Swage Panel SVR Rule Development

ABS

San Diego State University

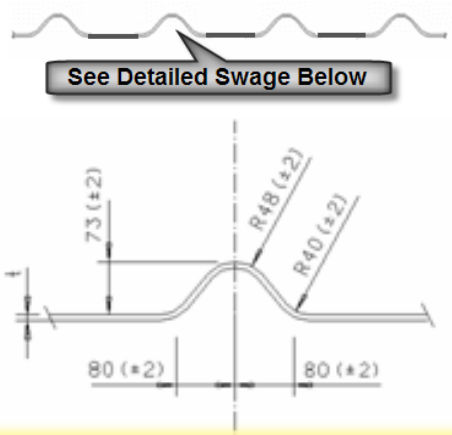
General Dynamics NASSCO

NSRP All Panel Meeting Charleston, SC
March 12, 2019

Presented by Jessica Green

Swaged Bulkhead Overview

- Plate pressed to form “bumps” at spacing similar to traditional stiffeners
- Also called swedged, pilaster, or crimped
- Reduce overall cost of ship design, construction, and life cycle maintenance
  - Reduced part count
  - Decreased welding
  - Improved paint application
  - Better paint adherence
  - Better accessibility



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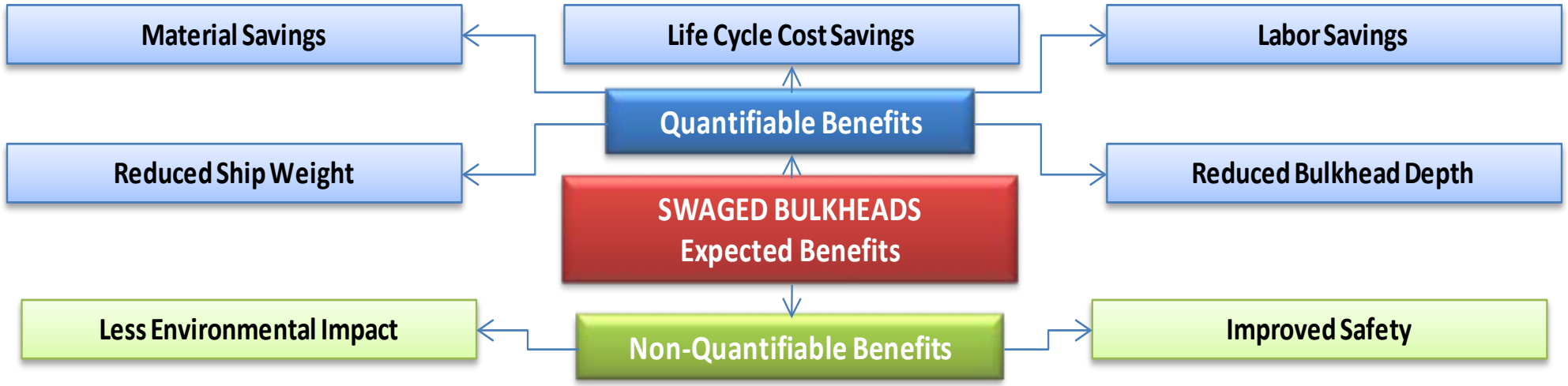
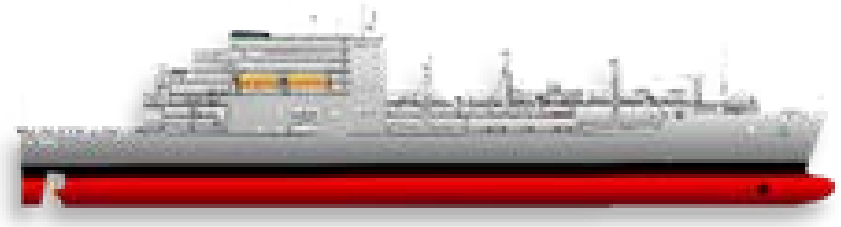
Expected Benefits of Swaged Bulkheads





- T-AKE Potential Cost Savings
- Total Savings of over $2.0 million
- Reduction in material costs close to $1.0 million
- Reduction in labor hours of +25,000
- Reduction in ship weight by close to 80 MT (per ship)

Past Study of Swage Technology

2005 Study of Swage Applicability on T-AKE:

Study focused on the application of swage panels in the deckhouse of T-AKE, limited to non-load bearing locations. Concluded that further investigation was needed to assess the potential application of swaged concept to structural bulkheads.

2010 Swage Panel Analysis Verification (NSRP Panel Project 2010-611):

Study validated the ability to obtain analytical results for swaged and traditionally stiffened bulkhead configurations under various load profiles, and compare those results to physical model tests.

2011 -2014 Swage Bulkhead Analysis Verification (NSRP Research Announcement 2011-459):

Phase I	Examined swage compared with traditional T and bulb stiffeners; compared steel and aluminum (partnered with MMC), as well as manufacturing cost comparison study.
Phase II	Examined effects of variation in swage geometry, plate thickness, and steel grade.
Phase III	Examined effect of real-world outfitting problems: bulkhead cutouts, penetrations, and additional attachments (large electrical panel for example).

Past Study of Swage Technology

2016 Qualification of Alternative Structures (2005-333)

Panel Project completed in 2016 with a goal to work towards the incorporation of swage panels into combatant vessels in order to reduce their overall construction and life-cycle cost.

This project laid the groundwork for swage panels to be used in combatant applications.

NASSCO worked with the Navy Technical Warrant Holders to complete this Plan for Structural Validation of Swage Panels on Combatants.

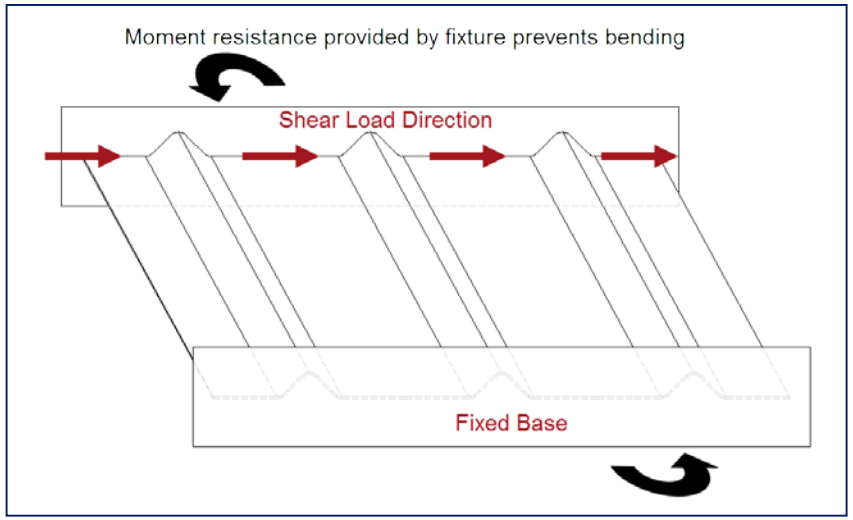
Proposed Test Matrix, including: Fatigue, shock, in-plane, out-of-plane, and combined loading

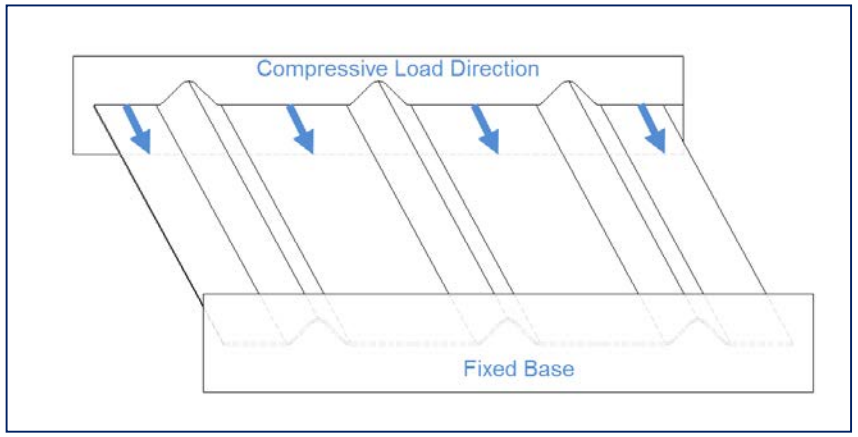
Structural Calculations and Finite Element Analyses

Swage Panel SVR Rule Development

RA 2015-402

- Project Objective: Create design guidance specific to the use of swage panels in load bearing applications that will be incorporated into the ABS SVR similar to what is found for traditionally stiffened structure in ABS SVR 3-2-11.
- Test specimens built at GD NASSCO were tested at SDSU Structures Lab in shear and compression loads.
- Test results were compared to non-linear FEA results to verify that swaged bulkheads show same or greater strength as traditionally stiffened bulkhead of similar section modulus.



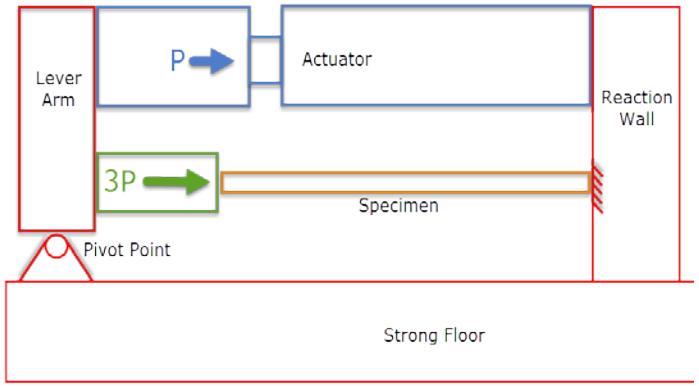


Integration of Outfitting and Structural Details on Swaged Bulkheads (2018-444)

- How do swaged bulkheads connect to other structure?
- How is outfitting incorporated into swaged bulkheads?
- Find out more at Nick Ratinaud's presentation on this project tomorrow at 2:30!

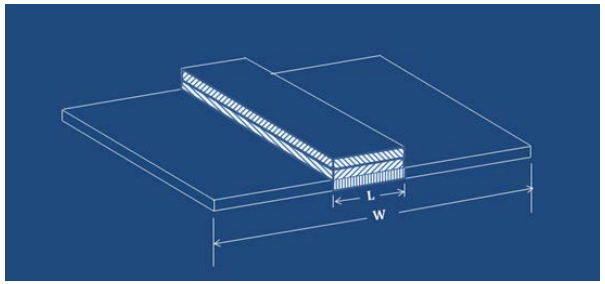
Testing and Finite Element Analysis

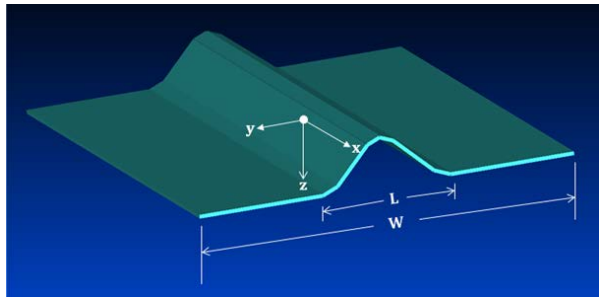
- Swage panel physical testing in compression and shear load directions at SDSU Structures Lab
- Load application technique and analysis based on lessons learned from previous studies
- Text Fixture designed, built, and then commissioned at San Diego State University Structural Lab in Phase I
- Test results verify non-linear FEA (Femap/NASTRAN)

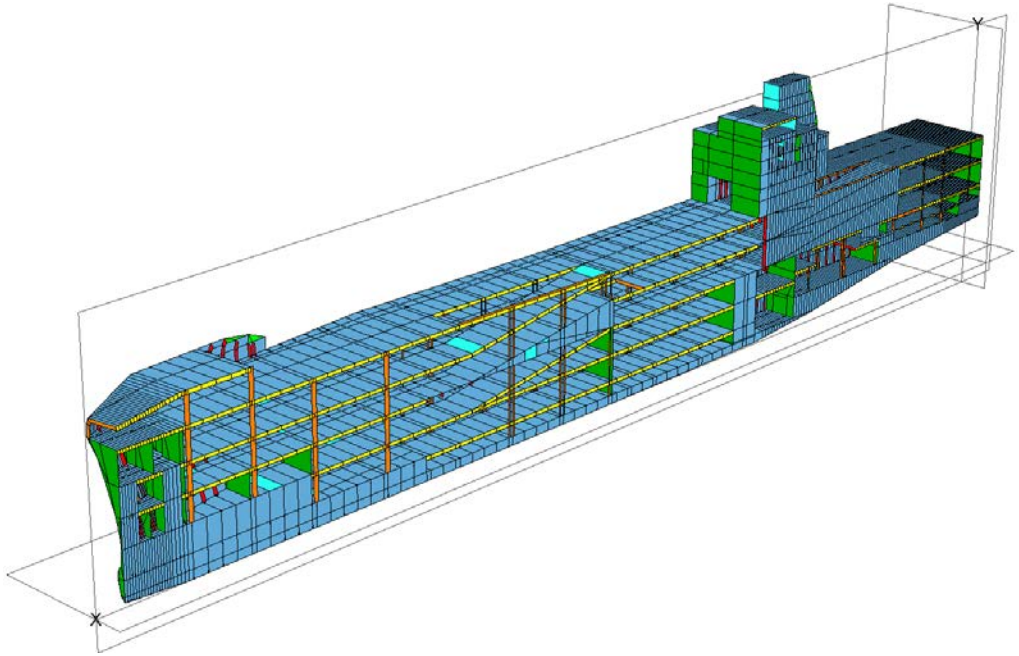


Swage Panel SVR Rule Development

- Global FEA (MAESTRO) performed to substitute swage equivalent properties for traditionally stiffened bulkheads
- Composite layered method representative of swage properties







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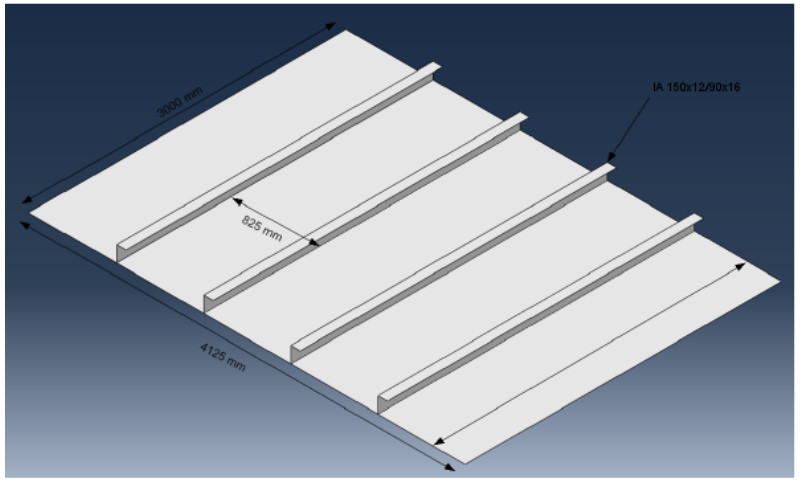
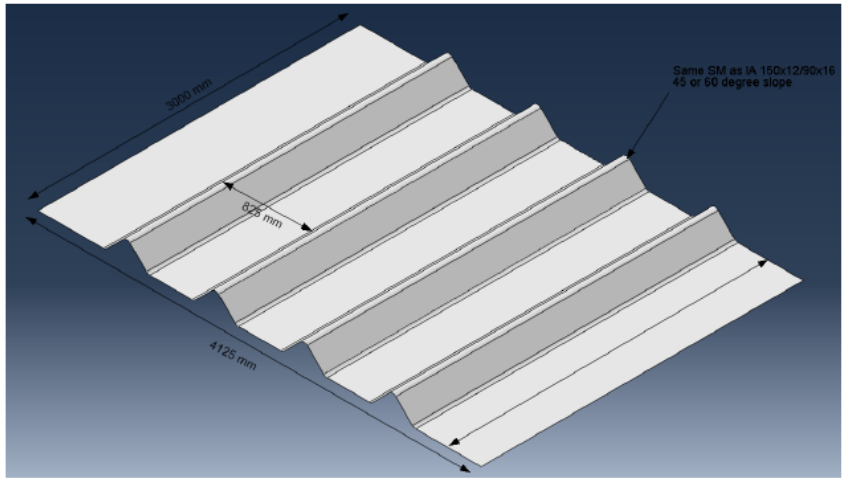
ABS Assessment

- A structural analysis using NLFEA has been performed to compare the behavior of swage panels to the behavior of the regular panels with the same plate thickness and section modulus of the swages/stiffeners with the attached plating.
- A panel in the first tier of the front exposed superstructure bulkhead on an existing tanker has been selected for the analysis.
- Various load cases have been investigated, trying to mimic the realistic loading situations the superstructure panel will be subjected to in reality.
- Two different swage angles (45 and 60 degrees) have been investigated.
- Five different connection types have been investigated for connections between the swages and deck stiffeners for non tight swage bulkheads.
- Force-displacement curves have been generated for each simulation.

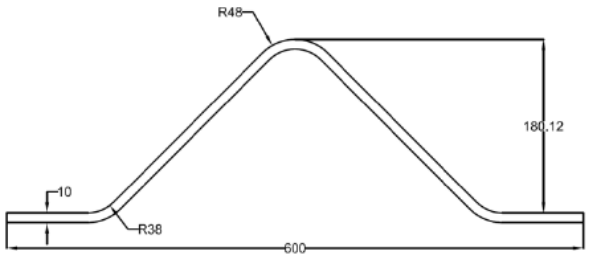
Panel Dimensions



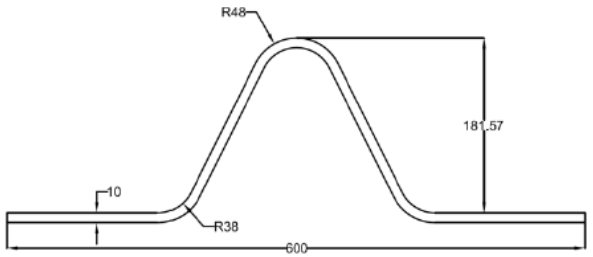


	SM [cm³]	t_p [mm]
IA 150x12/90x16	254.366	10
Swage 45 deg	254.229	10
Swage 60 deg	254.464	10

45 deg



60 deg



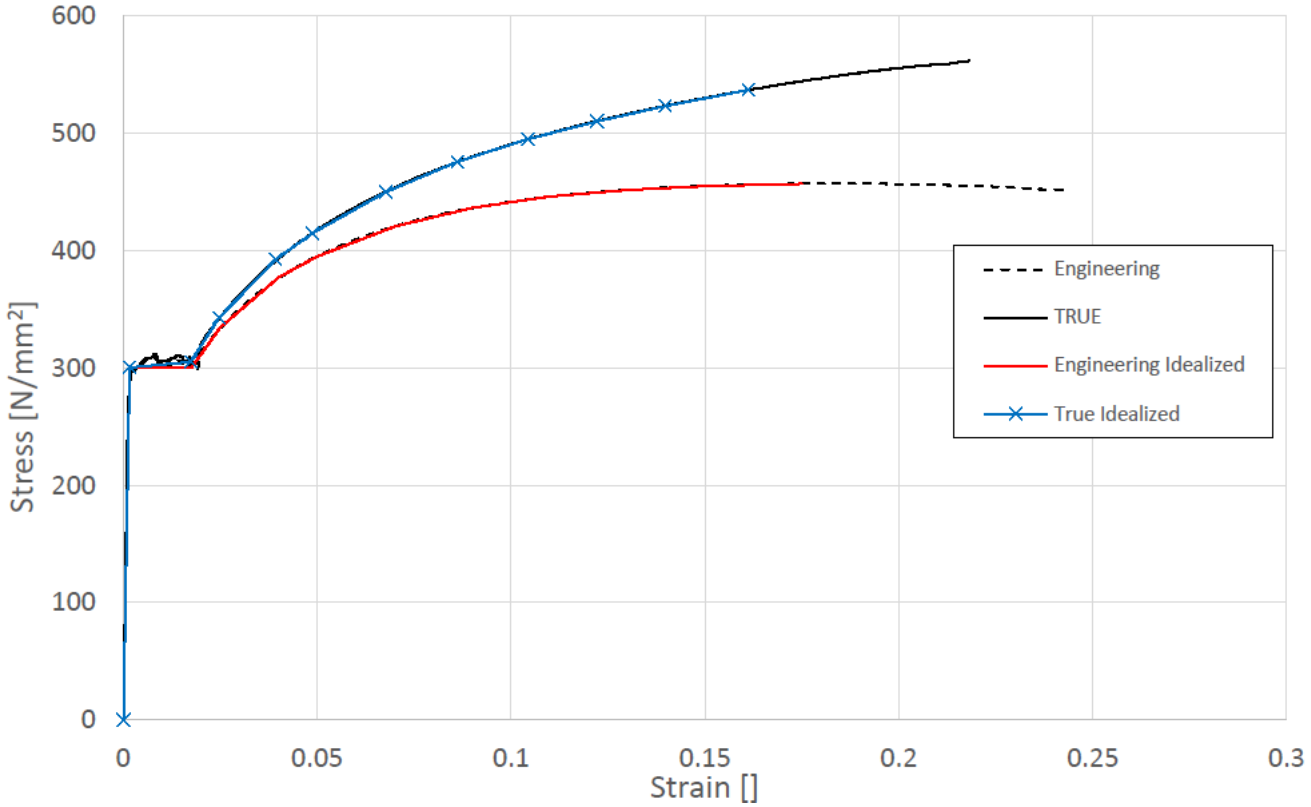
An iterative procedure was required to match the SM of swages with the SM of IA 150x12/90x16.

Non Linear FEA

- Implicit dynamic quasi-static analysis has been used.
- Loads have been applied using a smooth step function over a period of 100 seconds.
- Inverse mass scaling has been applied to minimize the inertial effects.
- Quasi-static condition has been achieved with a ratio of kinetic to internal energies well below 0.01% (limit is 1% to 5%).
- Only S4 full integration quadrilateral shell elements have been used.
- Mesh size was 25 mm.
- Full Newton-Raphson algorithm has been used.

Material Model

The material is mild steel with the stress-strain curve from experimental testing at SDSU.



Loads and Boundary Conditions

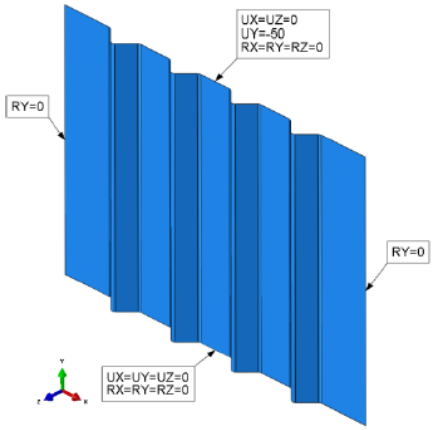
The following loads have been applied to swage panels:

- Compression along the swages (Y - direction);
- Compression perpendicular to the swages (X - direction);
- Shear (X - direction);
- Pure pressure equal to 10 x design head applied alternately to both sides of the panel.
- Combined compression along the swages, pressure 1 x design head, and shear displacement approximately equal to 50% of the shear displacement that causes first yielding.
- Racking at the top of the panel in +ve and –ve Z – directions.
- Torsion at the top.

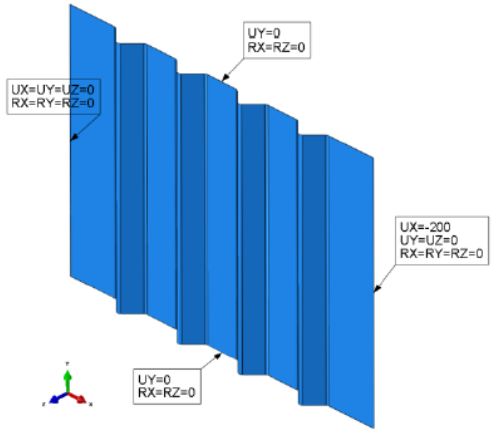
The same loads have been applied to 45 and 60 degree swage panels, as well as to the regular stiffened panels. The pressure on regular panels has only been applied from the outside (flat plate side).

Loads and Boundary Conditions Con't

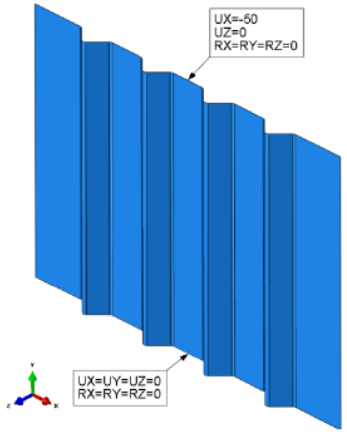
Compression Y



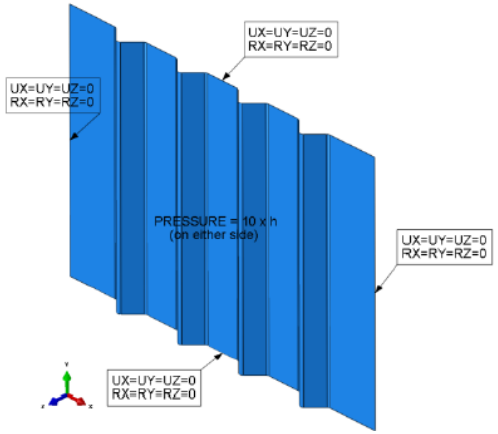
Compression X



Shear

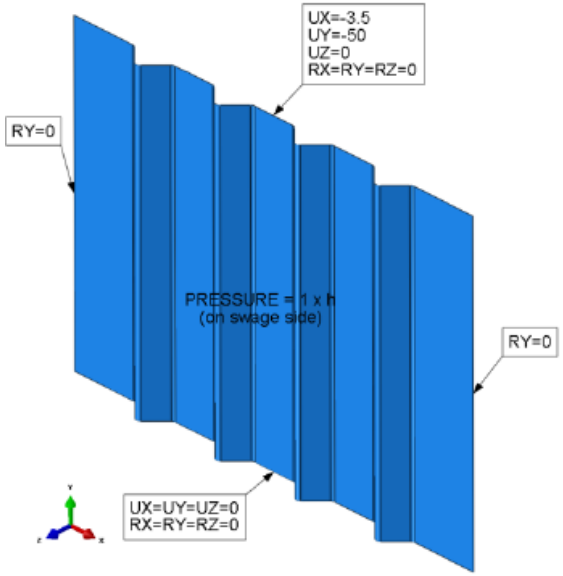


Pure Lateral Pressure

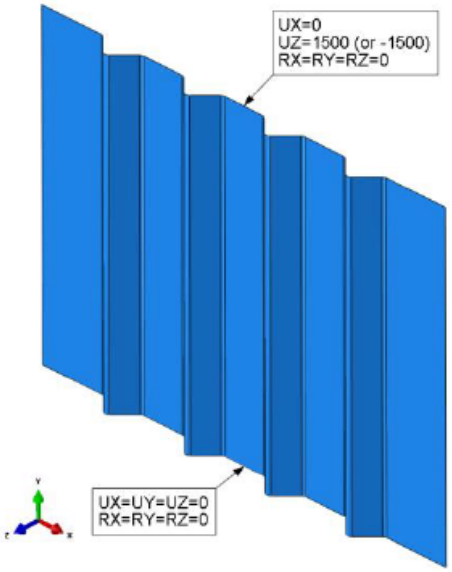


Loads and Boundary Conditions Con't

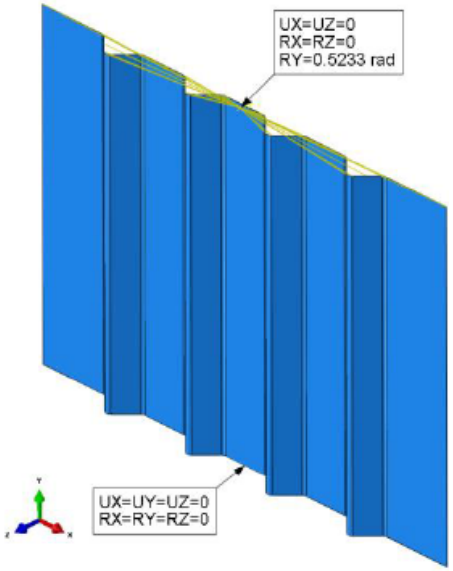
Combined Loading



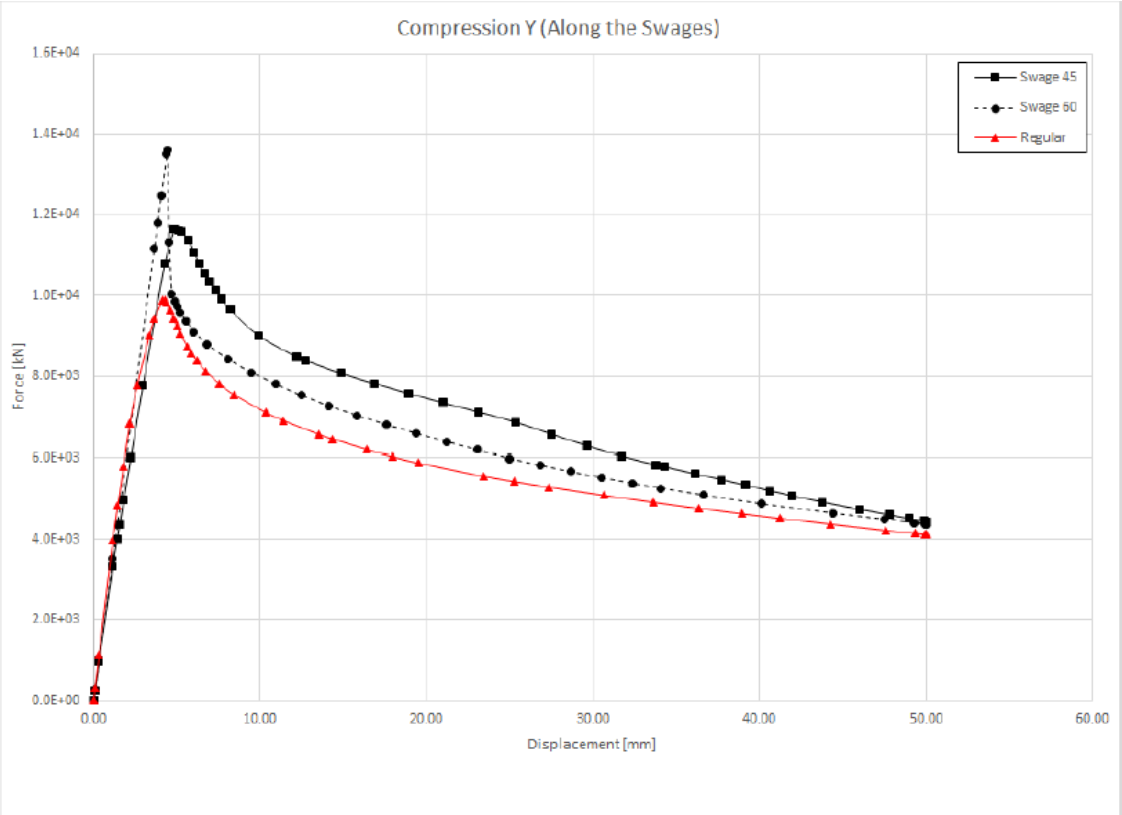
Racking in ±Z Direction

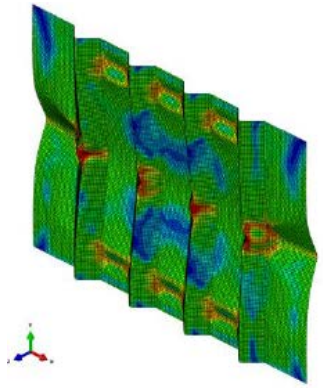


Torsion

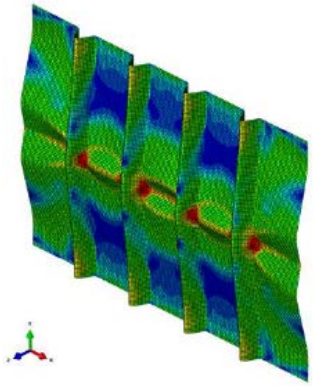


Results – Compression Y

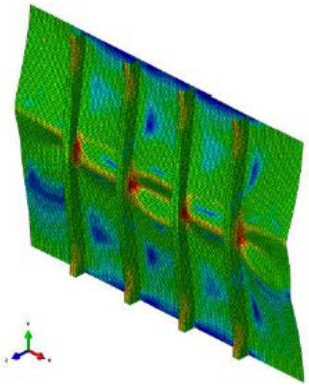




Swage 45

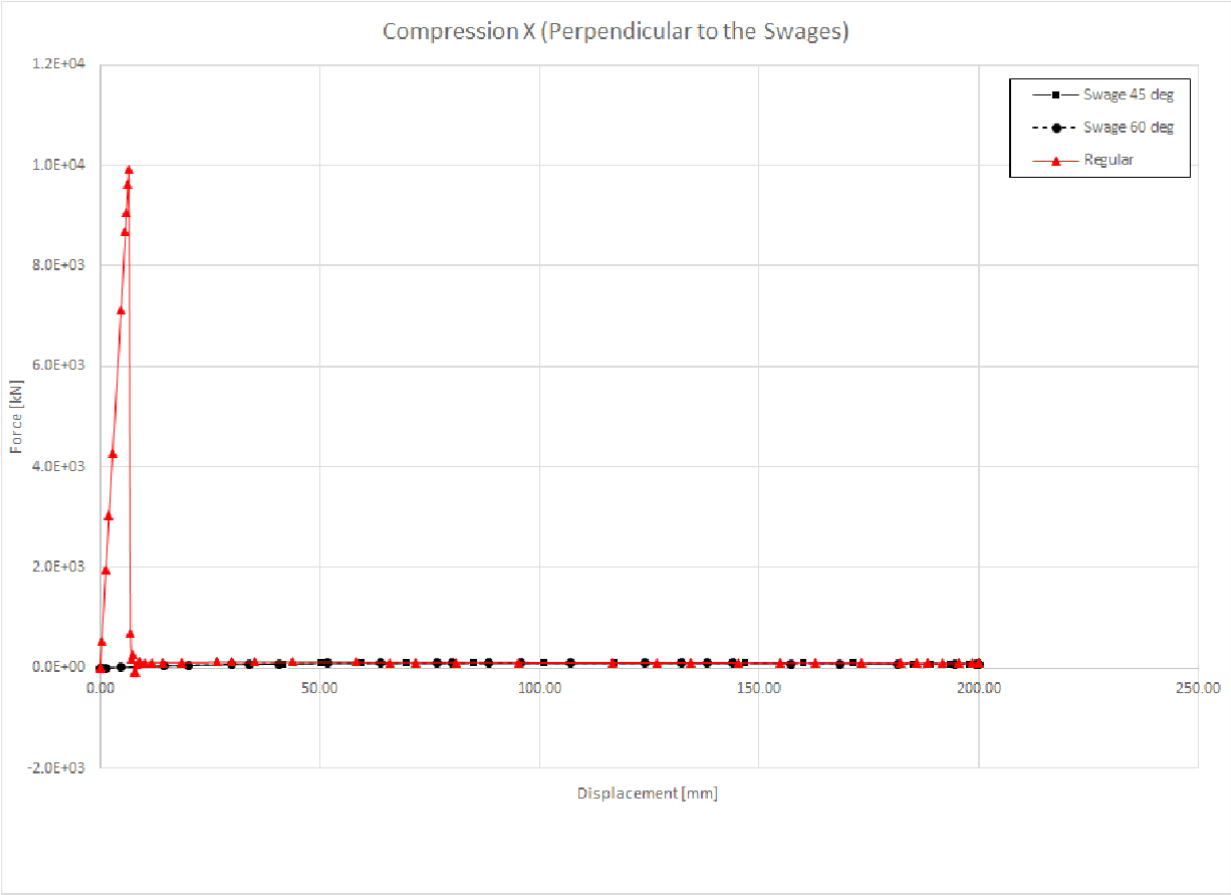


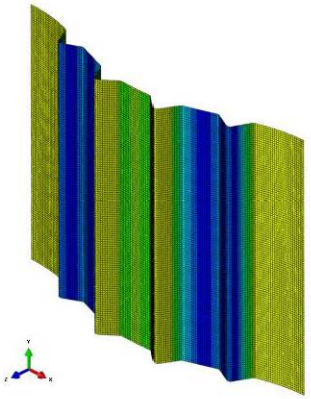
Swage 60



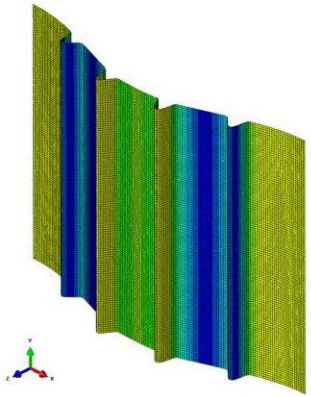
Regular

Results- Compression X

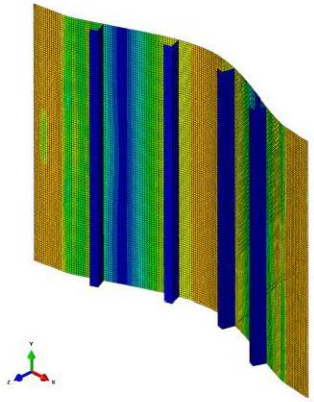




Swage 45



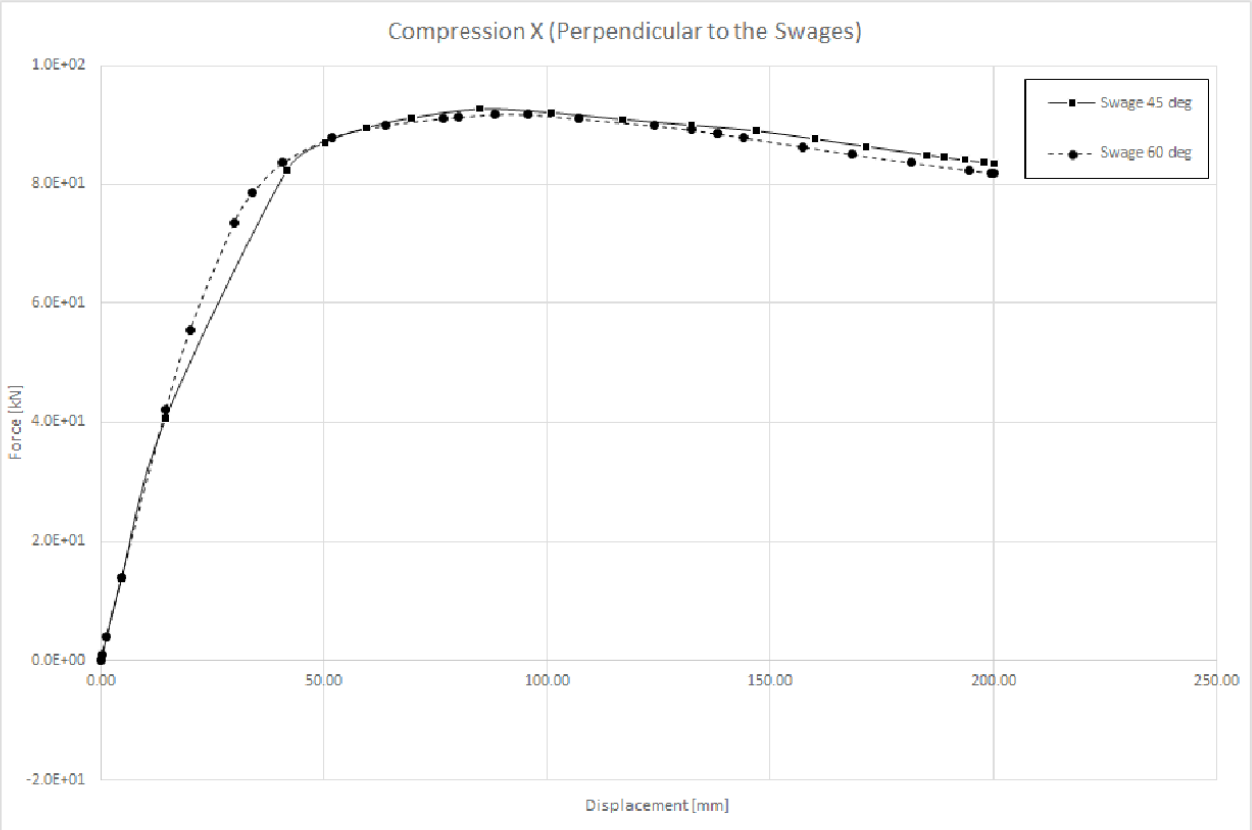
Swage 60



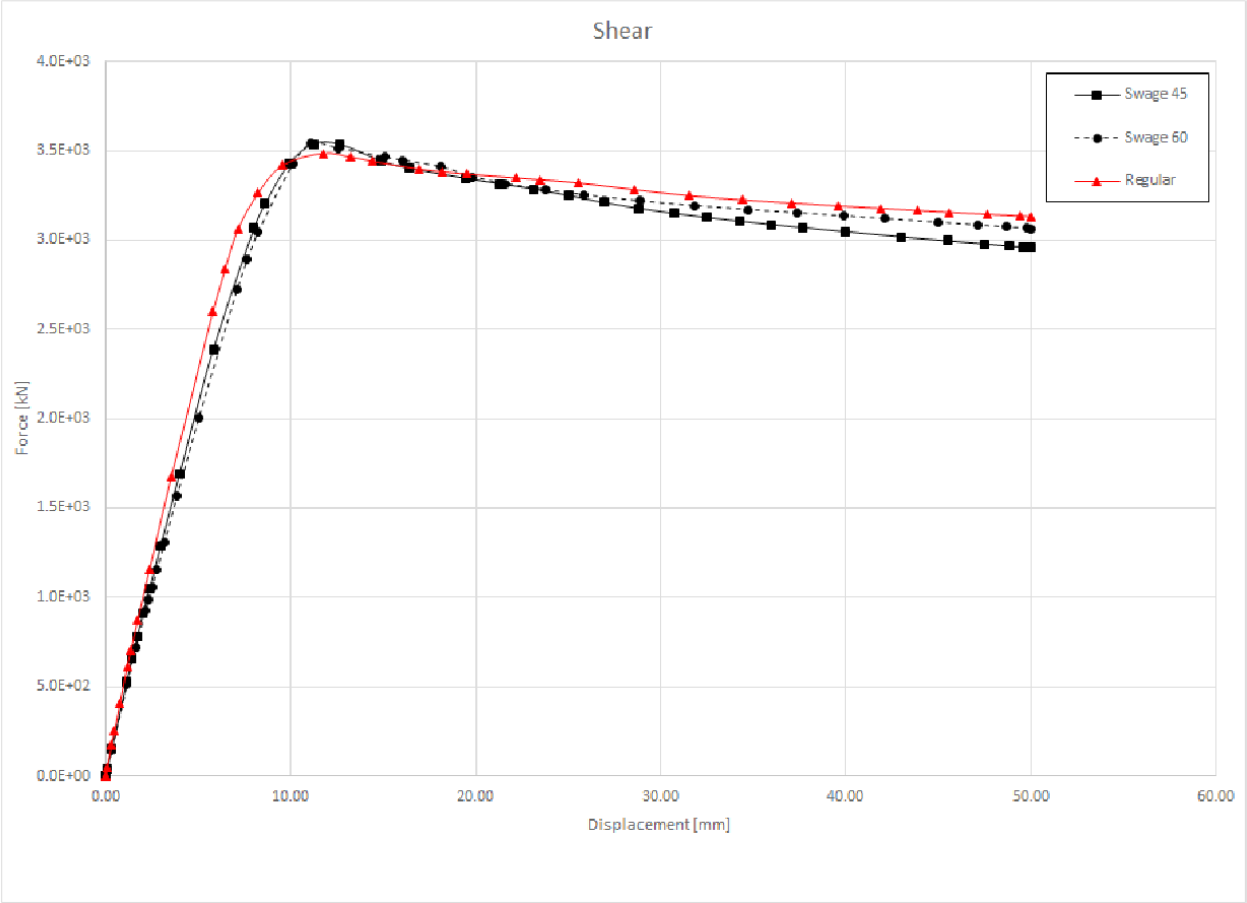
Regular

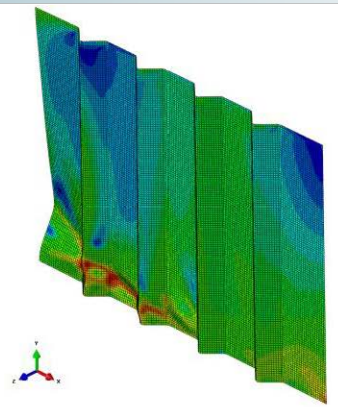
Results Compression X Con't

- Swage panels have virtually no resistance to the compressive loads perpendicular to the swages if the top and bottom edges are free to move. However, in reality, decks will provide resistance to compressive loads.

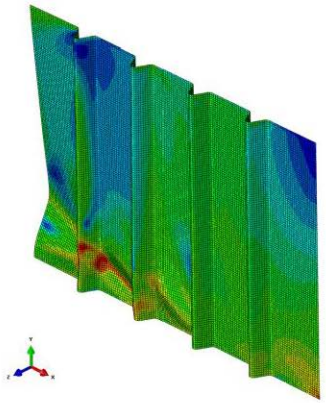


Results - Shear

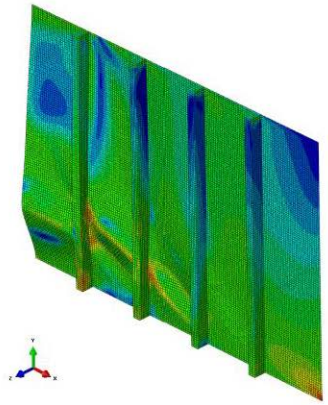




Swage 45

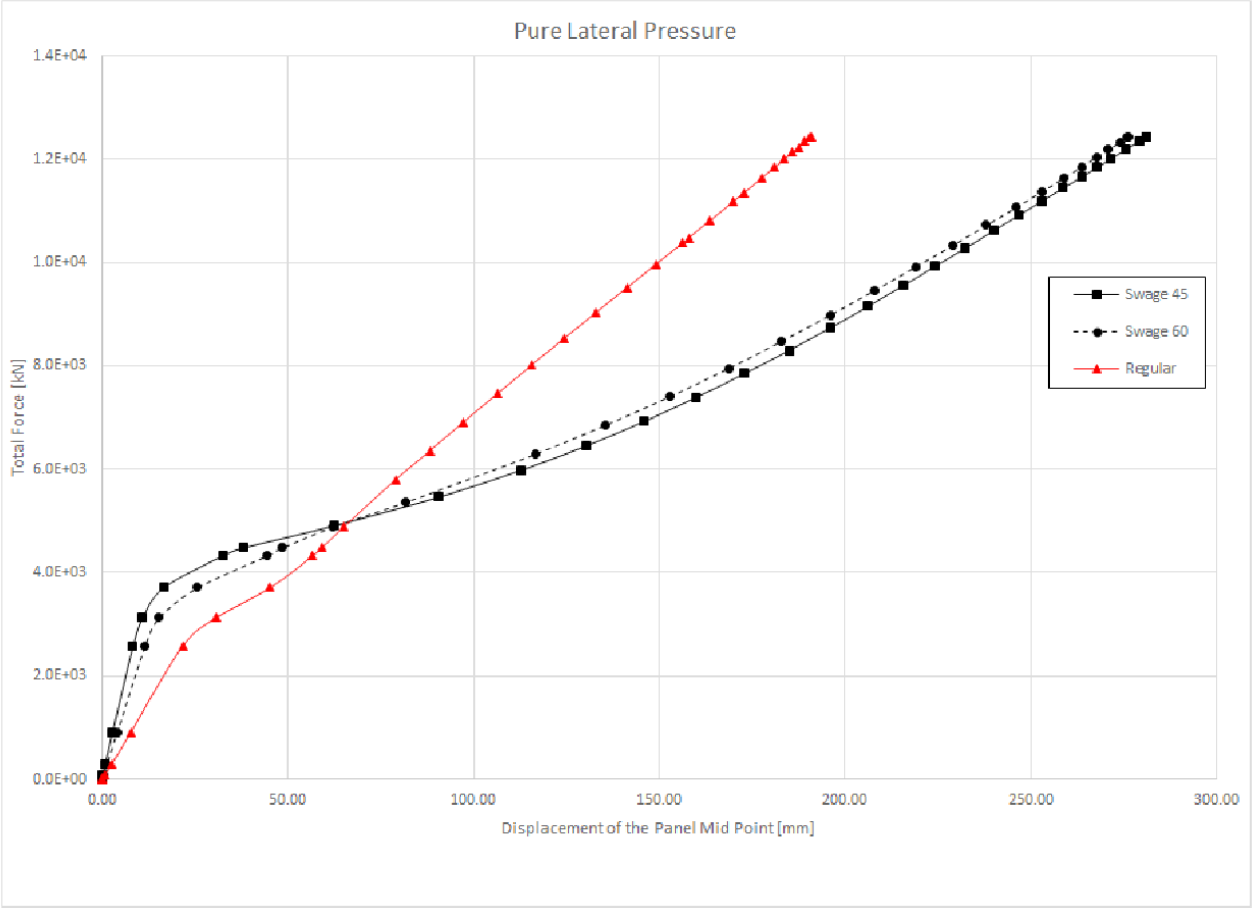


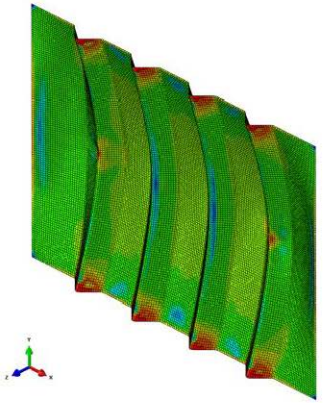
Swage 60



Regular

Results – Pure Pressure





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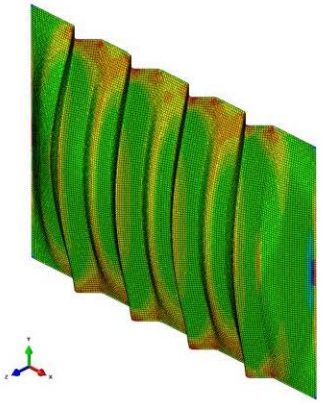
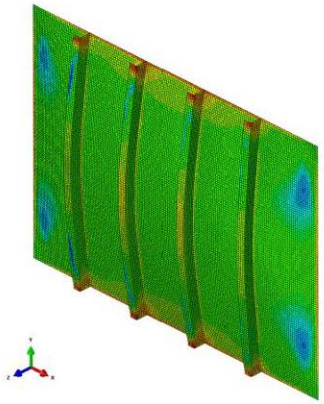
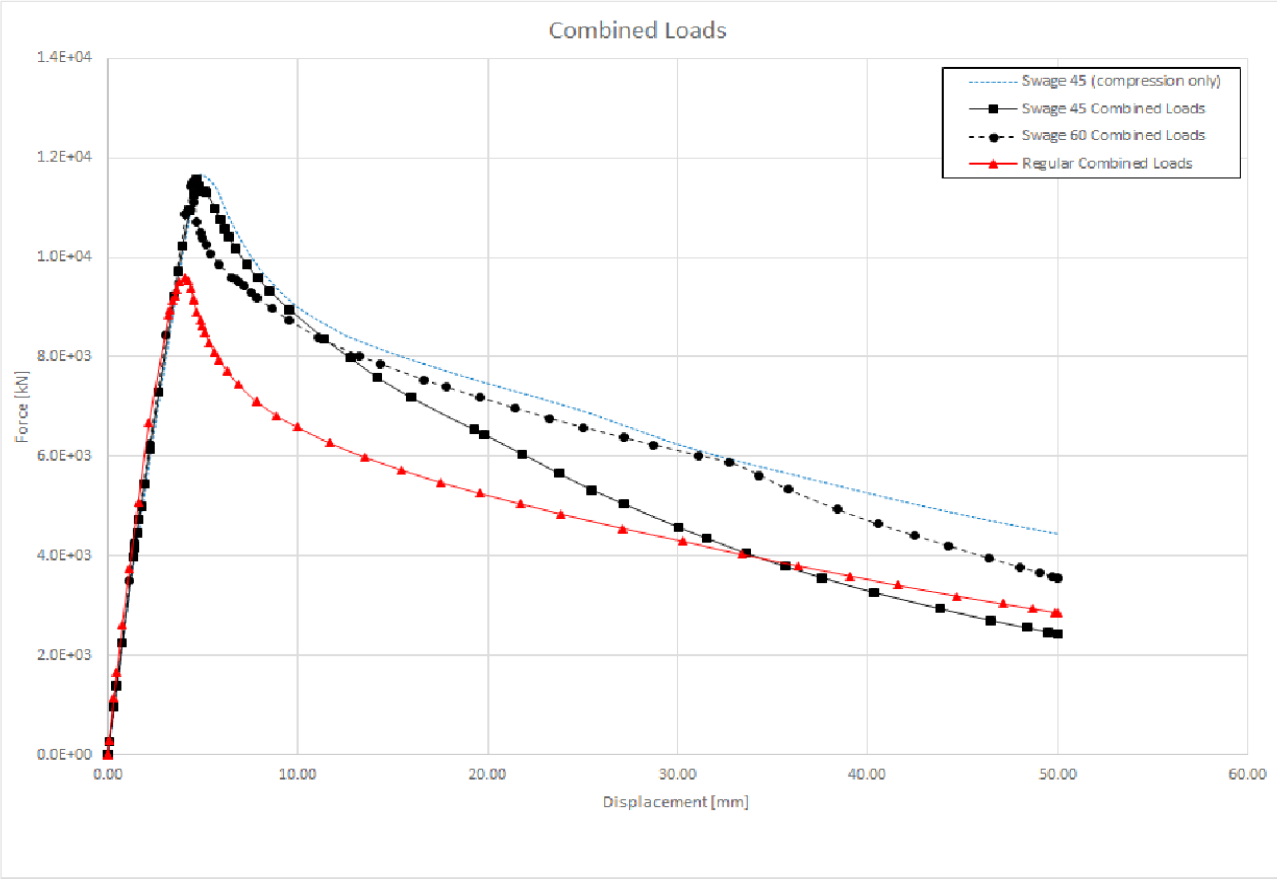


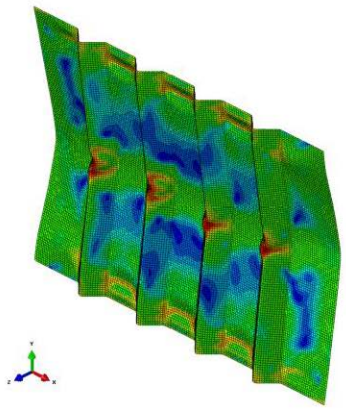
Swage 45 Inv.



Regular

Results – Combined Loads





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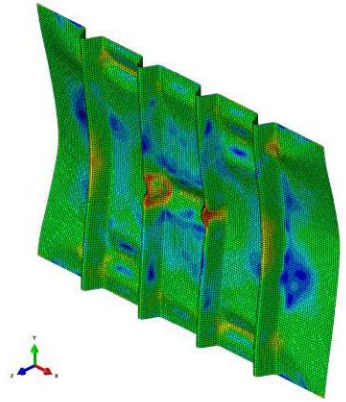
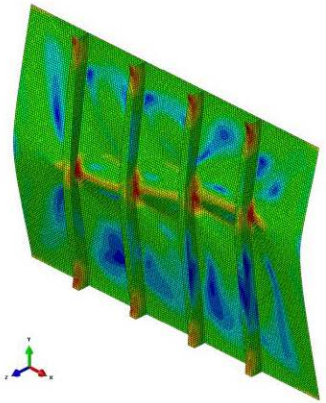
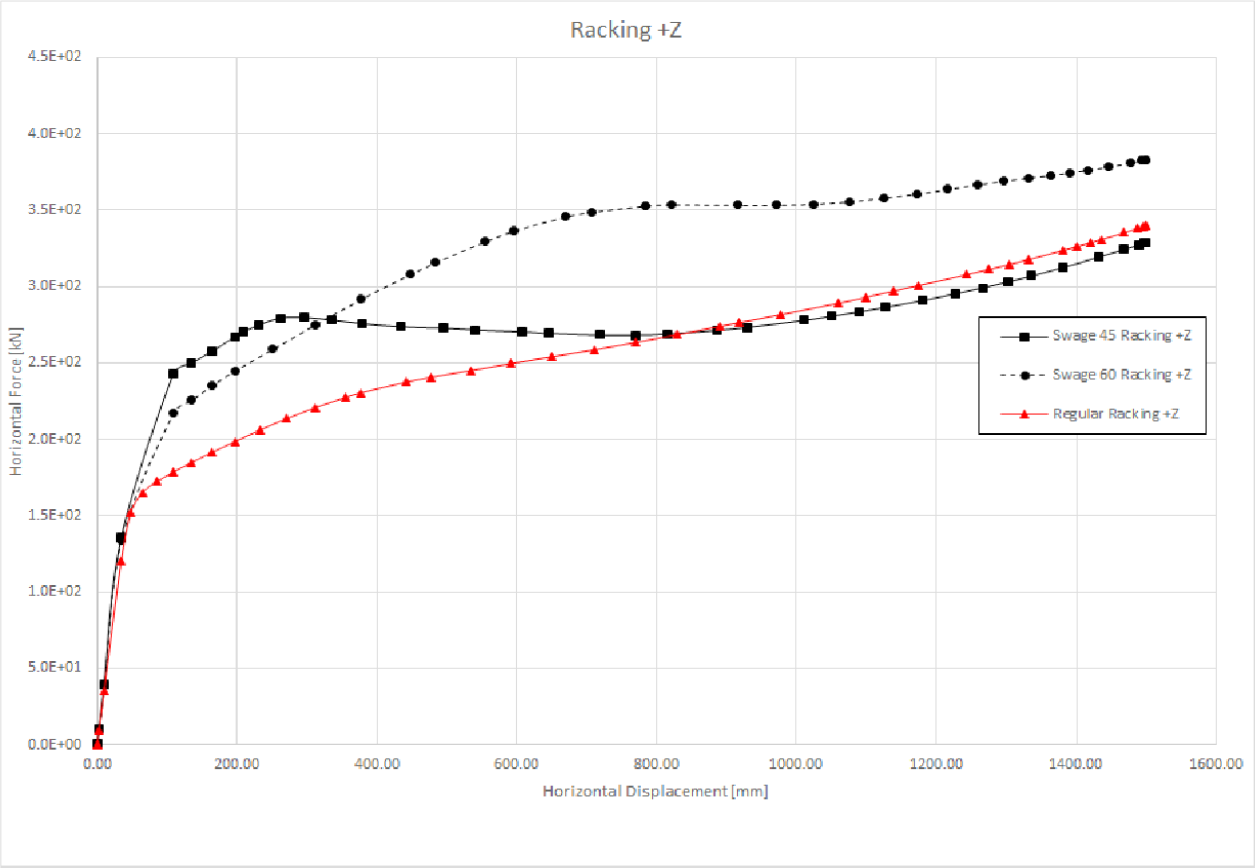


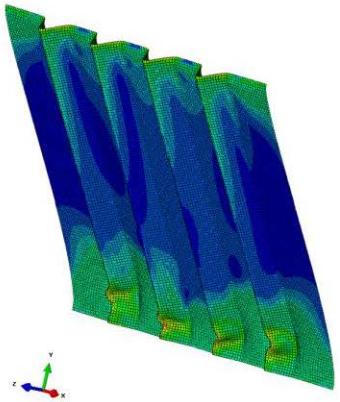
Swage 60



Regular

Results – Racking +Z





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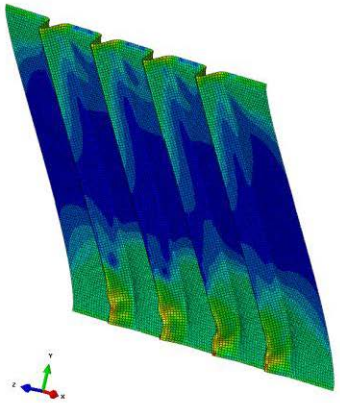
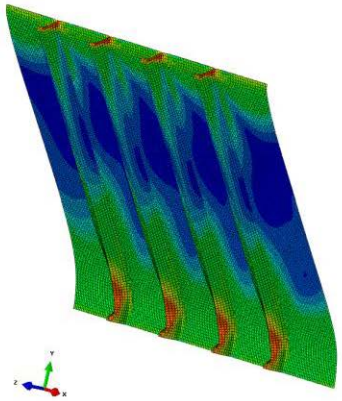
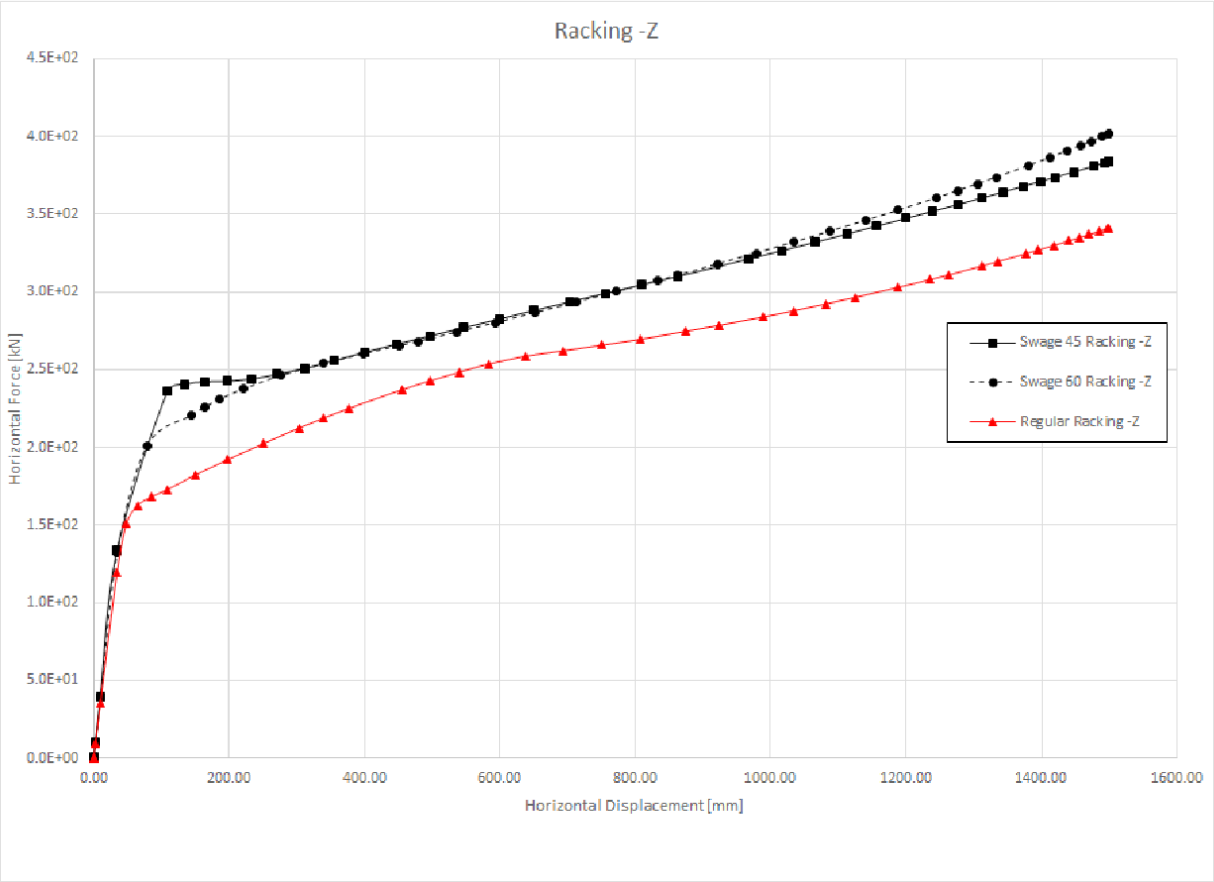


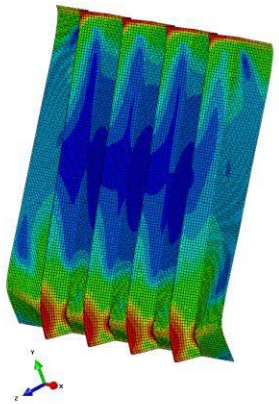
Swage 60



Regular

Results - Racking -Z





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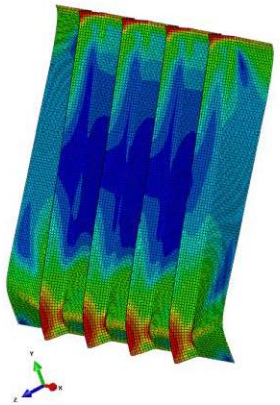
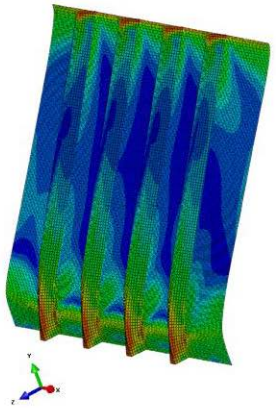
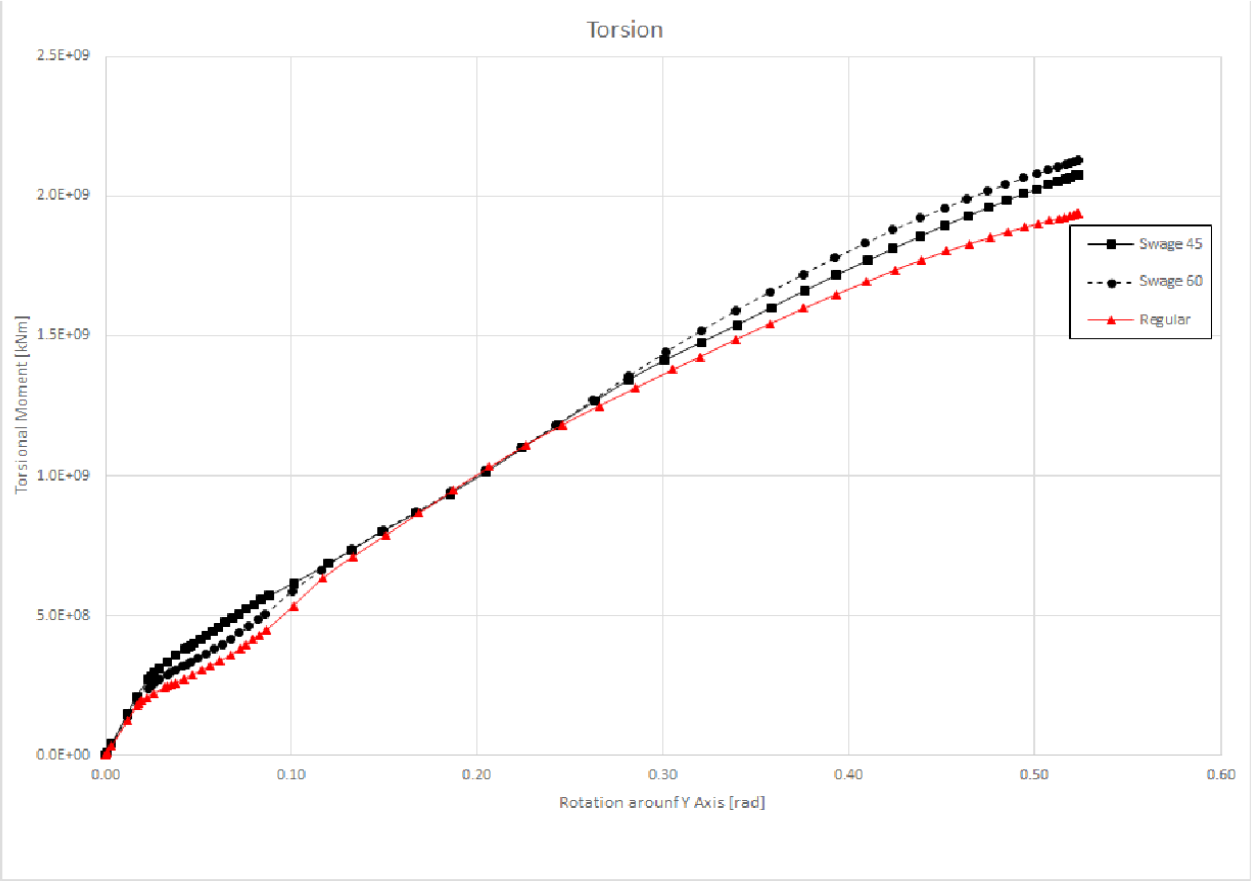


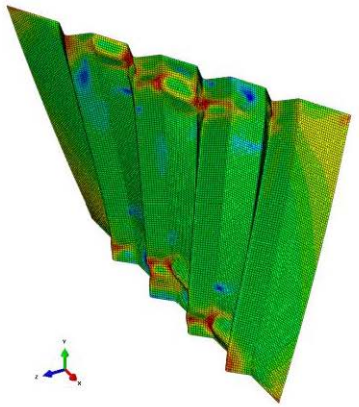
Swage 60



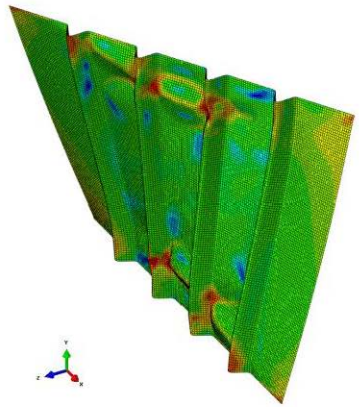
Regular

Results - Torsion

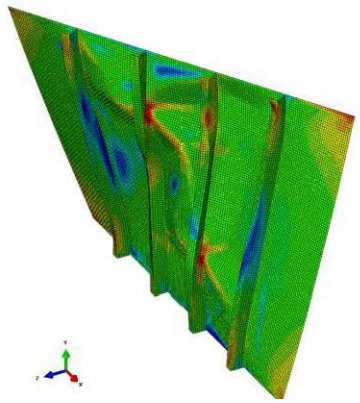




Swage 45



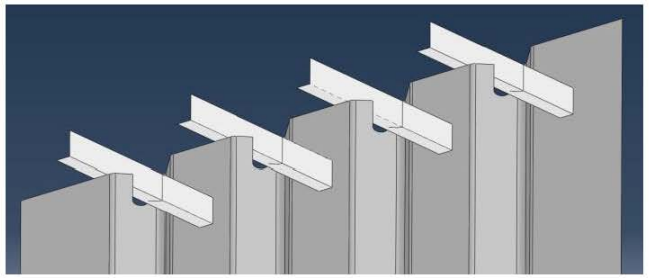
Swage 60



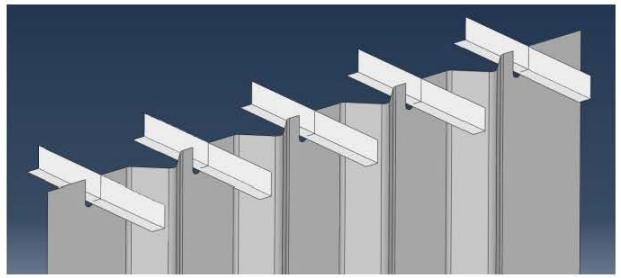
Regular

Results – Connection Types of Non-tight Bulkheads

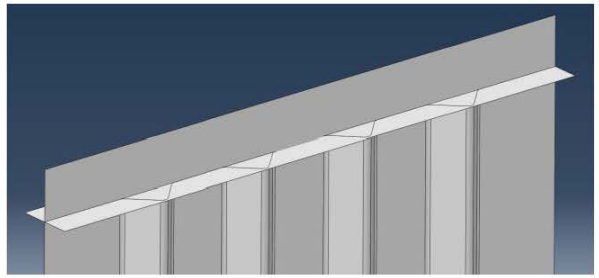
Type A



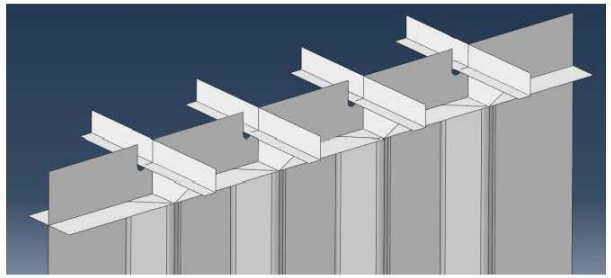
Type B



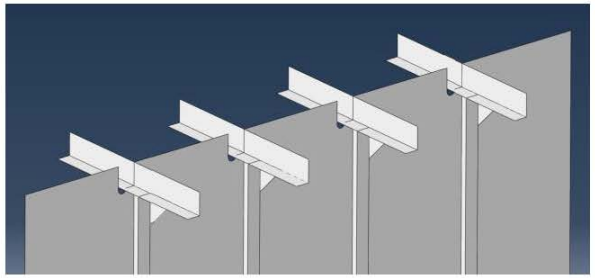
Type C



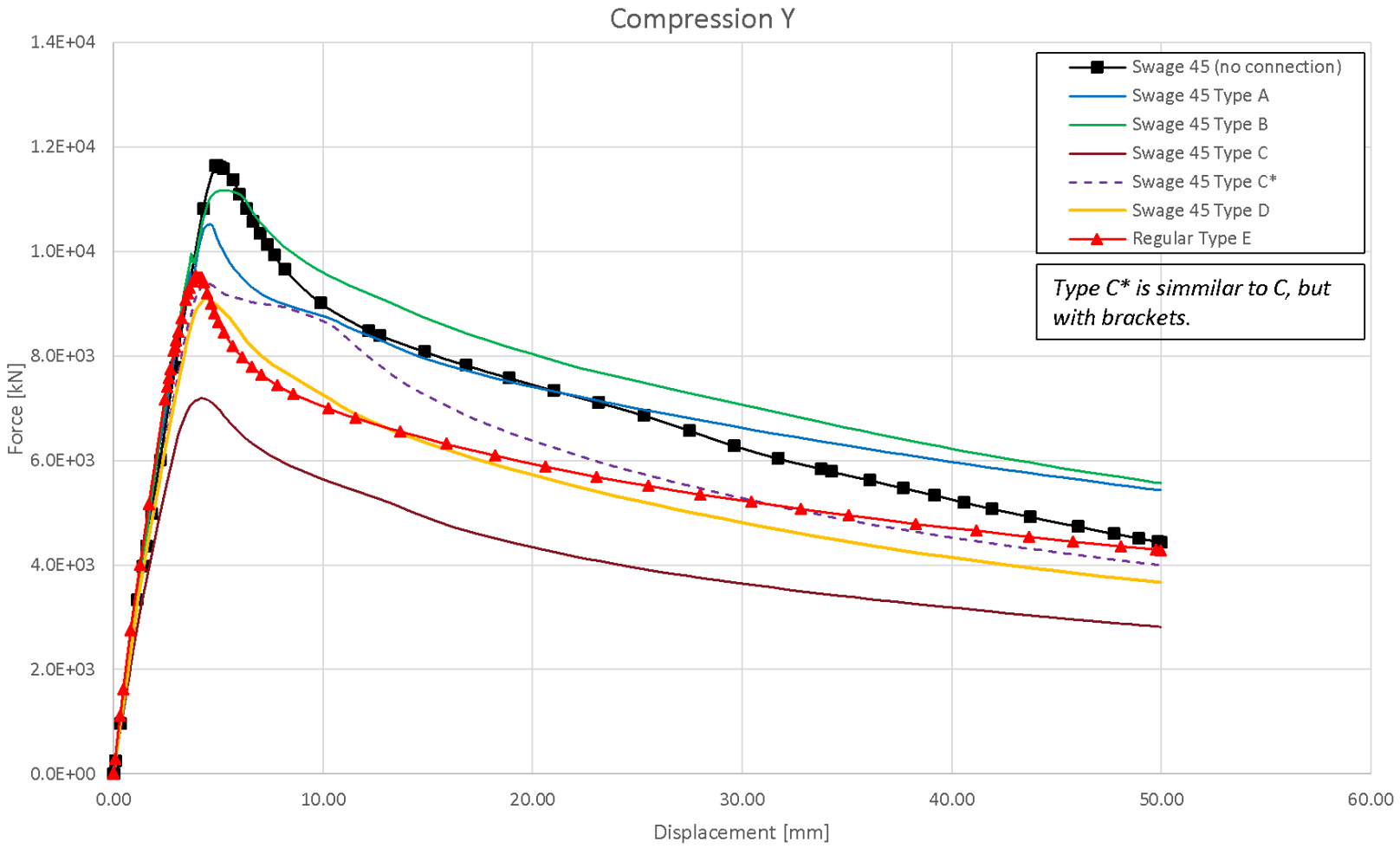
Type D



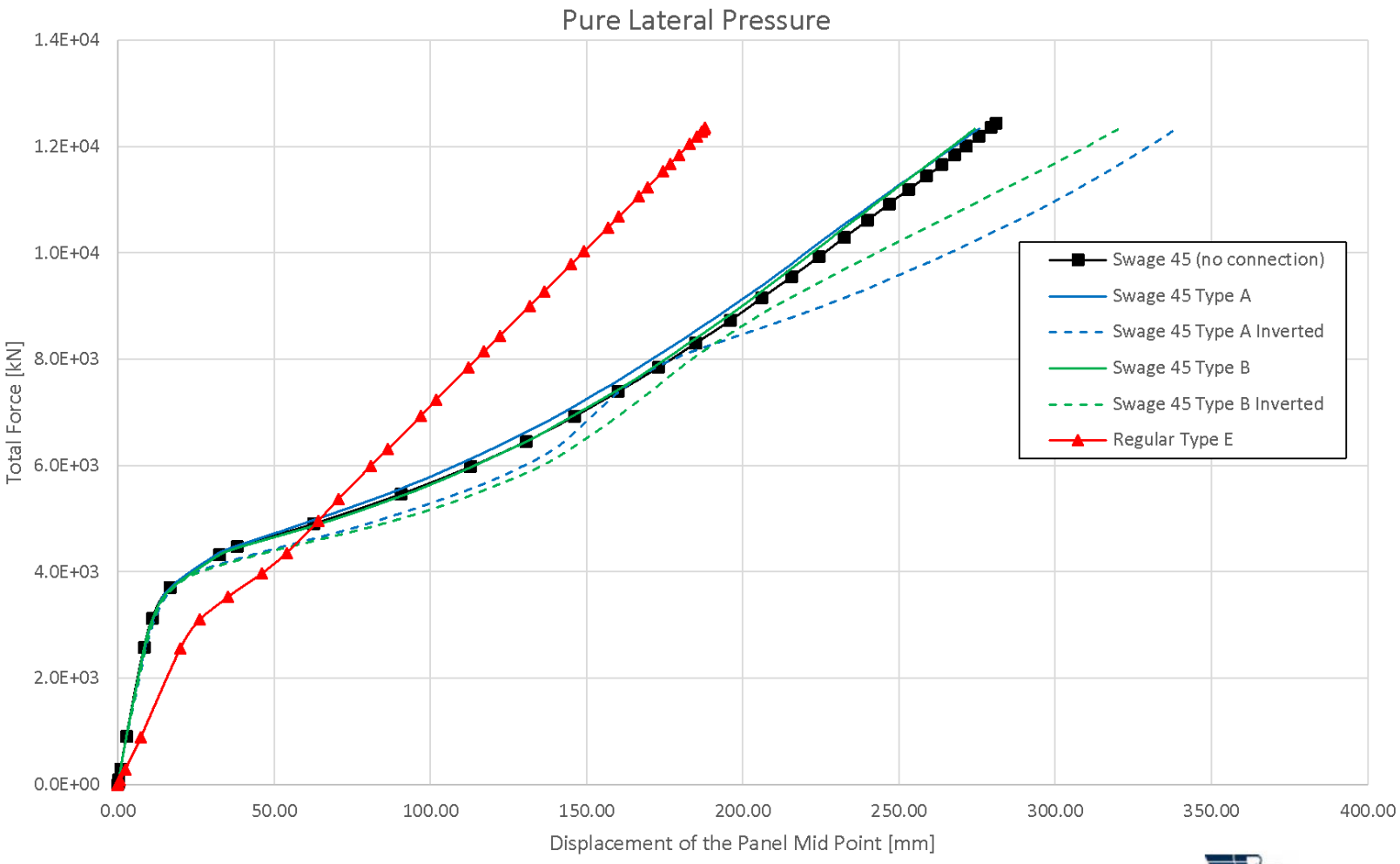
Type E



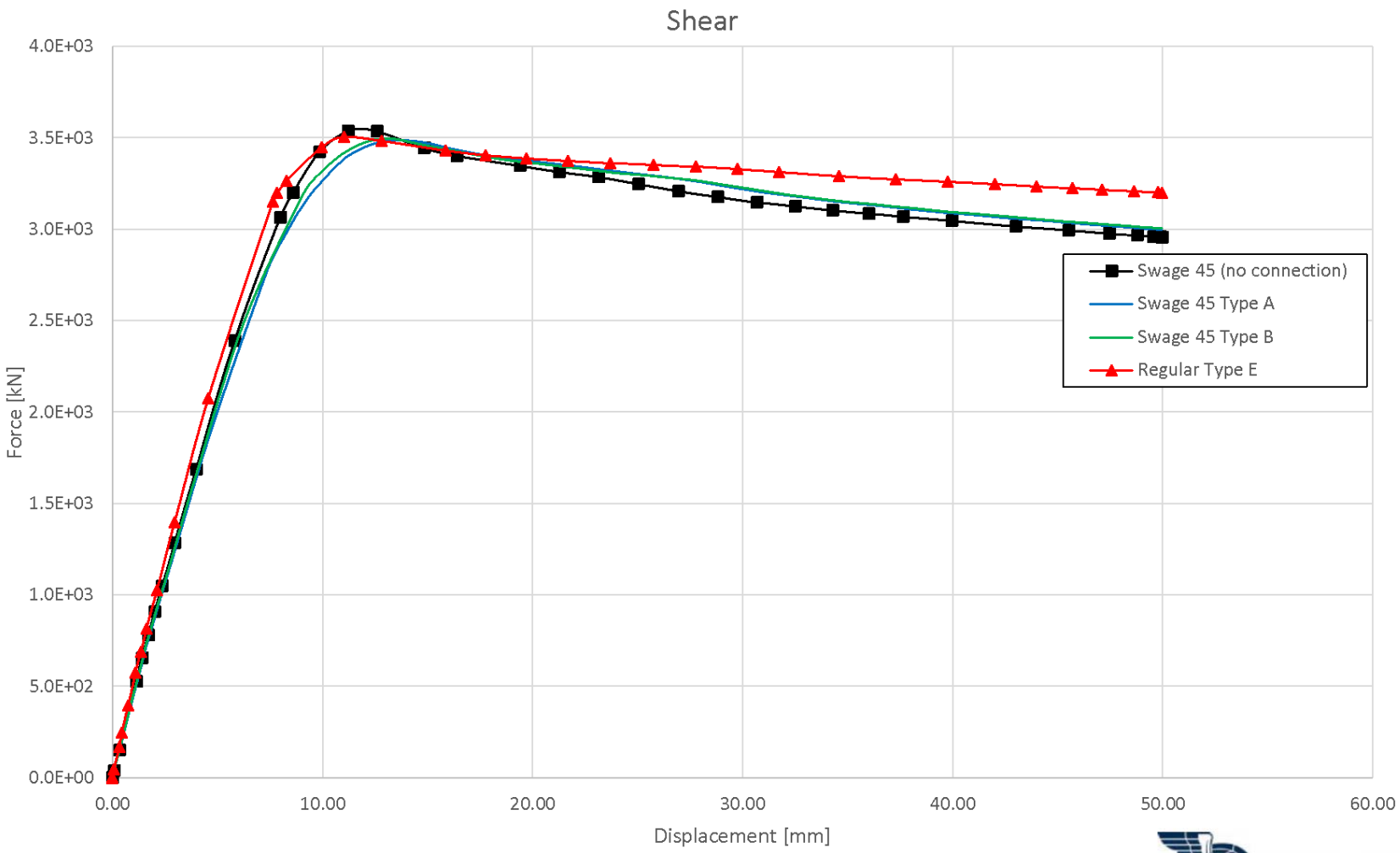
Results – Compression Y for Different Connections



Results – Pure Pressure for Different Connections



Results – Shear for Different Connections



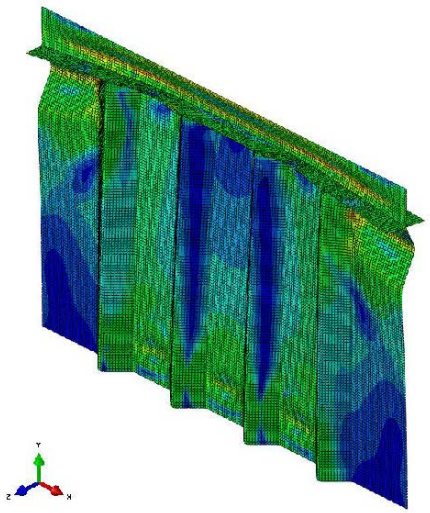
ABS Analysis Conclusions

- Swage panel of the same SM and plate thickness, significantly outperforms (first yield and ultimate strength) the regular panel in compression along the swages, combined loads, and racking.
- Swage panel slightly outperforms the regular in shear and torsion.
- Swage panel is much more stiff when pure pressure is applied, and the first yield occurs at higher pressure loads.
- No significant difference is observed between applying the pressure on the swage side or on the opposite side. The swage panel seems to be slightly more resistant to the pressure applied on the swage side.
- Swage panels have very little resistance to the compression perpendicular to the swages (about 100 times less than the regular panel). However, since the decks provide resistance to possible compressive loads in the panel, this load case is not considered relevant.

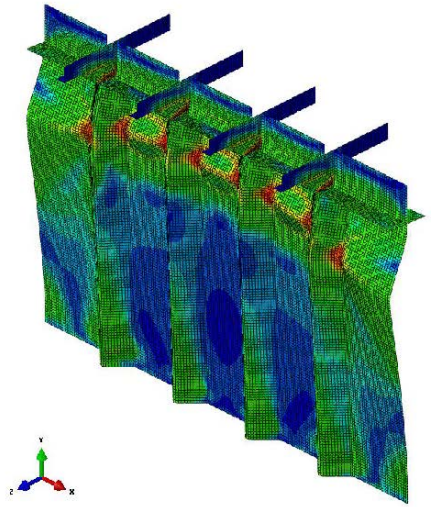
ABS Analysis Conclusions Con't

- The swage angle has a relatively small effect on the panel performance. The 45 deg swages usually outperform the 60 deg swages, except in compression along the swages.
- T-beam connection type without any brackets (Type C) behaves almost like a flat plate and is much more weak compared to the connection with brackets (Types C* and D).

Type C



Type D



ABS Analysis Conclusions Con't

- Type D connection is only slightly inferior to regular panel in compression along the swages. However, brackets need to have adequate thickness to effectively transfer the loads to the swages.
- There is not a significant difference between Type A and Type B connection types. Type B is much easier to manufacture and can be found on existing ABS ships on inner bulkheads.

Draft Proposed Rule Change

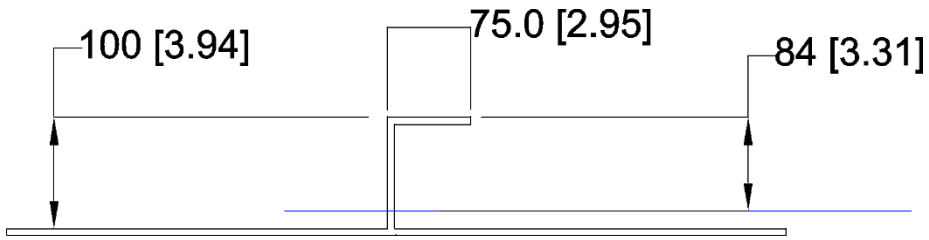
- Use ABS SVR 3-2-11 for SM and plate thickness of external swage bulkheads.
- Swage external bulkheads cannot be allowed in locations which participate in the longitudinal strength of the vessel (within 0.4L), or for forecastles and poop side plating where the plating thickness requirement comes from the side plate thickness requirements of the main hull (the side plating of poops and forecastles is an extension of the main hull side plating).
- Define Type A and B as the preferred connection types for locations where deck stiffeners penetrate the swage panel. Type C connection should not be used. Type D (or C*) should be further investigated.
- Type B should also be further investigated in the context of global load transfer in the superstructure since for this connection type swages are not aligned with deck stiffeners.

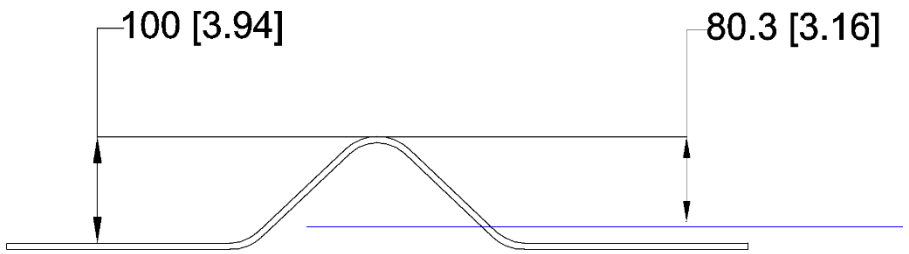
Phase III Completed December 2018

- 3 Shear Tests
  - 1 angle stiffened specimen
  - 2 swaged specimens
- 3 Compression Tests
  - 1 angle stiffened specimen
  - 2 swaged specimens
- Test Data was processed and compared to FEA results, and reviewed by ABS to validate the Draft PRC

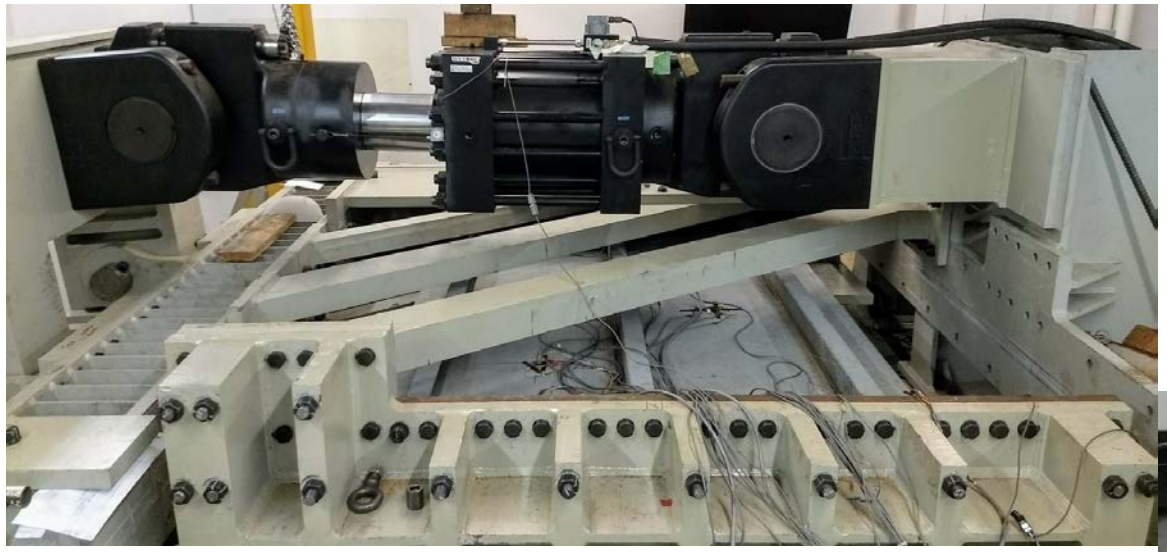
Phase III Specimen Design

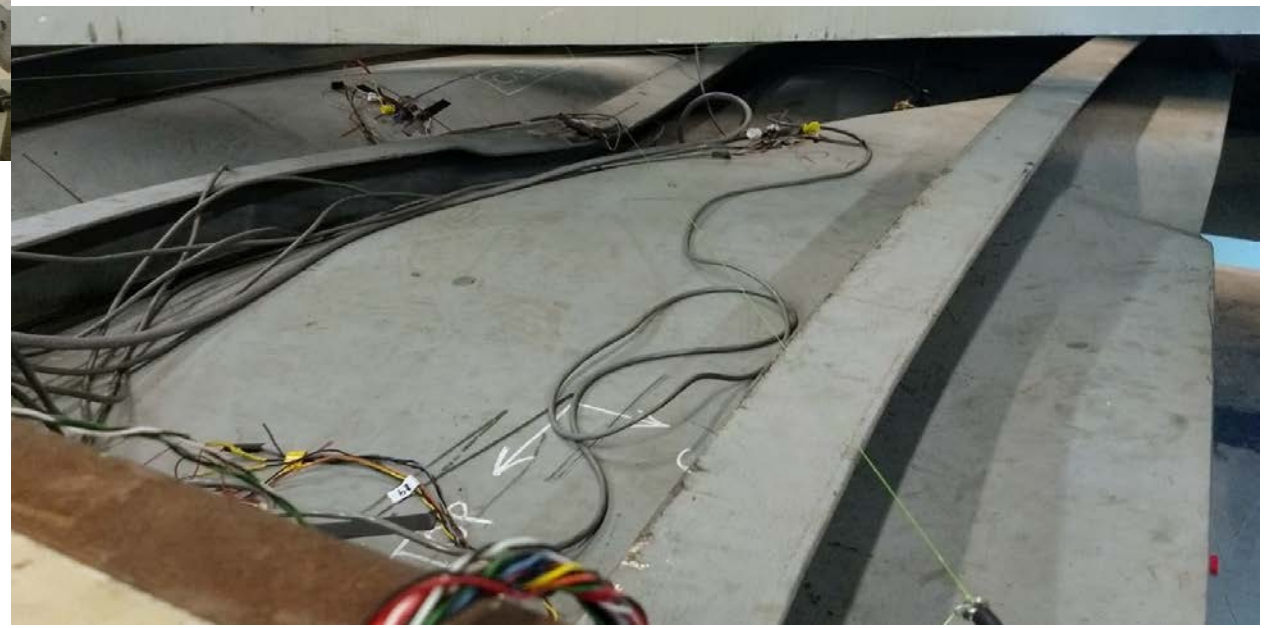
- Calculations performed based on ABS Draft PRC to develop test specimens.
- Angle stiffened and swaged have a comparable Section Modulus
- Plate thickness: 6 mm
- Calculated for an exposed bulkhead in 06 level of a deckhouse



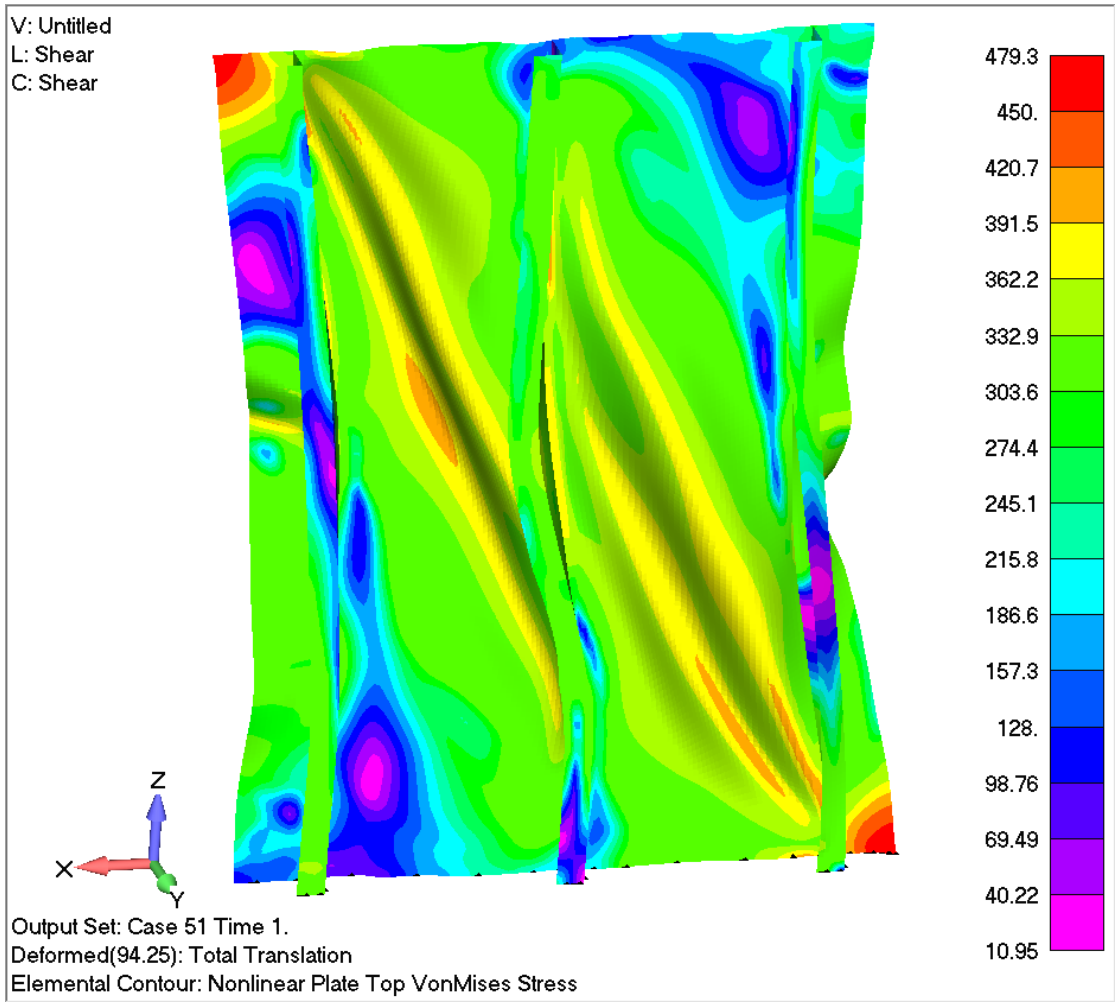


Shear Test – Angle Stiffened Specimen



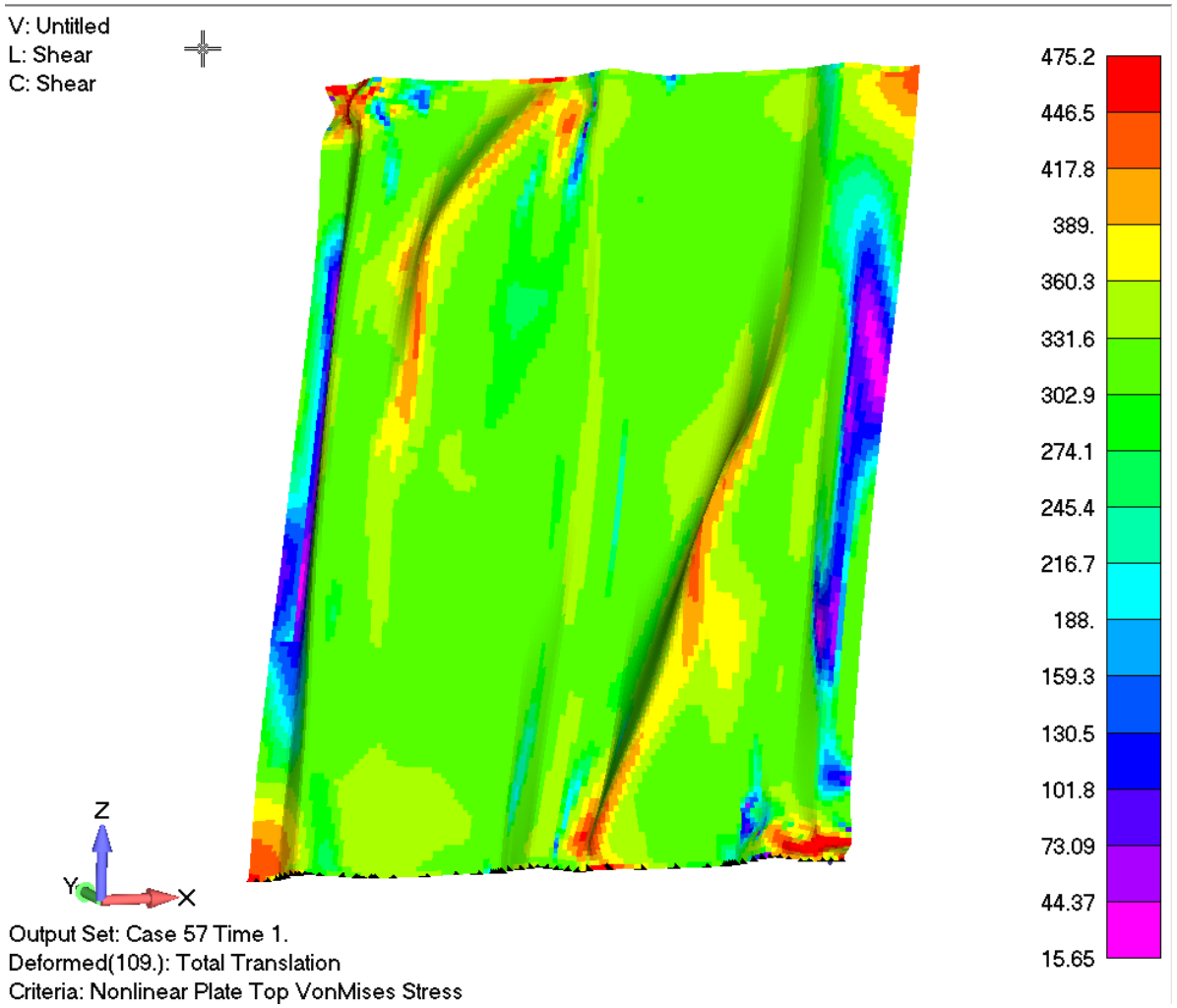


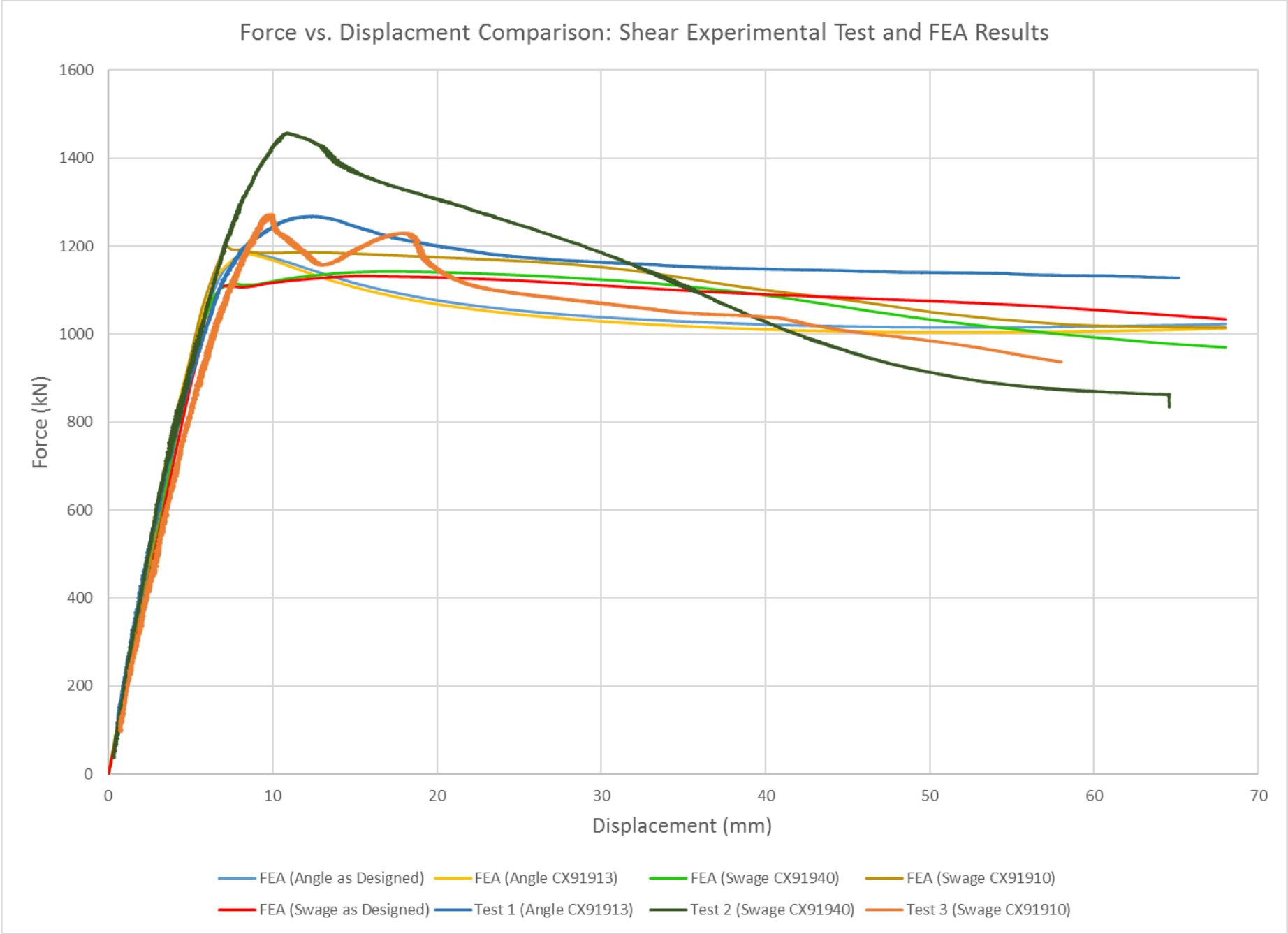
Angle Stiffened Shear Test and FEA Comparison



Shear Test – Swaged Specimen

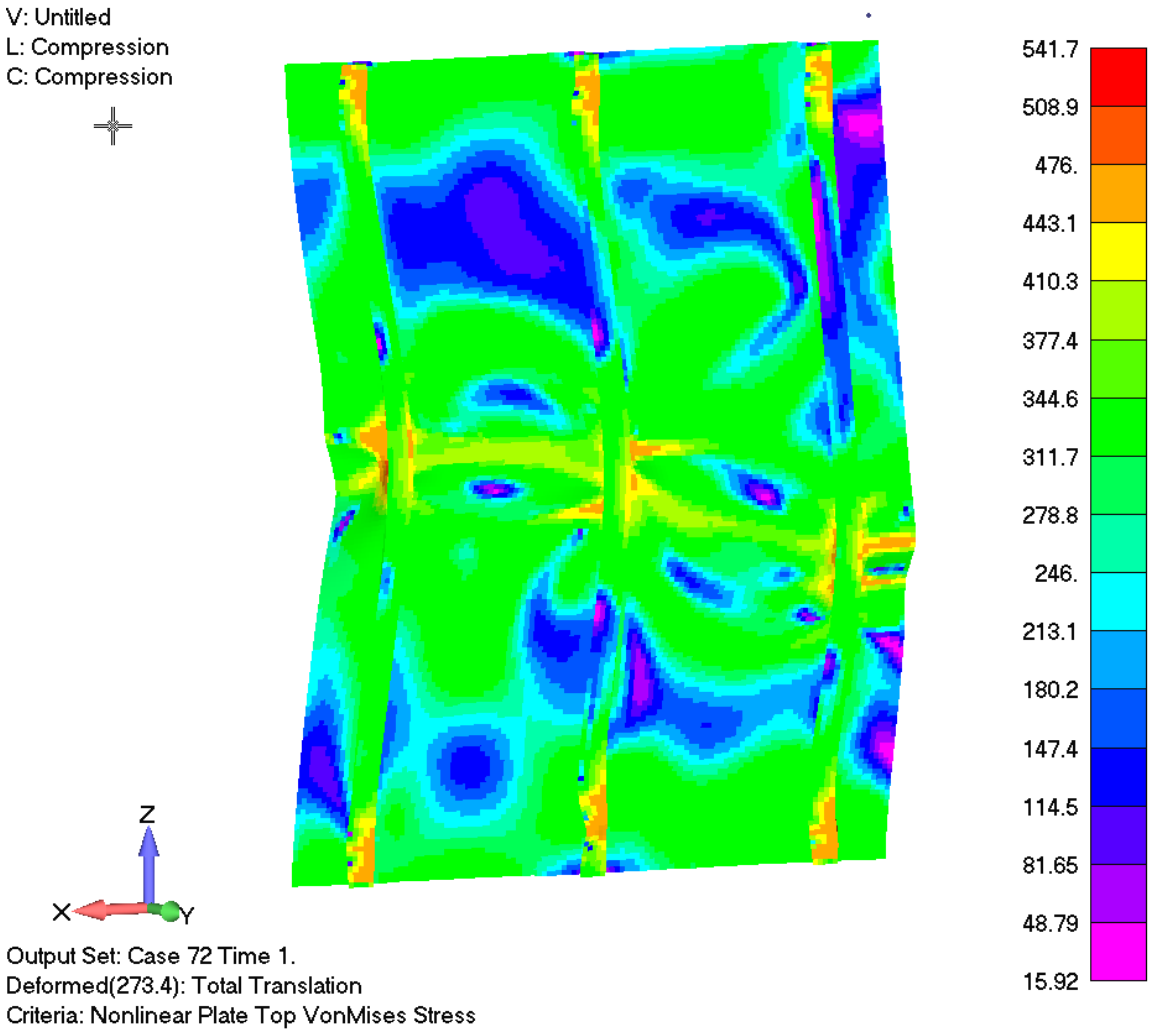
Shear Test and FEA Comparison




Force vs. Displacment Comparison: Shear Experimental Test and FEA Results
Force (kN)
1600
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
70
Displacement (mm)
FEA (Angle as Designed)
FEA (Angle CX91913)
FEA (Swage CX91940)
FEA (Swage CX91910)
FEA (Swage as Designed)
Test 1 (Angle CX91913)
Test 2 (Swage CX91940)
Test 3 (Swage CX91910)

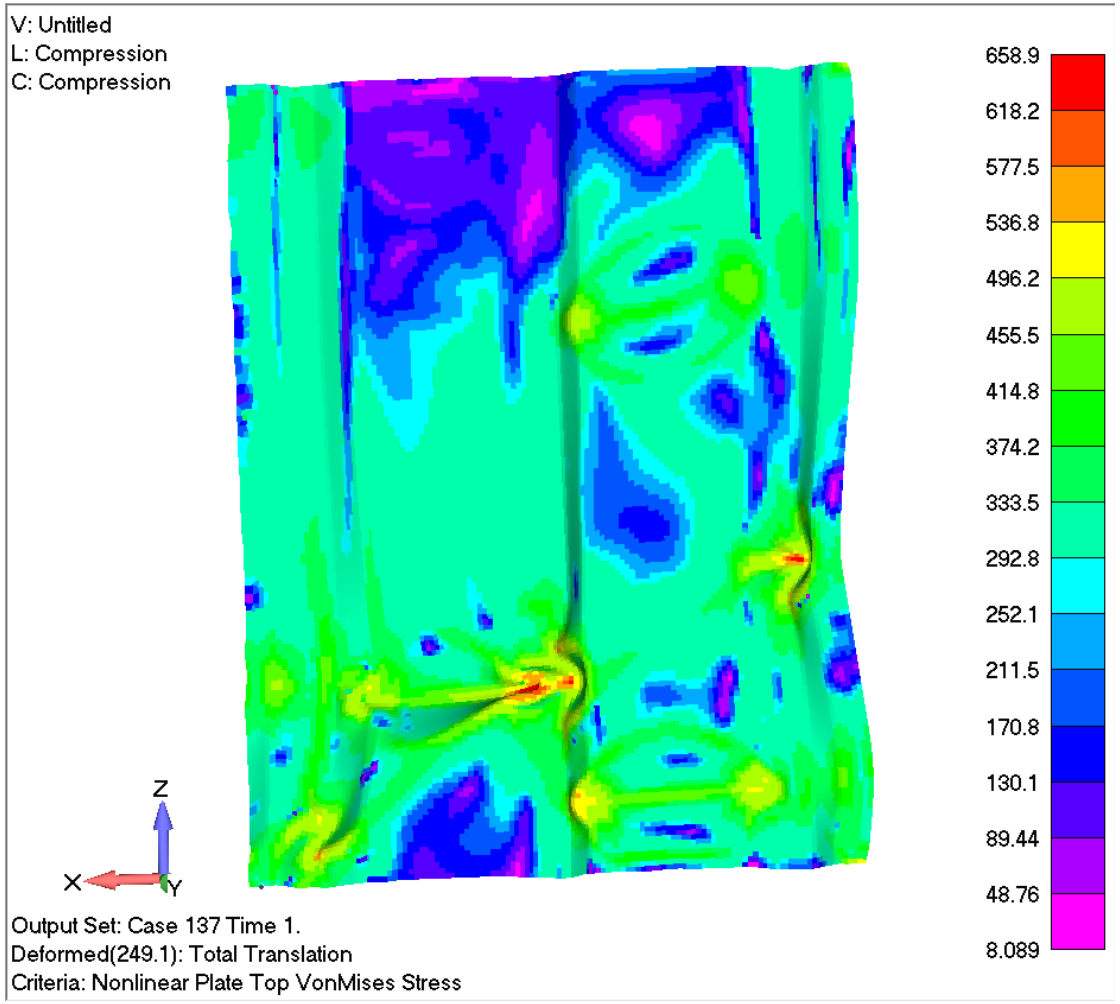
Compression Test – Angle Stiffened Specimen

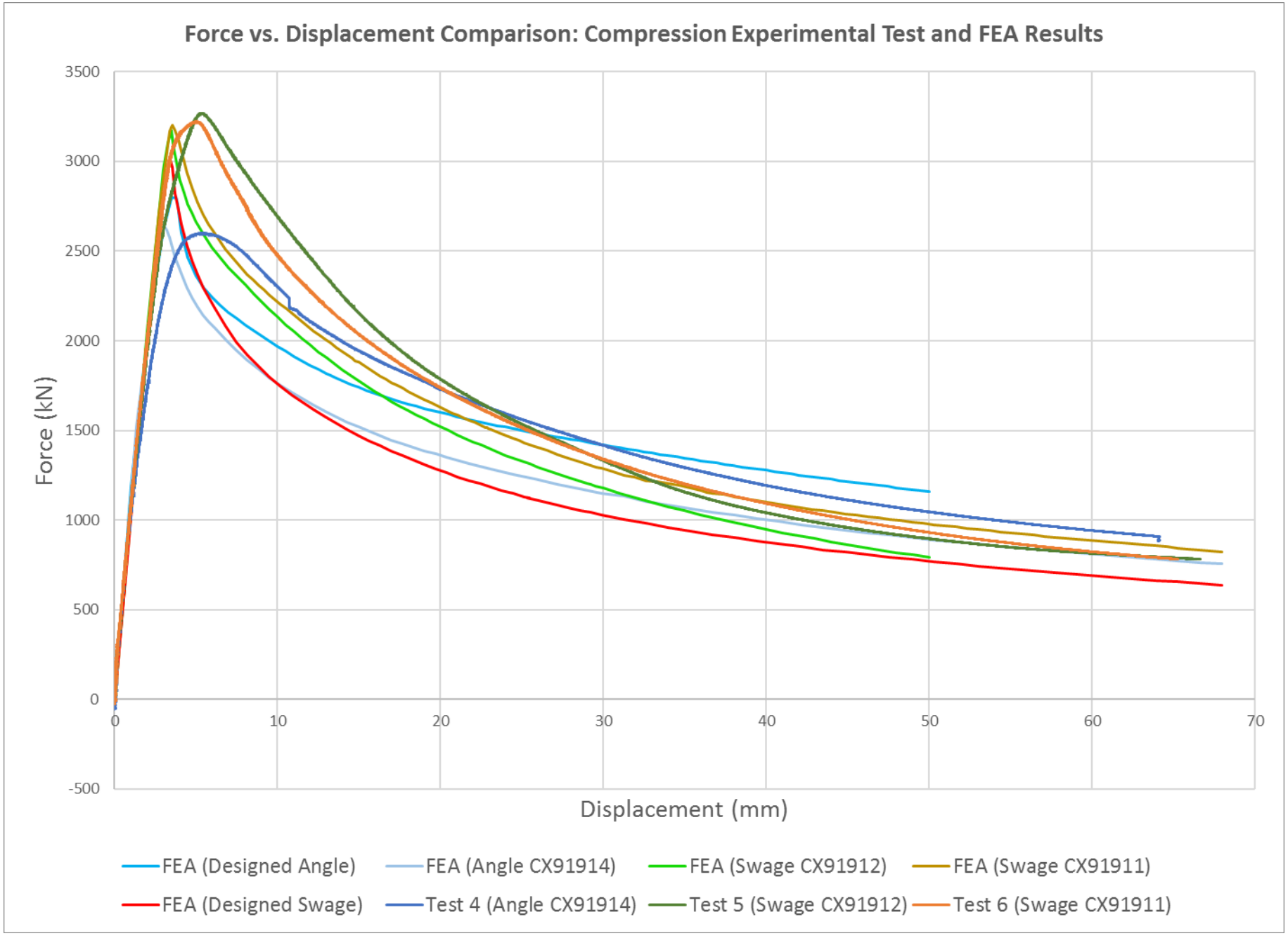
Angle Stiffened Compression Test and FEA Comparison



Compression Test – Swaged Specimen

Compression Test and FEA Comparison




Force vs. Displacement Comparison: Compression Experimental Test and FEA Results
Force (kN)
3500
3000
2500
2000
1500
1000
500
0
-500
0
10
20
30
40
50
60
70
Displacement (mm)
FEA (Designed Angle)
FEA (Angle CX91914)
FEA (Swage CX91912)
FEA (Swage CX91911)
FEA (Designed Swage)
Test 4 (Angle CX91914)
Test 5 (Swage CX91912)
Test 6 (Swage CX91911)

Conclusions

- Swaged bulkhead outperforms the similarly designed traditionally stiffened bulkhead
- Comparison of force vs. displacement test data to non-linear FEA data shows same result
- Additional project underway to examine the end connection details of swaged bulkheads
- ABS PRC will be submitted for review in September 2019 (annual ABS PRC review cycle)

Swage Research and Development (What's next?)

T-AKE Non- Structure Implement → Concept Investigation → Proof of Analysis Concept → Validation vs. Specification Loads To/With ABS → ABS SVR

2005 Study | 2010 Concept | 2011-2014 NSRP RA | 2014-2018 NSRP RA | 2019

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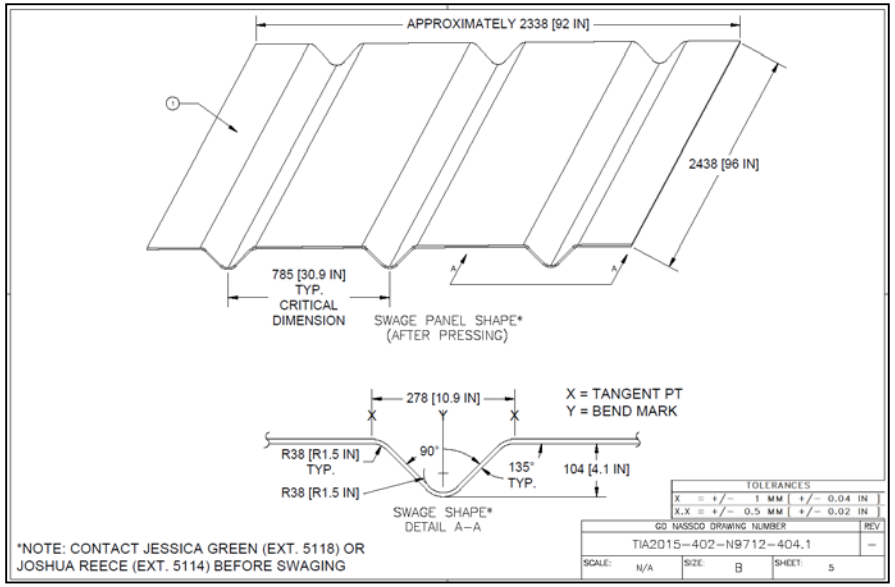

Qualification of Alternative Structures Initial US Navy TWH Involvement

2016 NSRP Panel Project

Design Details To/With US Navy Technical Warrant Holder → Production Information Detailing

2018-2019 NSRP RA | 2022-2024 NSRP RA

Specific Request From US Navy Technical Warrant Holder → NAVSEA TWH Acceptance

2019-2022 NSRP | 2022-2024

Questions?

Please send all questions or comments to:
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