



# **GENERAL DYNAMICS**

## **naesco**

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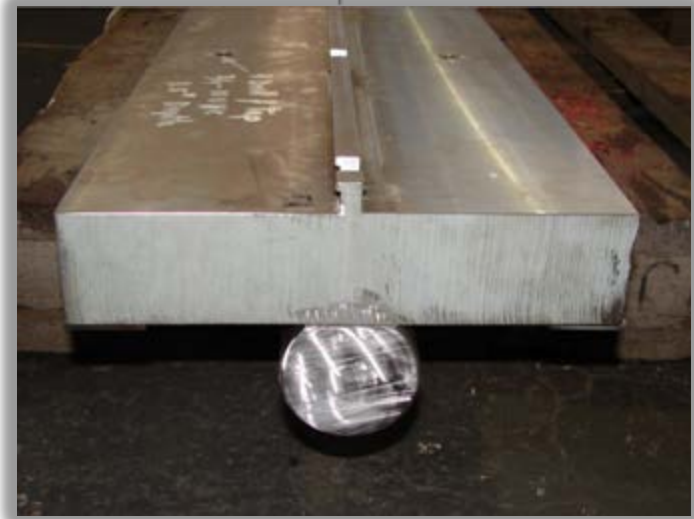
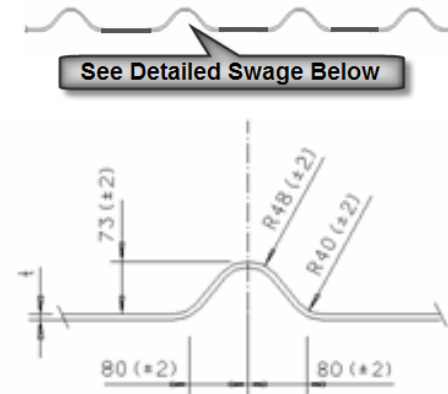
## **Swaged Bulkhead Analysis and Verification**

### **Ship Design & Material Technologies Panel**

October 2011

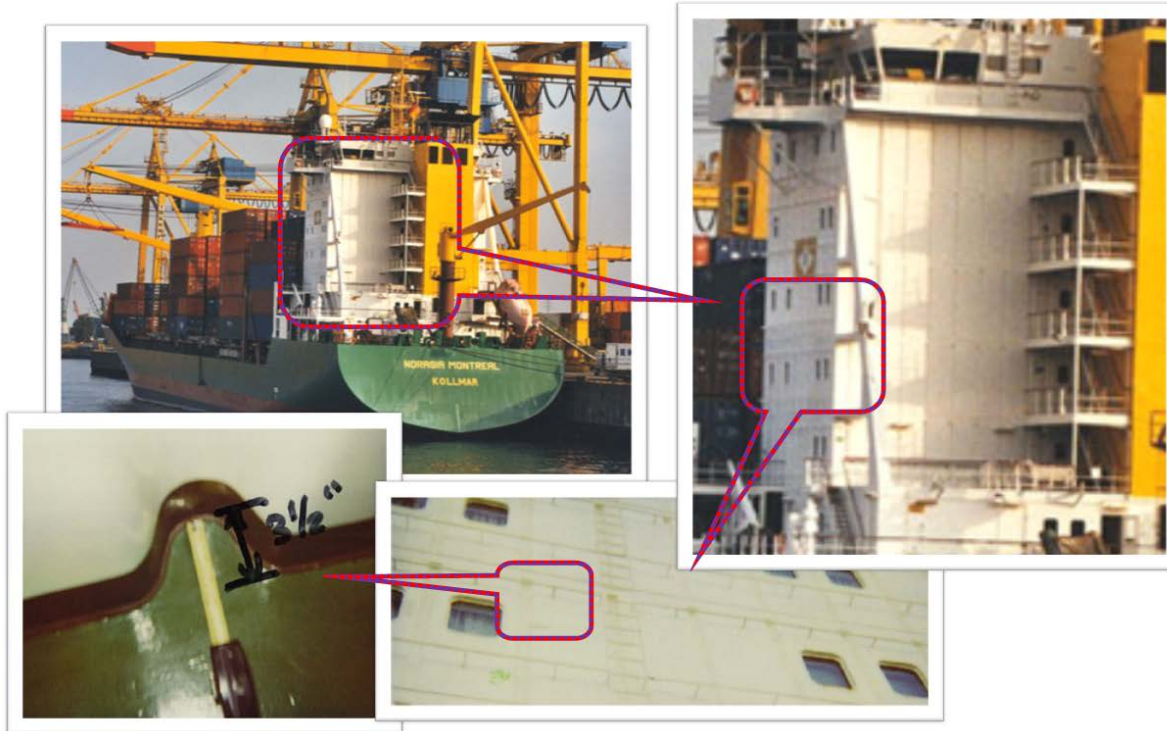
# Swaged Bulkhead Overview

- 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



# Swages Today

- Mainly used in non-load bearing applications
- No commonly accepted way of performing analysis
- No class rules defining a design methodology (ABS, DNV, Lloyds, GL, NAVSEA DDS, or ABS NVR)



**Polish  
commercial  
vessel with  
house exterior  
swaged  
bulkheads**

# Past Research

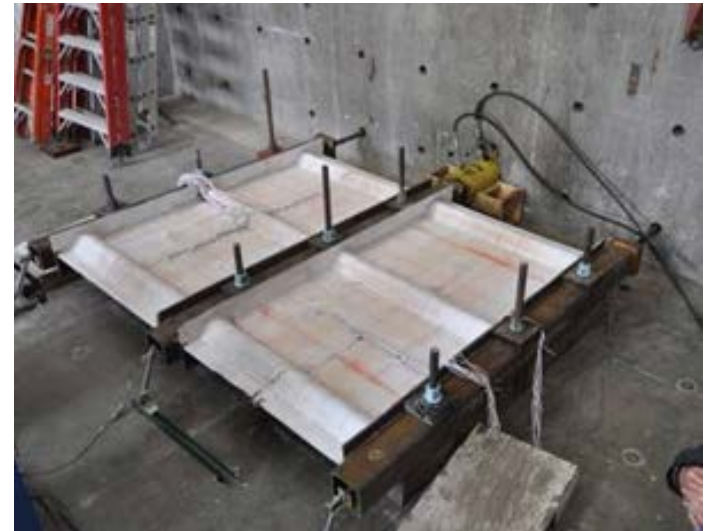
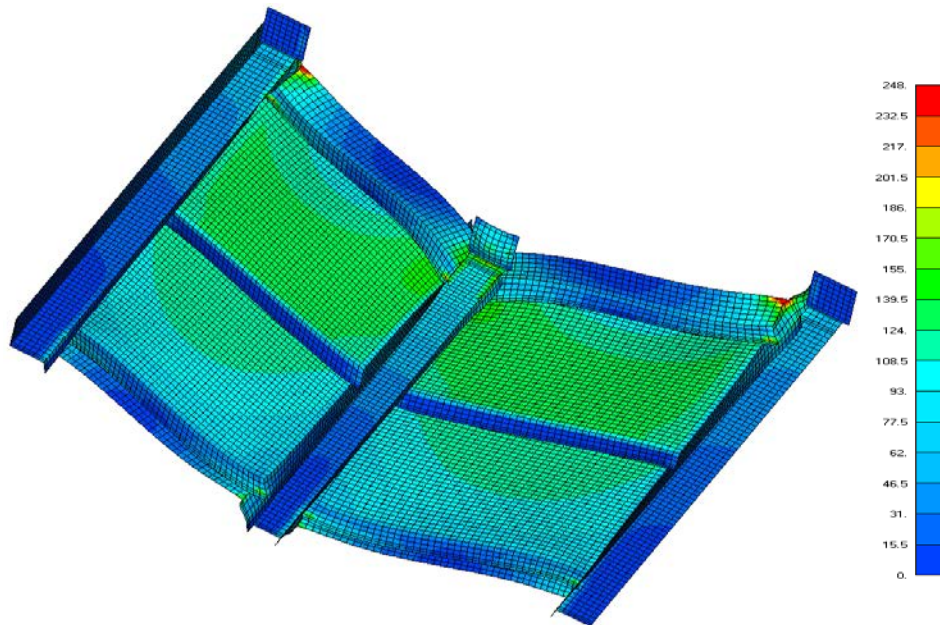
- 1963 London meeting of the Royal Institution of Naval Architects
- “Beam and Column Strength of Stiffened Plates”
  - Before Finite Element Analysis
  - Empirical calculations and destructive testing
  - Compression and lateral loading tests

TABLE I  
PROGRAMME OF AXIAL COMPRESSIVE LOADING TESTS

SWEDGES	FLAT BARS 3IN. CONNECTING WELDS AT 4" CENTRES EXCEPT WHERE INDICATED OTHERWISE	INVERTED ANGLES 3IN. CONNECTING WELDS AT 8" CENTRES	OVERALL DIMENSIONS
$A = 6.38 \text{ IN}^2$ $I = 0.914 \text{ IN}^4$ 	$A = 6.63 \text{ IN}^2$ $I = 1.43 \text{ IN}^4$ 		
$A = 6.45 \text{ IN}^2$ $I = 3.96 \text{ IN}^4$ 	$A = 7.00 \text{ IN}^2$ $I = 5.24 \text{ IN}^4$ 		
$A = 7.17 \text{ IN}^2$ $I = 11.02 \text{ IN}^4$ 	$A = 7.38 \text{ IN}^2$ $I = 12.74 \text{ IN}^4$  $A = 8.29 \text{ IN}^2$ $I = 14.11 \text{ IN}^4$  $A = 8.17 \text{ IN}^2$ $I = 14.02 \text{ IN}^4$ 	<b>THREE STIFFENER SPECIMEN</b> $I_y = 13.59 \text{ IN}^4$  $I_y = 14.13 \text{ IN}^4$  <b>FIVE STIFFENER SPECIMENS</b> $I_y = 14.13 \text{ IN}^4$  $I_y = 14.13 \text{ IN}^4$ 	
$A = 10.21 \text{ IN}^2$ $I = 29.38 \text{ IN}^4$ 		$A = 12.02 \text{ IN}^2$ $I = 29.71 \text{ IN}^4$ 	
$A = 11.84 \text{ IN}^2$ $I = 71.91 \text{ IN}^4$ 		$A = 14.29 \text{ IN}^2$ $I = 82.41 \text{ IN}^4$ 	
$A = 6.54 \text{ IN}^2$ $I = 3.40 \text{ IN}^4$ N.R. 576 ALUMINIUM ALLOY PLATE 			

# 2010 NSRP Panel Project

- Total of four specimens tested in two load profiles
- Completed linear FEA analysis
- Limited Scope
- Further testing necessary to benefit from knowledge gained



# Project Objectives

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- **Provide a body of comprehensive data**
  - Comparing calculated and actual strength characteristics
  - Shear, compressive, and out-of-plane loads
- **Develop Finite Element Analysis method allowing for the design of swaged bulkheads**
  - High level of reliability achieved for stiffened bulkhead design
  - Lead to use to wide range of applications
- **Perform studies to provide real data on cost savings**
  - Comprehensive paint adhesion study
  - Manufacturing cost comparison study

# Project Plan - Phase I

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- **Compare stiffened and swaged bulkheads**
  - **Structural behavior**
  - **Manufacturing**
  - **Life cycle costs**
- **Aluminum and Steel**
- **Swaged, bulb stiffeners, T – stiffeners**
- **Paint adhesion testing**
- **Manufacturing cost comparison study**
- **Start development of finite element analysis methodologies**
- **Perform physical testing at Powell Structural Labs, UC San Diego**
  - **Determine ultimate capacities**
- **Compare FEA predictions with testing results**



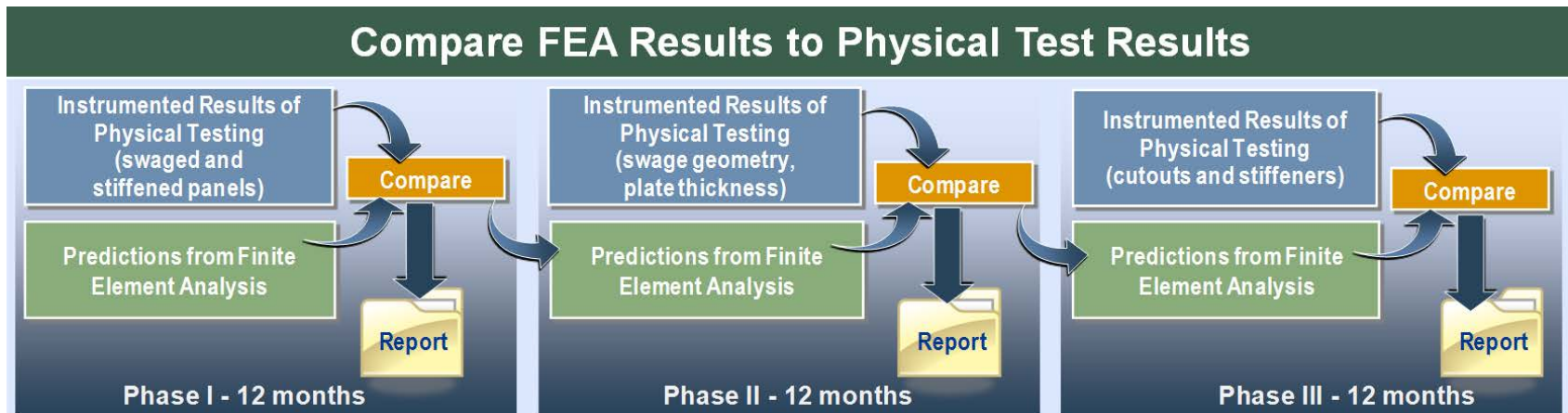
# Project Plan - Phase II

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- **Study the effects of geometric and material properties on swage bulkhead analysis**
- **Design and Manufacture three sets of swaged bulkheads**
  - **Two swage geometries**
  - **Two plate thickness**
  - **Two steel grades**
- **Review and apply FEA methodologies developed in Phase I**
- **Perform physical testing at Powell Structural Labs, UC San Diego**
- **Compare calculated and actual strength data for each combination of properties.**

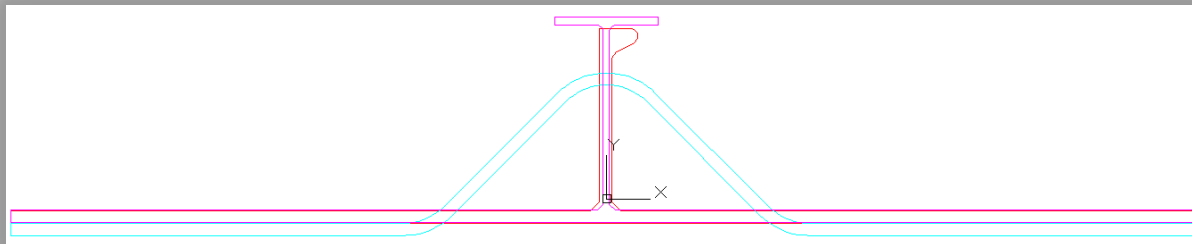
# Project Plan - Phase III

- Study the effects of cutouts and penetrations on swage bulkhead analysis
- Design and Manufacture three sets of swaged bulkheads
  - Cutouts and penetrations
  - Additional stiffeners
  - Combination of cutouts and stiffeners
- Review and apply FEA methodologies developed in Phase II
- Perform physical testing



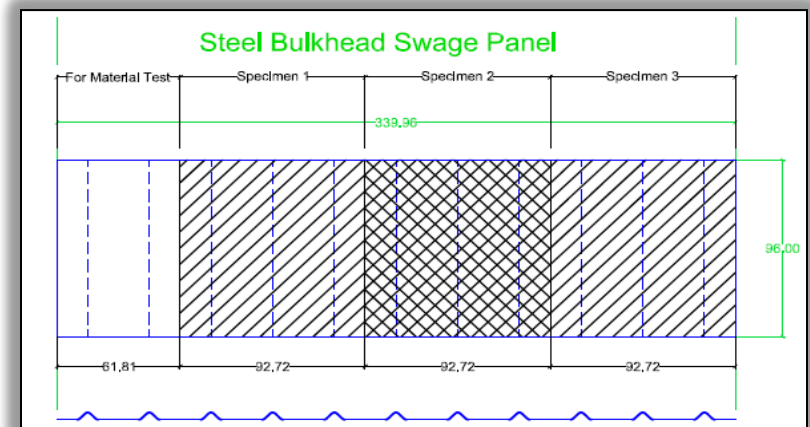
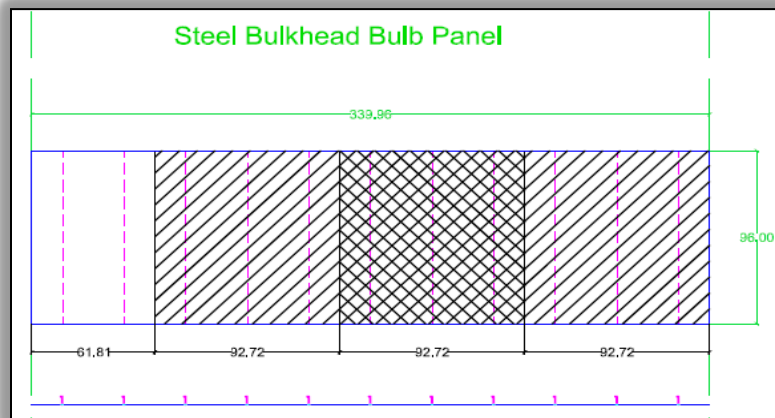
# Bulkhead Design

- **Bulkheads are designed at NASSCO using method to match section properties**
- **Start with stiffened section approved by Class for use on an existing ship**
  - Steel bulb stiffened plate from T-AKE
  - Aluminum T – stiffened plate from LCS
- **Develop swage geometry with comparable moment of inertia in the x-direction**
  - Change size of straight length without changing radius size
  - Ease of fabrication



# Bulkhead Design

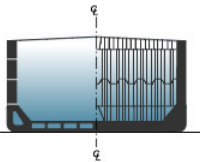
- Large bulkheads designed for paint adhesion testing at MMC
- Plates will be added to specimen edges to simulate a true ship environment, acting as decks and perpendicular bulkheads
- Next, separated into separate specimens for structural testing at UC San Diego
- Additional material available for measurement of residual stress induced from swaging process



# Finite Element Analysis Survey

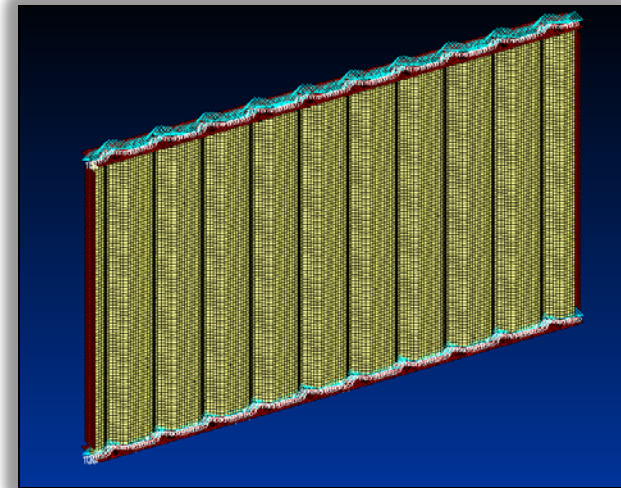
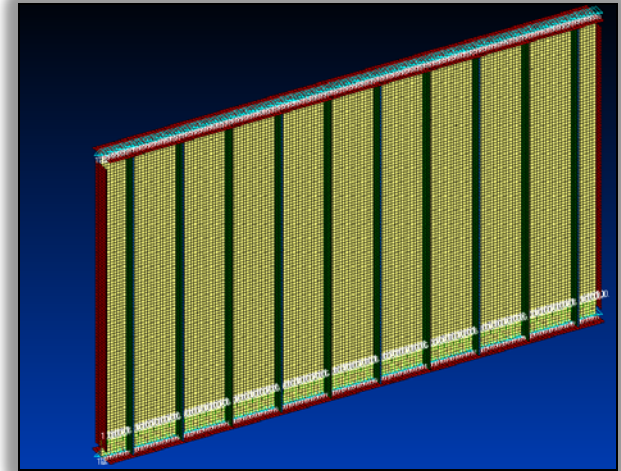
Software Package	Number of Users
Maestro	225+, including shipyards, U.S. Navy, design offices, and educational institutions
NEi Nastran	17, including major shipyards, 1 Class society, and U.S. Navy
Abaqus	1 major shipyard
MSC Patran	1 Class society, 1 foreign shipyard

**MAESTRO**  
GLOBAL STRUCTURAL ANALYSIS



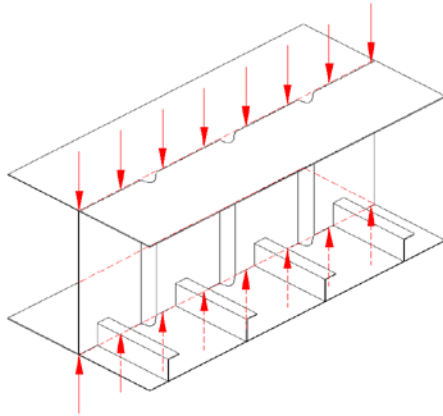
# Finite Element Analysis Survey

- Purpose of survey: identify potential FEA packages for use in this project
- NEi Nastran chosen as main tool for its capability to model/analyze relatively small sections of a ship
- Preliminary models have been created for both stiffened and swaged bulkheads
- Non-linear analysis with UC San Diego will also be done with Abaqus

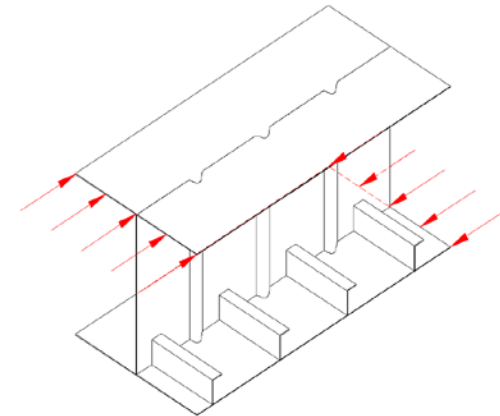


# Bulkhead Load Profiles

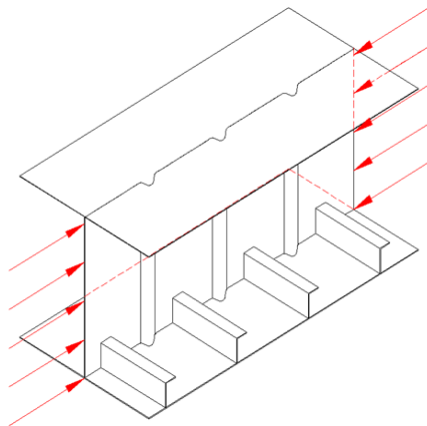
*Compression/ Vertical*



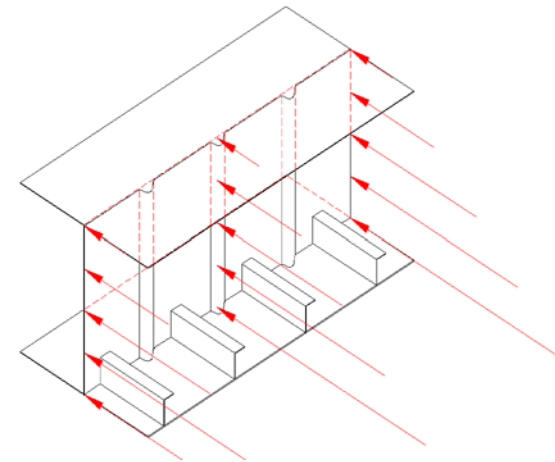
*Shear/Racking*



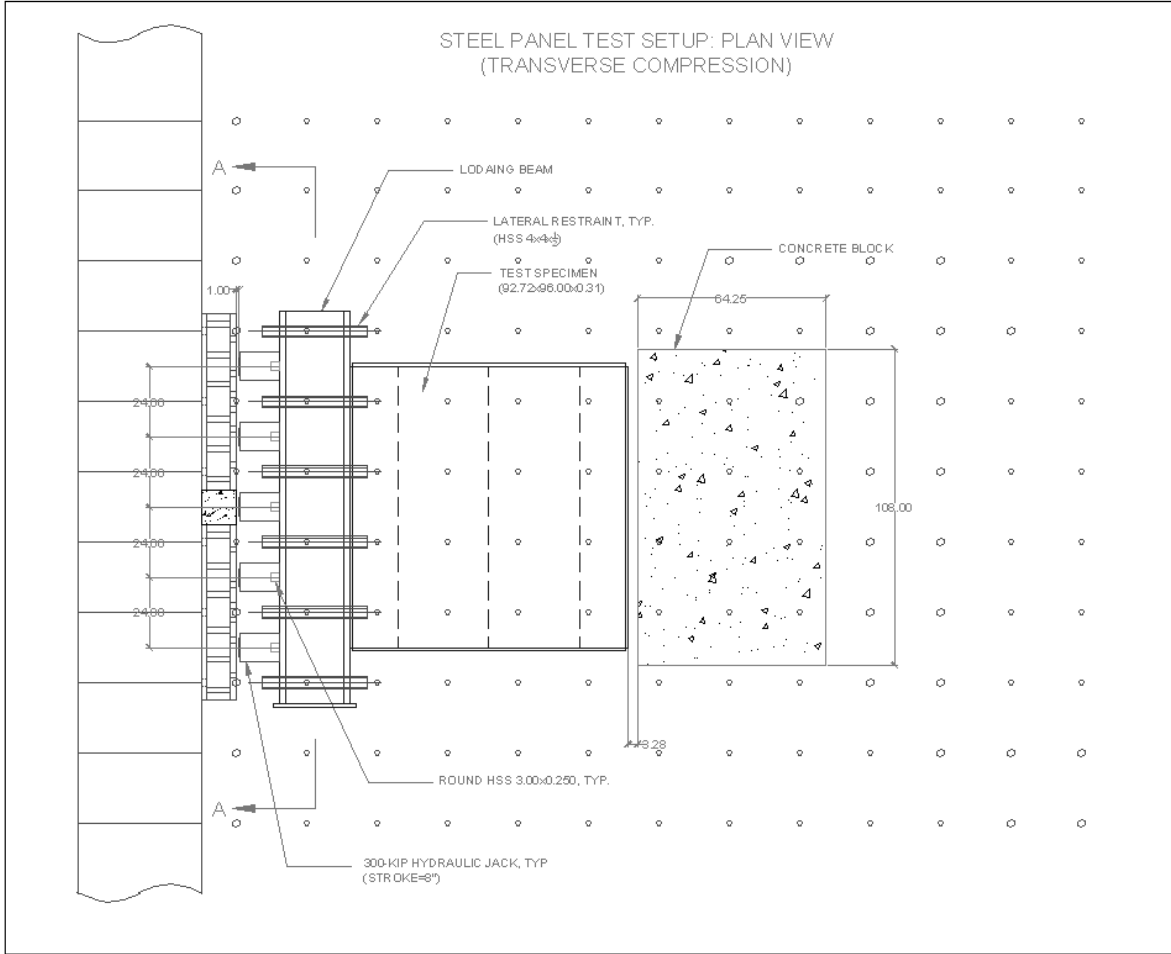
*Compression/ Longitudinal*



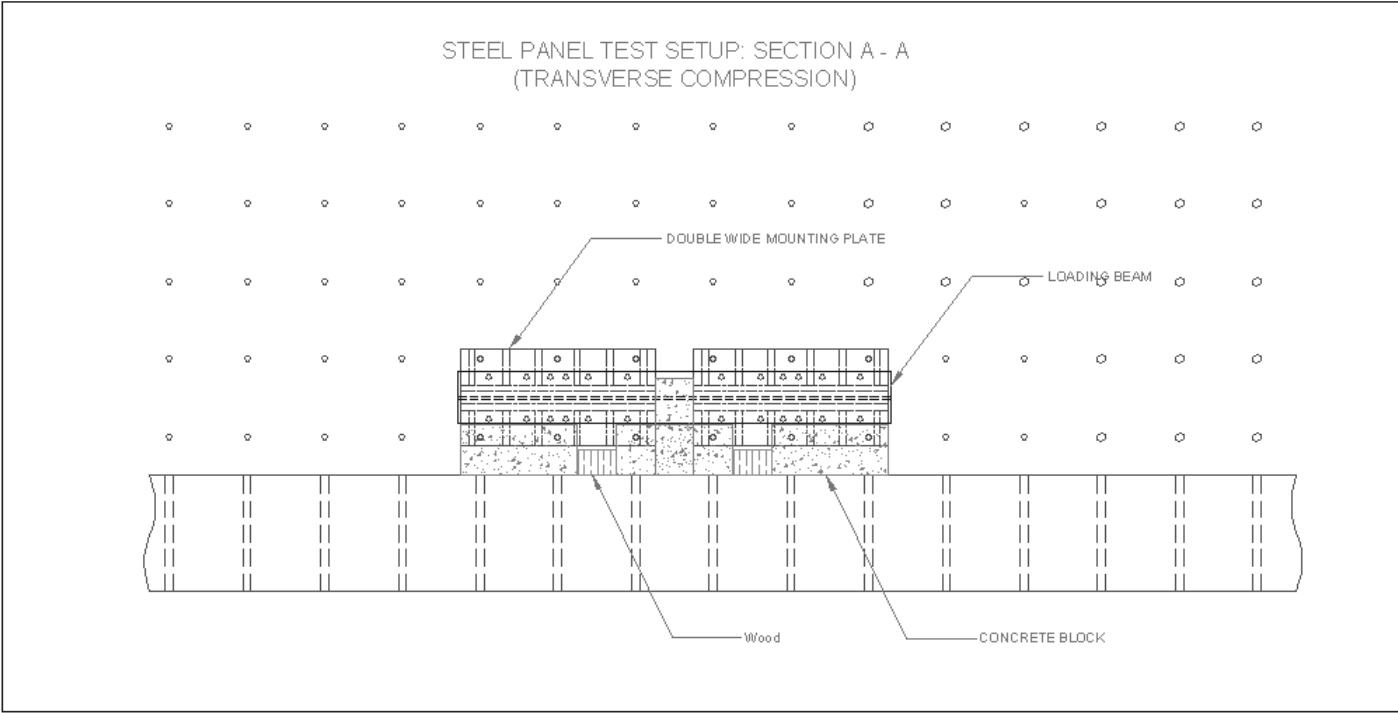
*Out-of-Plane/ Hydrostatic*



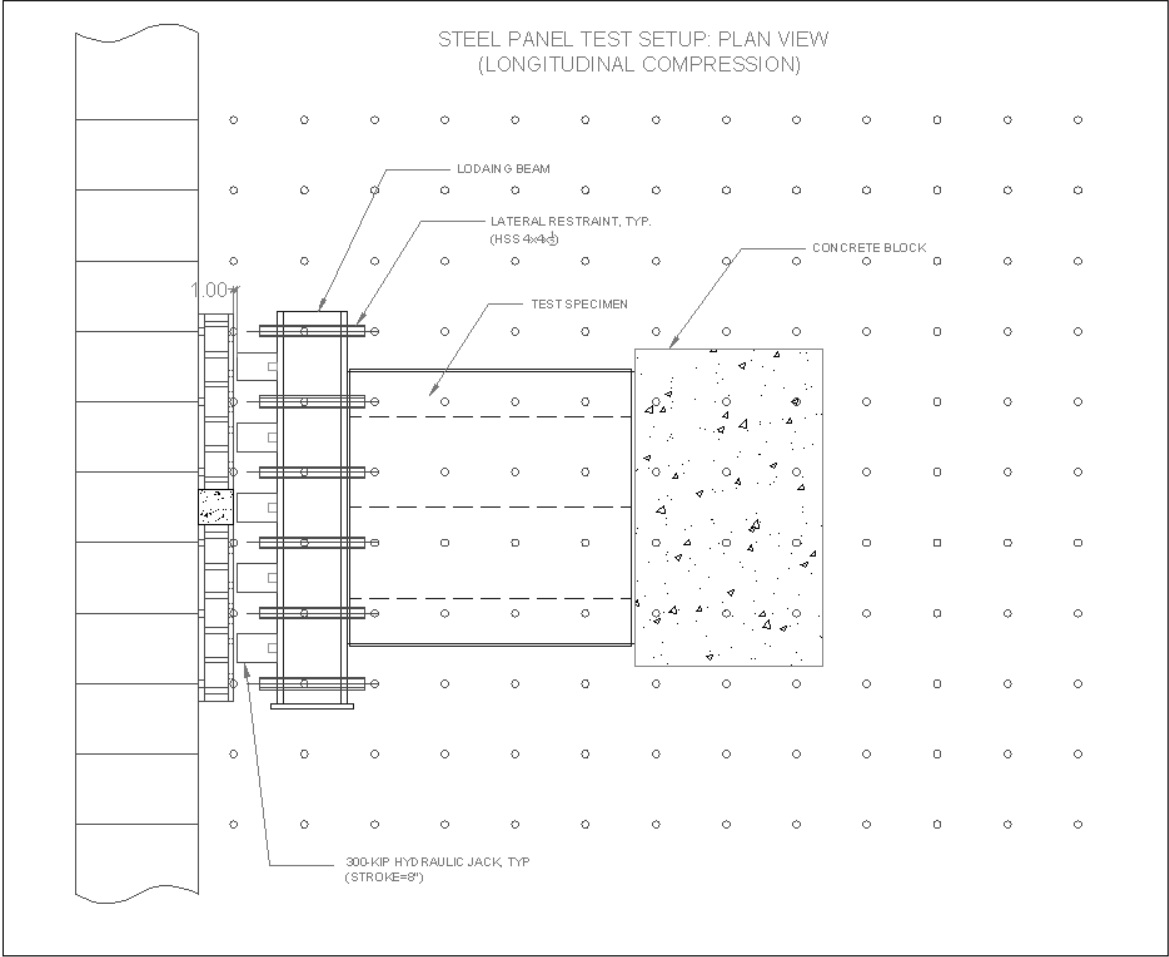
# Physical Test Plan



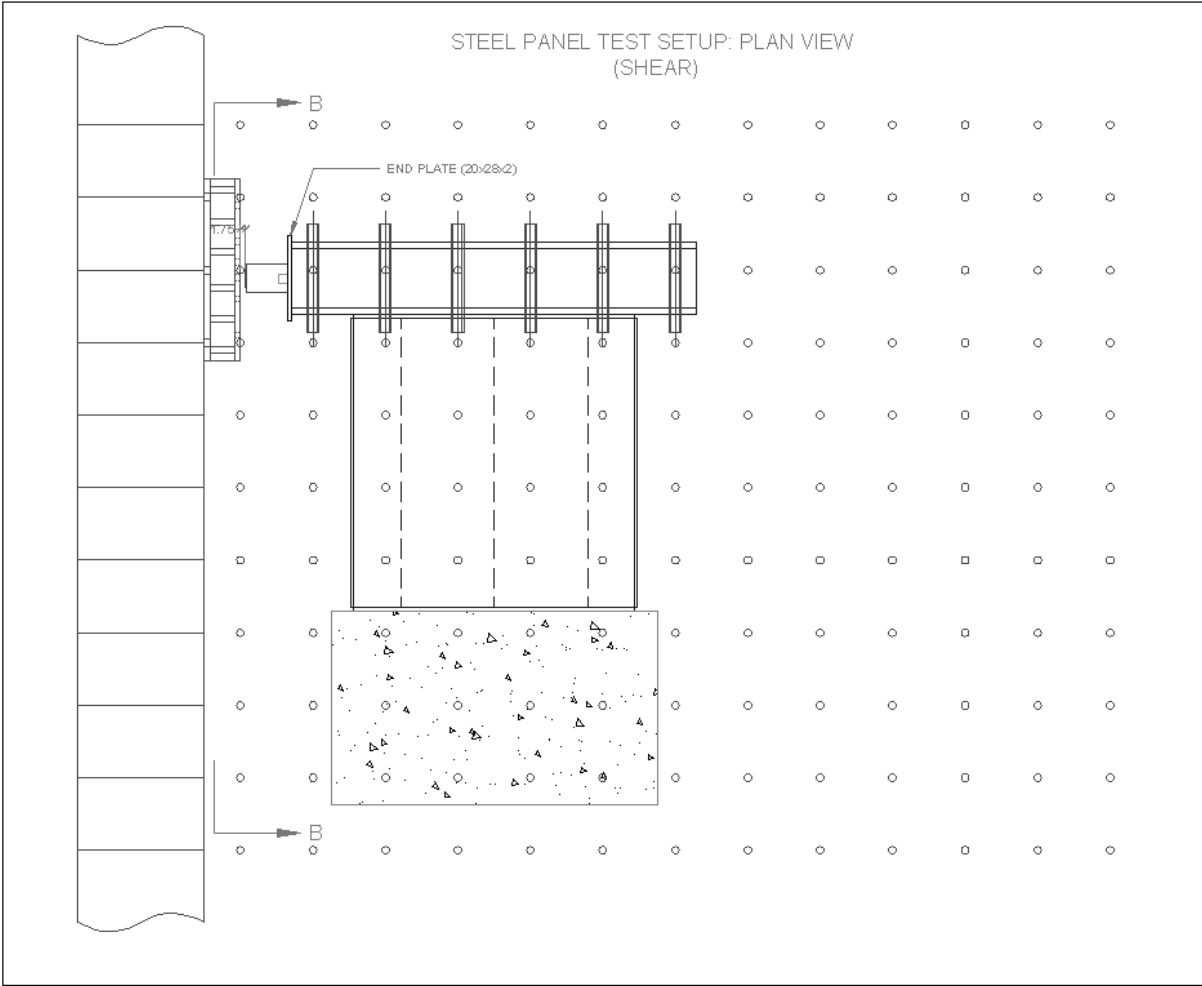
# Physical Test Plan



# Physical Test Plan



# Physical Test Plan



# Technical Progress Summary

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- **Steel and Aluminum Bulkhead design completed and provided to MMC for manufacturing**
- **Finite Element Analysis software survey completed**
- **Initial FEA methodologies developed using NEi Nastran FEA software package**
- **FEA modeling and analysis of the stiffened and swaged bulkheads initiated.**
- **Physical test configuration planning commenced with UC San Diego project team**
- **Manufacturing of test specimens underway at MMC**

# Expected Benefits of Using Swaged Bulkheads

Material Savings

Life Cycle Cost Savings

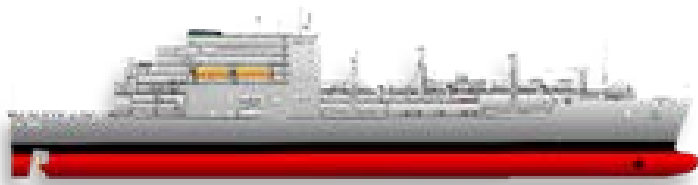
Labor Savings

Reduced Ship Weight

Reduced Bulkhead Depth

Less Environmental Impact

Improved Safety

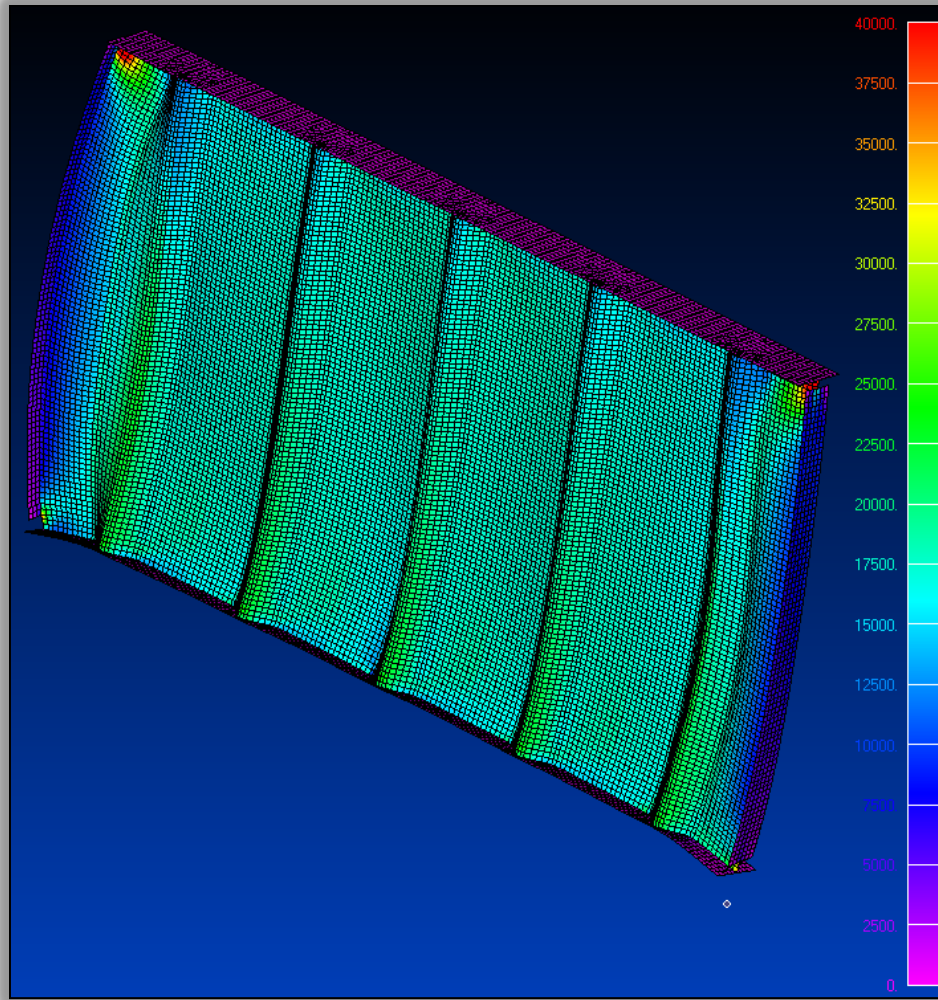


## T-AKE Potential Cost Savings

- 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)



# Thank You



**MMC**

a **FINCANTIERI** company



University of California  
**San Diego**