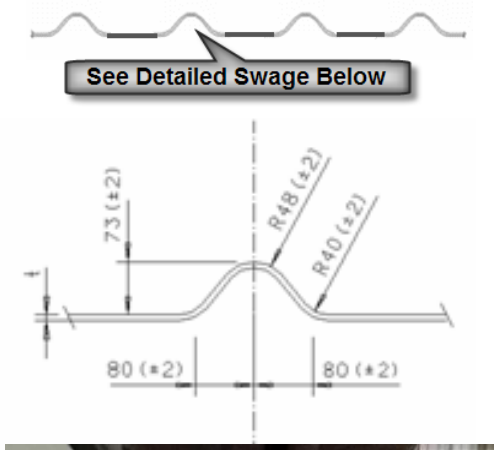
Fatigue Analysis of Swaged Bulkheads (#2018-454)

NSRP SDMT Panel Meeting

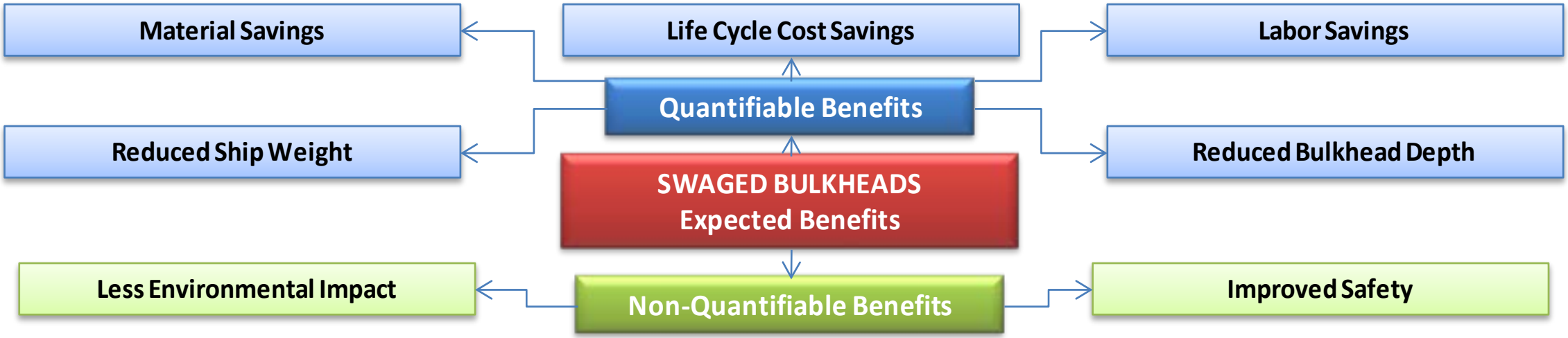
May 26, 2020

Swaged Bulkhead Overview

- Plate pressed to form “bumps” at interval 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 weld lengths
  - Easier paint application
  - Improved paint adherence



Expected Benefits of Swaged Bulkheads



T-AO 205 Class Potential Cost Savings (Per Ship)

- Cost reduction of ~$720k
- Decrease material expenses by ~$164k
- ~8400 hour reduction in labor
- Savings of ~80 tonnes in deckhouse weight

Previous Studies of Swage Technology

2005 Study of Swage Applicability on T-AKE

- Feasibility of application of swage panels in the deckhouse of T-AKE
- Limited to non-load bearing locations
- Concluded that further investigation needed regarding application to structural bulkheads.

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

- Validated analytical methods of applying various loads to swaged and traditionally stiffened bulkheads
- Results compared to physical model tests

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

Phase I
- Compared swages to traditional T and bulb stiffeners
- Worked with Marinette Marine to compare steel and aluminum
- Manufacturing cost comparison study

Phase II
- Examined effects of variations in swage geometry, plate thickness, and steel grade

Phase III
- Studied real-world outfitting: bulkhead cutouts, penetrations, and attachments (eg: electrical panel)

Previous Studies of Swage Technology

2015-2018 Swage Panel SVR Rule Development (NSRP RA 2015-402)

Phase I	• Text Fixture designed, built, and commissioned at SDSU Structural Lab in Phase I
Phase II	• Conducted global FEA of representative trailership to determine potential swage placement • Fabrication of testing of specimens to obtain data to support ABS rule change.
Phase III	• Two swage geometries and one traditionally stiffened panel were tested in both shear and compression. Data compared to FEA and reviewed by ABS to validate proposed rule change.

2016 Qualification of Alternative Structures (2005-333)

- Laid the groundwork for incorporation of swage panels into combatant vessels
- Worked with the Navy Technical Warrant Holders to complete validation plan for swage on combatants
- Proposed validation test matrix including fatigue, shock, in-plane, out-of-plane, and combined loading

Recently Completed Project: Integration of Outfitting and Structural Details on Swaged Bulkheads

Motivating Questions

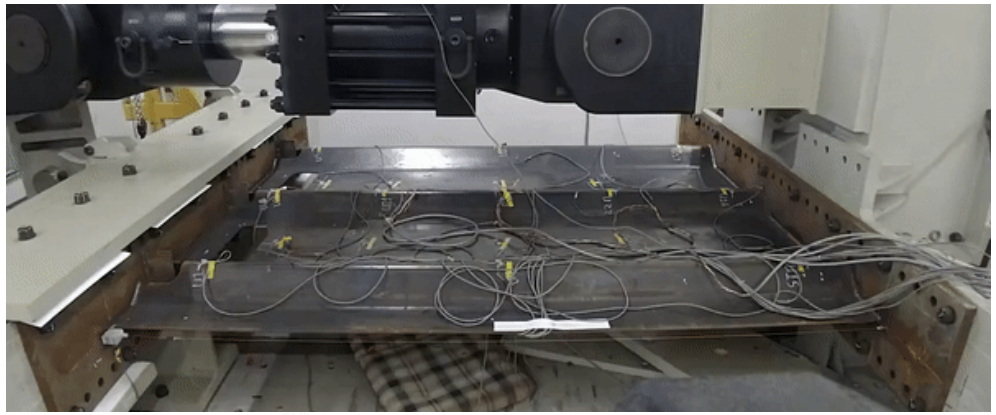
- How do swaged bulkheads connect to other structure?
- How is outfitting incorporated into swaged bulkheads?
  - What does the stiffening around an opening in a swaged bulkhead look like?
  - What is the impact on panel strength?
- Can outfitting details be accurately representing in FEA?

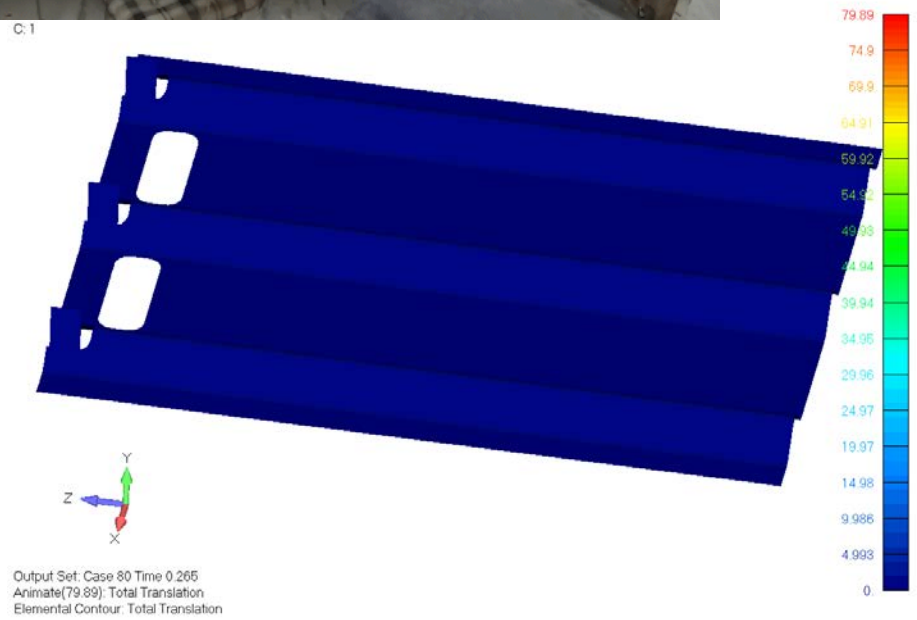
Project Goals

- Validate of the strength and behavior of swage bulkheads with outfitting and structural details
- Employ non-linear FEA software and compare with data collected during physical testing (accuracy within 25%)
- Progress towards technical maturity and ship implementation
- Produce design and production guidance for integrating swaged bulkheads into other ship structure
  - Include interfaces with outfitting systems (eg: piping & conduit) and non-swage standard structural elements.

Recently Completed Project: Integration of Outfitting and Structural Details on Swaged Bulkheads: Conclusions

- FEA predicts panel compression strength within goal of 25%
- Specimen failure modes well represented in FEA
  - More accurate in compression than shear
- Outfitting cutout size and placement significantly affect panel ultimate strength and failure mode
  - Cutouts and interruptions on swage peak should be minimized for strength
  - Strength considerations must be balanced with producibility





Fatigue Analysis of Swaged Bulkheads: Project Goals

- Investigate fatigue life of swaged bulkheads through physical testing and Finite Element Analysis and compare to the fatigue life of traditionally stiffened bulkheads
- Demonstrate that swaged bulkheads have equivalent fatigue strength or better than a structurally equivalent stiffened bulkhead.
- Additionally, in conjunction with BIW, a Ship Structure Program Plan will be created in order to facilitate the integration of swaged bulkheads into US Navy ships for specific applications by determining the next steps for testing.

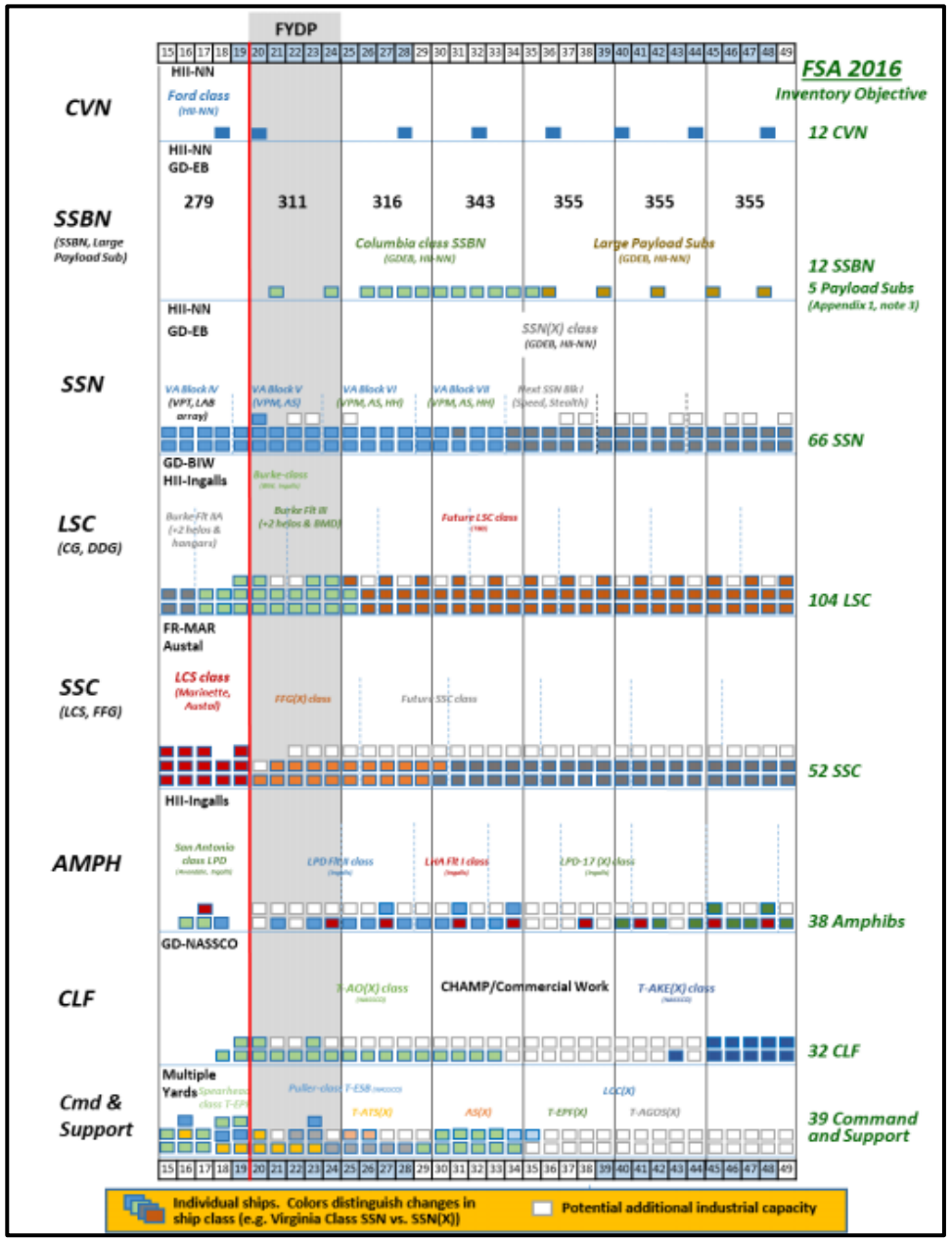
Fatigue Analysis of Swaged Bulkheads

Three Key Deliverables:

1. Implementation Plan
   - Partner: BIW
   - Phase 1: 8/1/19-7/31/20
2. Fatigue Analysis
   - Partner: SDSU
   - Phase 1 and 2: 8/1/19-7/31/21
3. Test Fixture Modification
   - Partner: SDSU
     - Test Fixture Design
       - Phase 1: 8/1/19-7/31/20
     - Test Fixture Construction
       - Phase 2: 8/1/20-7/31/21

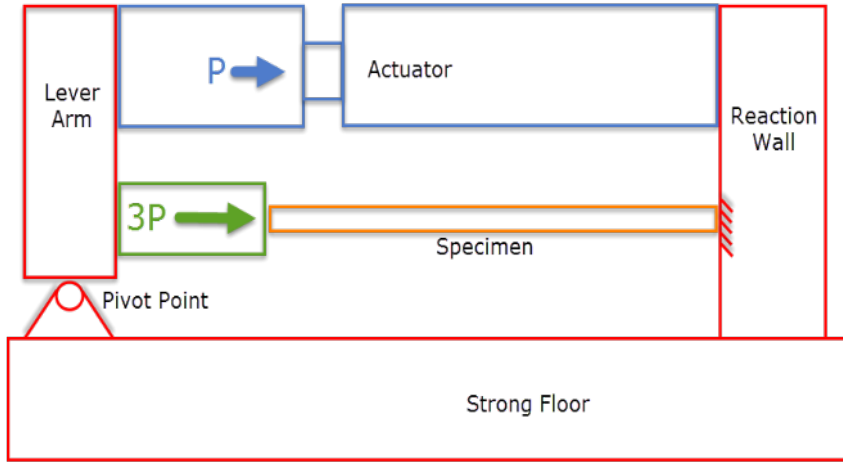
Implementation Plan

- Develop an Implementation Plan that will serve to accelerate the completion of requirements for Navy approval of swaged bulkheads.
- NASSCO is partnering with General Dynamics Bath Iron Works (BIW) and coordinate with Navy Technical Warrant Holders to identify future testing needed for implementation and prioritize said tests based upon upcoming ship construction programs.

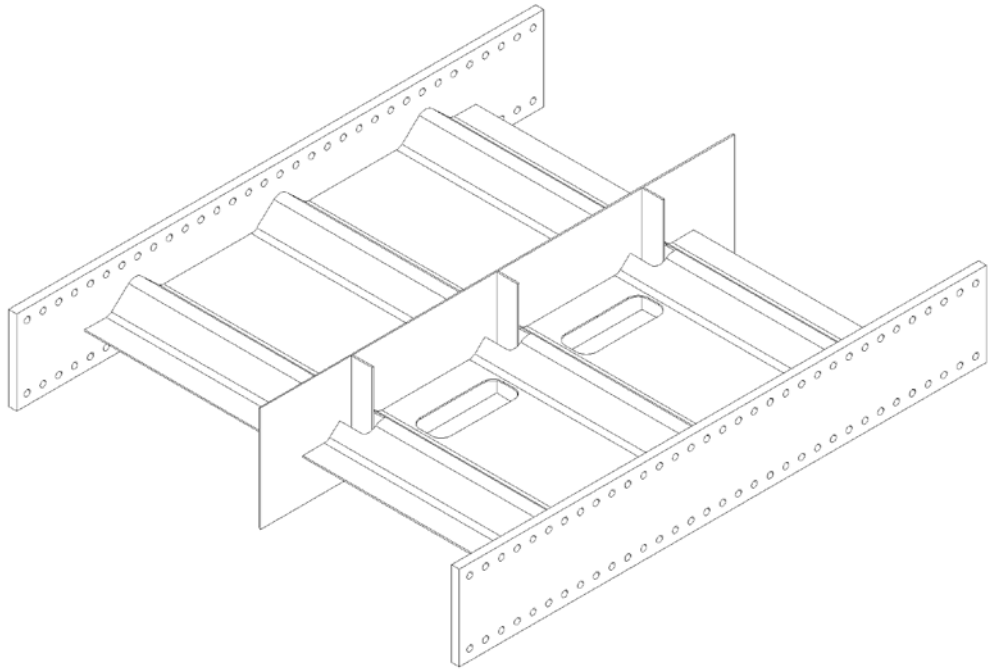


Fatigue Study Approach

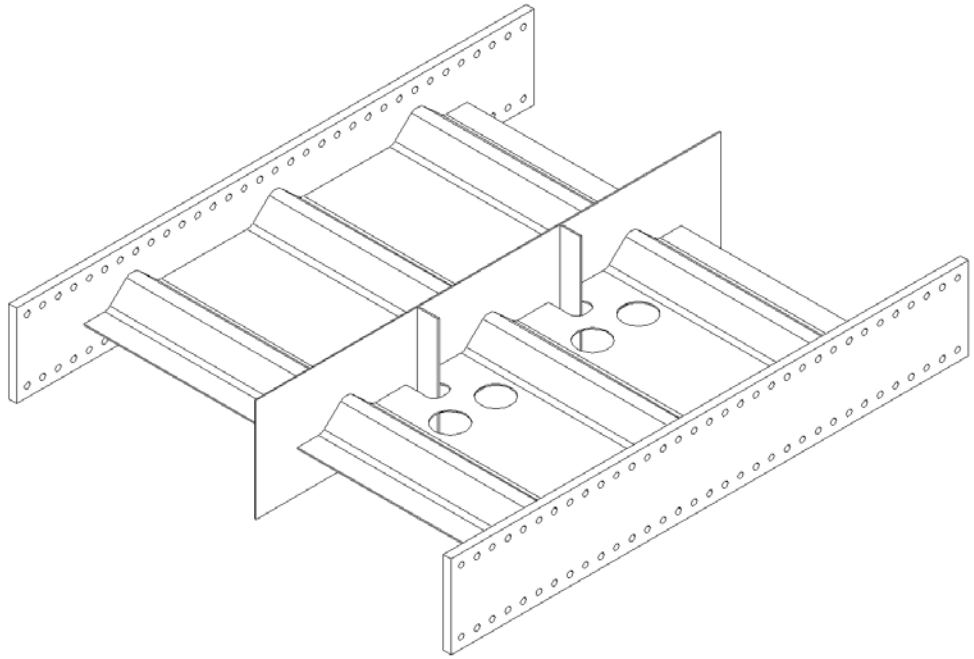
- Explore the fatigue properties of swage bulkheads through:
  - Finite Element (FE) models
  - Physical testing using cyclic loading
  - Compare swaged bulkheads and traditionally stiffened bulkheads using both methods
- The FE models will use a similar methodology to previous projects where the strength of swaged bulkheads was explored. The physical testing will be completed on the existing Swage Test Fixture at San Diego State University's (SDSU) Structural Engineering Laboratory.



Test Specimen Design

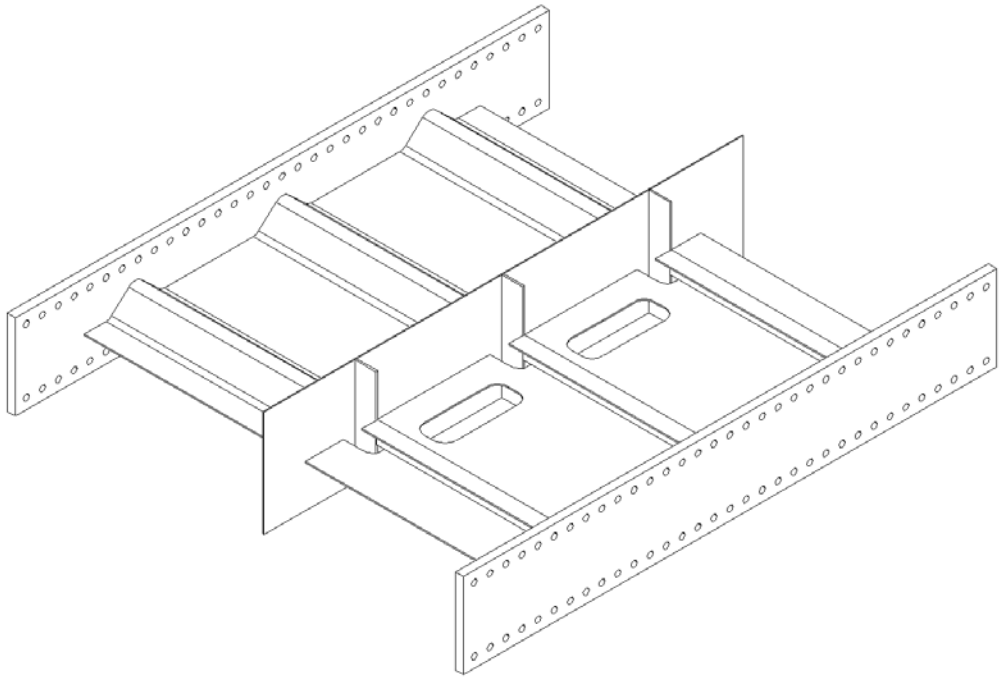


Swaged Bulkhead Above Swaged Bulkhead Type A w/Outfitting Penetrations

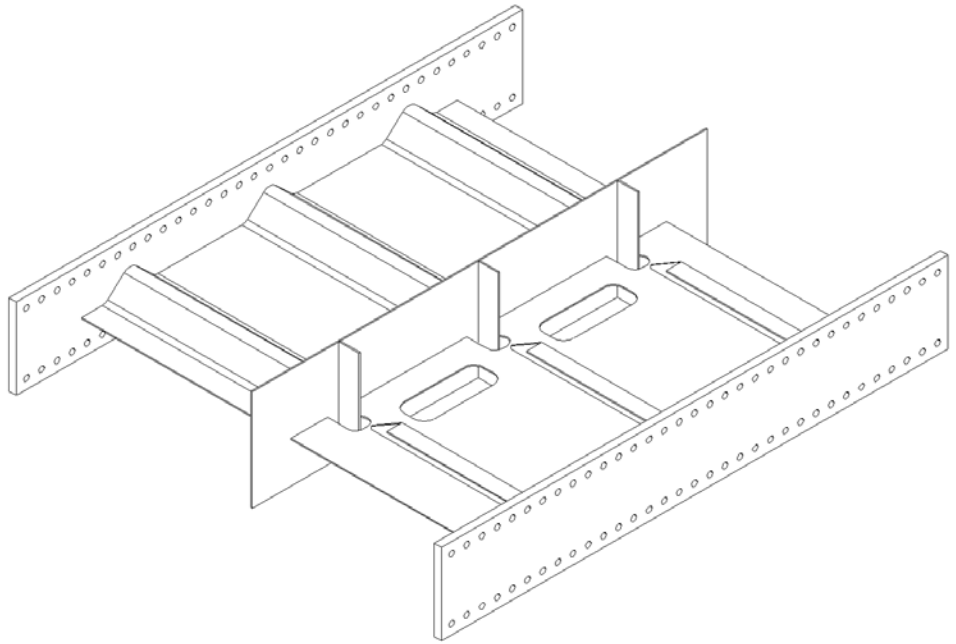


Swaged Bulkhead Above Swaged Bulkhead w/o Outfitting Penetrations

Test Specimen Design



Swaged Bulkhead Above Angle-stiffened Bulkhead, Fully Connected, w/Outfitting Penetrations



Swaged Bulkhead Above Angle-stiffened Bulkhead, Sniped, w/Outfitting Penetrations

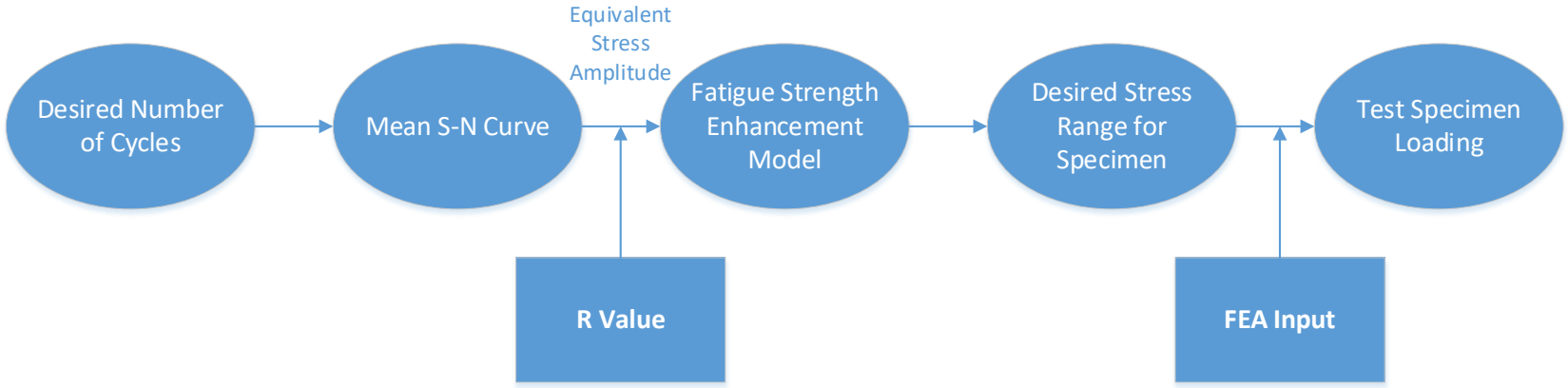
Proposed Testing Approach

Cycles Per second (Hz)	Number of Cycles					
	10^4	10^5	10^6	5×10^6	10^7	5×10^7
0.25	0.46	4.63	46.30	231.48	462.96	2,314.81
0.33	0.35	3.47	34.72	173.61	347.22	1,736.11
0.5	0.23	2.31	23.15	115.74	231.48	1,157.41
1	0.12	1.16	**11.57**	57.87	115.74	578.70
2	0.06	0.58	5.79	28.94	57.87	289.35
3	0.04	0.39	3.86	19.29	38.58	192.90
4	0.03	0.29	2.89	14.47	28.94	144.68

Length of test in days based on totally desired number of cycles and potential achieved cycles per second; test length goal is 10-14 days

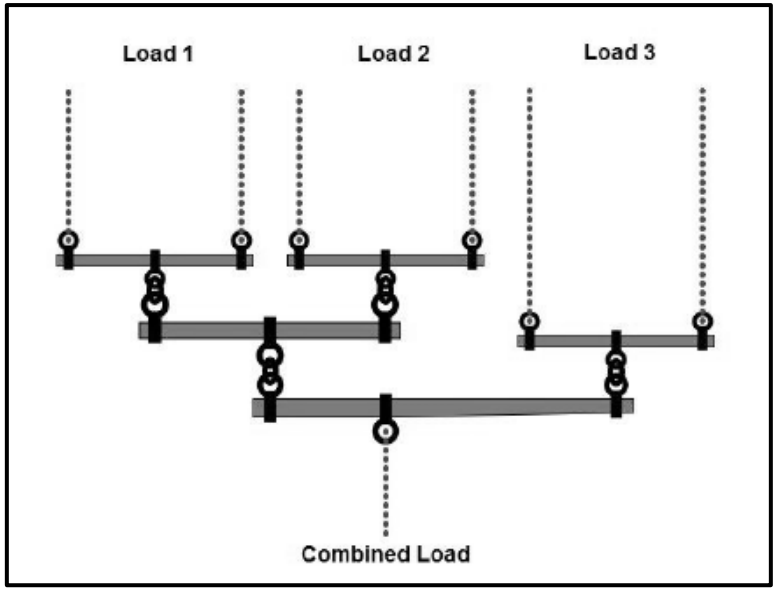
Proposed Testing Approach

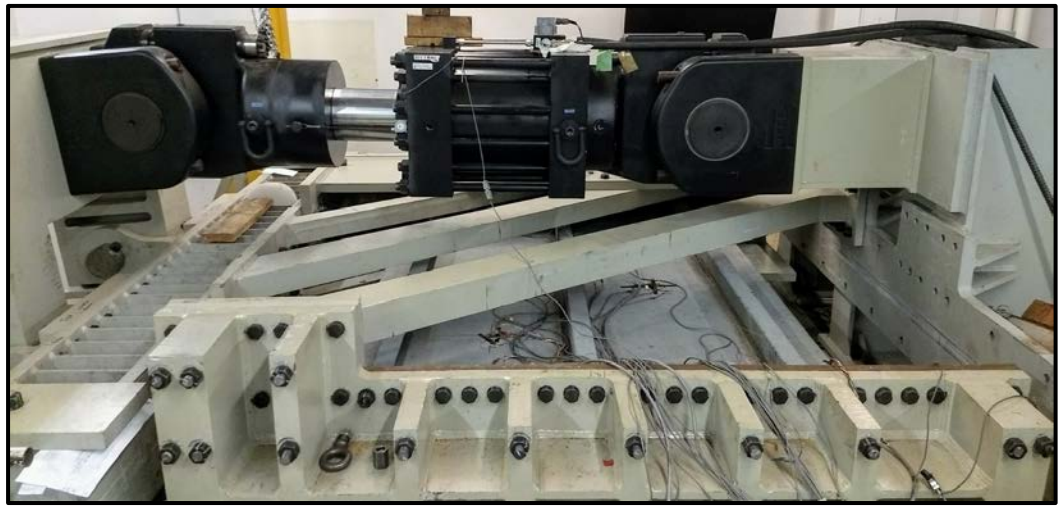
- Re-using existing Test Fixture (including hydraulic equipment)
- Constant amplitude cyclical loading on various swage details
- Loading to be force-control vs. previously used displacement-control to achieve prescribed stress ranges
- Determine number of cycles until fatigue failure/crack initiation
- Detailed instrumentation to capture failure/crack initiation
- Stress amplitude achieved and number of cycles create S-N Curve for each design detail



Test Fixture Modification for Out of Plane Loading

- Move forward in accelerating implementation of swaged bulkheads by the design of the parts needed to adapt the existing test fixture so that it may be used to apply out of plane load profiles.
- Phase I: Design
  - In Phase I NASSCO will work with San Diego State University (SDSU) on the research, calculations, and drawings as part of the design work to be able to apply the next load profile.
- Phase II: Fabrication and Installation
  - In Phase II NASSCO will build Test Fixture Modification designed in Phase I, and it will be installed at the SDSU Structural Laboratory.





Questions?