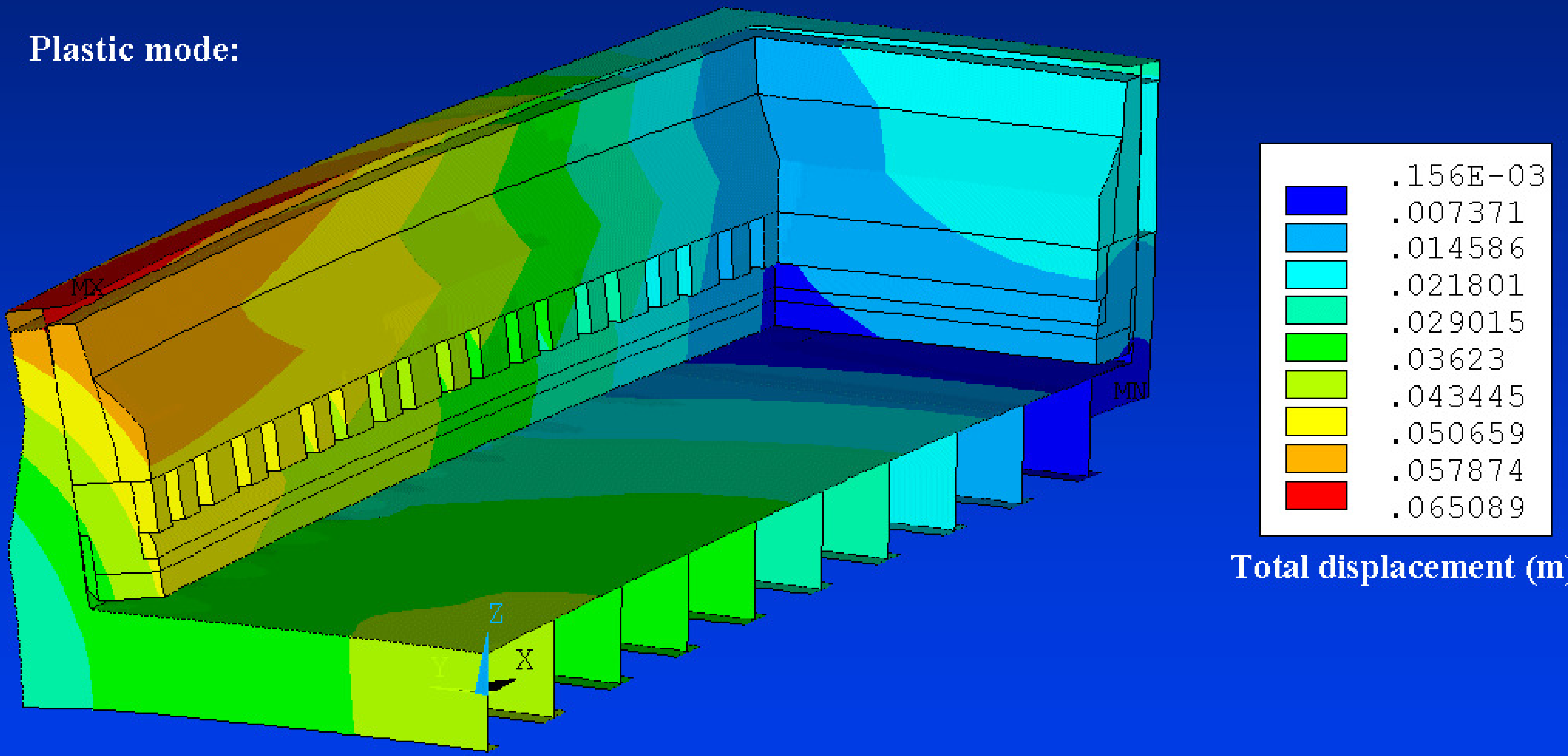


The "almost empty shell" potshell model have been improved by decoupling the 2D potshell mesh from the 3D side lining mesh and by reconnecting the two parts using ANSYS® CONTA174 and TARGE170 contact pair elements.

GENISIM

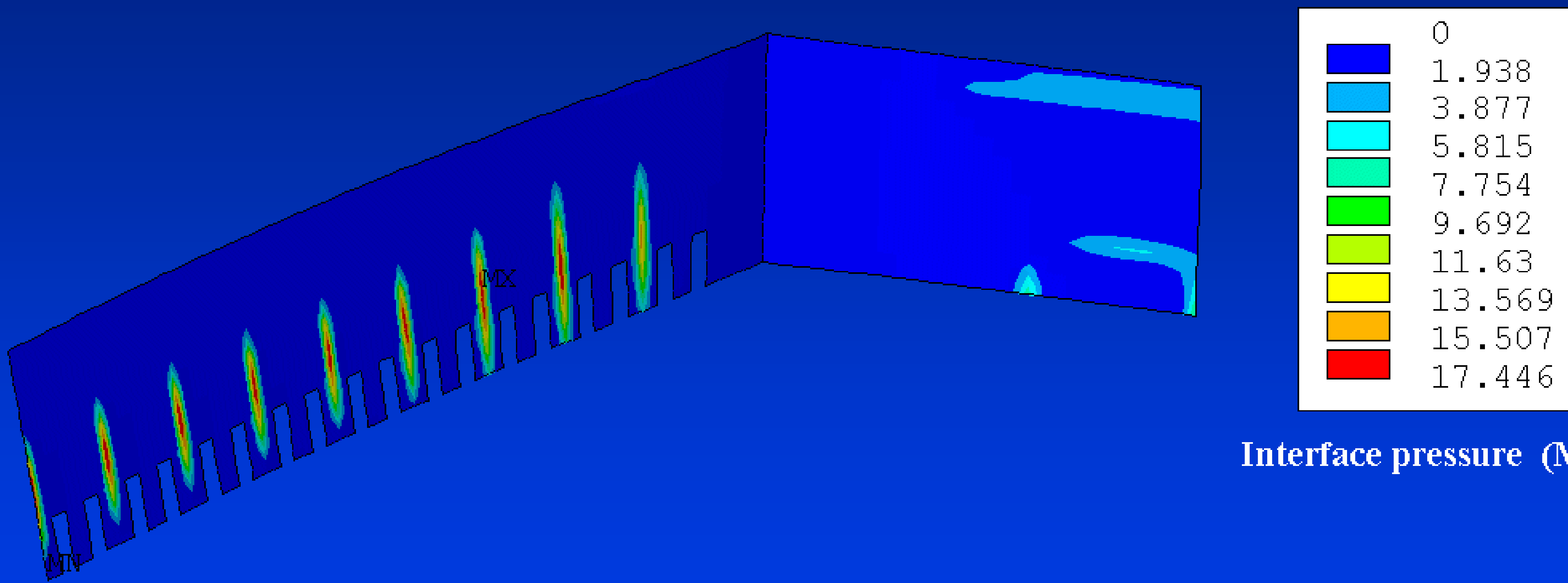
Improved "Almost Empty Shell" Potshell Model

Plastic mode:



Improved "Almost Empty Shell" Potshell Model

Plastic mode:



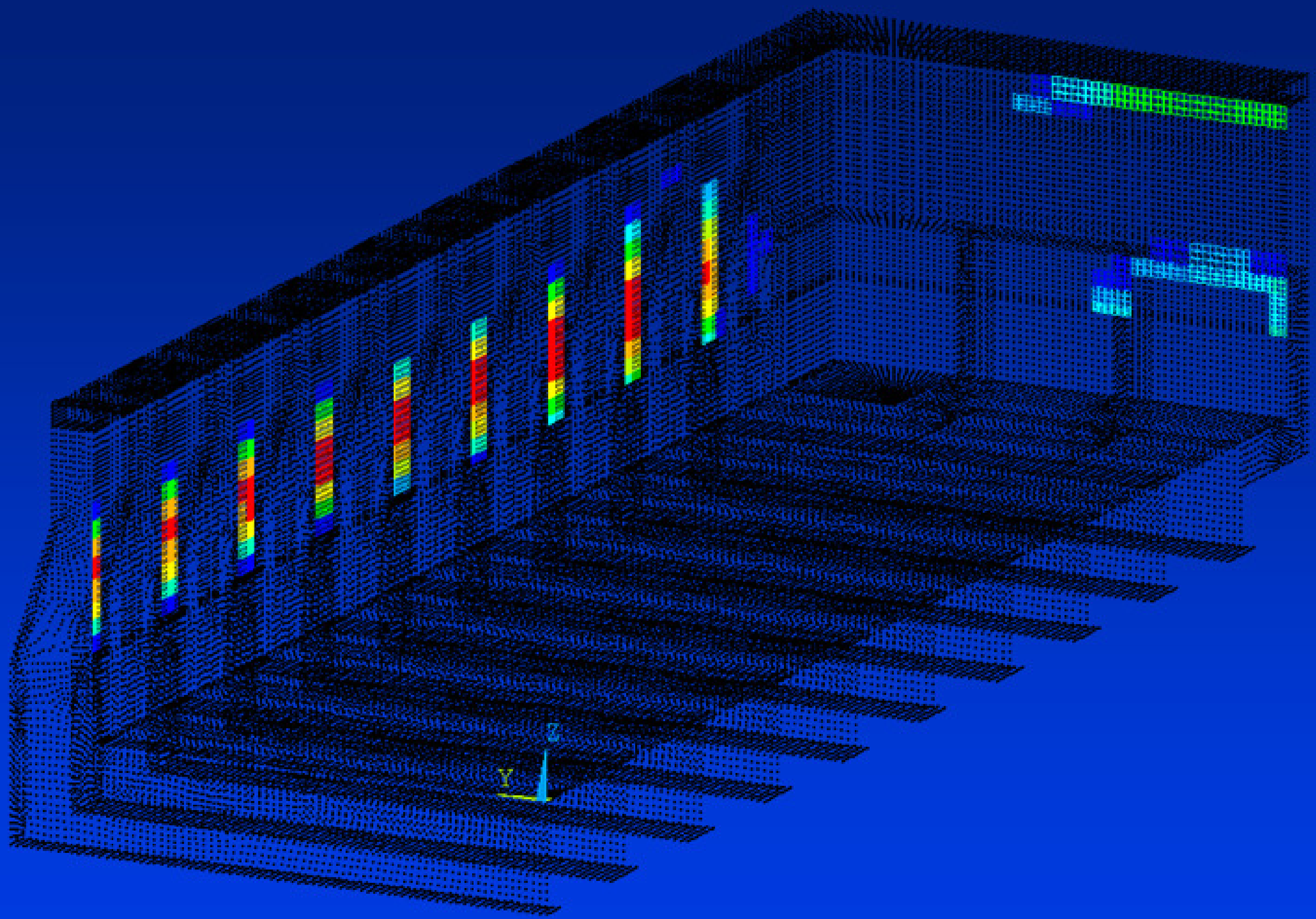
Interface pressure (MPa)

The pressure that the side lining is applying on the potshell through the contact interface can now be extracted from the solution.

"Empty Shell" Potshell Model

- Based on the usage of the quadrilateral Finite Strain shell element (SHELL181) in the commercial code ANSYS®.
- Temperature distribution obtained from the full cell quarter thermo-electric model applied as a body load to the entire potshell structure.
- Internal pressure (or forces) loading scheme based on the cathode block size and position relative to the potshell. That loading scheme is at best semi-empirical and is typically considered as a trade secret.
- Elastic mode: solving the mechanical problem only by considering only the elastic properties of the potshell steel.
- Plastic mode: solving the temperature dependent isotropic hardening von Mises plasticity behavior of the potshell steel structure using the MISO non-linear hardening option in ANSYS®.

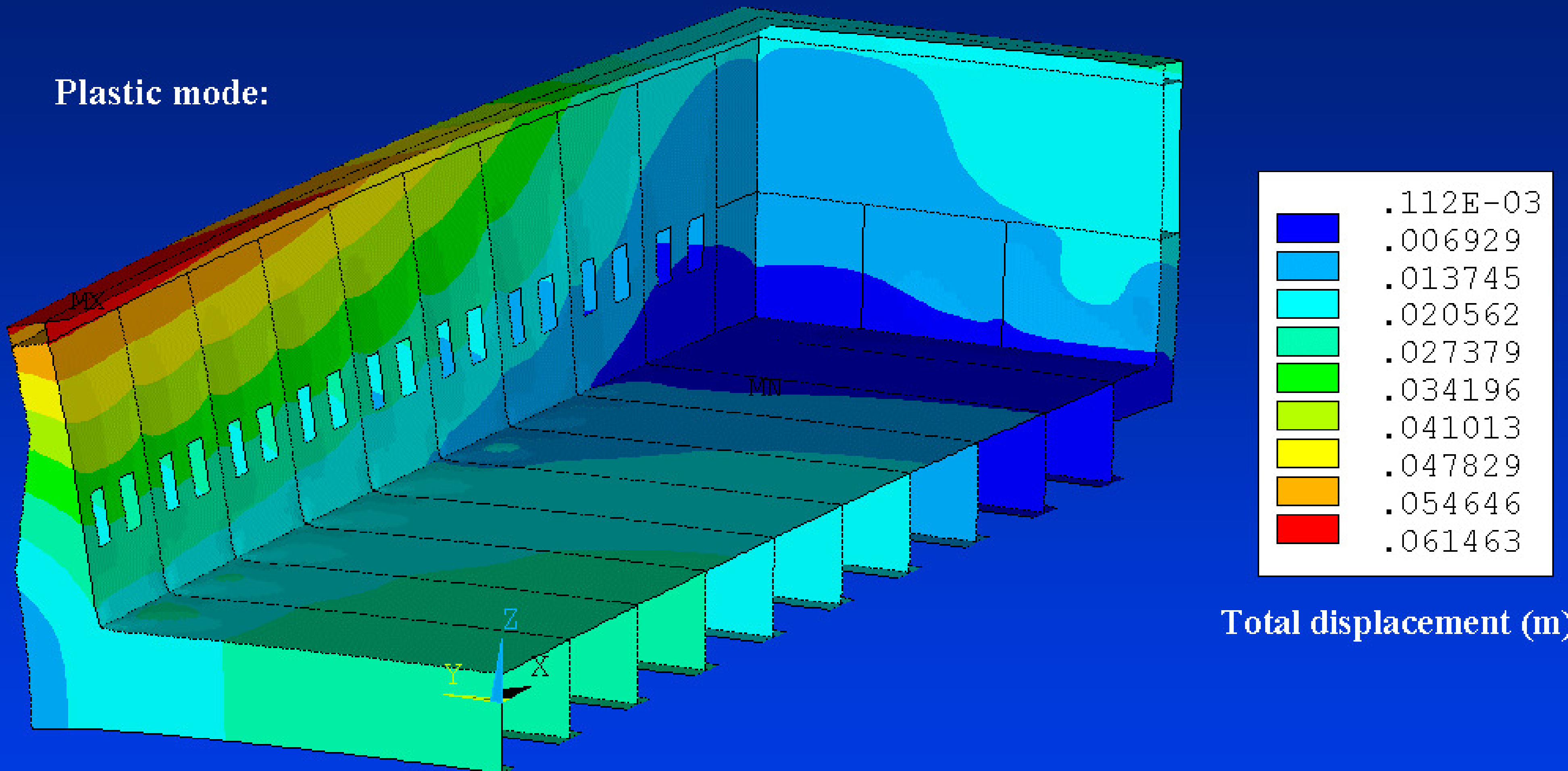
Improved “Empty Shell” Potshell Model



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.

“Improved Empty Shell” Potshell Model

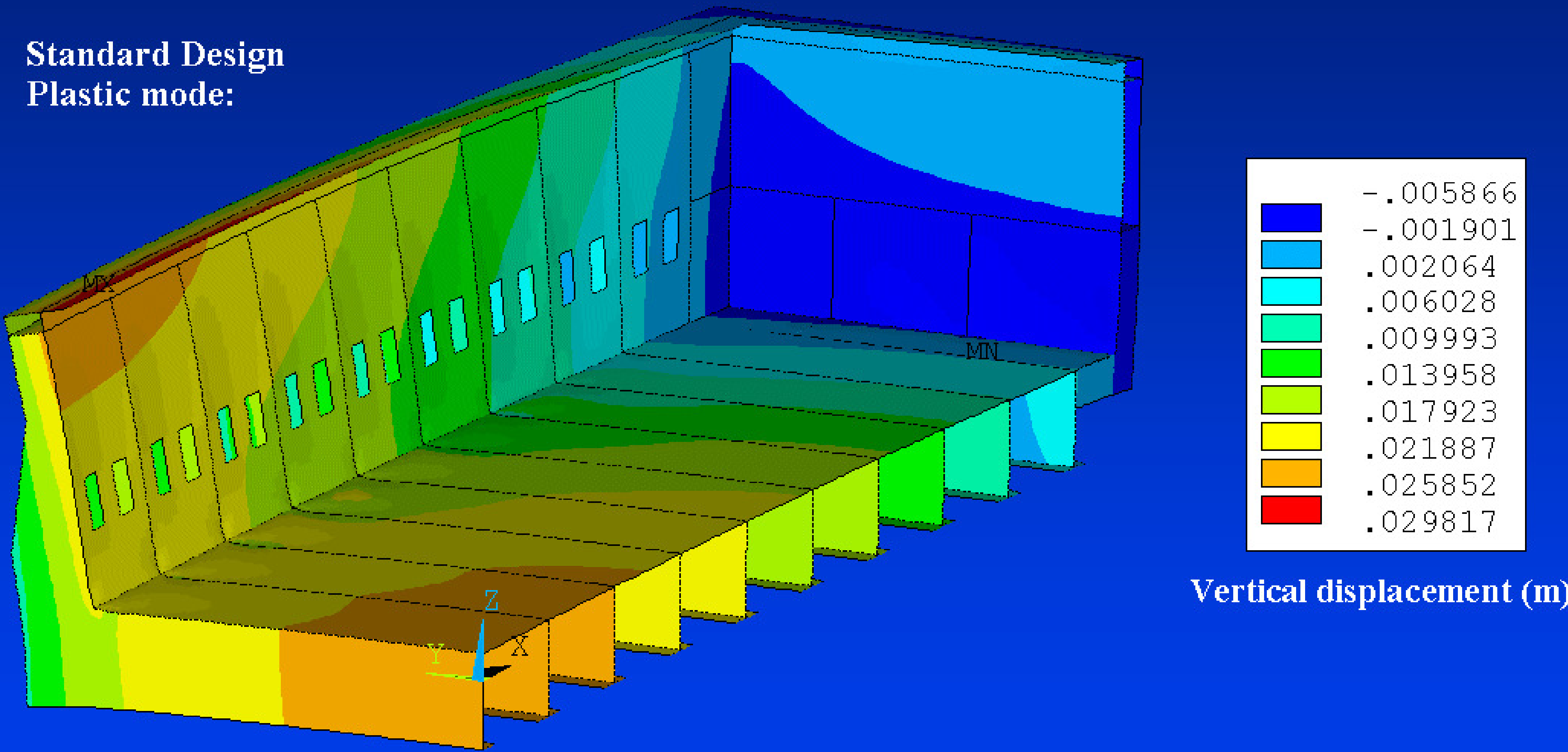
Plastic mode:



The resulting improved “empty shell” model displacement solution is now quite similar to the “almost empty shell” model displacement solution.

Testing a New Potshell Design Aiming at Eliminating the Vertical Potshell Displacement with the Improved "Empty Shell" Model

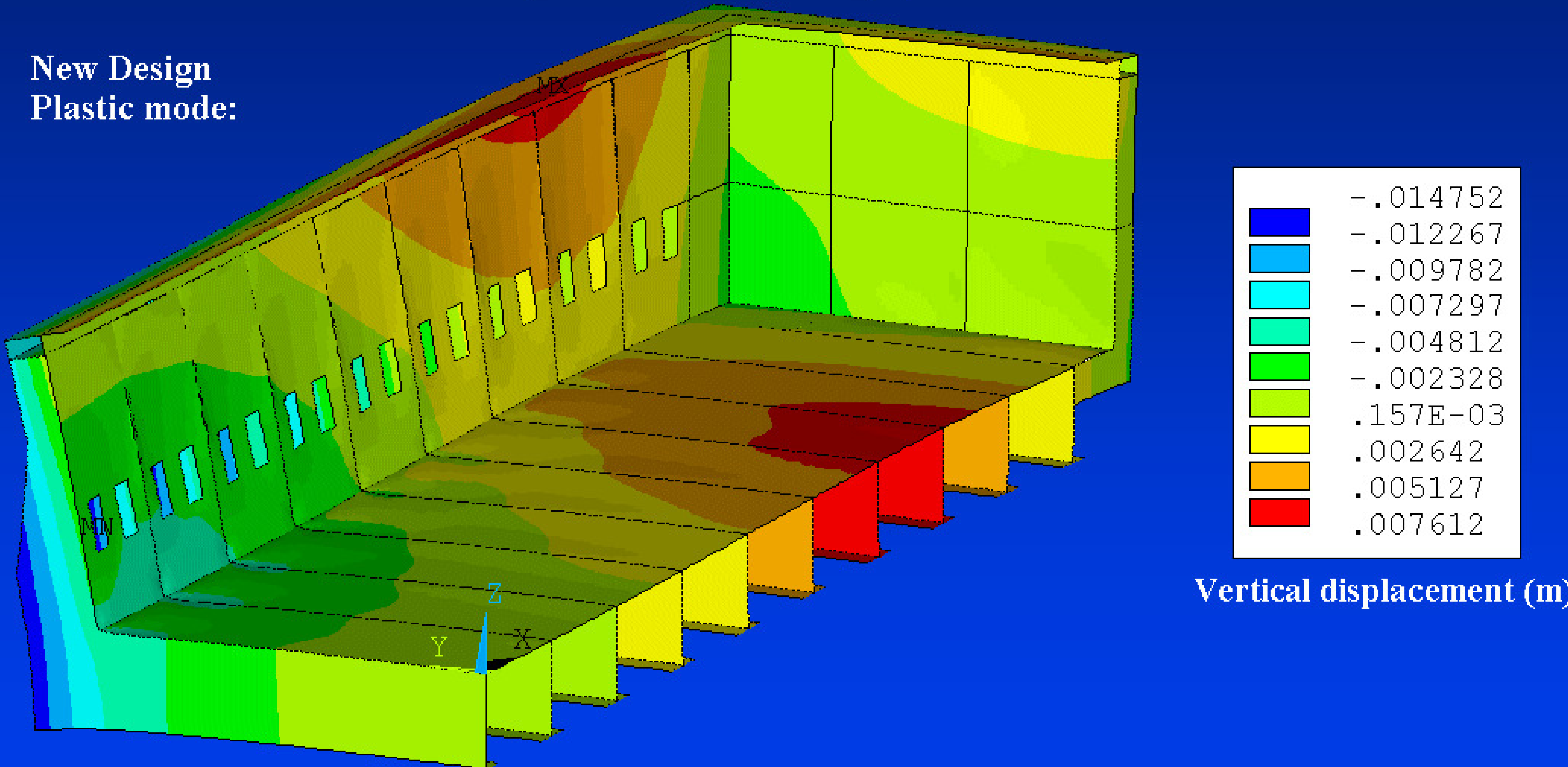
Standard Design
Plastic mode:



GENISIM

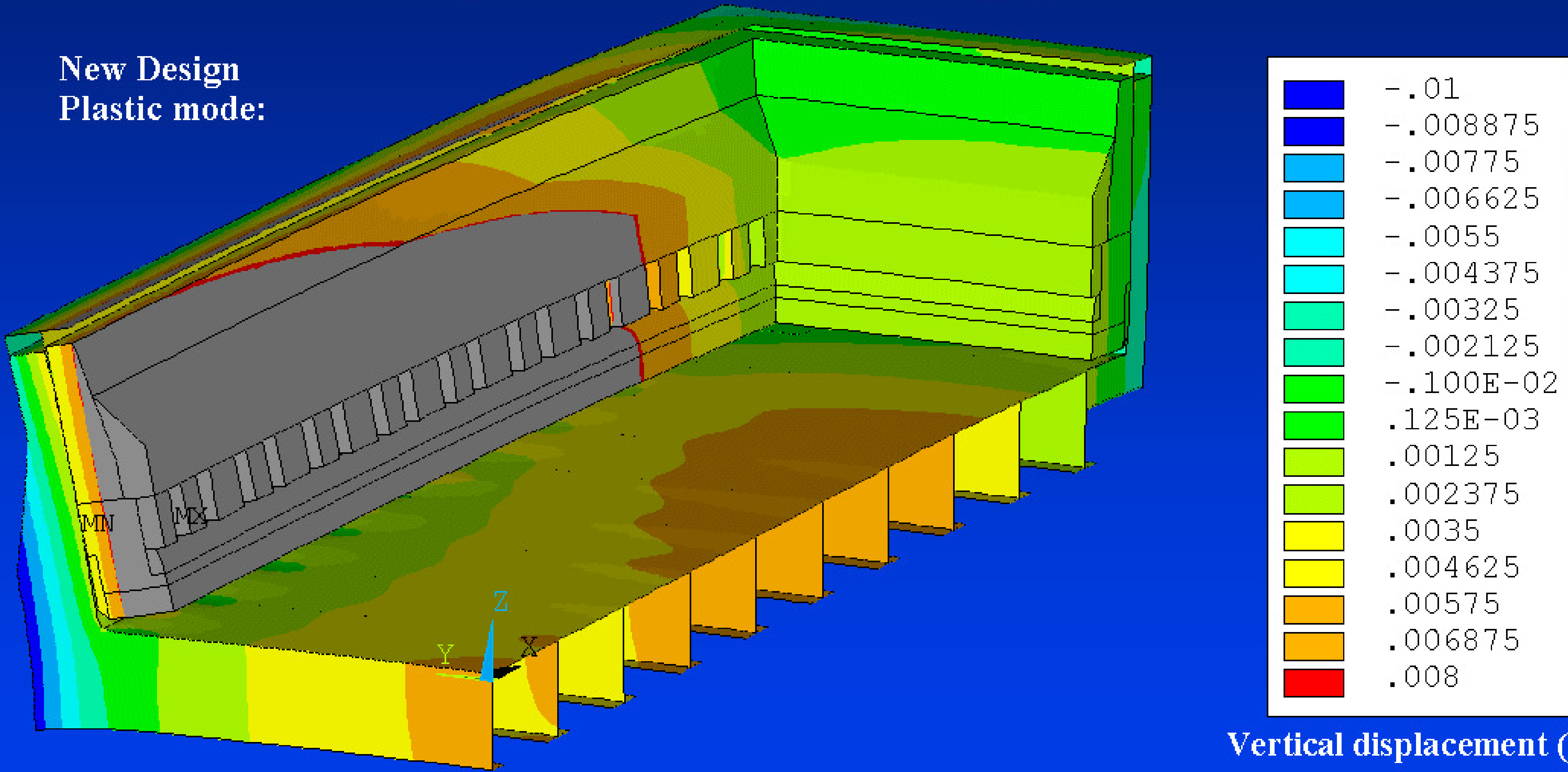
Testing a New Potshell Design Aiming at Eliminating the Vertical Potshell Displacement with the Improved "Empty Shell" Model

New Design
Plastic mode:



Testing a New Potshell Design Aiming at Eliminating the Vertical Potshell Displacement with the Improved "Almost Empty Shell" Model

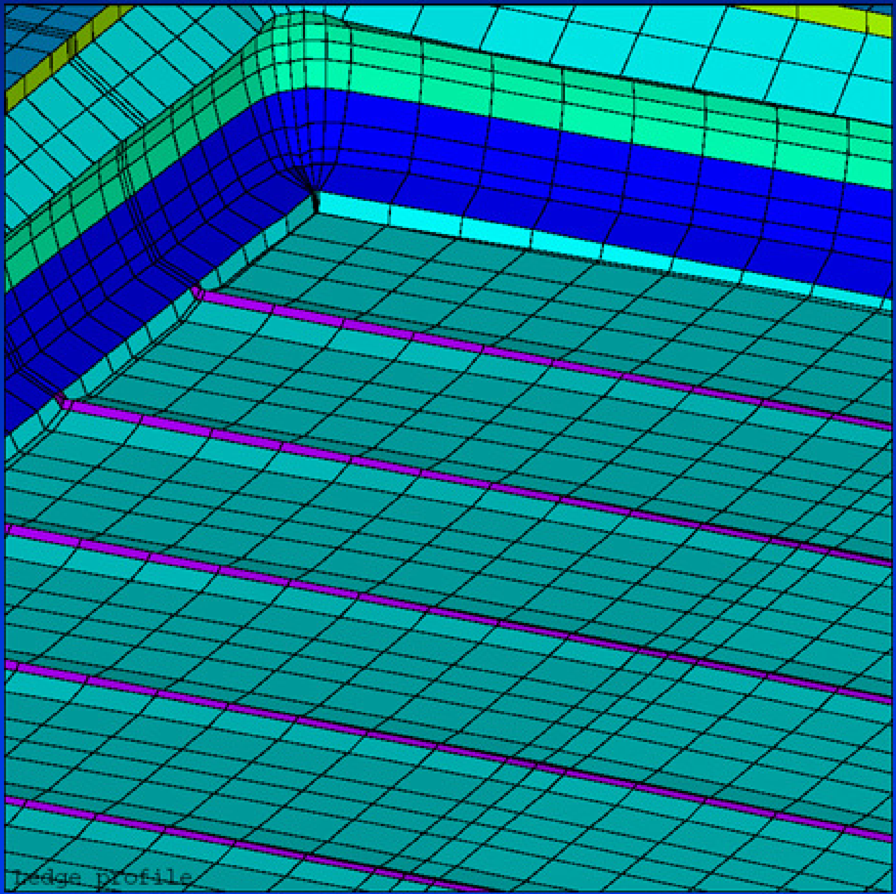
New Design
Plastic mode:



Vertical displacement (m)

GENISIM

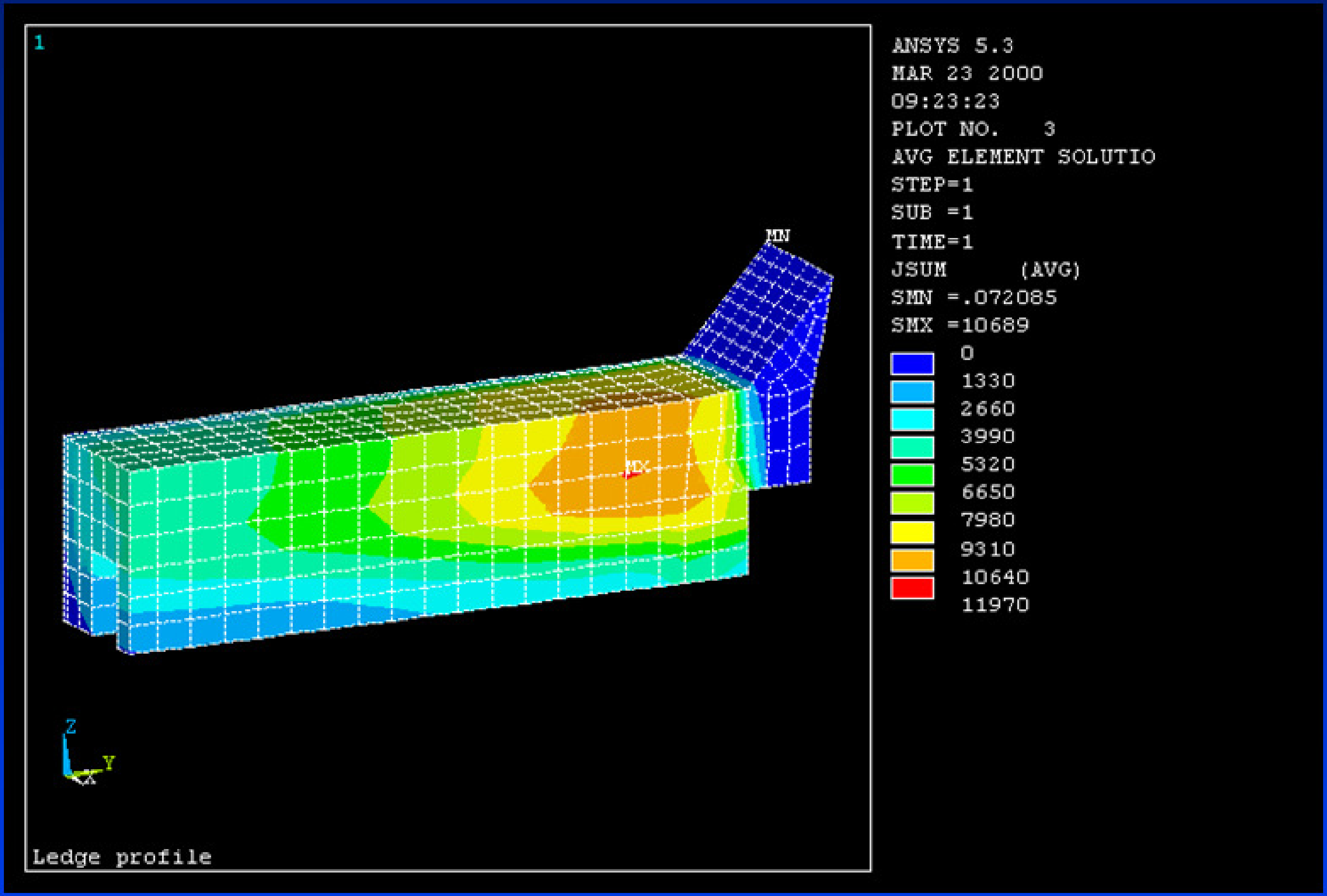
Testing a New Potshell and Lining Design Aiming at Increasing the Cell Life of High Amperage Cells using Graphitized Cathode Blocks with the Improved "Almost Empty Shell" Model



In 2000, 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.

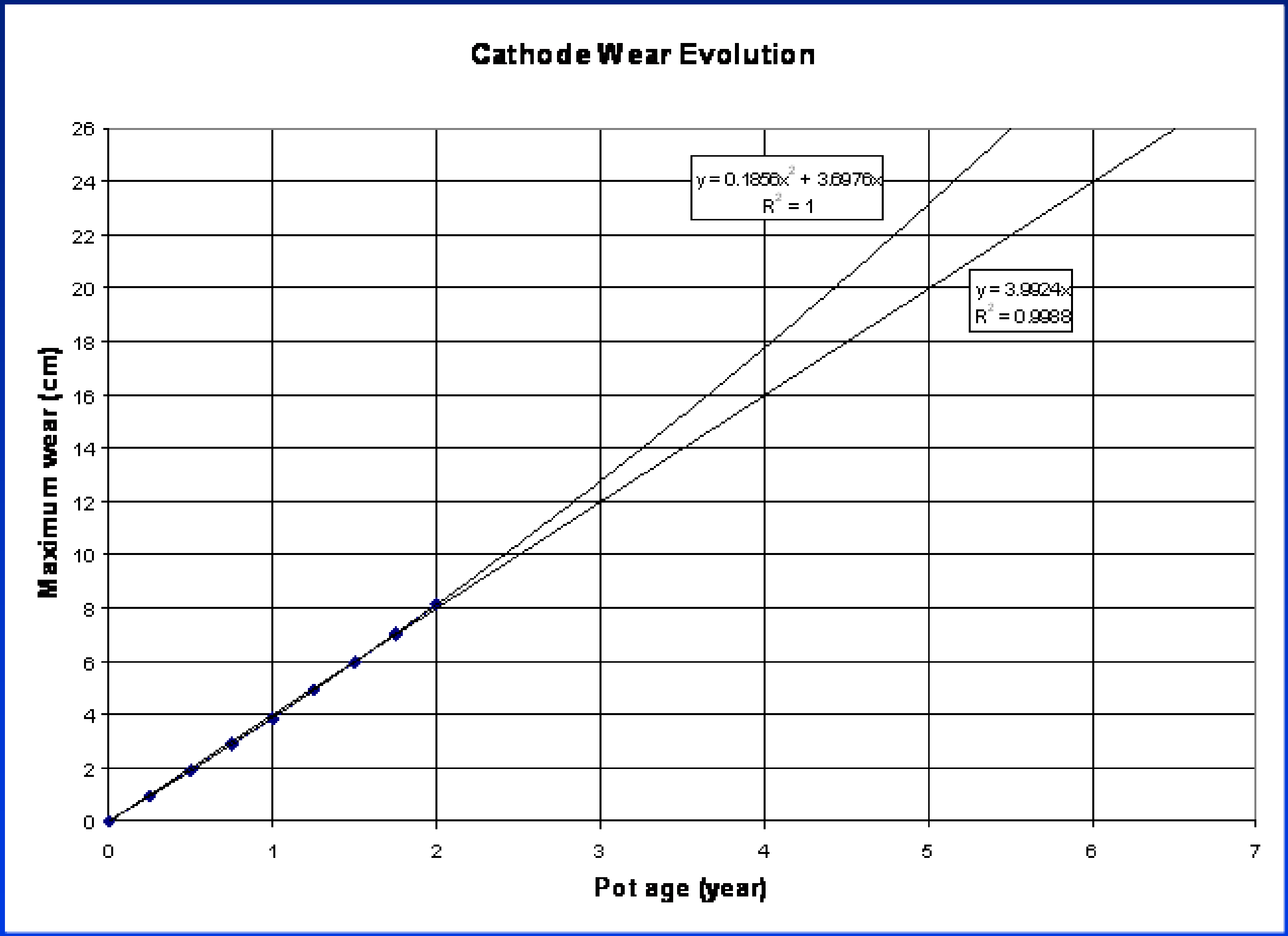
GENISIM

Erosion Model Base Case Model Solution



- Erosion profile animation of the base case model for the first 2 years

Erosion Model Base Case Model Solution

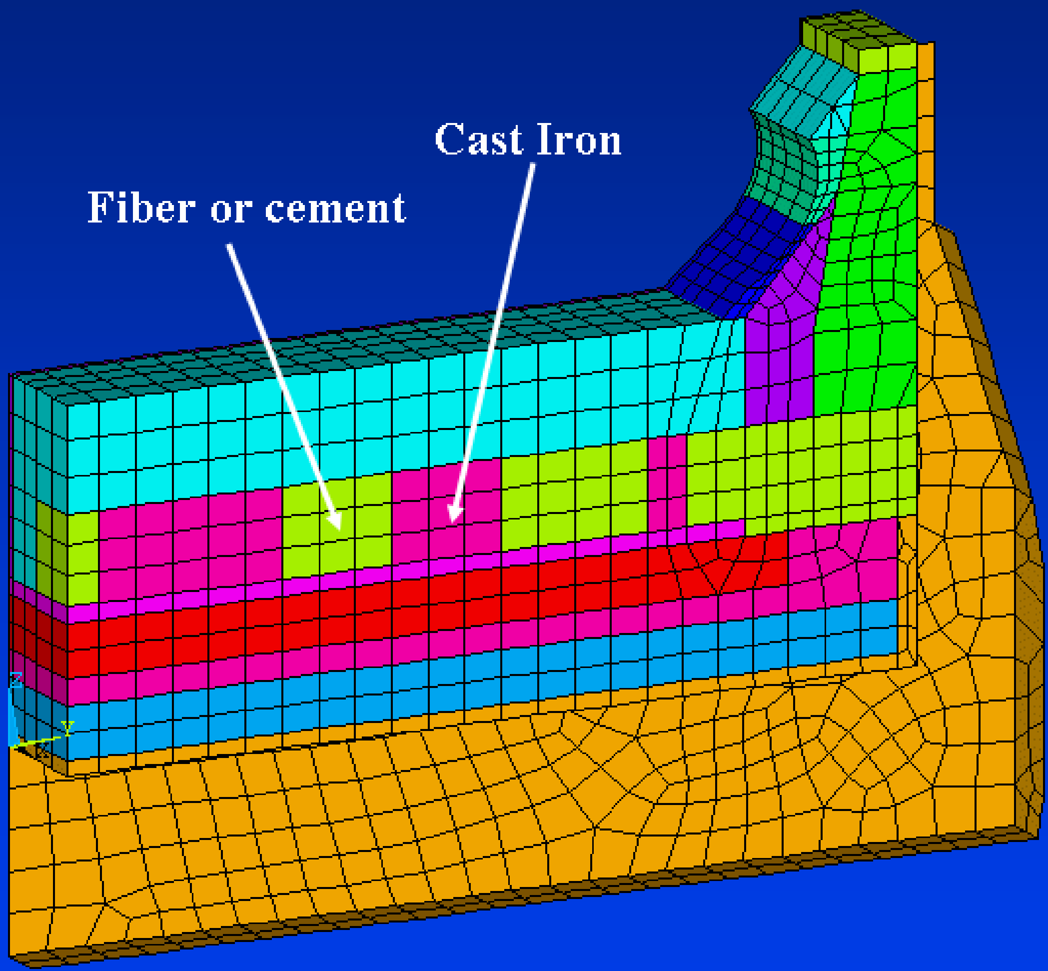


- Evolution of the maximum erosion of the base case model

Erosion Model
Analysis of First Retrofit Proposal

- Partial cast iron rodding in order to promote a uniform current density at the surface of the cathode block

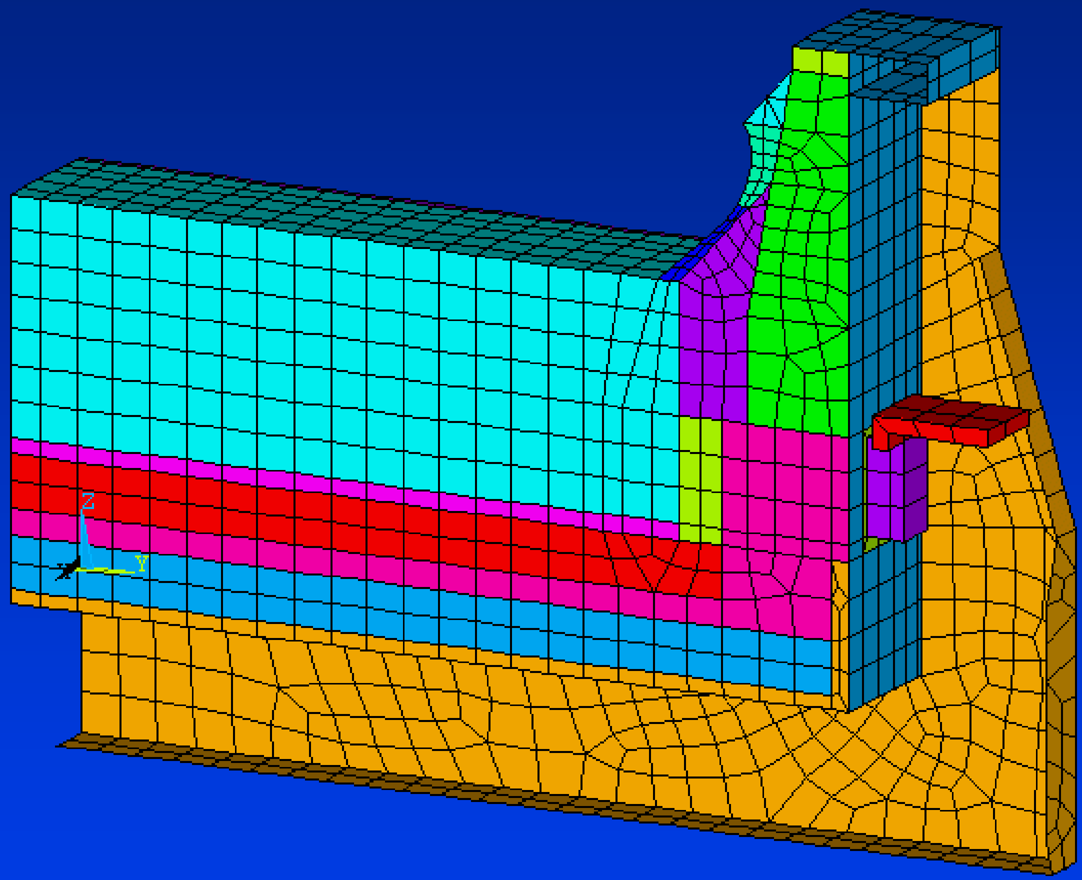
- Increase of 20% of the collector bar width from 10 to 12 cm



GENISIM

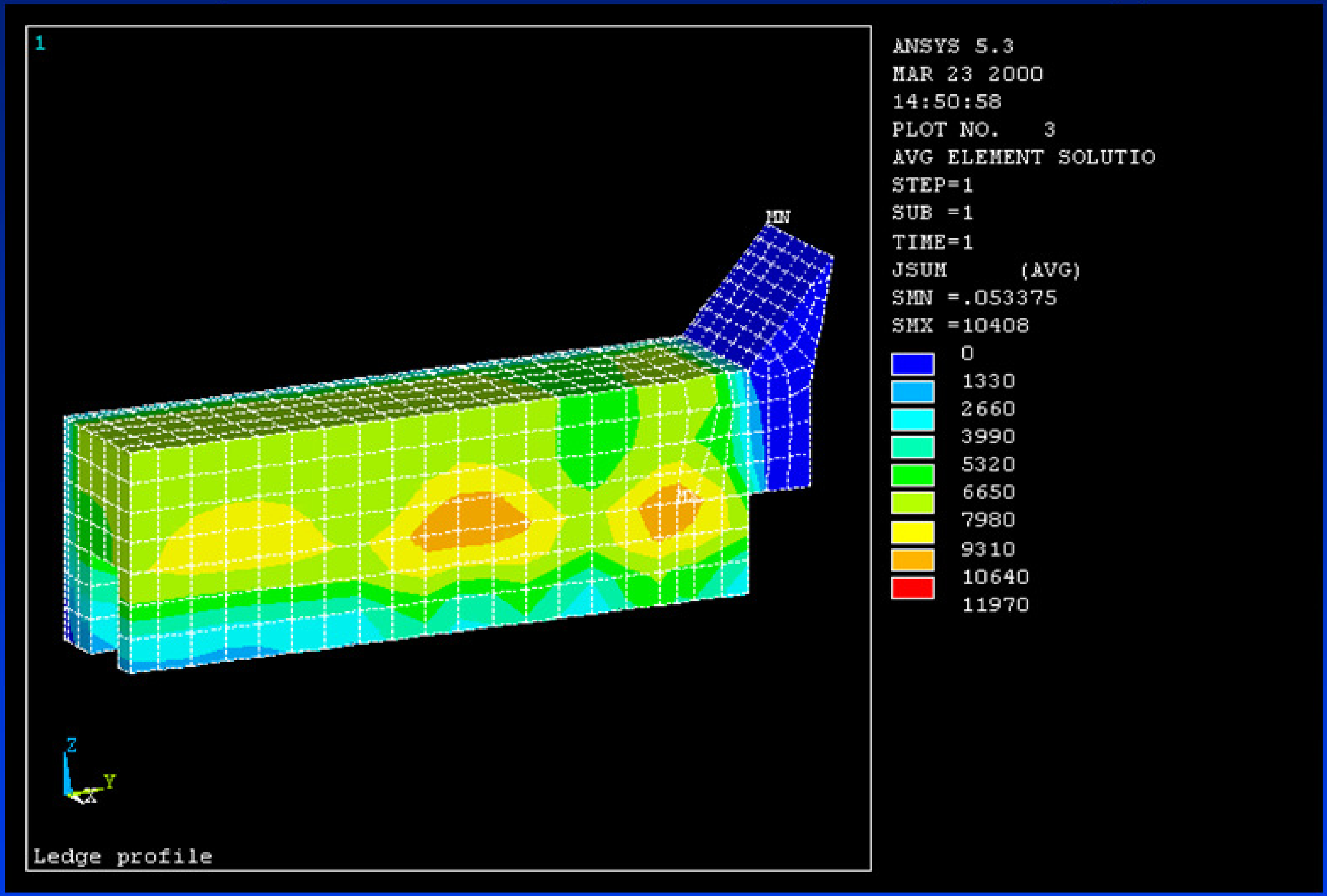
Erosion Model
Analysis of Second Retrofit Proposal

- Same changes as first proposal
  +
- Increase the collector bar height by 20% from 20 to 24 cm
- Increase of 10 cm of the block height
- Decrease the floor position by 10 cm by reducing the height of the horizontal cradles web under the pot shell floor



GENISIM

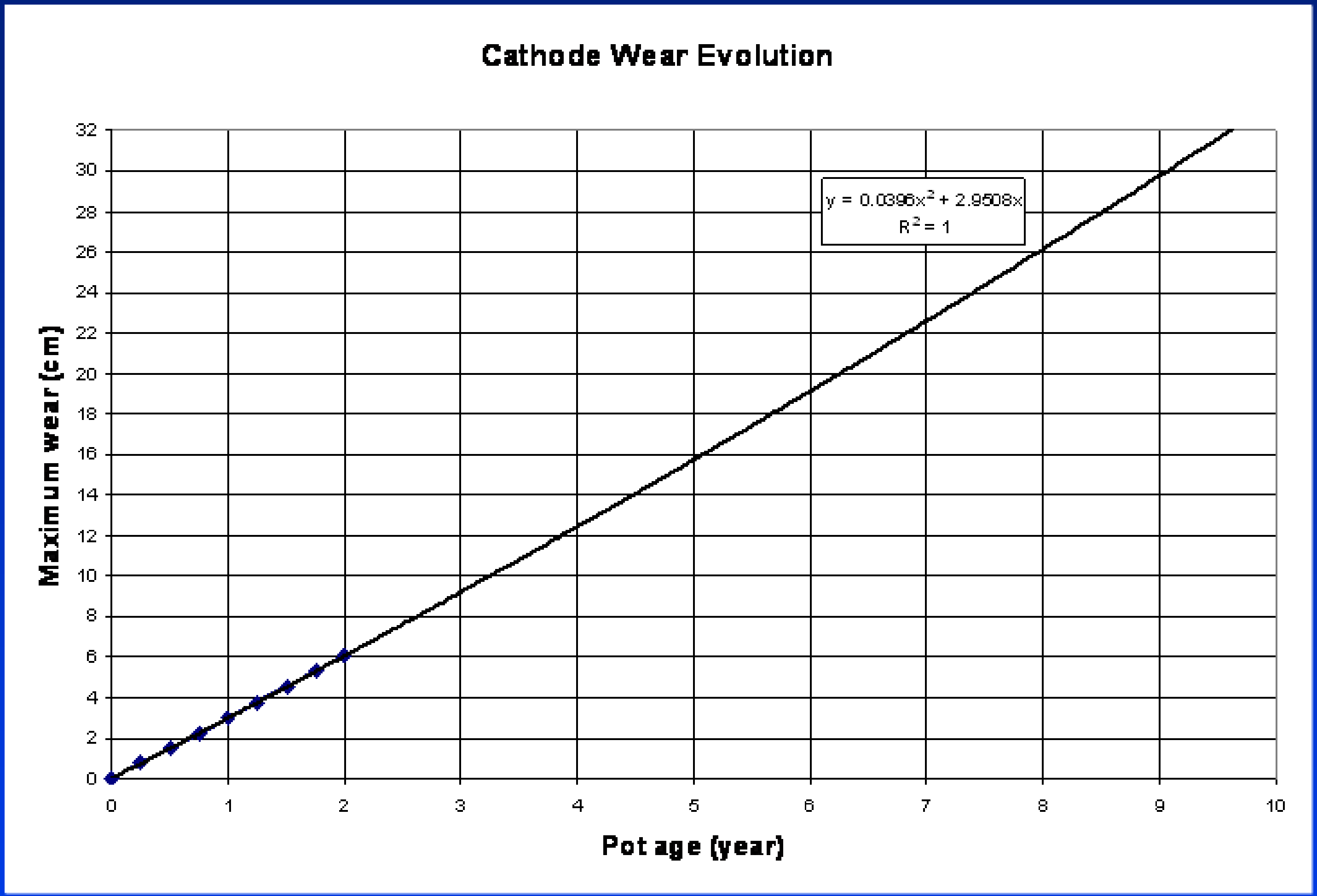
Analysis of Second Retrofit Proposal



- Erosion profile animation of the second retrofit proposal for the first 2 years

GENISIM

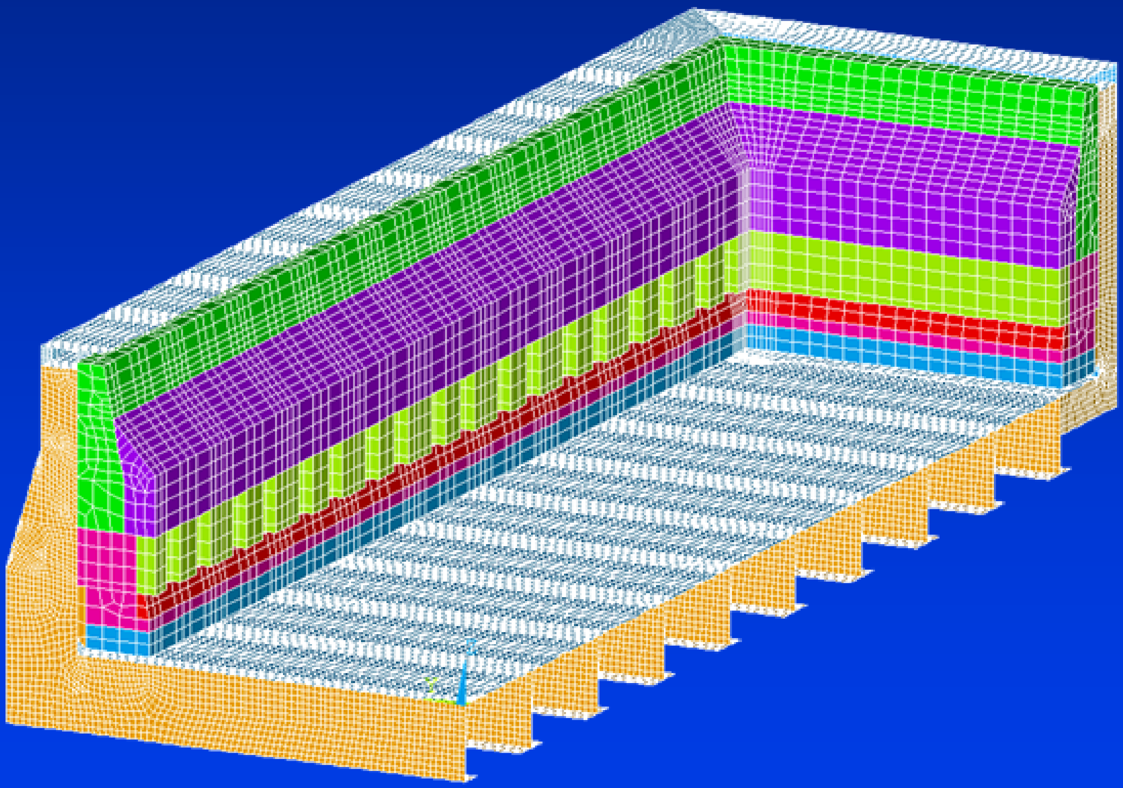
Analysis of Second Retrofit Proposal



- Evolution of the maximum erosion of the second retrofit proposal

GENISIM

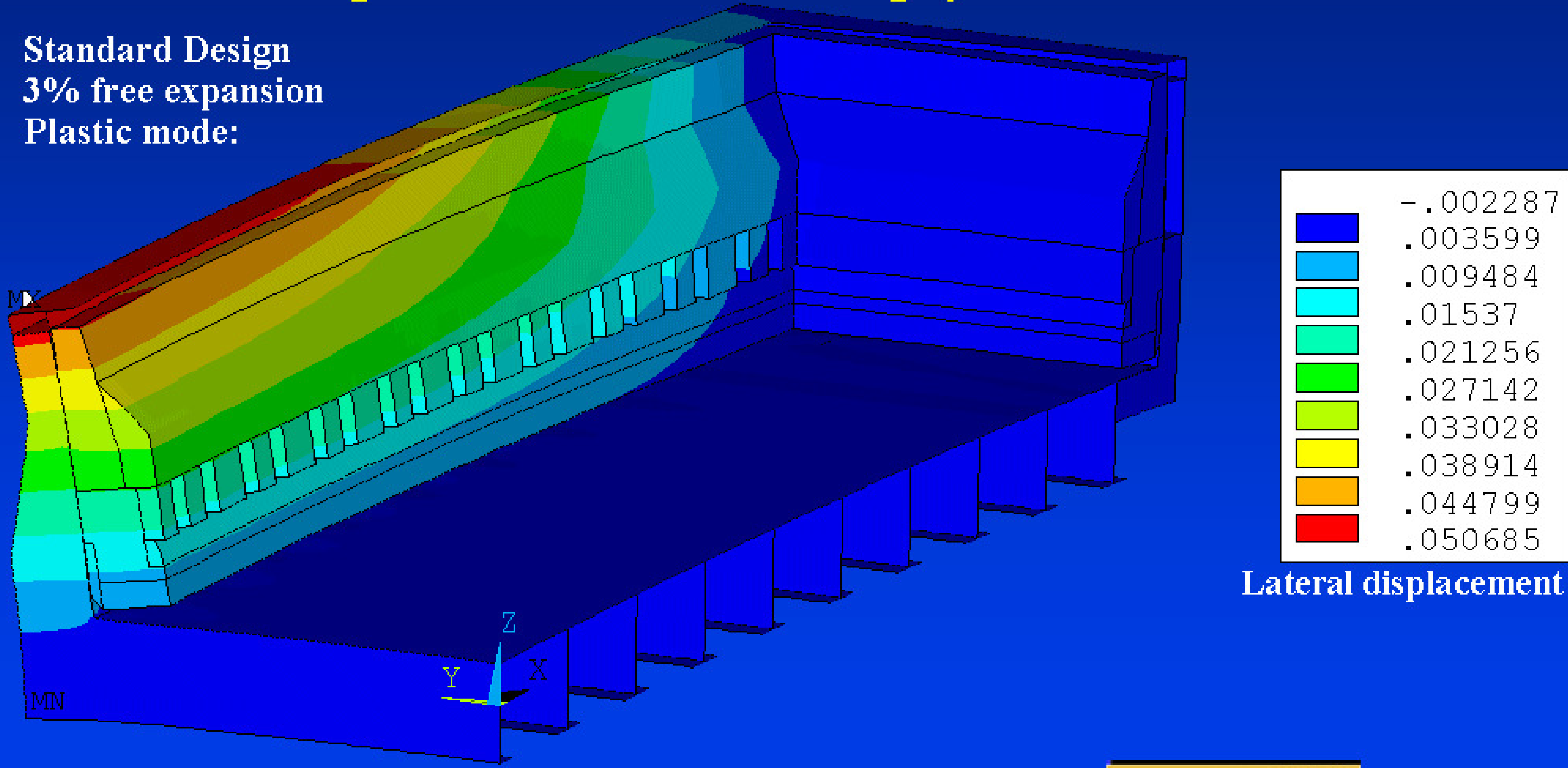
Testing a New Potshell and Lining Design Aiming at Increasing the Cell Life of High Amperage Cells using Graphitized Cathode Blocks with the Improved "Almost Empty Shell" Model



So, 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, this hypothesis can now be tested.

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

Standard Design
3% free expansion
Plastic mode:

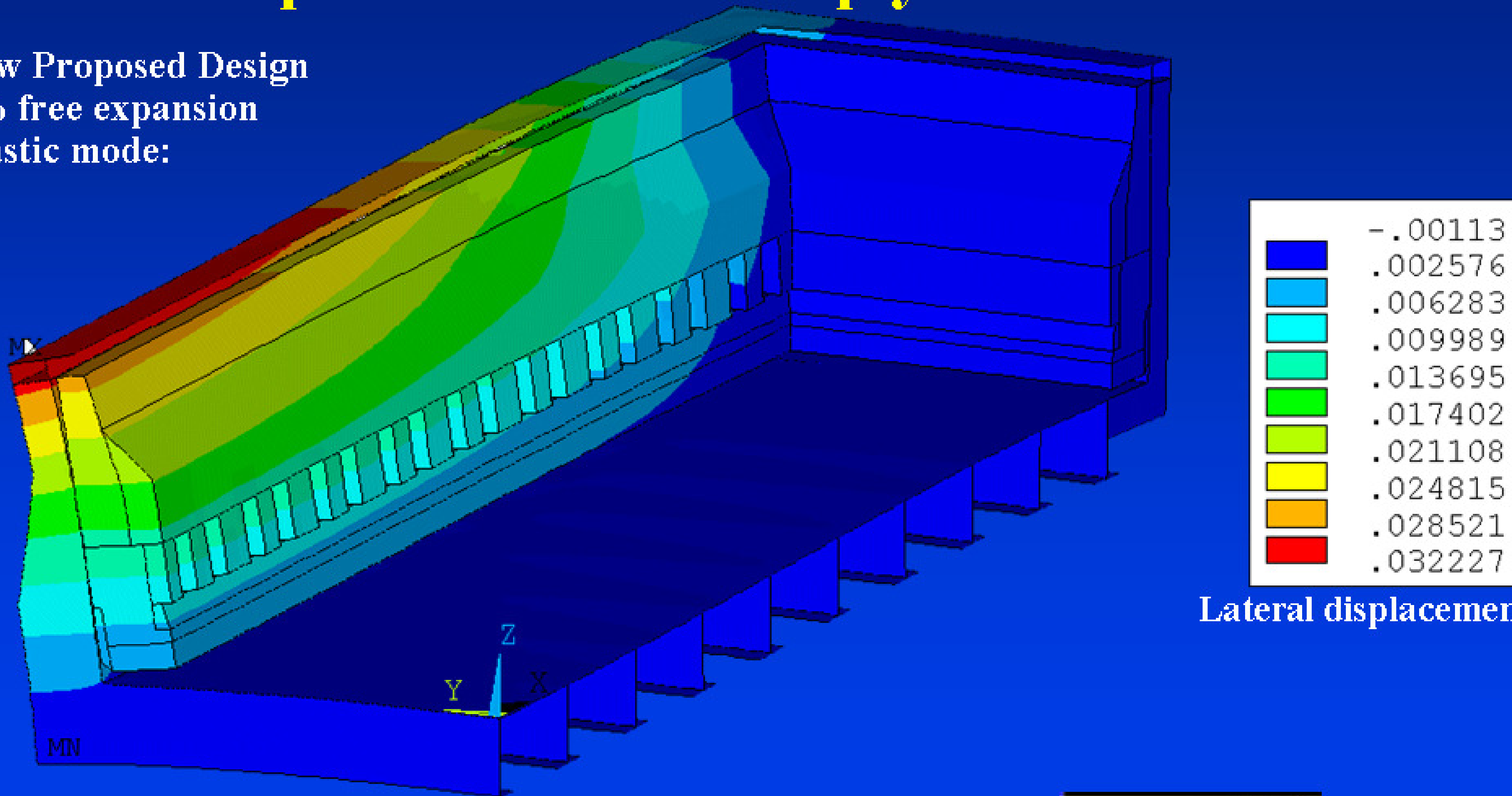


Lateral displacement (m)

GENISIM

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

New Proposed Design
1% free expansion
Plastic mode:



Lateral displacement (m)

GENISIM

"Half Empty Shell" Potshell Model

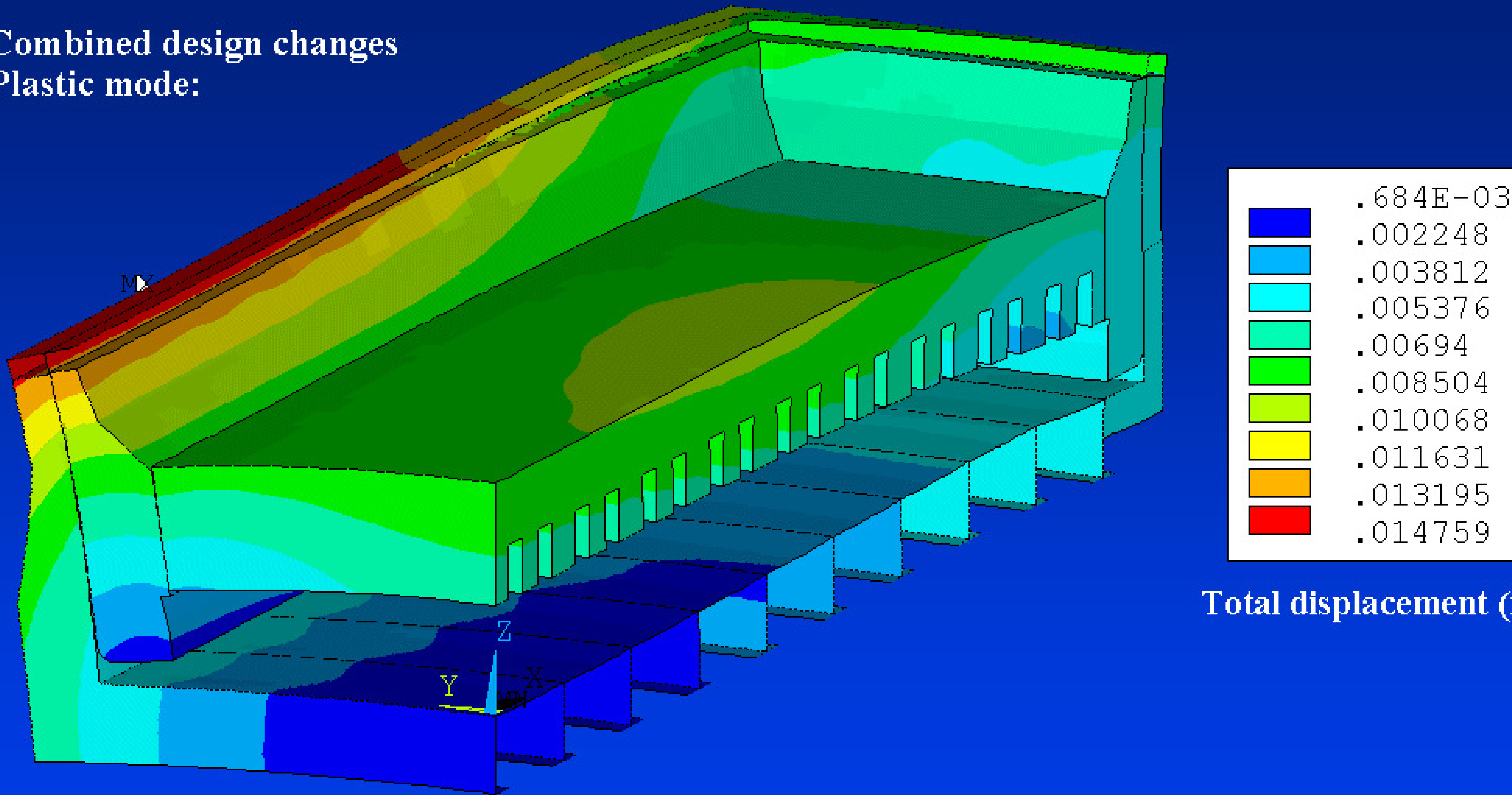
- Based on the usage of the quadrilateral Finite Strain shell element (SHELL181) in the commercial code ANSYS®.
- Temperature distribution obtained from the full cell quarter thermo-electric model applied as a body load to the entire potshell structure.
- The geometry the lining material located between the potshell walls and the cathode carbon of the cathode blocks themselves is also includes, the Dewing sodium expansion behavior of the cathode blocks is treated in ANSYS® as a "creep-like" behavior.
- Elastic mode: solving the mechanical problem only by considering only the elastic properties of the potshell steel.
- Plastic mode: solving the temperature dependent isotropic hardening von Mises plasticity behavior of the potshell steel structure using the MISO non-linear hardening option in ANSYS®.

“Improved Half Empty Shell” Potshell Model

- The “half empty shell” potshell model has been improved by decoupling the 2D potshell mesh from the 3D lining mesh and by completely refining the 2D potshell mesh.
- 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.
- 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 previous model version.

"Improved Half Empty Shell" Potshell Model

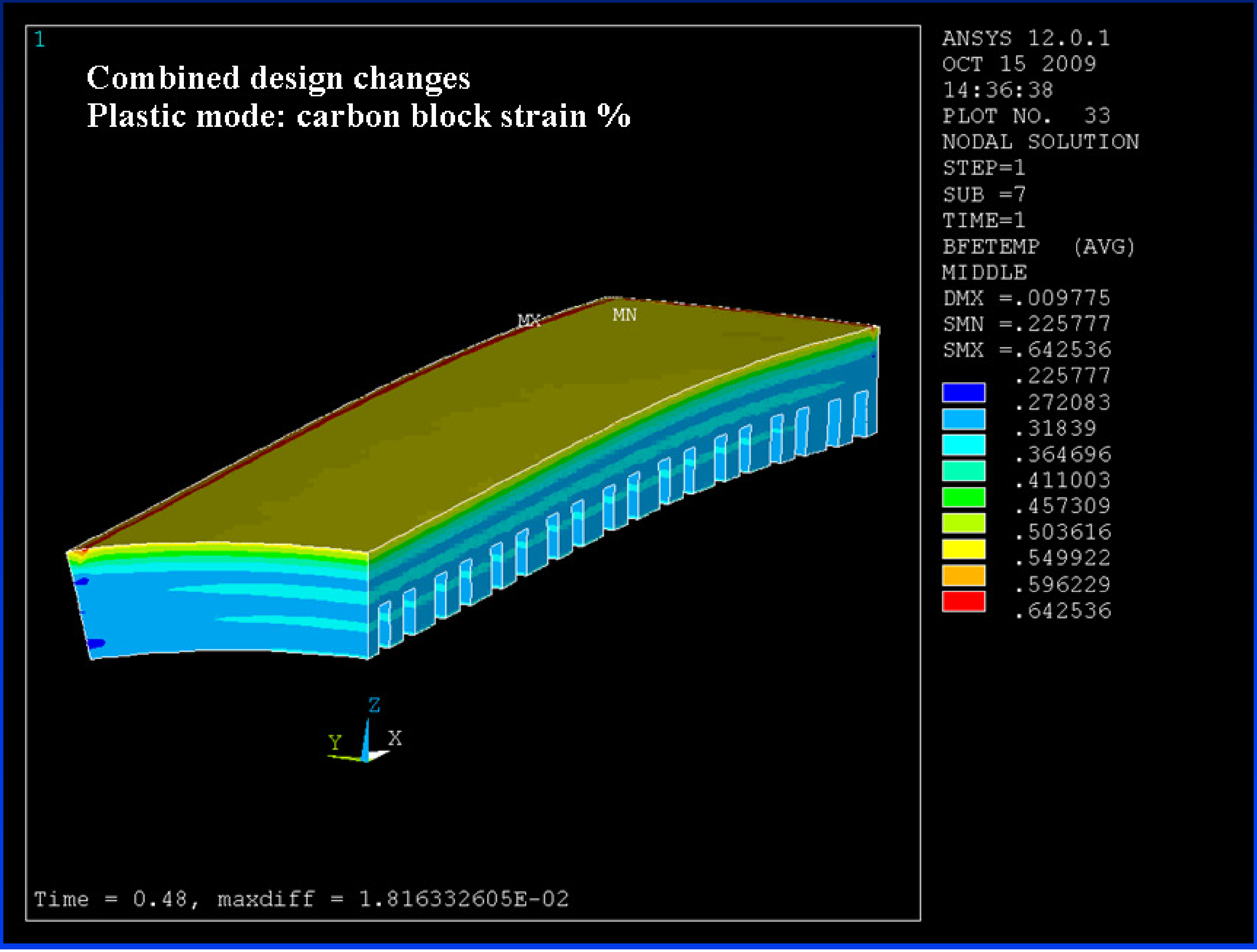
Combined design changes
Plastic mode:



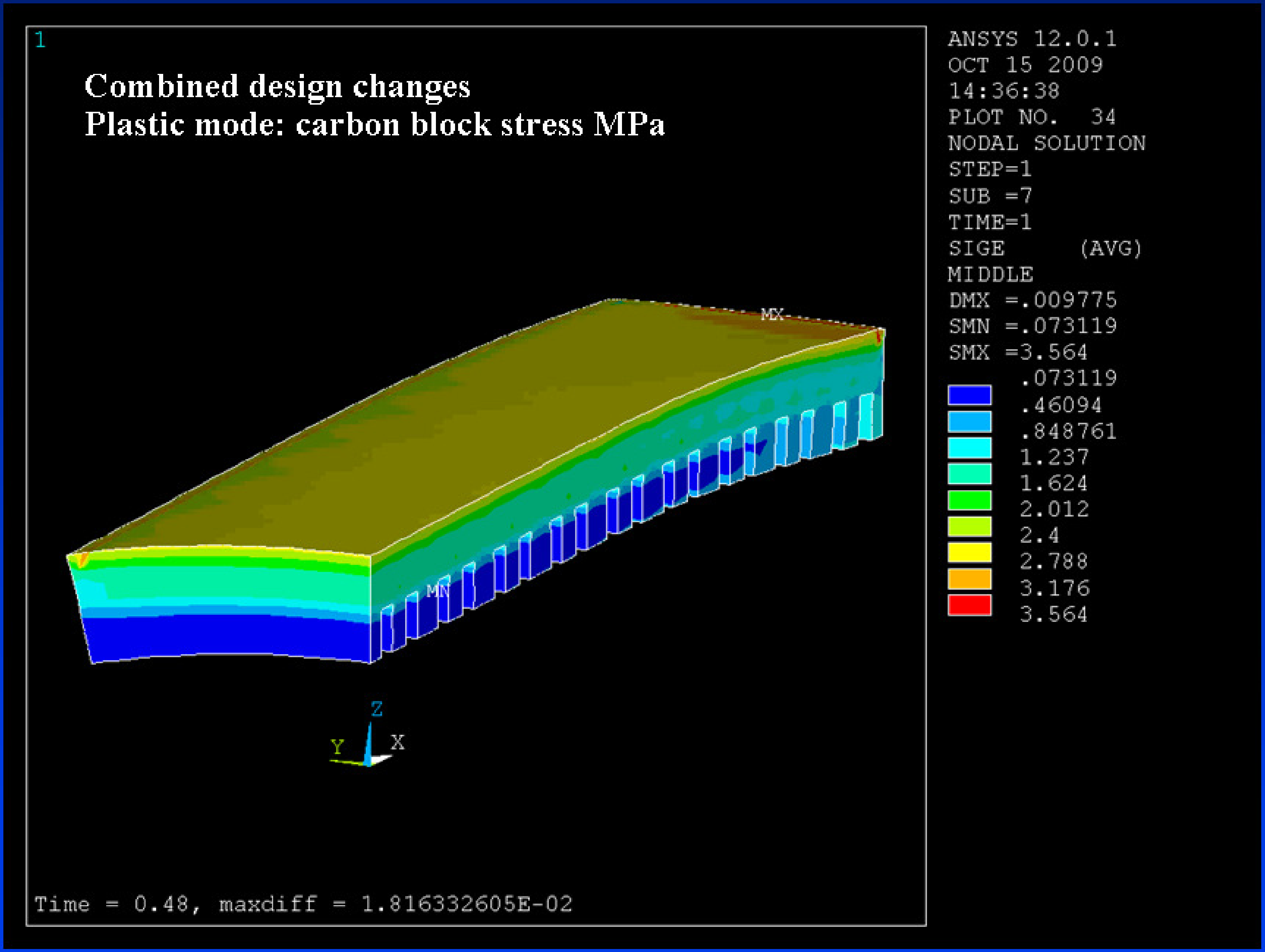
Total displacement (m)

Displacement solution due only to the temperature load.

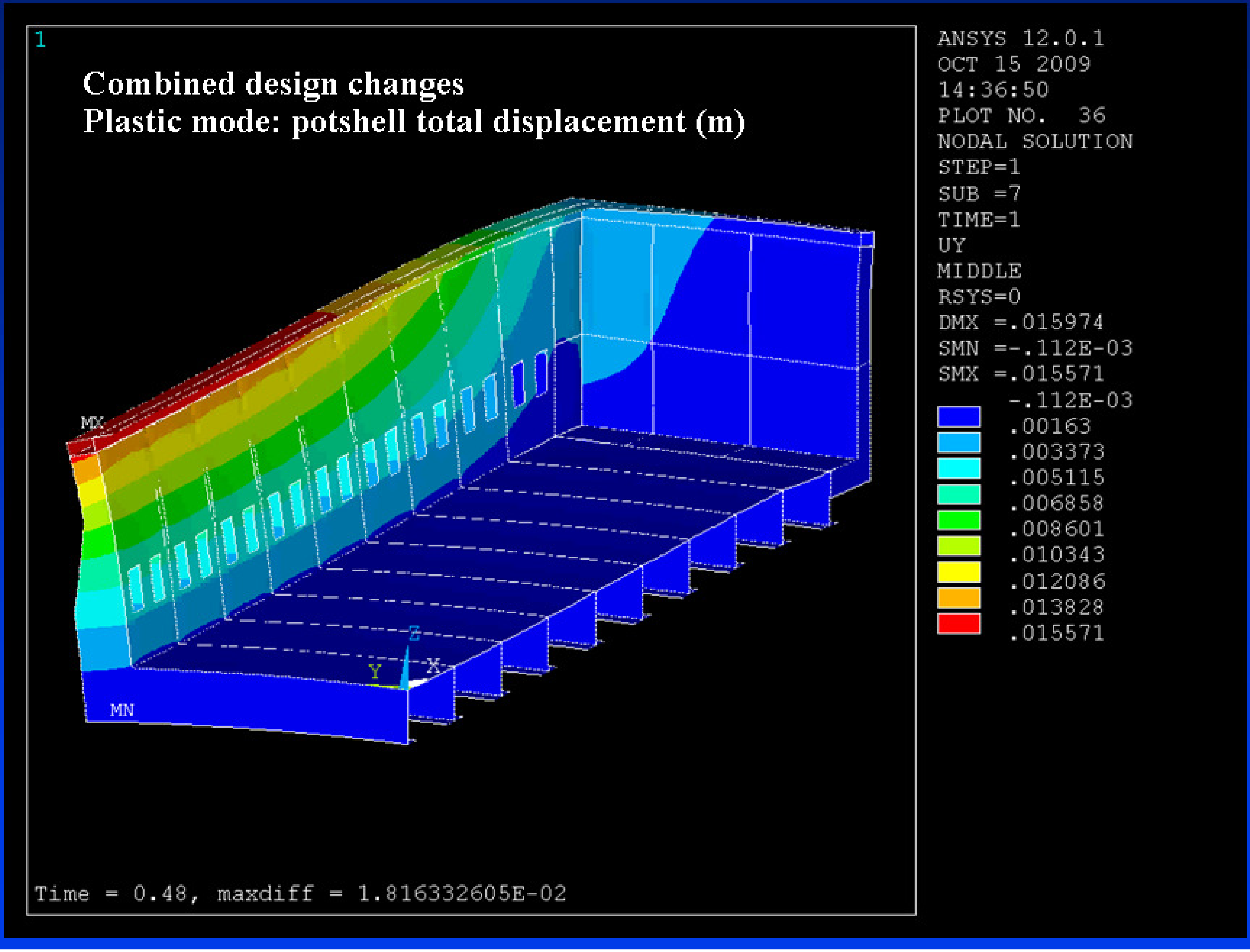
" Improved Half Empty Shell" Potshell Model



“ Improved Half Empty Shell” Potshell Model

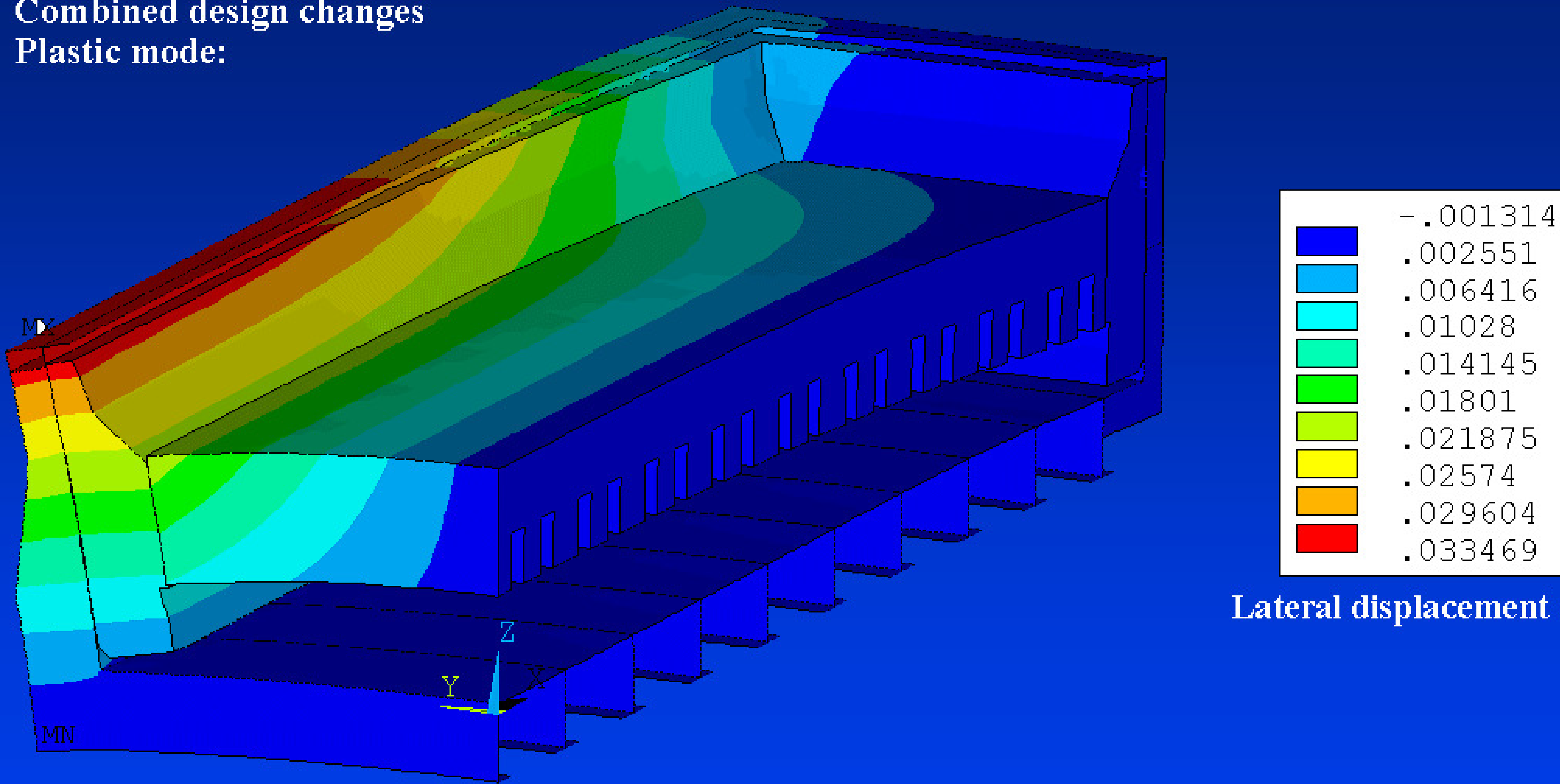


"Improved Half Empty Shell" Potshell Model



"Improved Half Empty Shell" Potshell Model

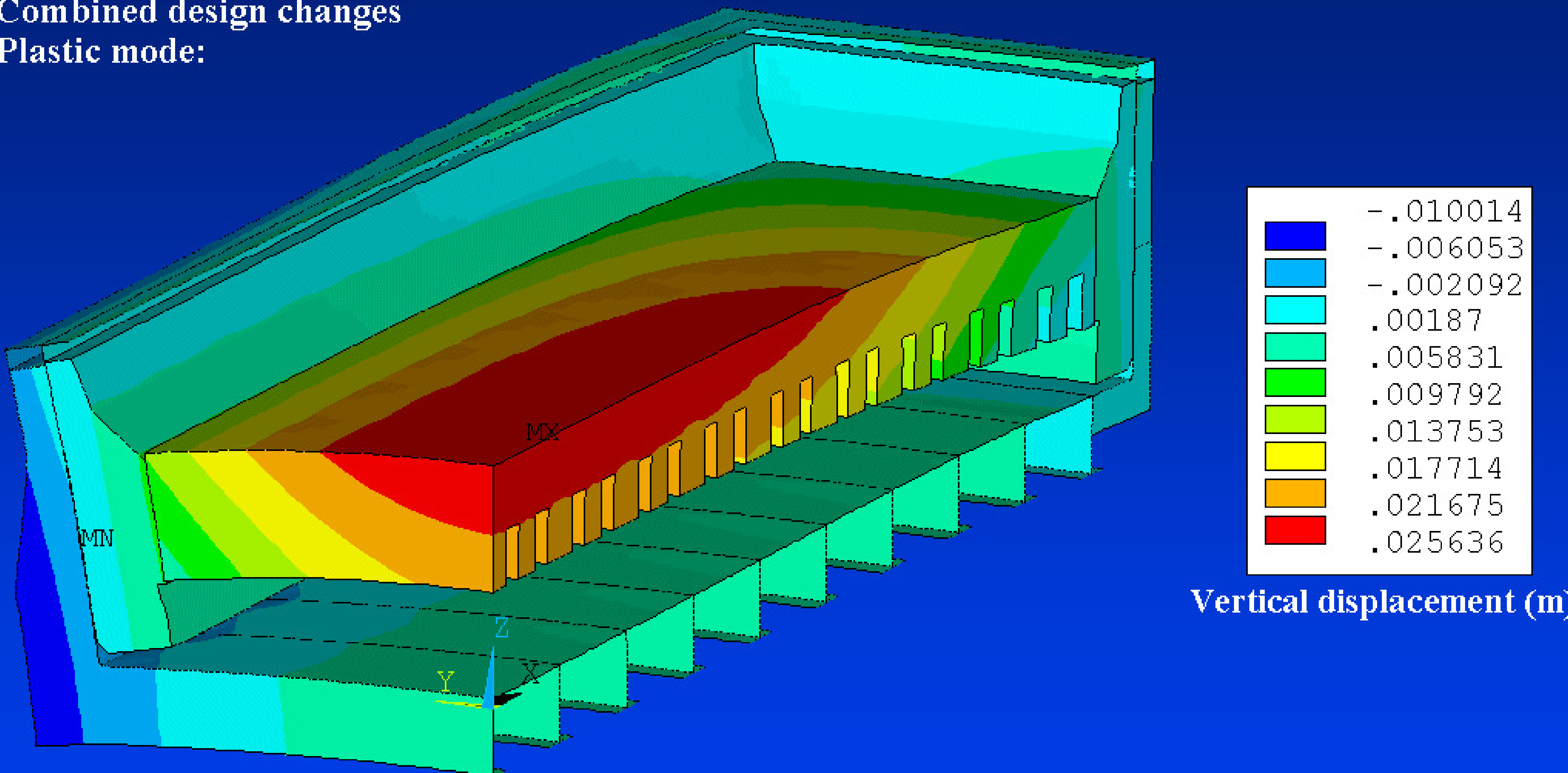
Combined design changes
Plastic mode:



Lateral displacement (m)

"Improved Half Empty Shell" Potshell Model

Combined design changes
Plastic mode:



Conclusions

- Redeveloped thermo-chimio-mechanical models presented at the 2010 TMS conference have been improved adding up to date ANSYS® contact elements technology into them.
- 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 whole aluminium industry through GeniSim Inc .

GENISIM