The Structural Model of HDPE Fish Cages using the FEA Package MSC/Marc

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Overview

Presently working on a project with Heritage Salmon at their twenty-cage site in Eastport, ME USA to evaluate the structural integrity of their deployed system for exposed applications.

1. **Identify historical Problem Areas**

2. **Deploy Instrumentation**
   - **Nine Load Cells in Moorings and on Cages**
   - **Three Current Meters (waves – insignificant)**

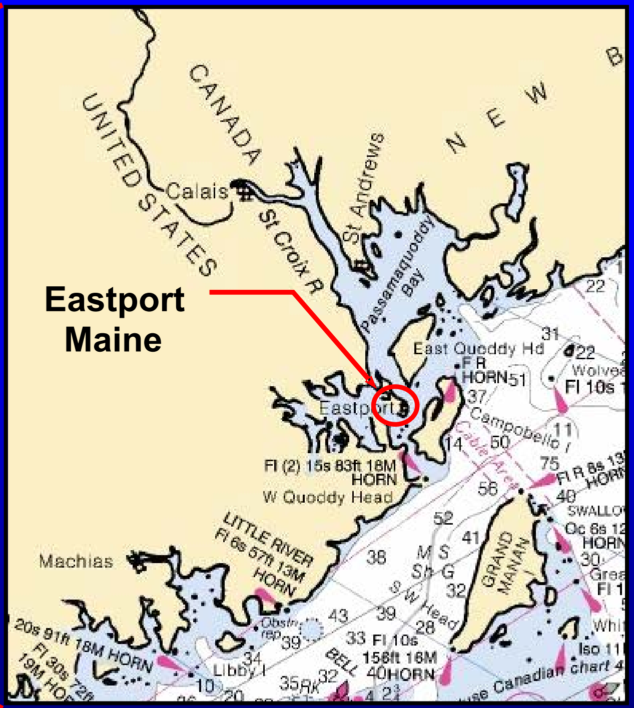
3. **Evaluate Computer Models for Calculating Loads**

4. **Build Structural Models of Cages***

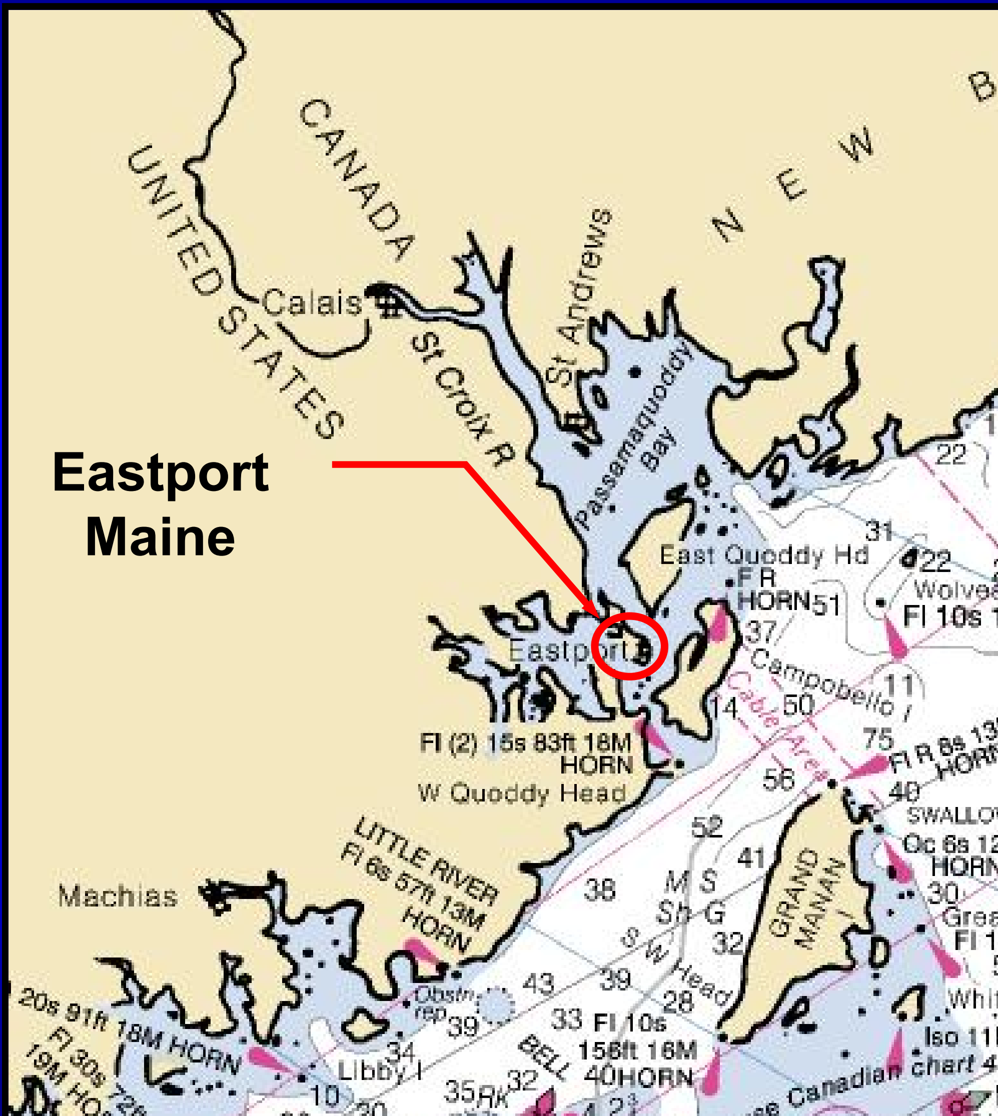
5. **Identify Possible Exposed Sites**
   - **Obtain Wave Data**
   - **Obtain Current Data**

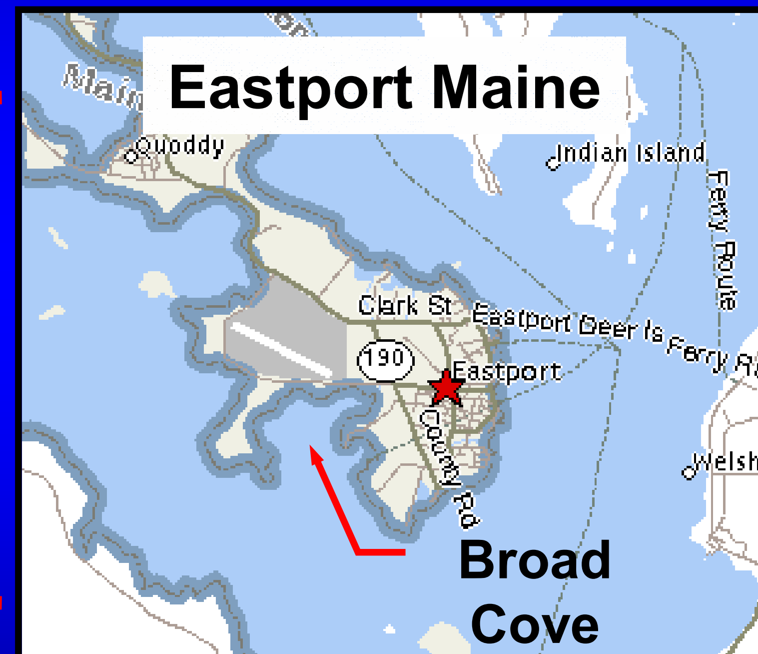
6. **Use Exposed site environmental data as input to validated computer models to assess gear survivability**

Eastport Maine Salmon Farm Site



Eastport Maine Salmon Farm Site





Field Study: The “Focus Area”

Cage Rim Properties

1. **Cage**
   - Material - HDPE
   - Circumference - 100 m
   - Diameter – 32 m

2. **Rims**
   - Double Rimmed
   - Pipe Diameter – 316 mm
   - Thickness – 15 mm

3. **Stanchions**
   - Overall Height – 1.2 m
   - Pipe Diameter – 140 mm
   - Slides over rims

4. **Handrail**
   - Pipe Diameter – 110 mm

Cage Rim with attached Load Cell Data Recorder

Cage Structural Modeling (MSC/Marc)

Methodology

1. Modeling HDPE
   - Localized Failure and Shell Elements
   - Stress-strain characteristics
   - Rates of Loading
2. Lab Tests
   - Circular Ring Experiments
   - Material Tensile Experiments
3. Circular Ring FEA
   - Material Properties/B.C
   - Results
4. FEA of the Net Pen

Modeling HDPE Pipe

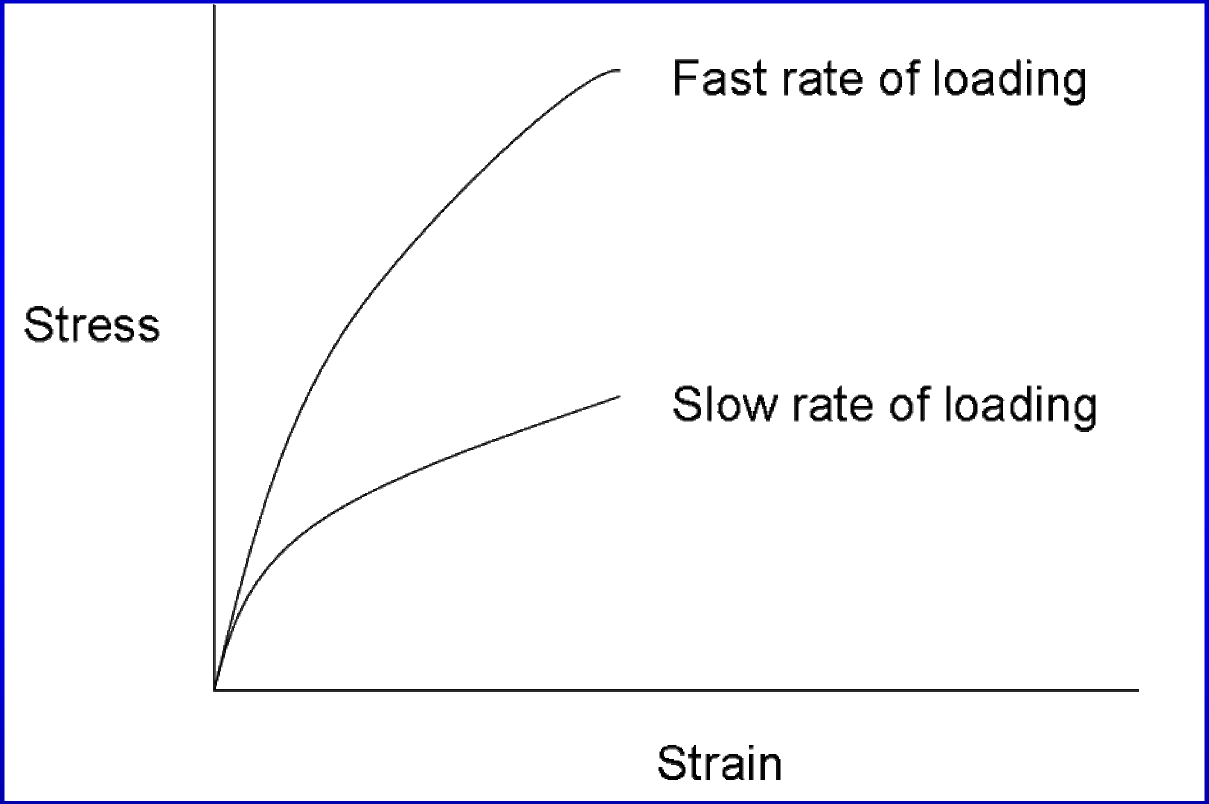
1. It was decided to model the curved cylindrical pipe by focusing on **local** as opposed to global failure

2. Shell Elements: Appropriate for Pipe. In this case thick-walled shell elements were used

Thickness/radius = 0.122

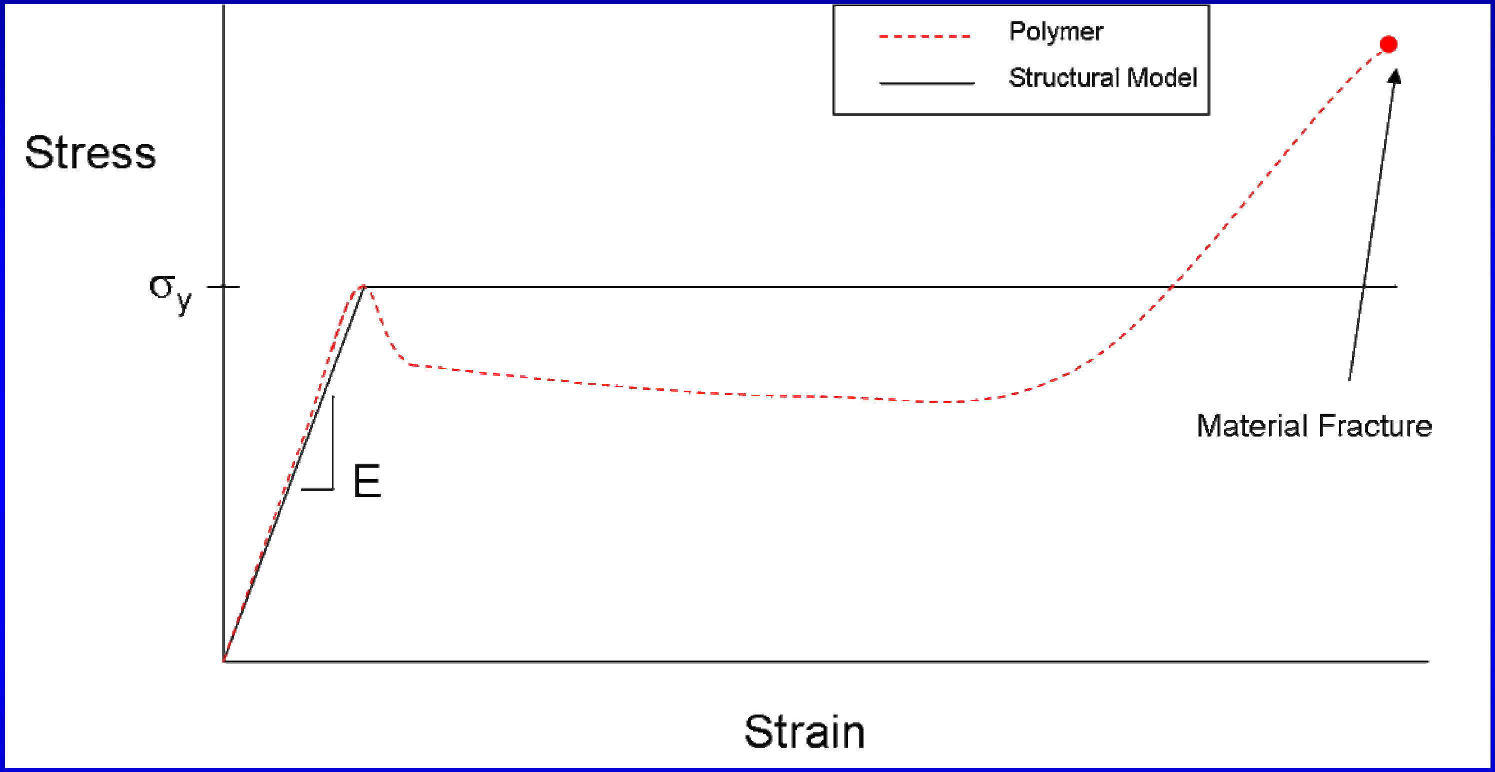
Modeling HDPE Pipe

What are the material properties?



Visco-elastic Material: Properties depend on load rates.

Modeling HDPE Pipe



The difference between the polymer and the structural model curves depends upon the rate at which the specimen is loaded

Localized Failure of Curved Cylindrical Shells

- **The model is constructed and boundary conditions are applied.**
- **A load, representing the net drag, is increased with time. As the simulation progresses (and the load increases), the stress in each element increases.**
- **Once the stress in the element reaches the yield stress, the applied load is distributed to the surrounding elements.**
- **This continues and causes a localized material failure.**
- **The model was deemed to fail when over ½ of the pipe diameter elements reached the yield stress.**

Modeling HDPE Pipe

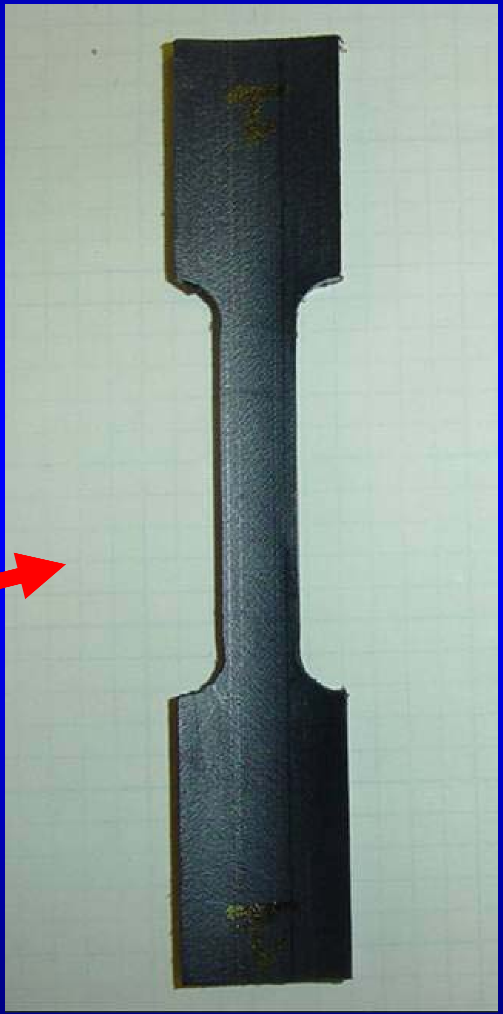
What do you use for Load Rate and Young's Modulus ?

HDPE Material Tensile Tests

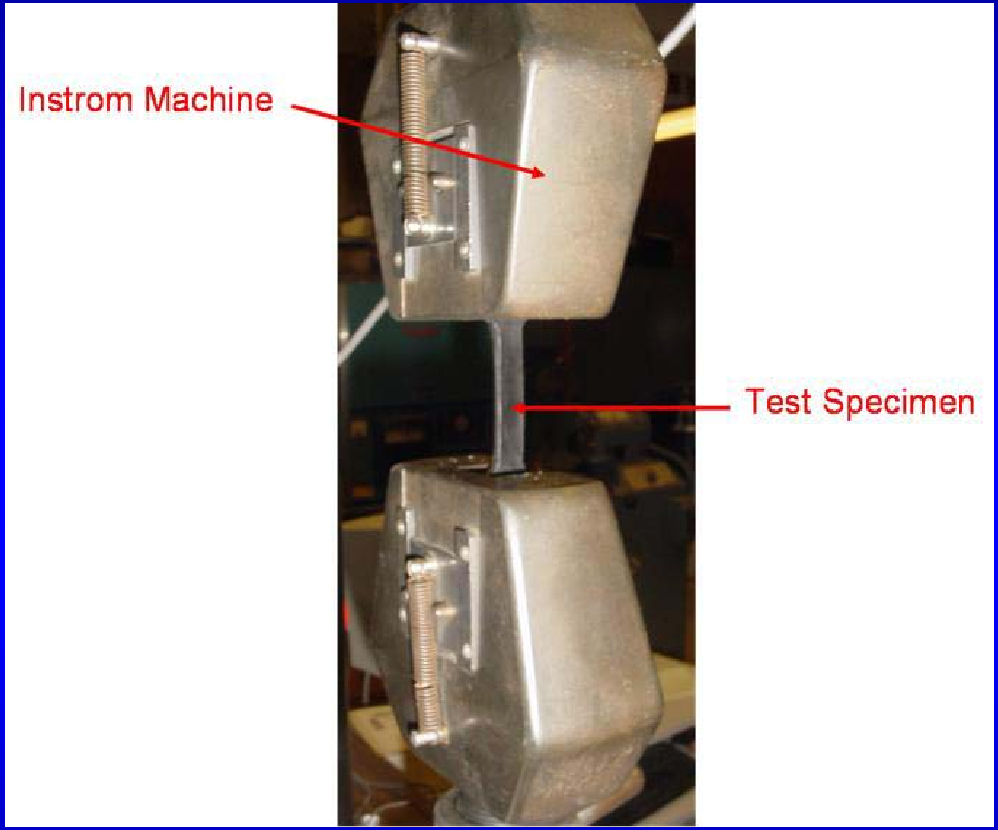
Test Samples !!

A sample of HDPE before it was tested.

The length of the sample is approximately 5 inches



HDPE Material Tensile Tests

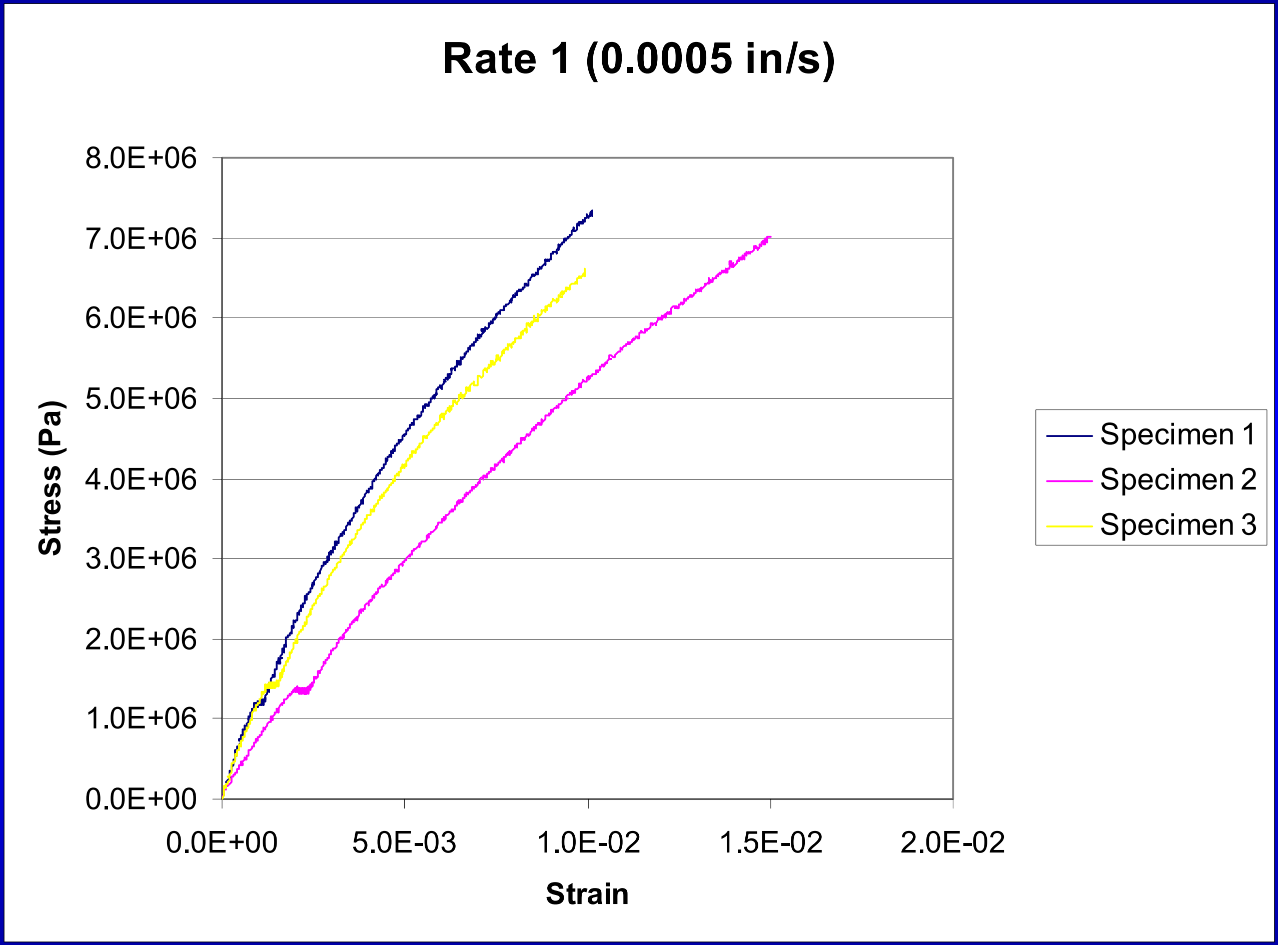


HDPE sample placed into the 88.9 kN (20,000 lbf) instron machine for testing

HDPE Material Tensile Tests

Sample tested to failure. It was displaced at total of 6.35 cm (2.5 inches).

HDPE Material Tensile Tests



Stress strain plot of the 3 samples loaded at 0.0127 mm/sec (0.0005 in/s)

HDPE Material Testing

The modulus of elasticity values obtained from the experiments

Sample	Modulus of Elasticity Rate 1 0.0127 mm/s	Rate 2 0.127 mm/s	Rate 3 1.27 mm/s
1	7.794×10^{8} Pa	9.524×10^{8} Pa	1.179×10^{9} Pa
2	5.090×10^{8} Pa	6.728×10^{8} Pa	7.717×10^{8} Pa
3	7.126×10^{8} Pa	9.267×10^{8} Pa	1.165×10^{9} Pa
Average	6.670×10^{8} Pa	8.373×10^{8} Pa	1.039×10^{9} Pa

Value used in the FEA model

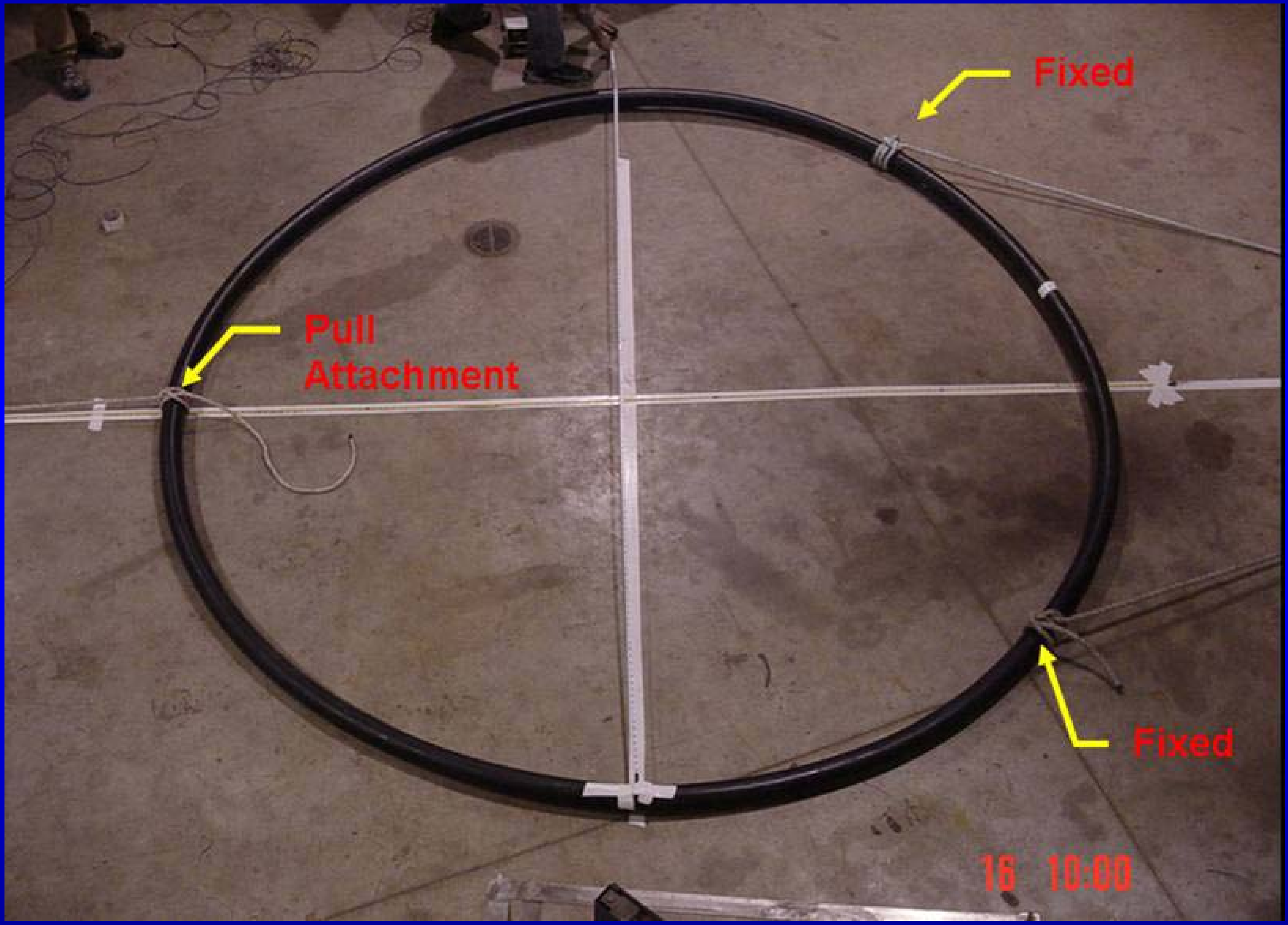
Circular Ring Experiments

The next step was to get our hands dirty

1. **Failure Test using Circular Rings**
   - **3.66 m diameter**
   - **8.9 cm pipe**
   - **5.60 mm Thickness**

2. **Five individual Tests**

Circular Ring Experiments



Un-deformed rim before load was applied

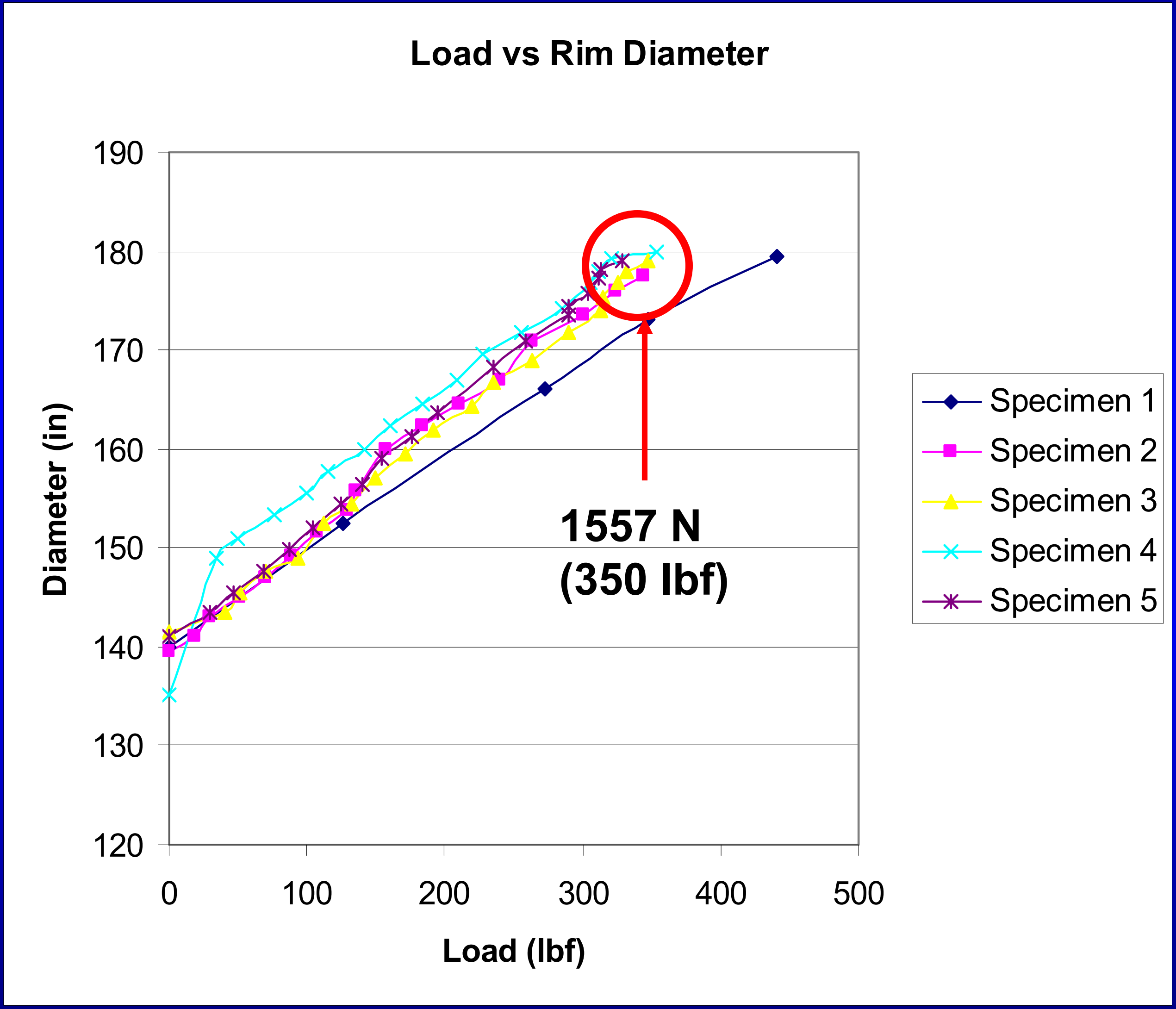
Circular Ring Experiments

Deformed rim under load

Circular Ring Experiments

Local buckling occurred at line attachment

Circular Ring Experiments



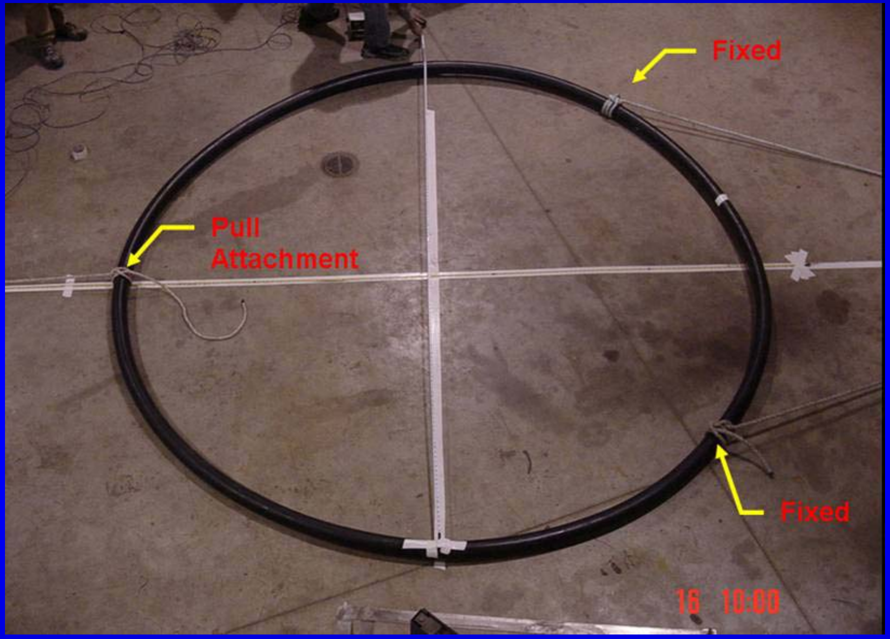
Structural Modeling HDPE Pipe Circles

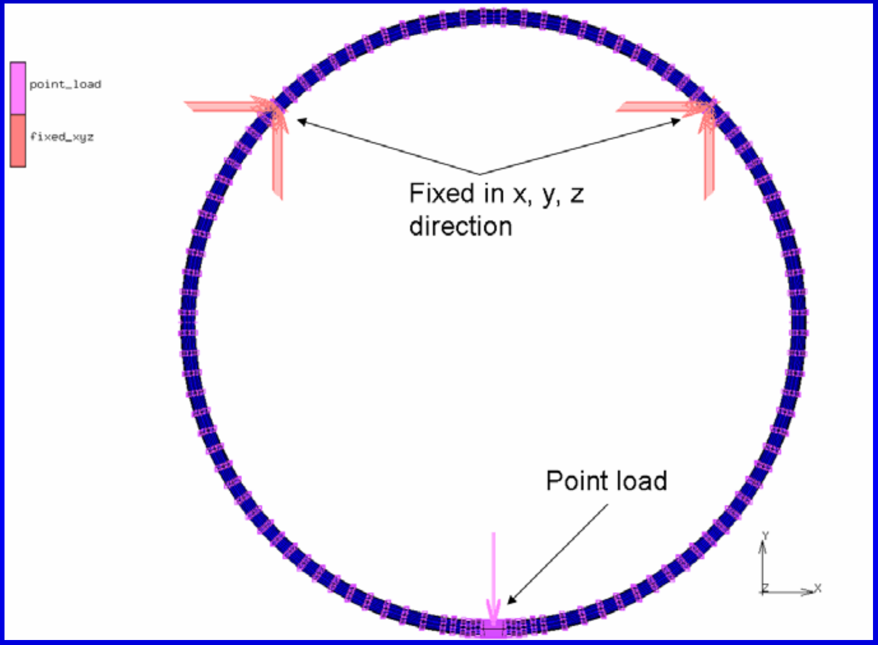
The Lab test was "simulated" using the FEA Model

Parameter	Value
Overall Diameter	3.66 m
Pipe Diameter	8.89 cm
Wall Thickness	0.574 cm
Material	HDPE
Modulus of Elasticity	6.67×10^{8} Pa
Poisson's Ratio	0.42
Yield Stress	2.413×10^{7} Pa

The geometric and material properties of the pipe circle

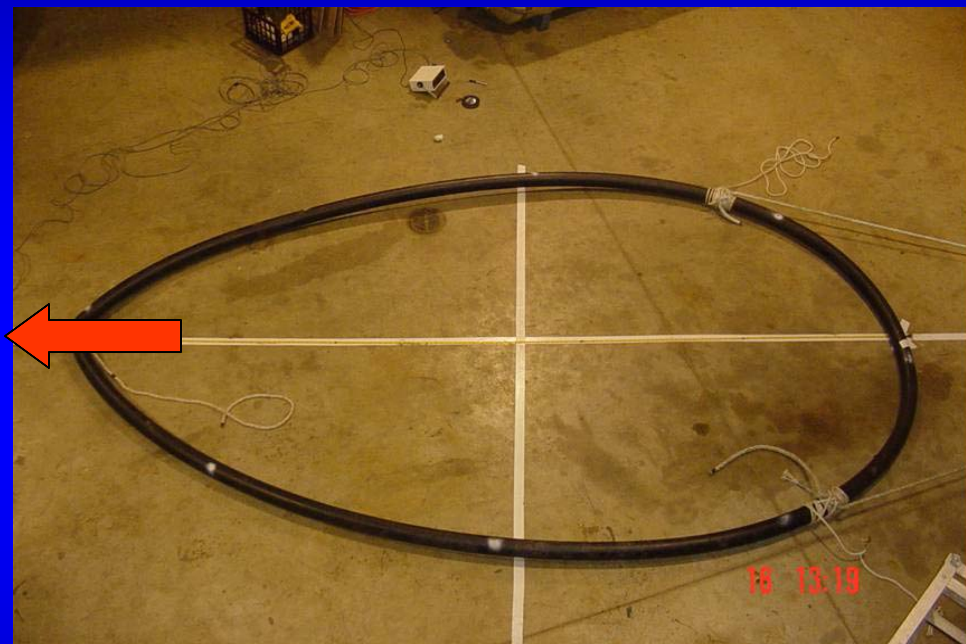
Structural Modeling HDPE Pipe Circles

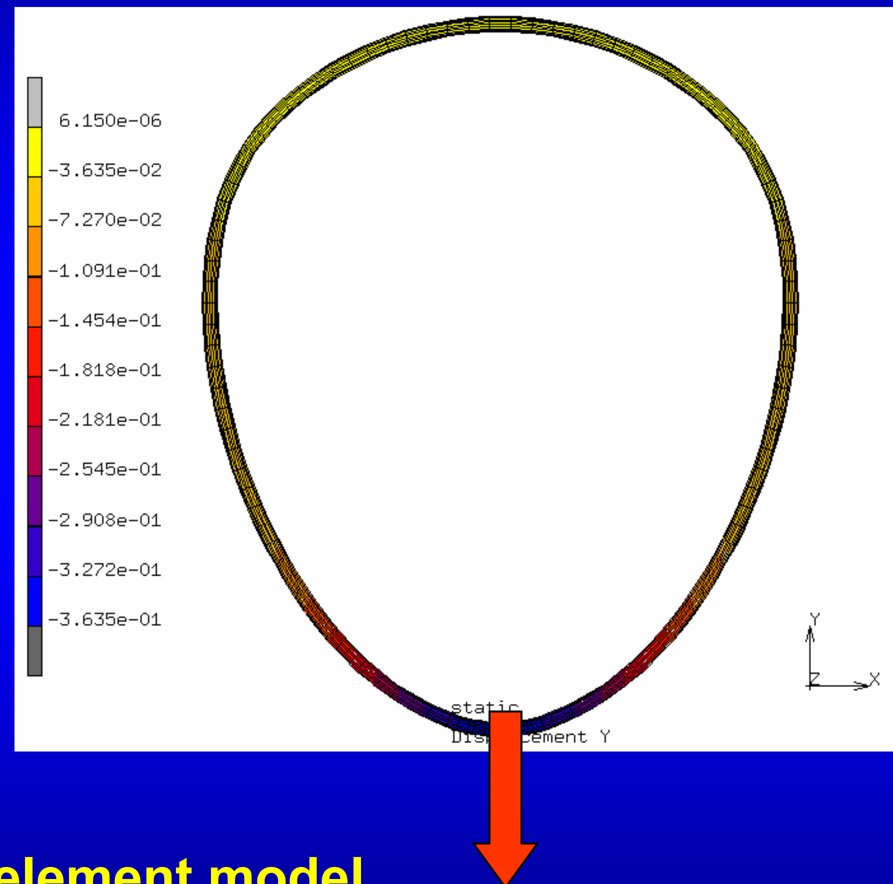




The boundary locations of the circular ring model

Structural Modeling HDPE Pipe Circles

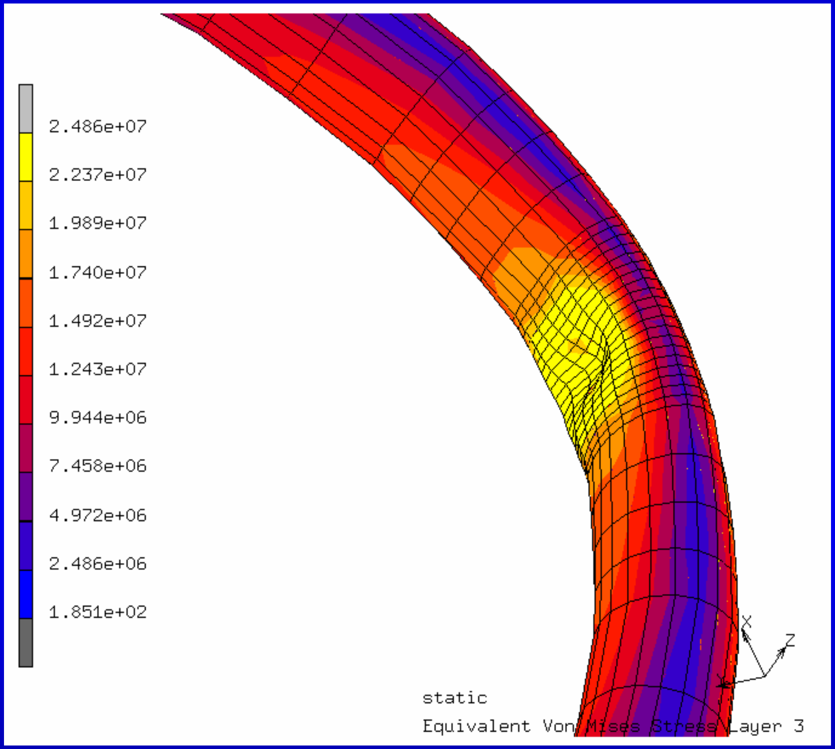




The entire rim deformed in the finite element model. The shape is similar to the deformed rim tested in the laboratory

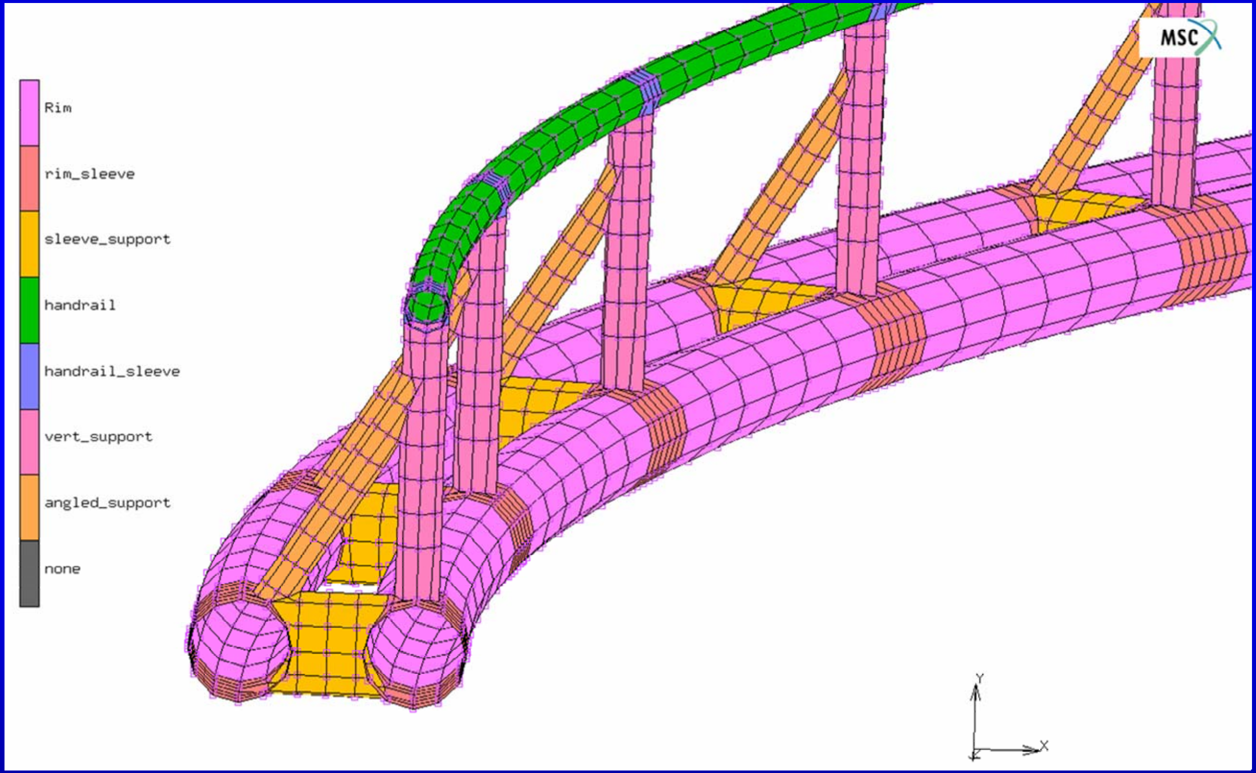
Structural Modeling HDPE Pipe Circles

Local buckling in MSC/MARC. The deflection is magnified 3 times



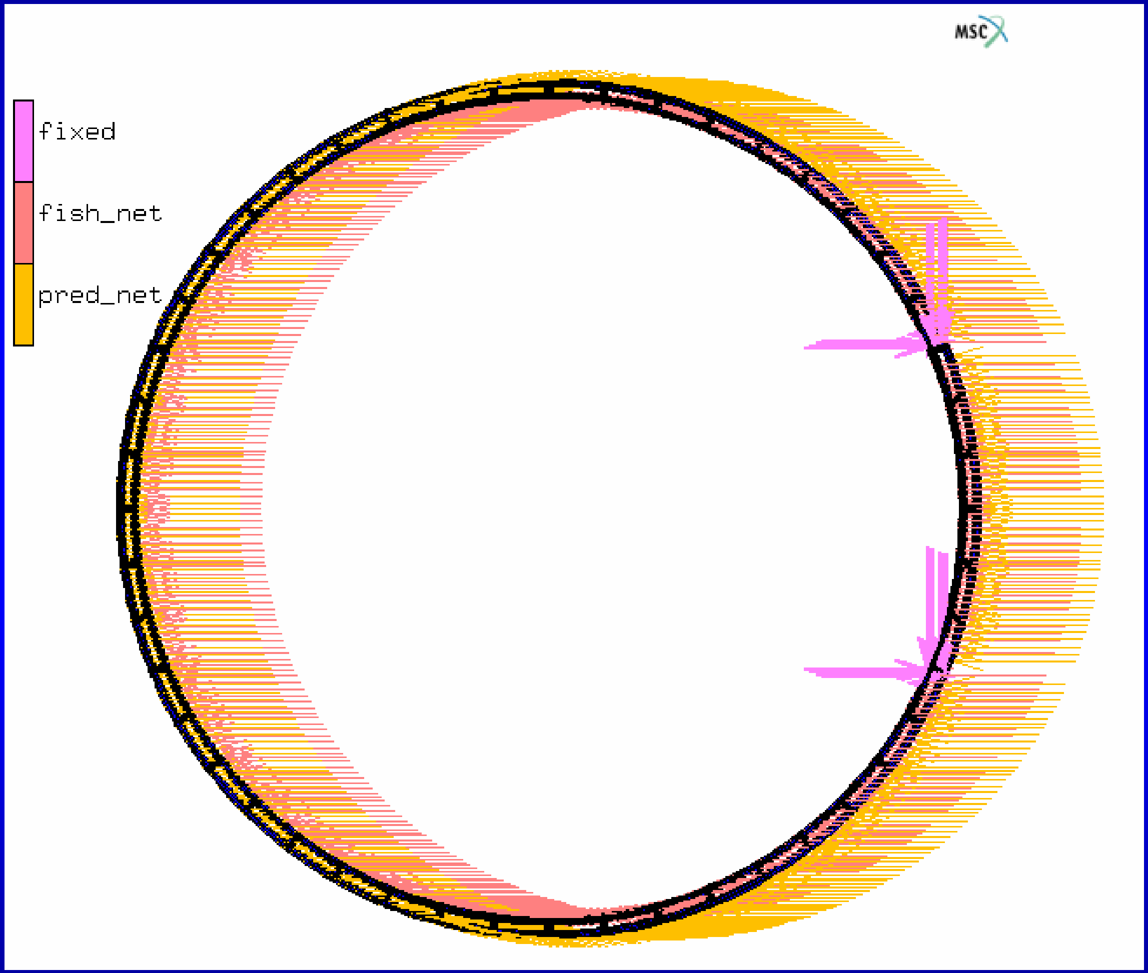
The resulting load at material failure was 1777 N (399 lbf), 14.7% larger than the average measured critical load

Structural Modeling of the HDPE Net Pen



An FEA model of a portion of the surface rings used in a salmon net pen

Structural Modeling of the HDPE Net Pen



The boundary conditions used with the surface ring model of the net pen

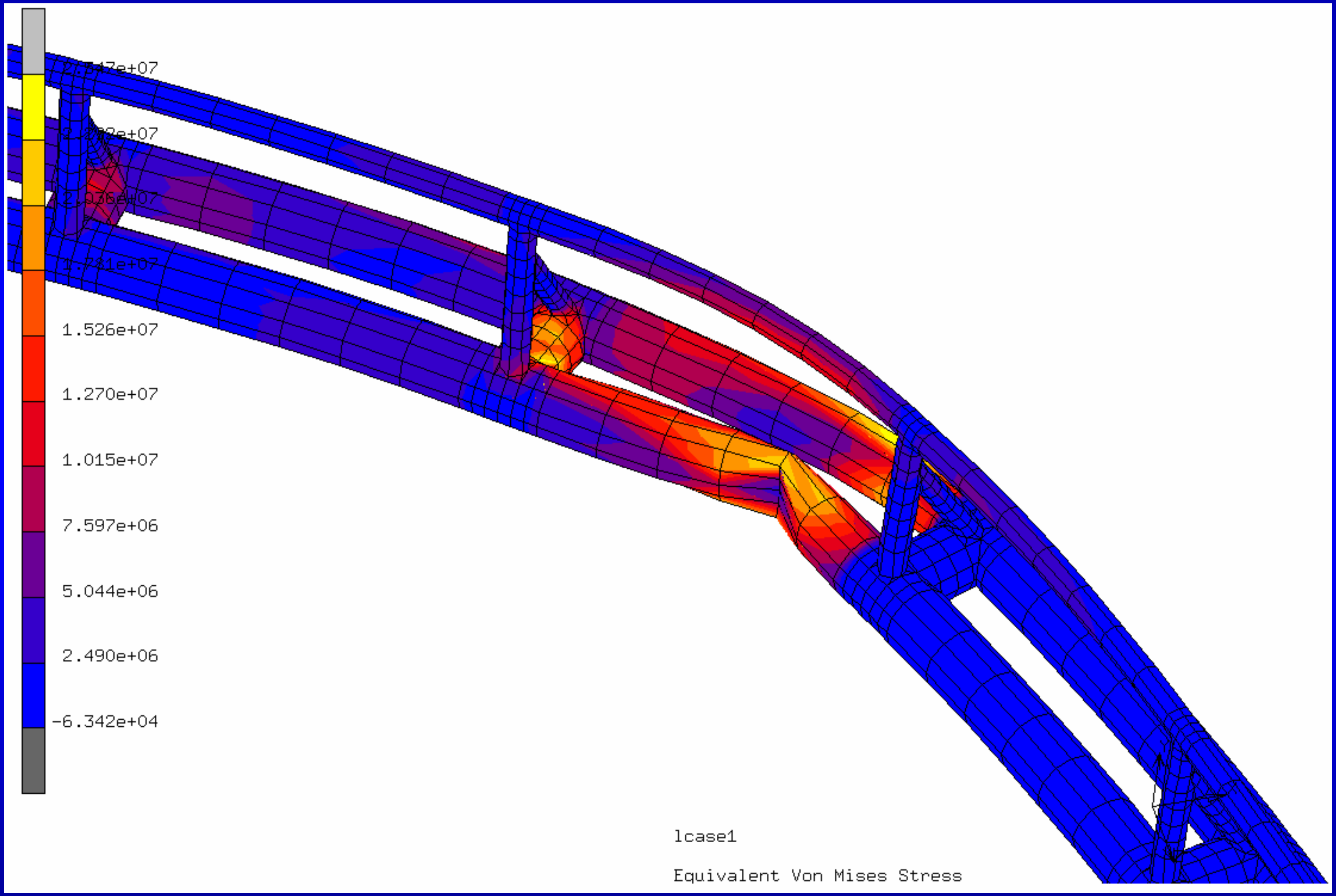
Structural Modeling of the HDPE Net Pen

The cage modeling particulars used in the FEA model

Component	Parameter	Value
Cage	Overall Diameter	31.8 m
	Circumference	100 m
	Material	HDPE
	Modulus of Elasticity[a]	6.67×10^{8} Pa
	Poisons ratio[a]	0.42
	Yield Stress[a]	2.413×10^{7} Pa
Rim(s)	Pipe diameter	0.3238 m
	Thickness	0.0198 m
Rim Sleeve	Pipe diameter	0.4064 m
	Thickness[b]	0.0690 m
Sleeve Support	Pipe diameter	0.3238 m
	Thickness	0.0198 m
Handrail	Pipe diameter	0.1143 m
	Thickness	0.0057 m
Handrail Sleeve	Pipe diameter	0.1413 m
	Thickness[b]	0.0242 m
Vertical Support	Pipe diameter	0.1413 m
	Thickness	0.0134 m
Angled Support	Pipe diameter	0.1143 m
	Thickness	0.0108 m

[a] All components used in the model has the same modulus of elasticity, poisons ratio and yield stress.
[b] Sleeves take the rim or handrail pipe thickness into account.

Structural Modeling of the HDPE Net Pen



It was determined that the cage rims would fail if the load at one attachment location reached <u>10,265 lbf</u>

Important Modeling Considerations

1. Boundary Conditions
   - Cage Attachments
   - Nets
   - Flotation

2. Load Rates
   - Changes Modulus of Elasticity
   - Quantify in Wave and Currents

3. Yield Stress (e.g. failure criteria)
   - Are we doing it right?
   - Does it change due to weathering?