# Recent 20-Hurricane Tests on Samson Subropes

## Summary of Test Results and Implications for a Rope Remaining Life Model

# Project Tasks

1. *Evaluate Damaged Rope (a)* ***Remaining Strength****, and (b)* ***Remaining Life Methods.***
2. *Evaluate Non-invasive Inspection of Damage.*
3. *Develop New Concepts for Non-Invasive Inspection*
4. *Identify the Most Reliable Insert Tests to Determine Fitness For Service. Emphasis will be on remaining life predictions but we will describe and evaluate other methods*
5. *Determine the Value of Insert Recovery & Testing vs. the Risk*.

# Recent Samson Rope Test Results

- In an MMS project in progress, we subjected Samson subropes to the equivalent of 20 Hurricane Katrinas – 20,000 cycles of 60%/30%.
- 20 Hurricanes, the equivalent of one Hurricane Katrina making a direct hit each year for a 20-year life, caused a measured reduction in breaking strength of about 6%.

# Test Results

| Samson Subrope Test Summary | | |
|---|---|---|
| | | |
| Sample | "New" Rope Break Strength | "Cycled" Rope Break Strength |
| 1 | 79.19 | 75.56 |
| 2 | 80.45 | 74.21 |
| 3 | 80.36 | 76.24 |
| Avg. Break, Kips | 80 | 75.34 |
| COV | 0.88% | 1.37% |

# Cycling 4 Subropes in Parallel

# Yarn Tensile Test Results

| Textile yarn | Mean Breaking Strength N | SD N | CV % | Mean Breaking Extension % | SD N | CV % | Number tested |
|---|---|---|---|---|---|---|---|
| Inner | 78.1 | 5.1 | 6.5 | 11.5 | 1.0 | 8.8 | 15 |
| Outer | 77.4 | 4.6 | 6.0 | 11.4 | 0.9 | 7.9 | 16 |

New Rope Results

| Textile yarn | Mean Breaking Strength N | SD N | CV % | Mean Breaking Extension % | SD N | CV % | Number tested |
|---|---|---|---|---|---|---|---|
| Inner | 74.0 | 7.3 | 9.9 | 10.2 | 1.1 | 11.1 | 15 |
| Outer | 78.9 | 6.4 | 8.2 | 11.0 | 1.0 | 9.2 | 11 |

Cycled Rope Results

# Conclusions 1

1. The only major cause of rope structural integrity loss during a 20-year project life was found to be third-party damage to the mooring system components. Only *in-situ* inspection of the mooring ropes by ROV video (not insert recovery/testing) can effectively discover this damage.
2. Because of the demonstrated structural integrity of polyester ropes, the major concerns of rope creep and cyclic wear damage have been proven to be unfounded.

# Conclusions 2

1. Based on a risk/benefit analysis, insert recovery/testing has been determined to have no benefit in reducing the risk of normal operations. Consequently, recovery and testing of inserts in installed mooring systems should be discontinued.
2. The accuracy of subrope damage detection using current methods (ROV video fly-bys) should be sufficient to detect rope jacket damage, which should in turn be inspected in more detail by methods recommended in this report.

# Conclusions 3

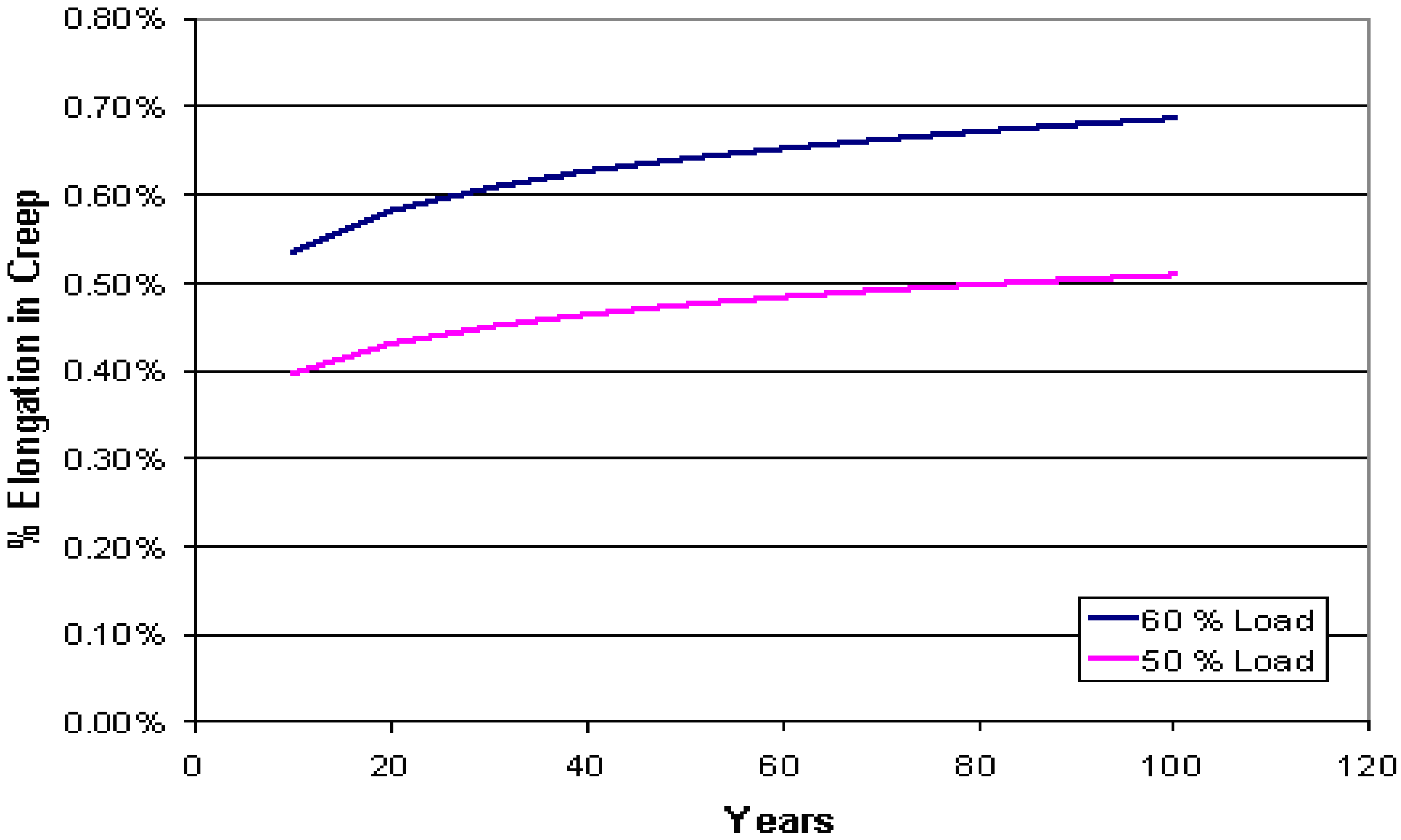
- A mooring rope found with jacket damage should be considered a critical inspection zone. Damaged rope segments should be replaced as soon as possible.

- A rope cycling test based on being subjected to 20 hurricanes with the strength of Katrina should be adopted as a "benchmark" for qualification testing of different designs and brands of polyester rope. Rope creep is less affected by the specifics of design and more affected by the number of fibers resisting the load, so no specific test is needed for creep.

# Conclusions 4

- A new strain-based hypothesis is presented for estimating the remaining life performance of a polyester rope, based on a prediction of major hurricane exposure and the design life of the mooring system.

# Creep % Elongation vs. Years



# Creep Life Predictions (TTI)

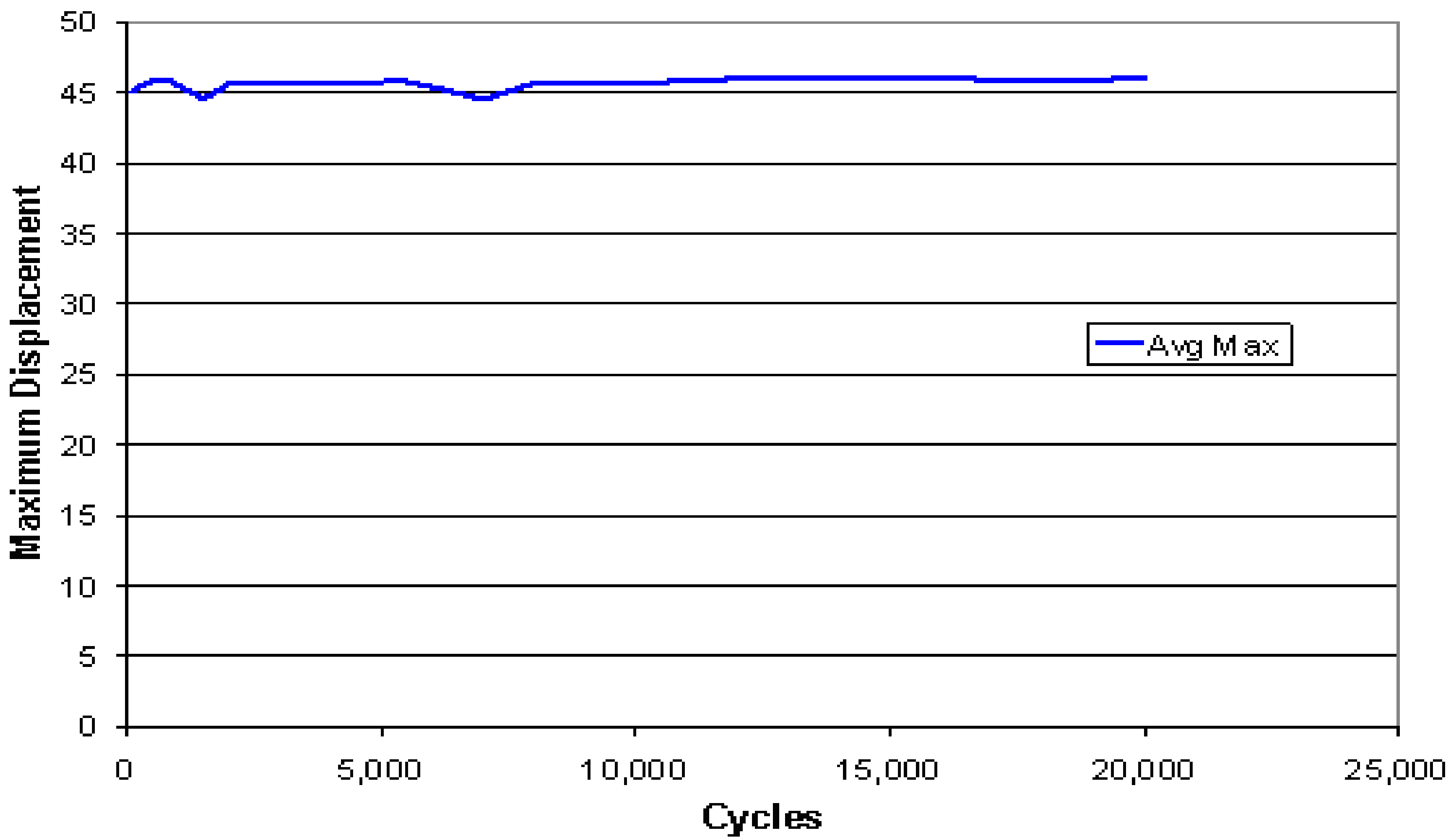
| Tested Break Strength | Calculated Potential Strength | Creep Rupture Life Prediction |
|---|---|---|
| 50% | 36.7% | 8992 yr |
| 55% | 40.4% | 2040 yr |
| 60% | 44.1% | 463 yr |
| 65% | 47.7% | 105 yr |
| 75% | 55.1% | 5.4 yr |
| 85% | 62.4% | 102 days |

# The 20-Hurricane Test

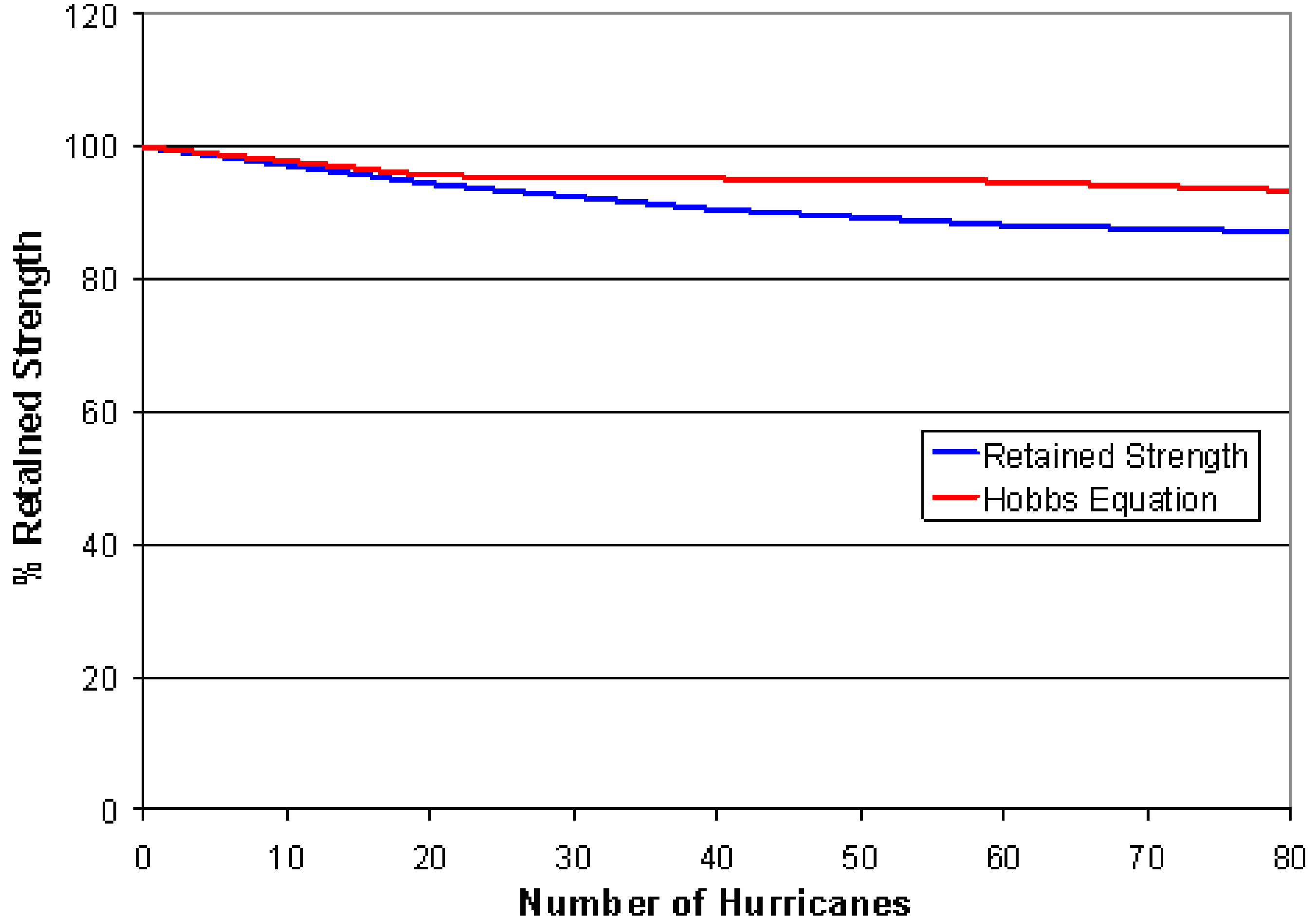
**Two years have passed since hurricanes Katrina and Rita struck various production structures in the Gulf of Mexico, and even now the memories of the destructive power of those storms is vivid in the industry.**

**We propose that a useful and meaningful measure of the ability of a polyester mooring system to perform under the worst storm cycles would be to determine how the rope in a mooring leg would resist 20 hurricanes with the strength of Katrina, with a direct hit from 1hurricane/yr for a period of 20 years.**

# Subrope Elongation vs. # Cycles



# Subrope Strength vs. No. Hurricanes



# Rope Damage Mechanisms (MMS JIP)

- **Strain Concentration**
- **Unwind.**
- **Damaged Length.**
- **Recoil Damage**
- **Rope Jacket Tightness.**
- **Subrope Pitch.**

# Strain-Based Failure Hypothesis

$$\%\epsilon_{\text{FAILURE}} = \%\epsilon_{\text{WEAR}} - \%\epsilon_{\text{CREEP}}$$

Where $\%\epsilon_{\text{WEAR}}$ varies between say 10% or 10.5% for an un-cycled but bedded-in rope to the strain associated with maximum cyclic wear 60% load occurring at over 8 million cycles. The failure % elongation for this latter condition would be 60% of 10.5% (the new rope breaking strain), or 6.3%.

# Strain-Based Failure Hypothesis 2

$\%\epsilon_{CREEP}$ = 0.5% for 20 years (for example)

We can then use the cyclic wear break load decay curve in prior figure to determine the $\%\epsilon_{WEAR}$.

# Rope Failure Mechanisms

***Undamaged Rope:***

1. Exceeding maximum allowable rope tension at some time over rope life
2. Failure due to rope creep caused by sustained tension loading over life
3. Failure due to cyclic wear over project life

# Rope Damage Mechanisms

- **Third-party damage** such as down lines severing the polyester
- **Poor quality splices** which reduce rope strength. The greater the number of inserts placed in the mooring spread, the higher the risk of a bad splice.
- **Dropped rope** causing possible ingression of sand, which increases potential rope wear during cycling

# The Characteristics of Damaged Rope 1

1. A partly damaged subrope in the rope body will tend to break completely before the rope reaches its undamaged break strength.
2. External damage, like a knife cut caused by rubbing wire rope, will tend to cause at least partial damage to at least 4 to 8 subropes in the rope body.
3. When certain subropes break, the strain energy released tends to heat up and melt adjacent subropes as the damaged subropes release strain energy.

# The Characteristics of Damaged Rope 2

4. As we consider the 3 points above, the ROV-attended bug would need to find a "necking down of the rope", either with or without jacket damage.
5. If any measurable necking down is found, the rope segment affected would need to be replaced, because it is almost impossible (based on testing in the MMS JIP) to have a 10% or less strength reduction.

# FMEA Format

- **Potential failure modes**
  - The physical description of the manner in which a failure occurs
- **Potential effects of failure**
  - The outcome or consequences of the failure
- **Causes of failure**
  - The root cause of the listed failure

# FMEA Format

- Occurrence Index
  - The likelihood that failure mode will occur during the design life
- Severity Index
  - The ranking associated with the most serious effect for the given failure mode
- Detection Index
  - The ranking associated with the best detection design control

# FMEA Format

- **Risk Priority Number (RPN)**
  - **The product of Occurrence, Severity, and Detection**

$$RPN = O * S * D$$

# FMEA Process

- Select the team
- Review scope for details / limits

- Qualitative FMEA
  - Brainstorm potential failure modes
  - List the potential effects of each failure mode
  - List the root causes for each failure mode

- Quantitative FMEA
  - Assign a severity rating for each effect
  - Assign an occurrence rating for each failure mode and/or effect
  - Assign a detection rating for each failure mode and/or effect
  - Assign a remediation cost rating for each failure mode and/or effect
  - Calculate a risk priority number (RPN) for each effect

# Operations Risk Analysis

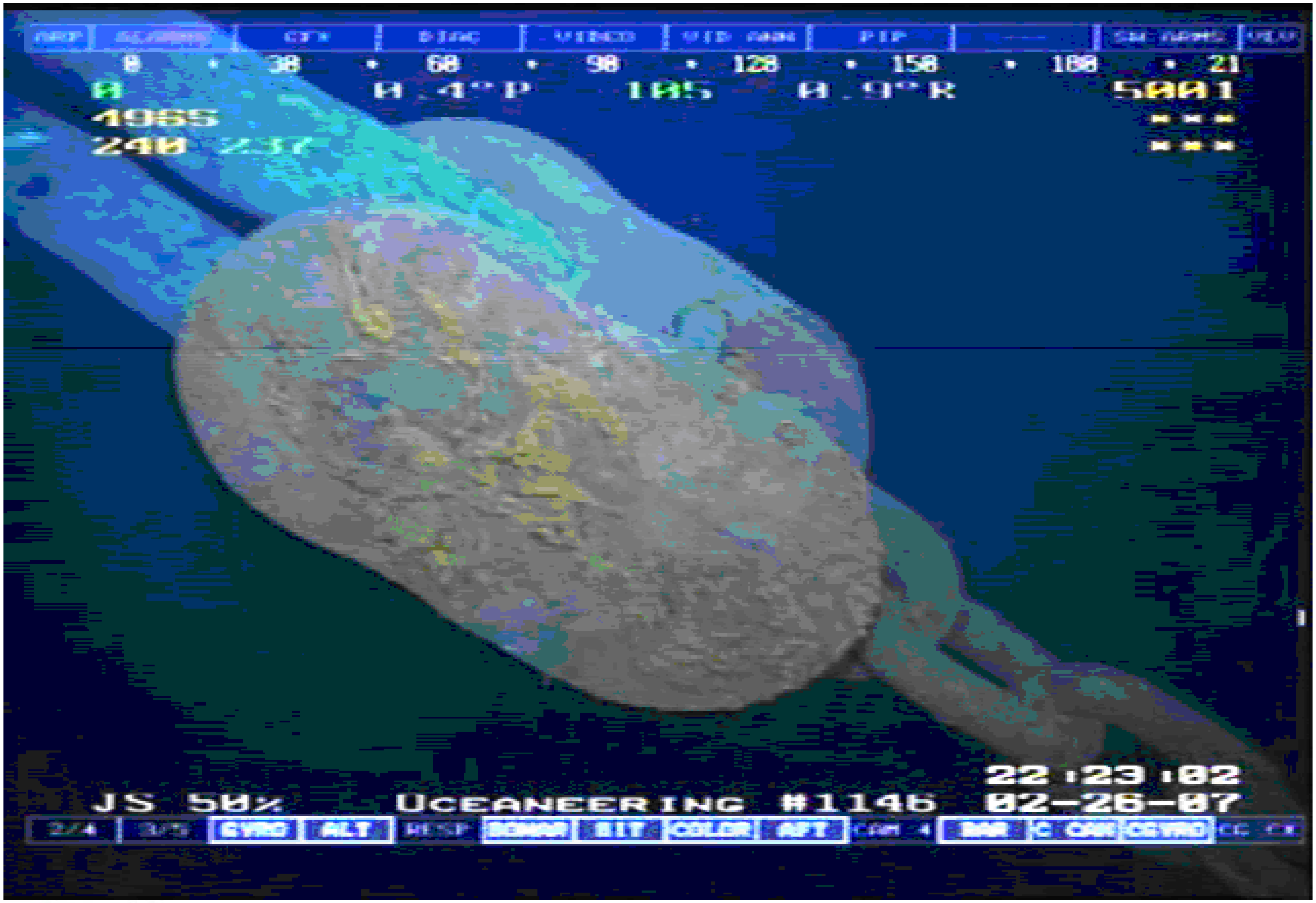
1. Normal Operations (20 yrs.)
2. Insert Recovery (75 days)
3. ROV Inspection (75 days)

# Risk Results

| Poly Mooring System Operational Processes | Number of Failure Modes | Approx. Exposure Time | RPN = Sum of Product of Severity and Occurrence Indices |
|---|---|---|---|
| Normal Operations | 6 | 20 years | 129 |
| Insert Recovery Operations | 19 | 75 days (20 times) | 399 |
| ROV Inspections | 5 | 75 days (20 times) | 112 |

# Mooring Leg Inspection 1

# Mooring Leg Inspection 2

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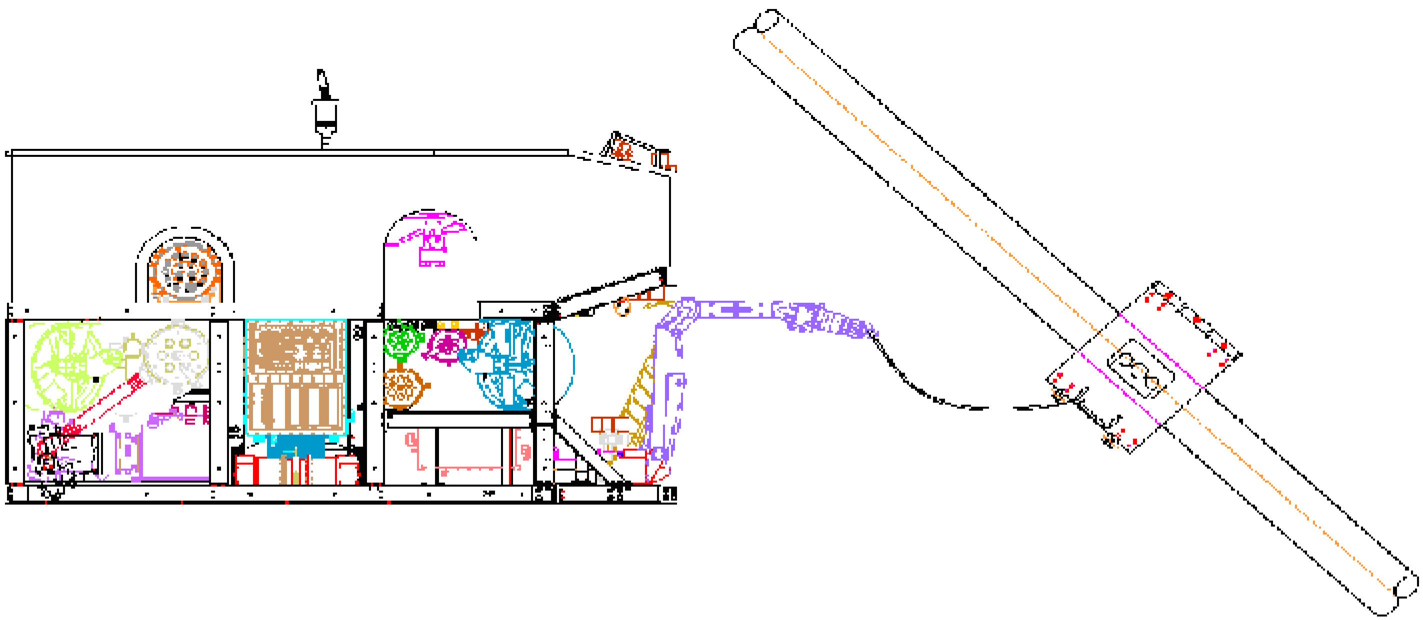
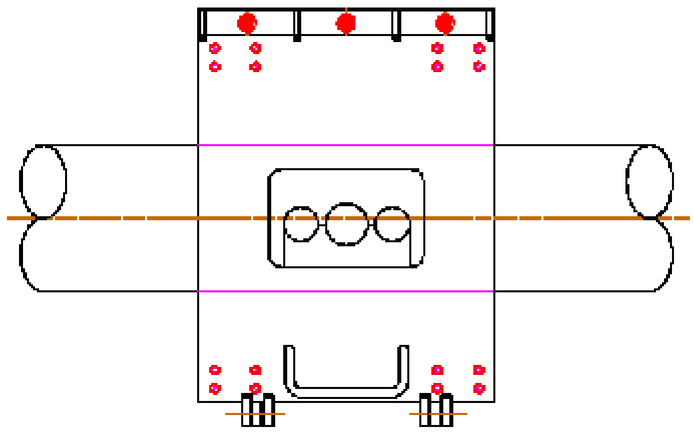
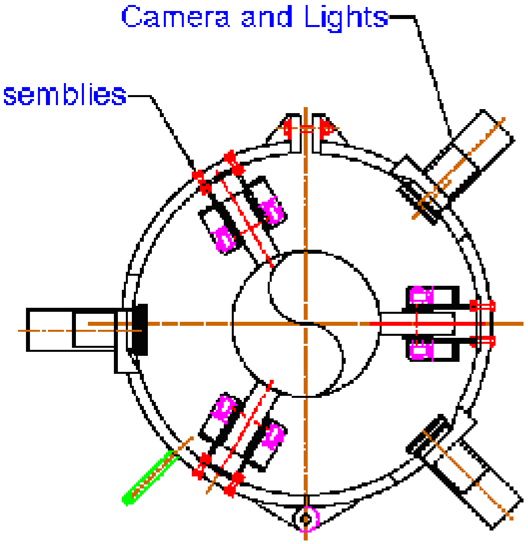
# Proposed Measurement Bug



# Clamp On Device Details





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