Monitoring of Dynamic Stress and Fatigue in Riser and Wellhead Systems

AADE Deepwater and Emerging Technologies Riser Meeting

01-29-2014

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Taking on your toughest technical problems

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Overview

- Riser/wellhead monitoring
- Standalone Subsea Vibration Data Loggers (SVDLs)
  - Description
  - Applications
- Real-time Riser Fatigue Monitoring System (RFMS)
  - Description
  - Applications

Riser/Wellhead Monitoring

- If we did a good job designing the riser system, why do we need a monitoring system?
- Reduce the risk due to uncertainty
  - Environmental effects (loads, corrosion, embrittlement, fluid-structure interaction, soil properties, etc.)
  - Vessel response
  - Material properties
  - Manufacturing defects
  - Weld properties
  - Modeling idealizations/assumptions
  - Numerical simulation accuracy

Real Reason:
We get ourselves in a bind!

- **Use rig with large motions in adverse wave environment**
- **Inadequate VIV suppression**
- **Put wellhead with low fatigue resistance in region with high fatigue demand**

Riser/Wellhead Monitoring

- Uncertainties associated with the exploration and production frontier
  - Sour service
  - HPHT
  - Strong currents
  - Unknown soil properties
  - Iceberg interaction
  - New equipment designs (e.g., wellheads, 6^{th} generation drilling rig BOP stacks)
  - New drilling methods (Managed Pressure Drilling, Dual Gradient Drilling)

Riser/Wellhead Monitoring

- Uncertainties associated with Vortex Induced Vibration (VIV) due to currents
  - High damage rate
  - Difficult to predict (semi-empirical methods needed)
  - Response is very sensitive to current speed/profile, riser shape (fairings, strakes, protection system)
    - Affects lift coefficient, damping, reduced velocity, etc.

Riser/Wellhead Monitoring

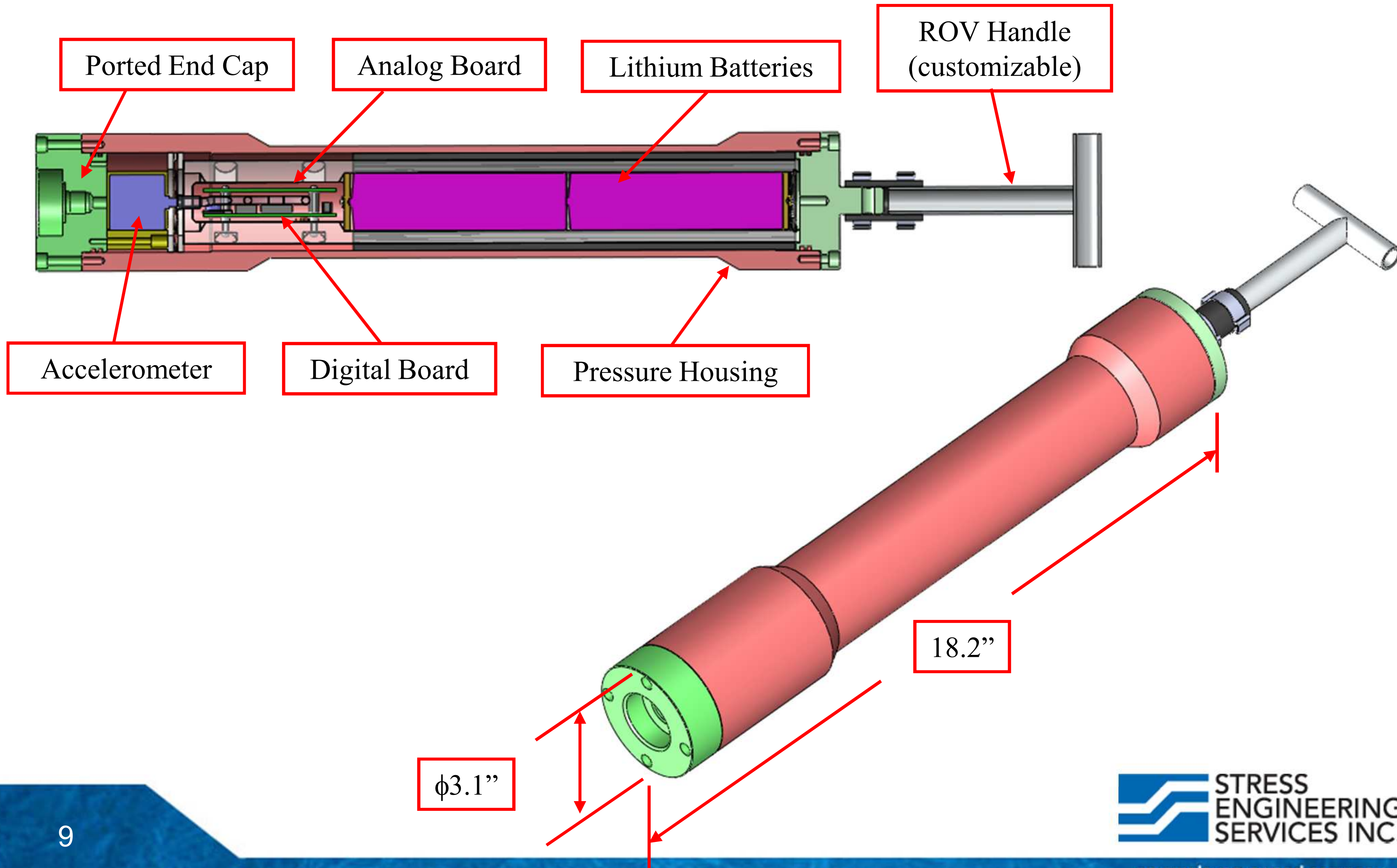
- In the following slides we will discuss the fatigue monitoring instrumentation and data analysis results provided by Stress Engineering

- Philosophy
  - Use reliable instrumentation for measuring motions accurately
    - Accelerometers, angular rate sensors, inclinometers
    - Strain gauges are delicate and require bonding to the material, not appropriate for subsea environment in the long term
  - Do the math and physics in a robust manner to determine stress and fatigue
  - Perform thorough testing and validation of the system

STANDALONE SVDL

Standalone (Battery-Powered) SVDL

SVDL Cross Section



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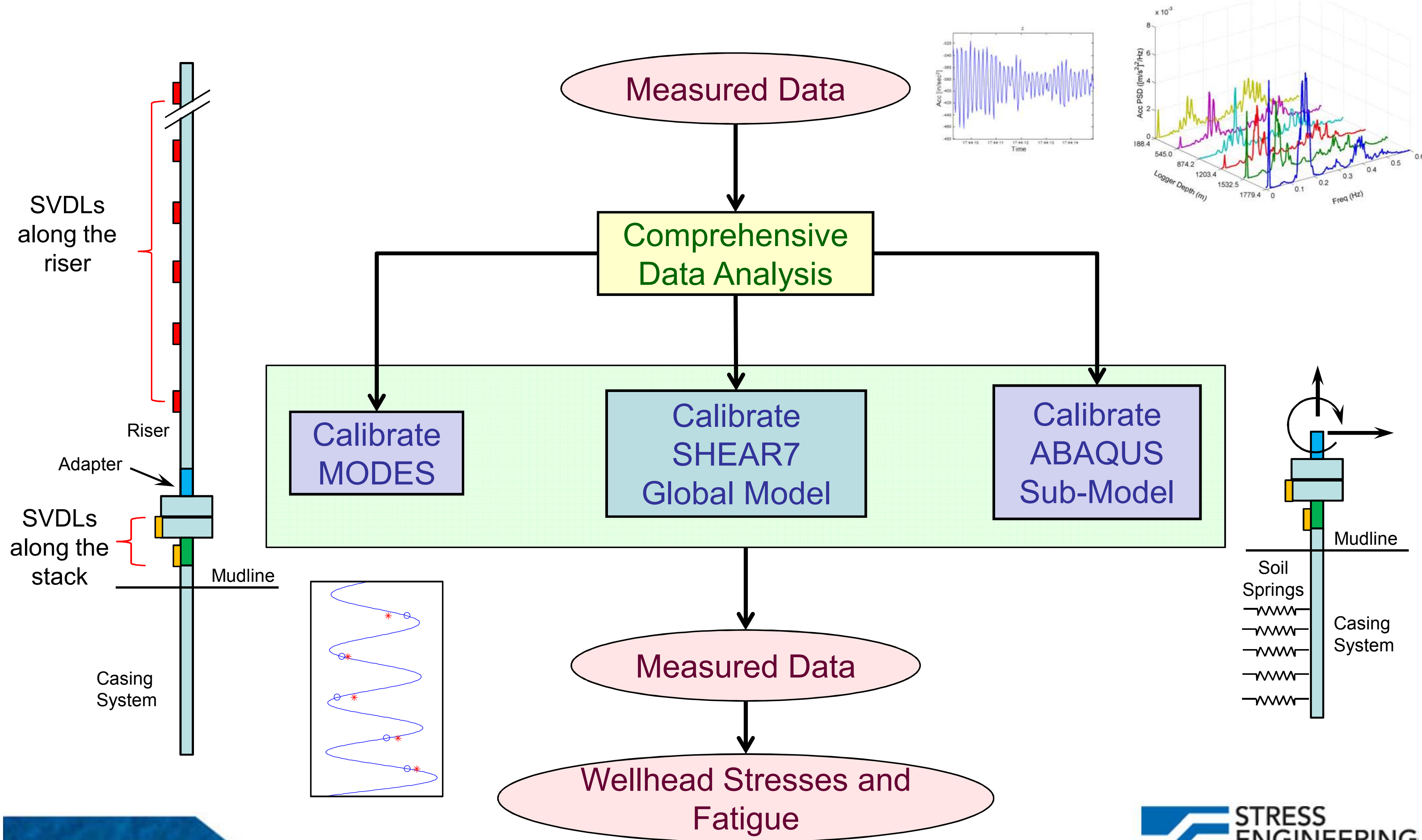
Wellhead Monitoring using Standalone SVDLs



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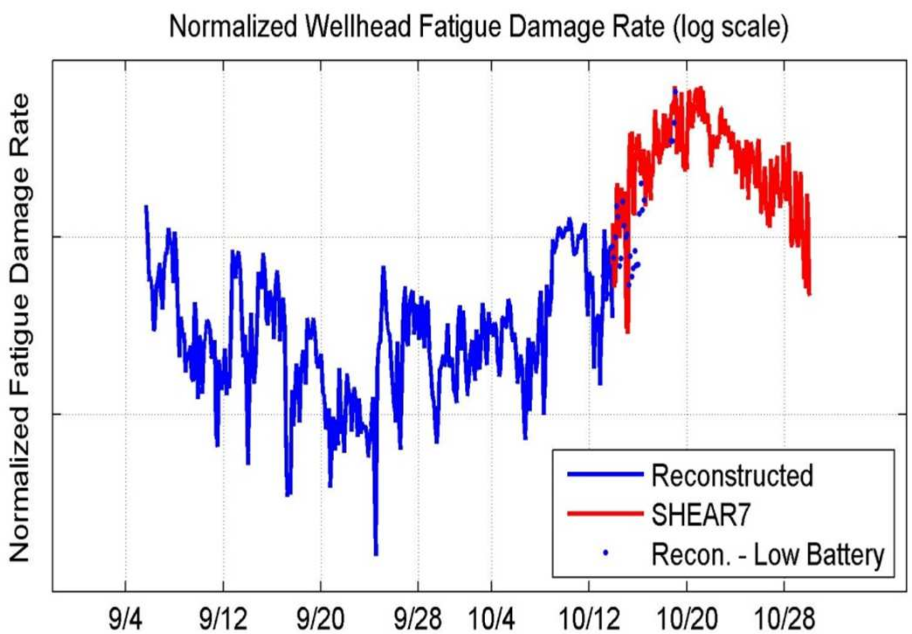
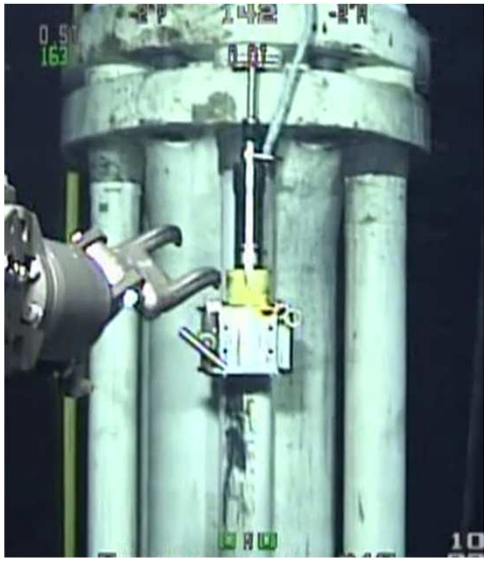
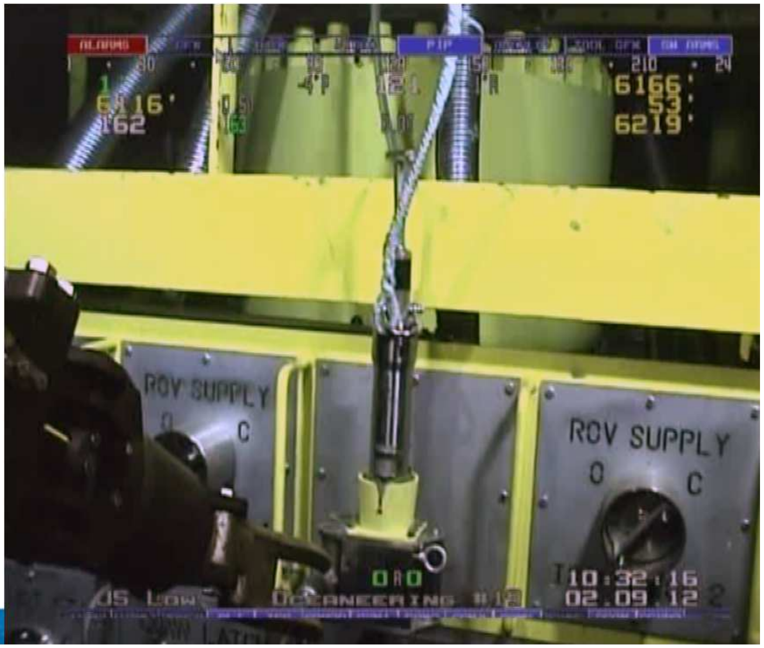
Standalone SVDLs and Normalized Fatigue Damage





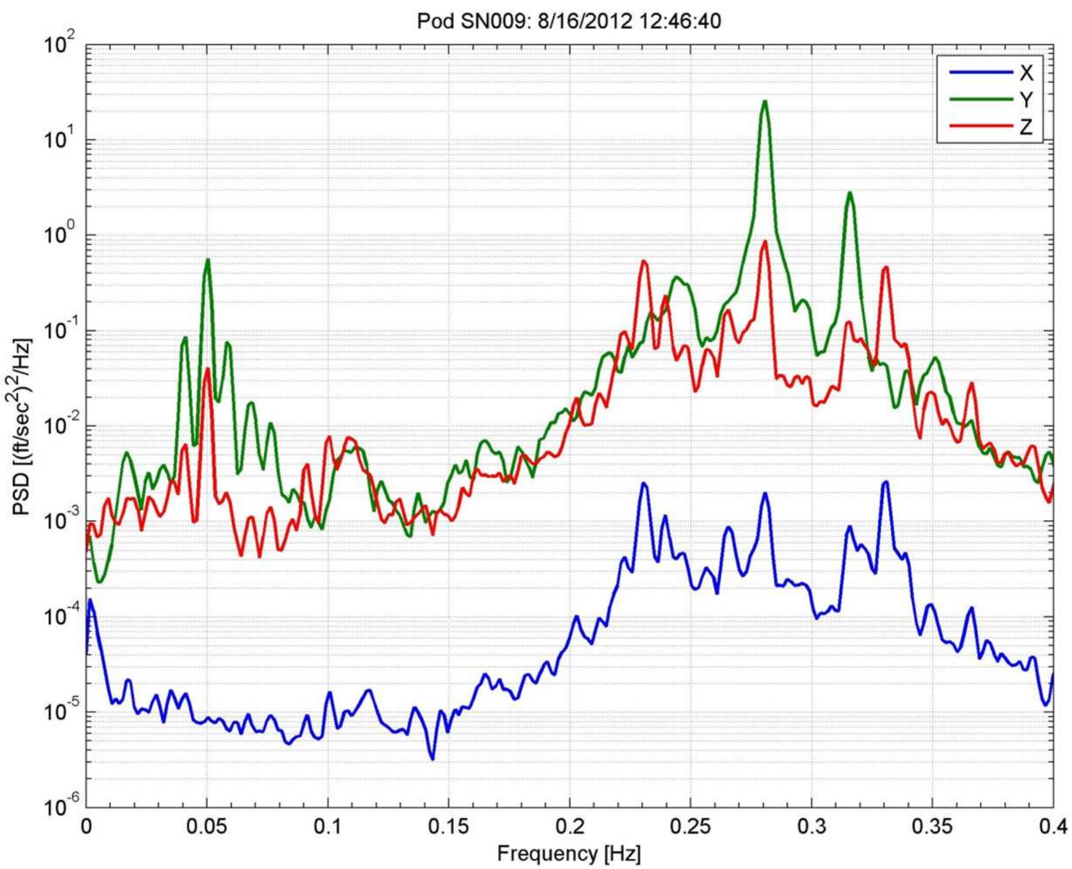


Installation in a high current region

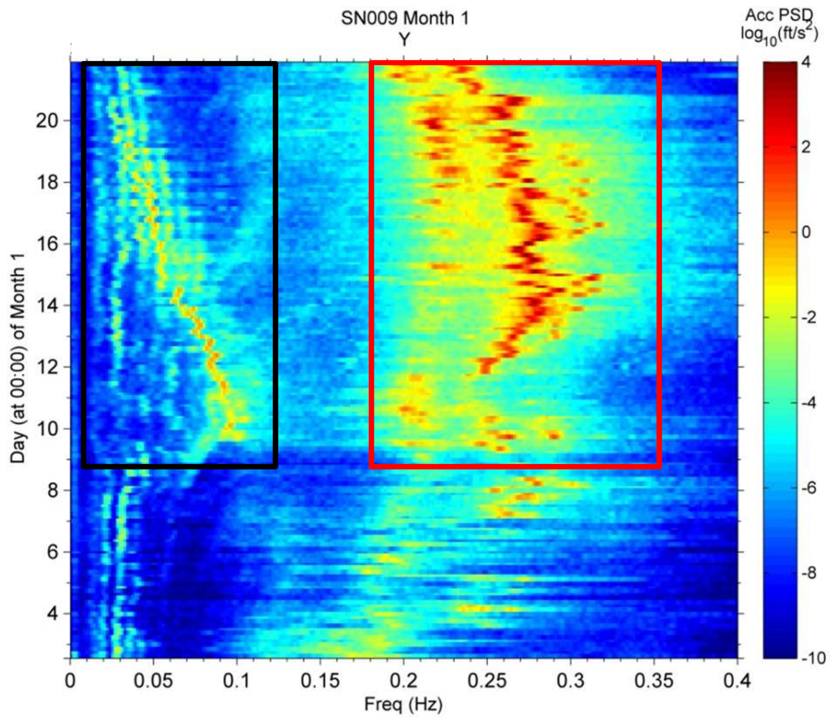
6000+ ft of water, high current, uncertain soil properties, loggers on BOP and riser

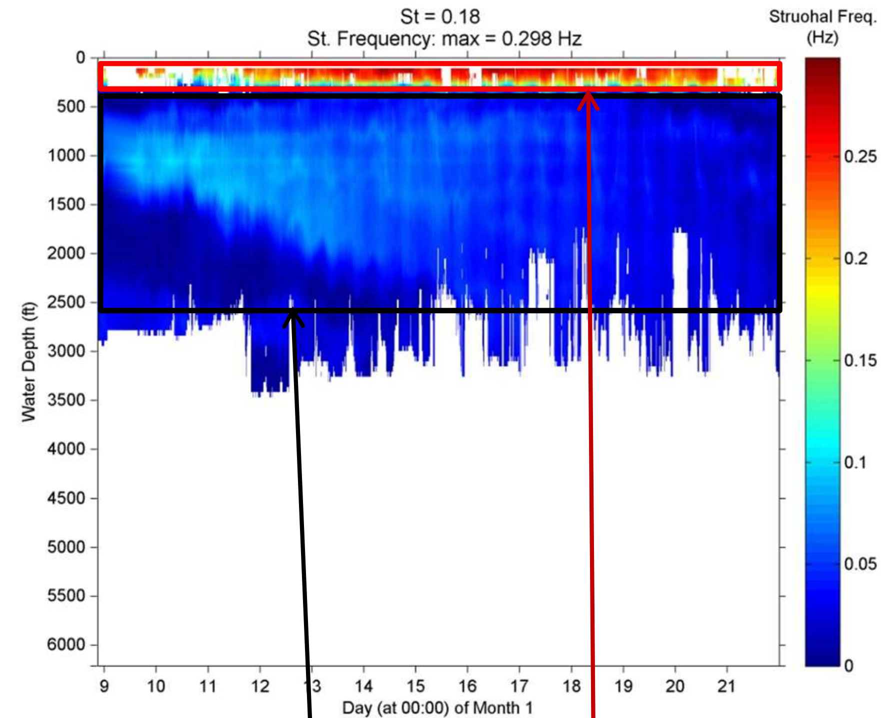
To appear: OTC-25403-MS (2014)

VIV Measurements



VIV and current correlation





Secondary acceleration "energy"

Excited by deeper currents.

Frequency decreases over time.

Dominant acceleration "energy"

Excited by near-surface currents.

Frequency varies within a range.

Strouhal frequencies near the surface are fairly uniform

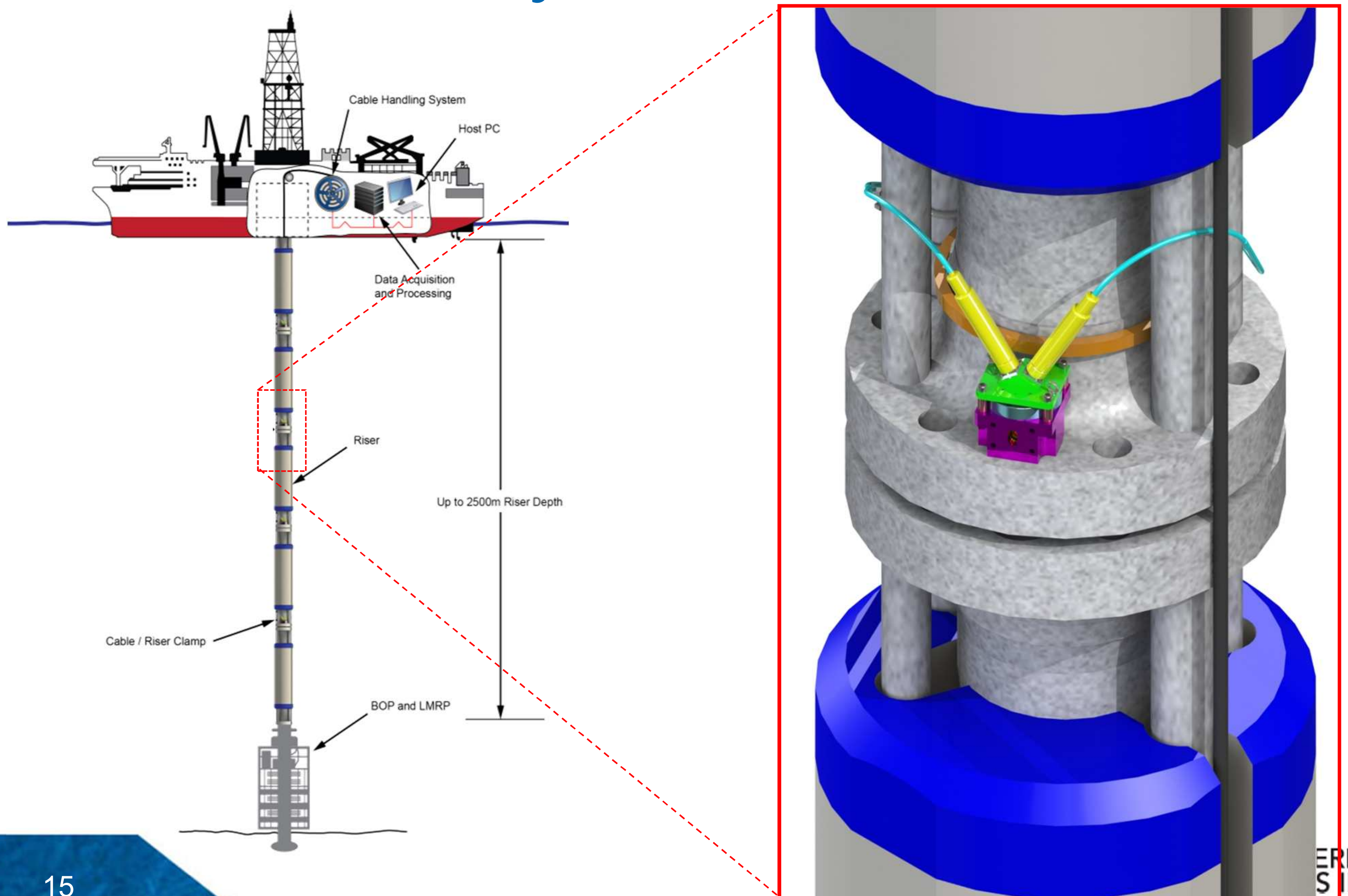
Strouhal frequencies at greater depths diminish over time

REAL-TIME FATIGUE MONITORING SYSTEM

Data in this section appears in:

March 2013 World Oil
OTC 24216-MS (2013)
OMAE2013-11540

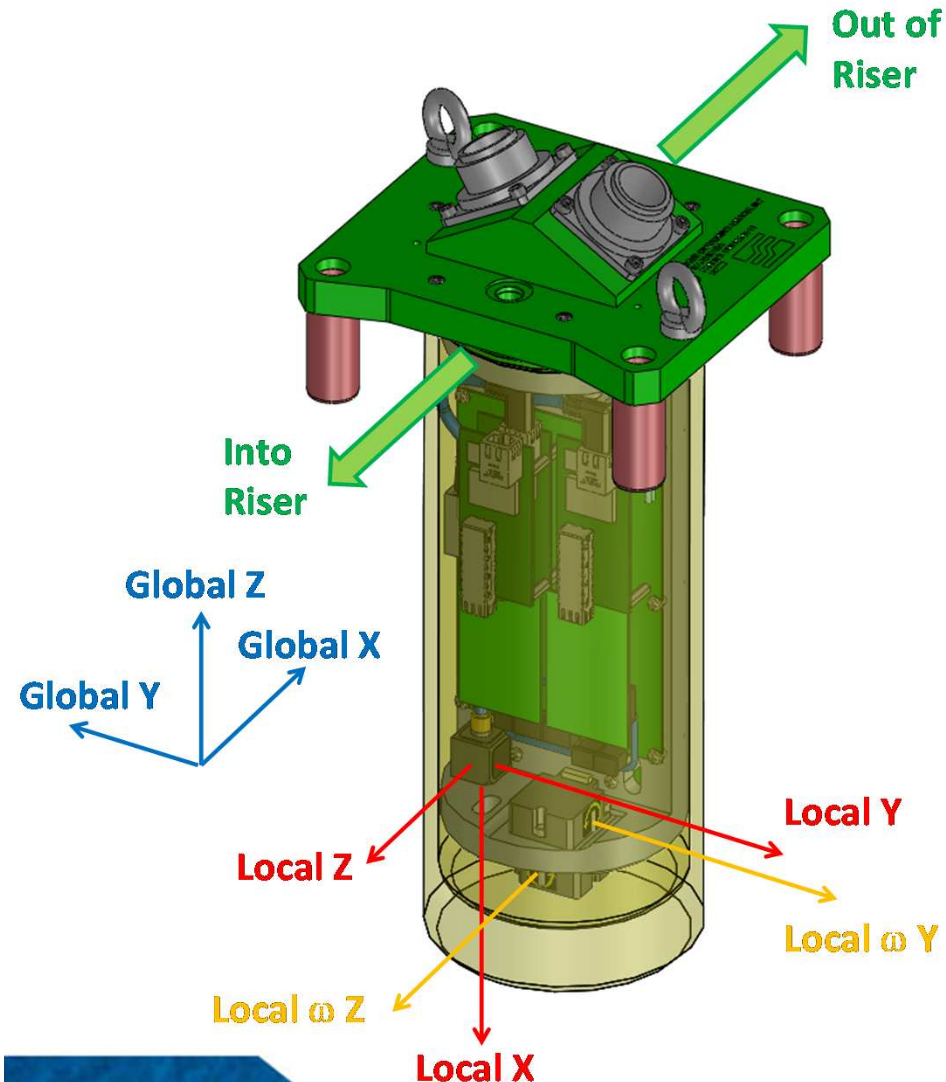
RFMS System Schematic

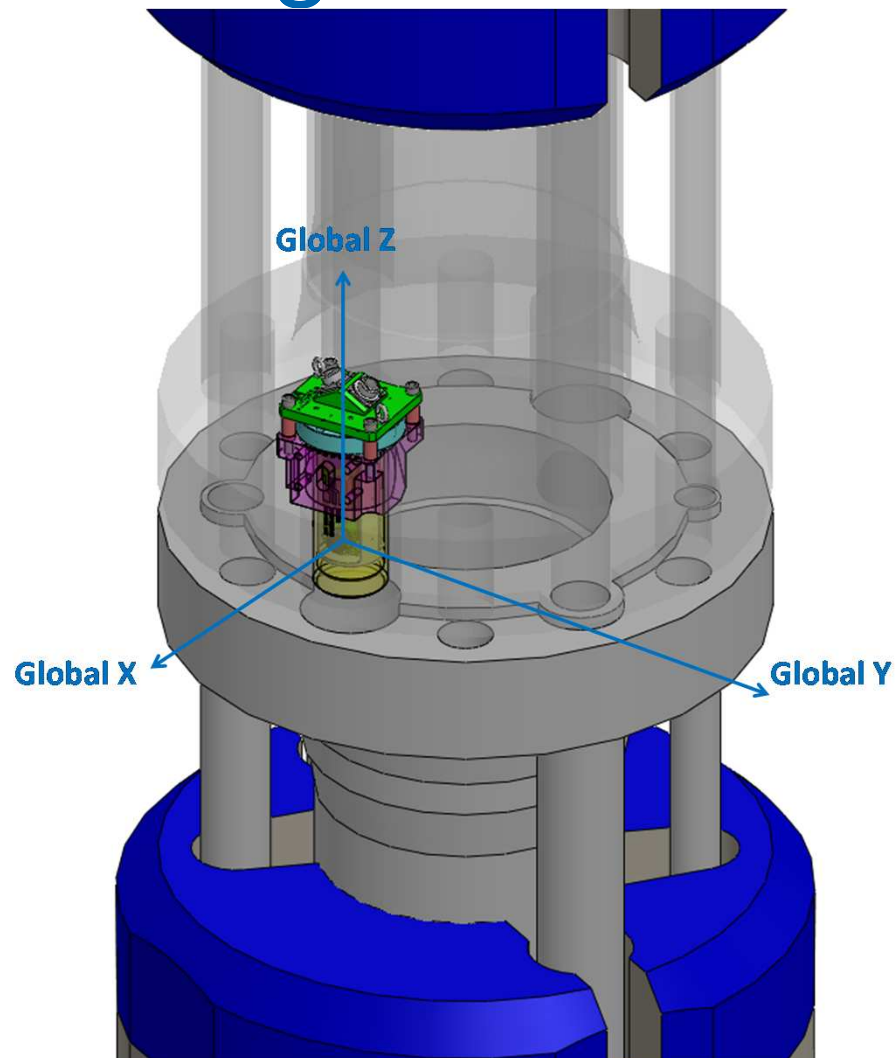


RFMS Design

- Up to seven Subsea Vibration Data Loggers (SVDLs) bolted to riser during running
  - Each logger contains a triaxial accelerometer and a two angular rate sensors (5 DOF measurement)
  - Signals are amplified, filtered, digitized and logged locally
  - Each logger contains redundant fiber optic transceivers for communication with the surface via fiber optic cable
  - Redundant power provided by topside
- Subsea cable (hybrid copper / fiber) powers loggers and transmits data between loggers and topside
- Topside unit collects data from each logger and assembles into files
  - Data collected by redundant real time controllers
  - Incoming data is displayed in real time
  - Data is stored in server (RAID architecture)
- Fatigue damage algorithm runs on server and processes incoming data at 15-minute intervals
  - Fatigue damage rates and cumulative damage reconstructed over entire riser length
- Mechanical design & deployment procedures intended to minimize impact on riser running operations (minimum installation & retrieval times)

SVDL Internal Arrangement





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Clamp Installation on RTS Cart

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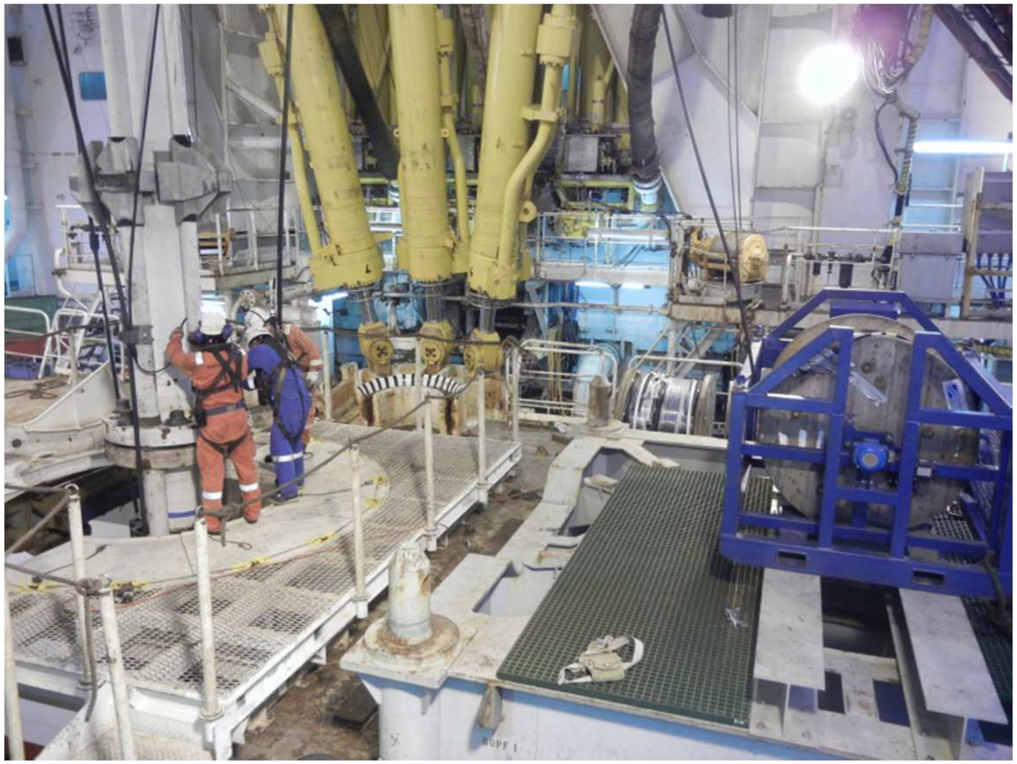
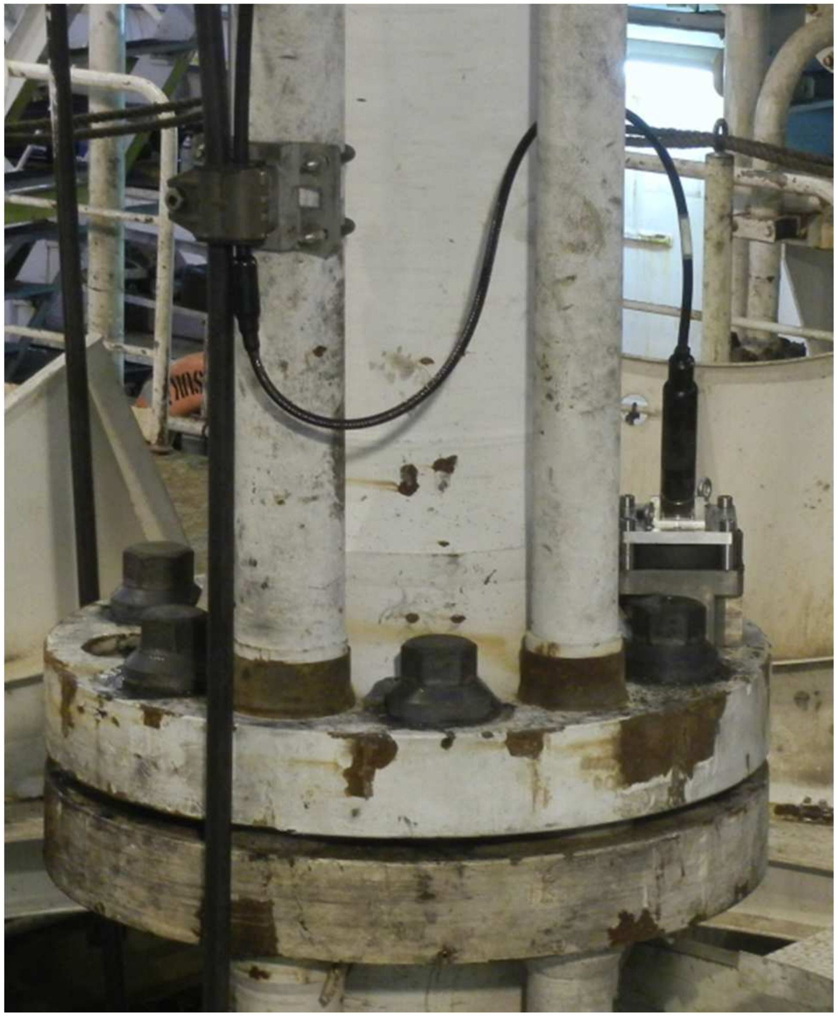
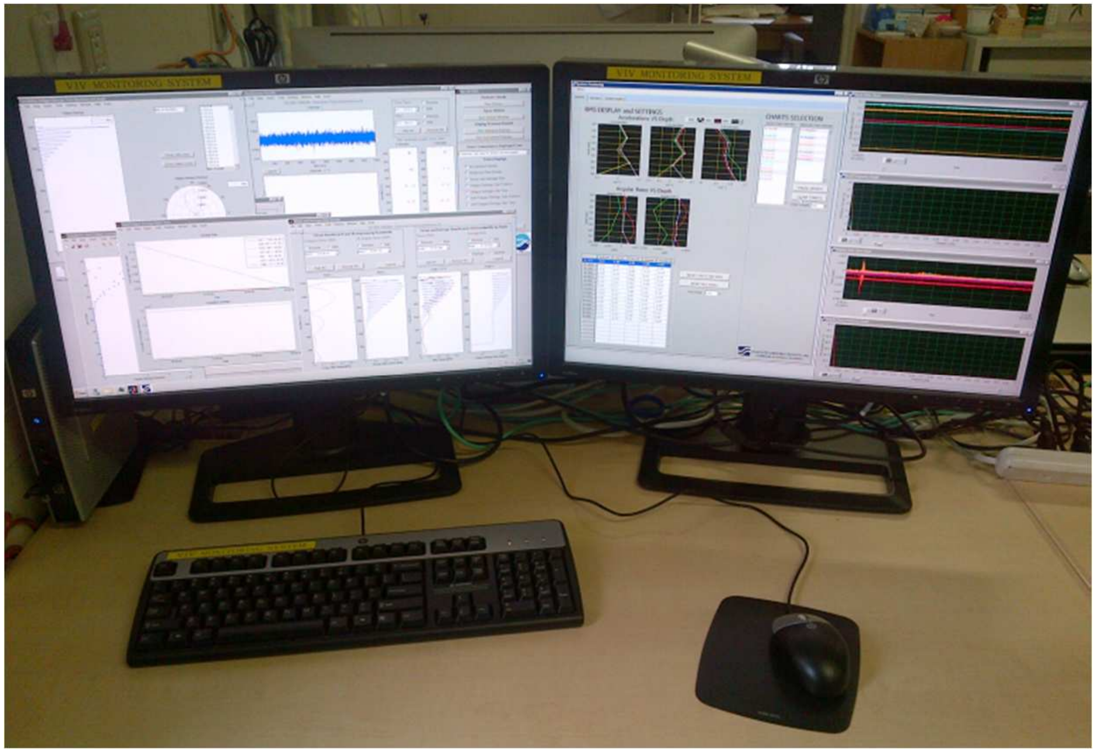
SVDL Installation on Drill Floor

Cable Installation at Moonpool





Topside Data Collection and Interface

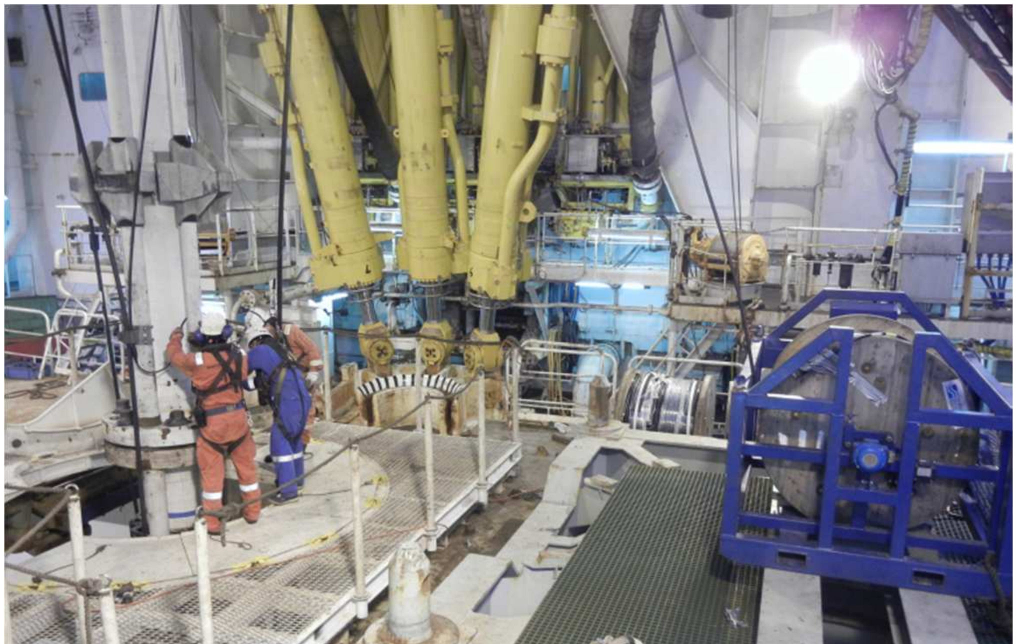


RFMS – Japan, August 2012

Deployed at well site off the coast of Japan with mild (1-2 knots) currents as a test case with four loggers

Demonstrated operability and sensitivity of the system (especially with reduced logger count)

RFMS – Japan, October 2012



Full System Deployed at well site off the coast of Japan with severe (4-6 knots) current

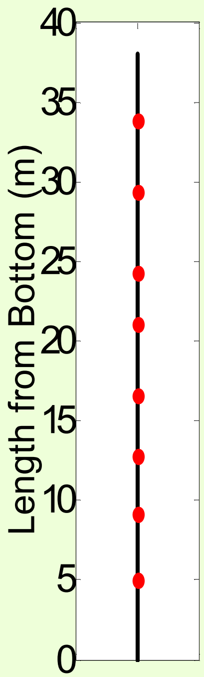
Recorded riser response and reported riser fatigue during several high-current events while connected to wellhead and during EDS and drifting event.

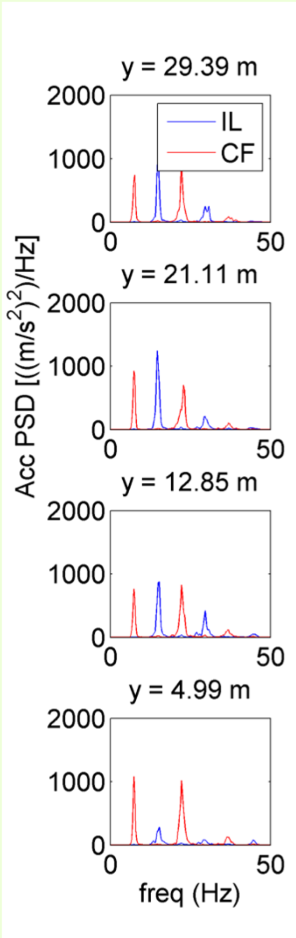
Enabled operability in severe conditions

RFMS Stress and Fatigue Software - Methodology

- The objective is to estimate stress and fatigue damage throughout the entire riser using only accelerometer and angular rate measurements at 5-10 locations – 15 minute updates
- Enabling technology is the enhanced Modal Decomposition and Reconstruction (MDR) algorithm (OMAE2011-49469)
- Enhanced MDR routine comprises the core of the software

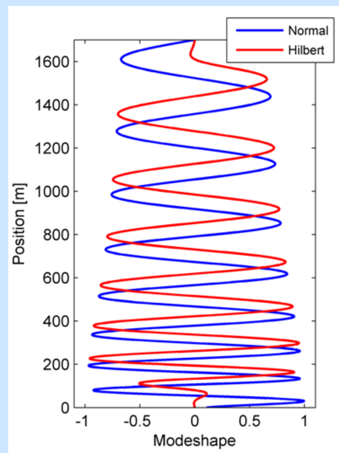
Modal Decomposition and Reconstruction (MDR)



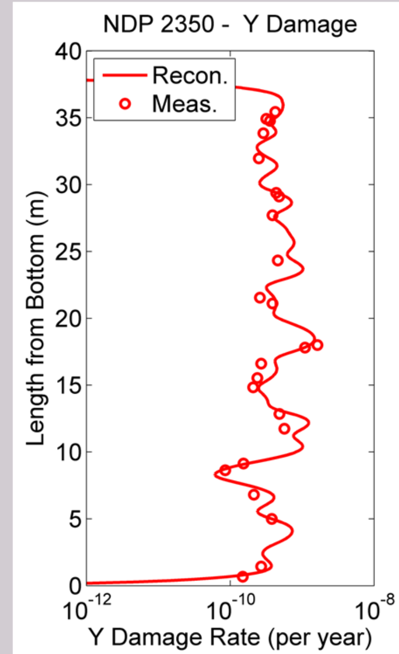


Data, measured at few discrete locations

Modal Decomposition and Reconstruction



Analytical modes and additional basis vectors



Damage reconstruction along entire riser

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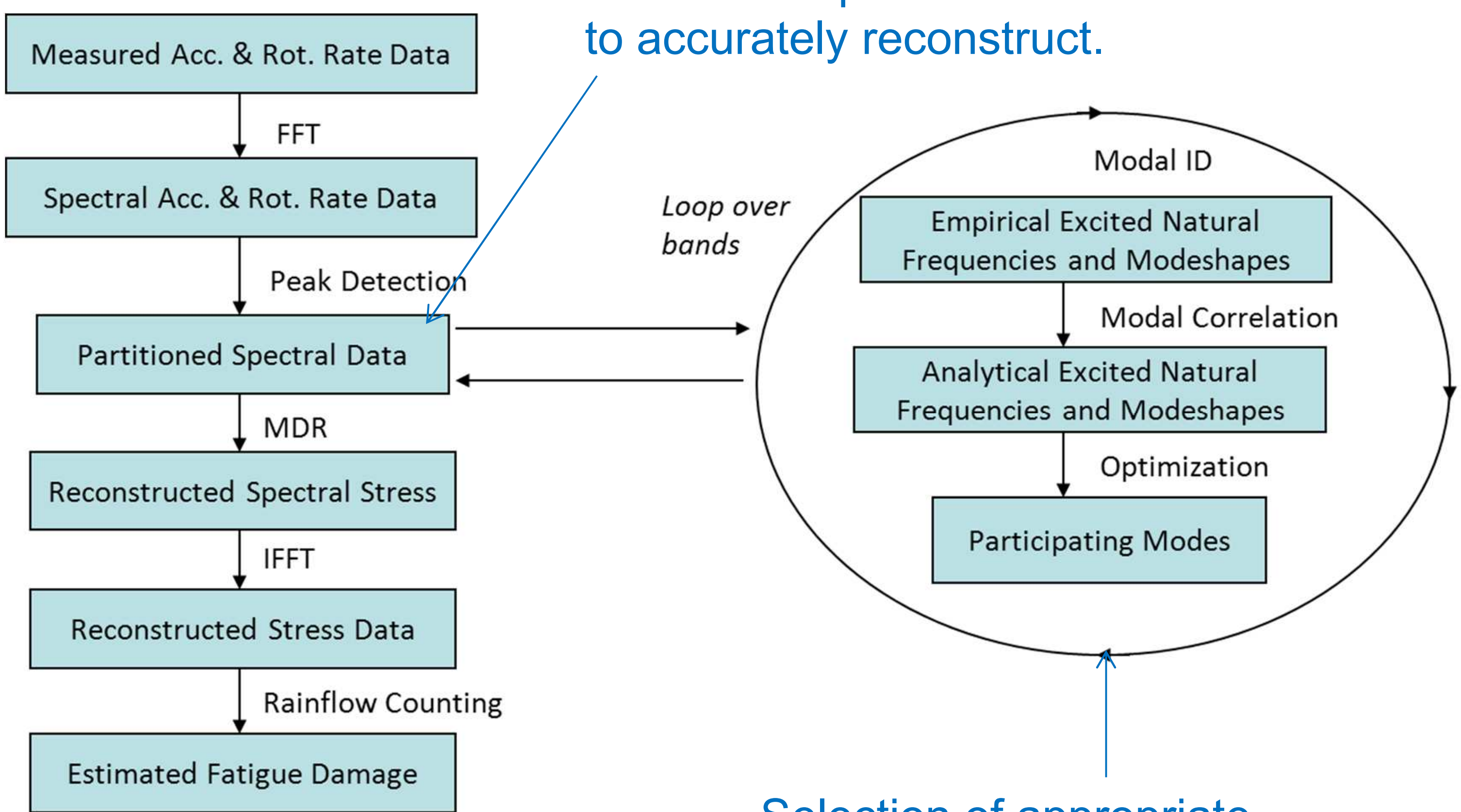
Enhanced MDR

Break up the vibration spectrum into smaller sub-problems that are easier to accurately reconstruct.



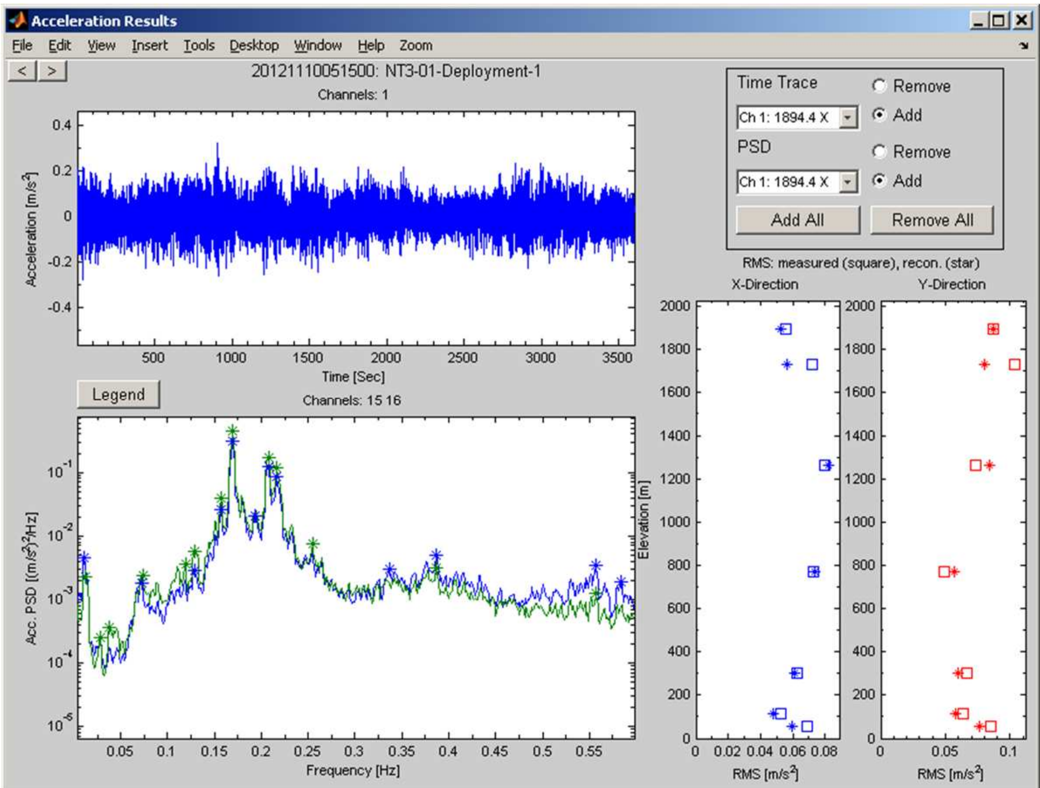
Selection of appropriate participating modes is critical!

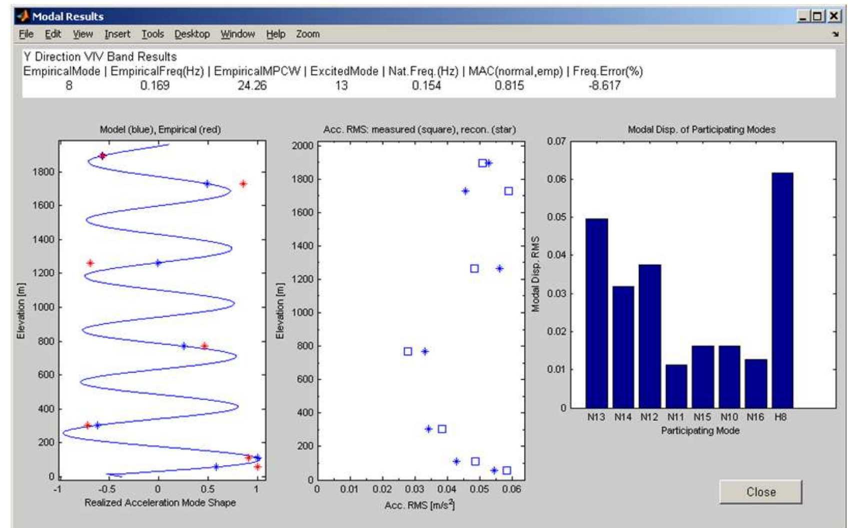
Detailed in OMAE2011-49469

Benefits of Enhanced MDR

- No need to derive excitation and deal with fluid-structure interaction
- Can use a few robust vibration sensors
- Vibration response is measured directly
- More accurate assessment of VIV
  - Higher harmonics easily included
  - Travelling waves included
  - Both in-line and cross-flow response analyzed
- Reconstruct stress and fatigue due to other sources of excitation

NT3-01 – Connected Riser VIV (brief period of VIV – few hours)





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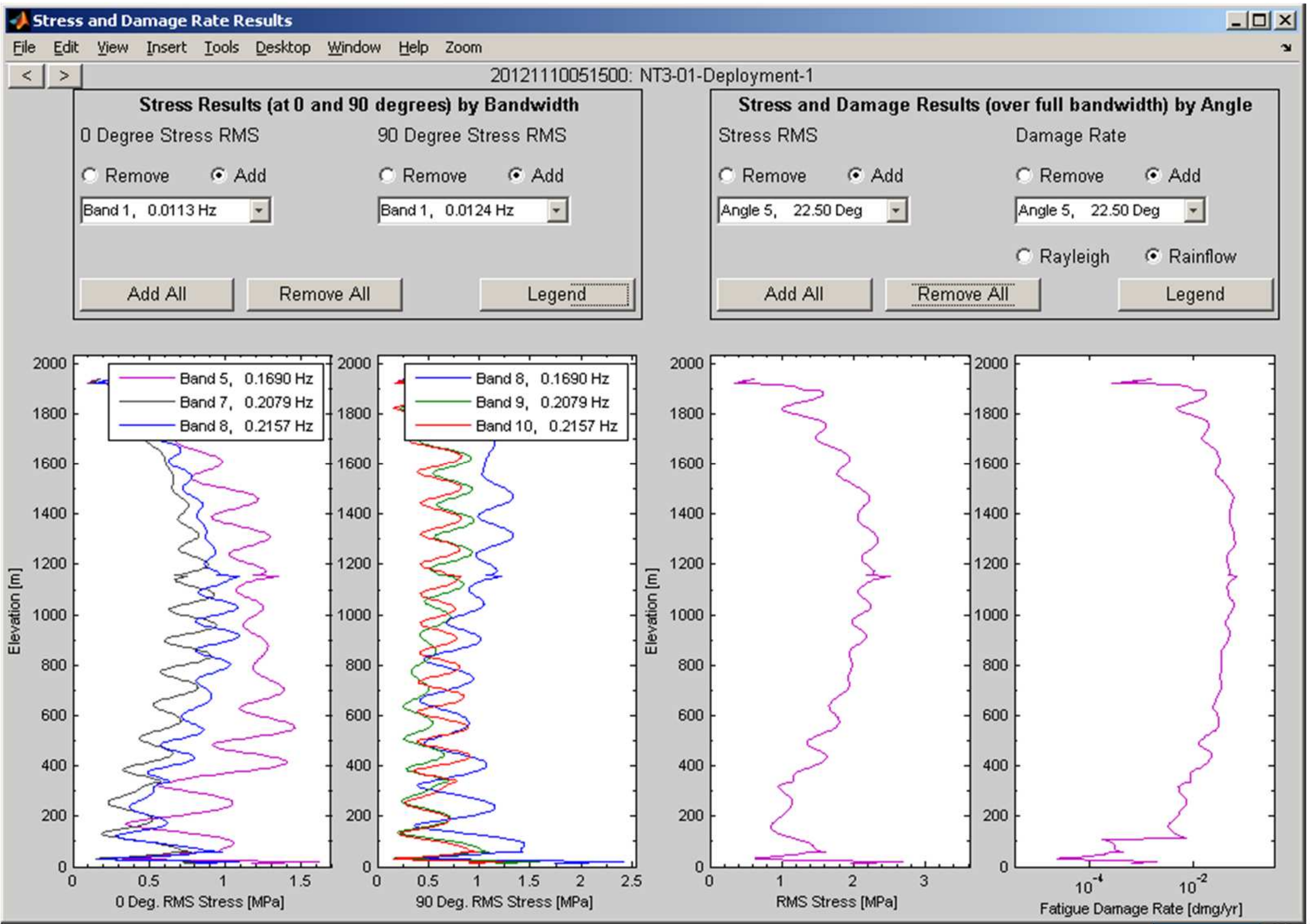
NT3-01 – Connected Riser VIV (brief period of VIV – few hours)



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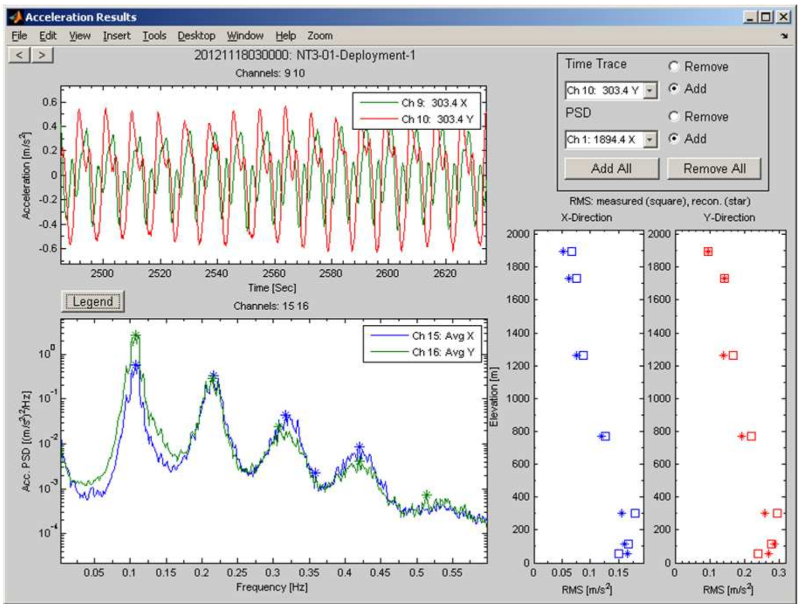
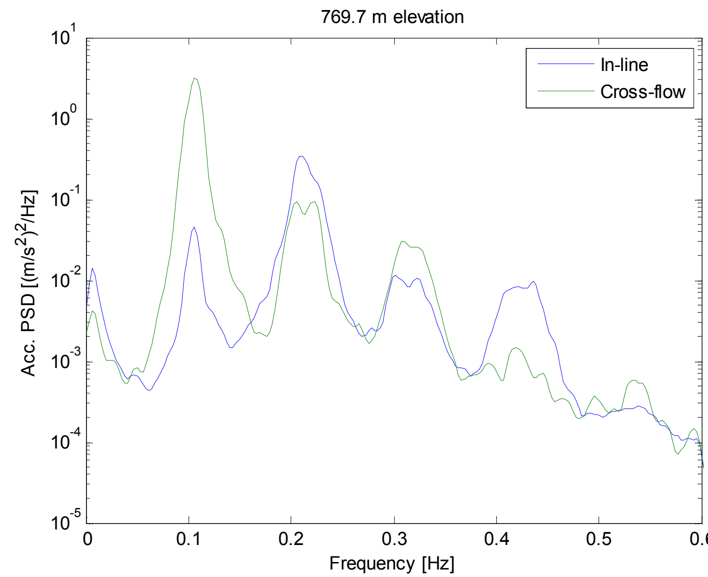
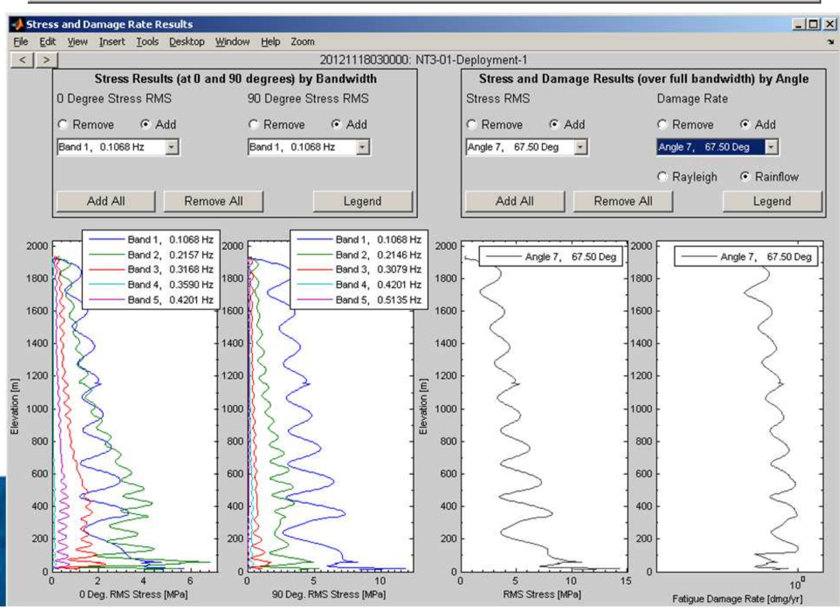
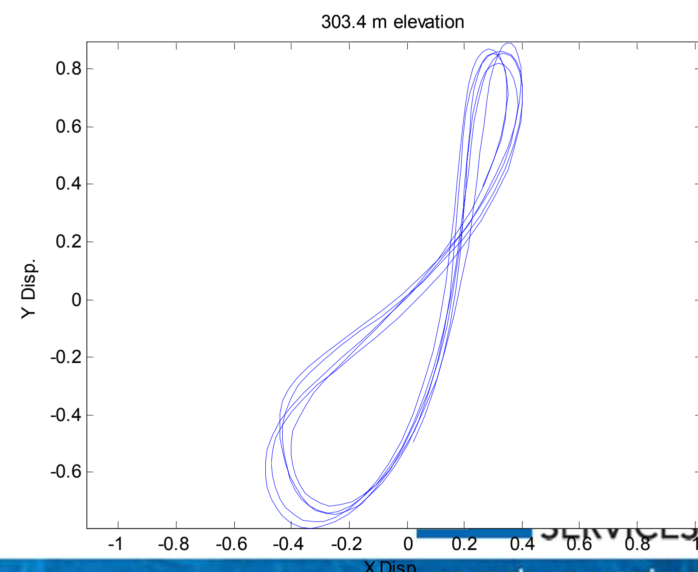
Disconnected Riser VIV (Rig in transit)

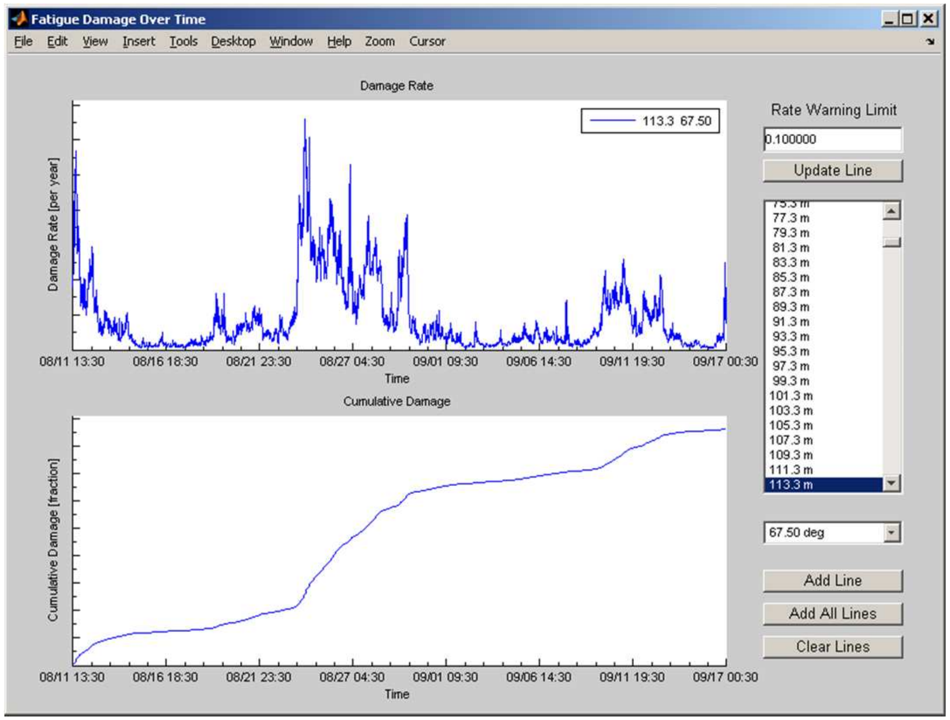


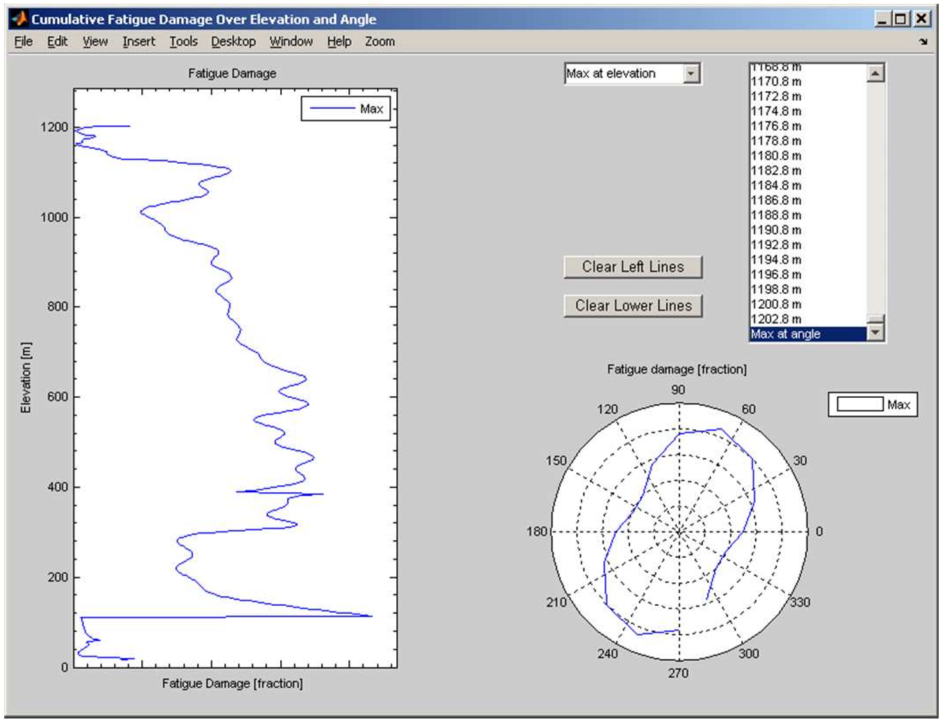






Fatigue Damage Results





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More Information on RFMS System

- March 2013 World Oil article
- OMAE2011-49469
- OTC 24216-MS (2013)
- OMAE2013-11540
- OTC-25403-MS (2014)
- OMAE2014-24035
- United States Patent Application 20120303293

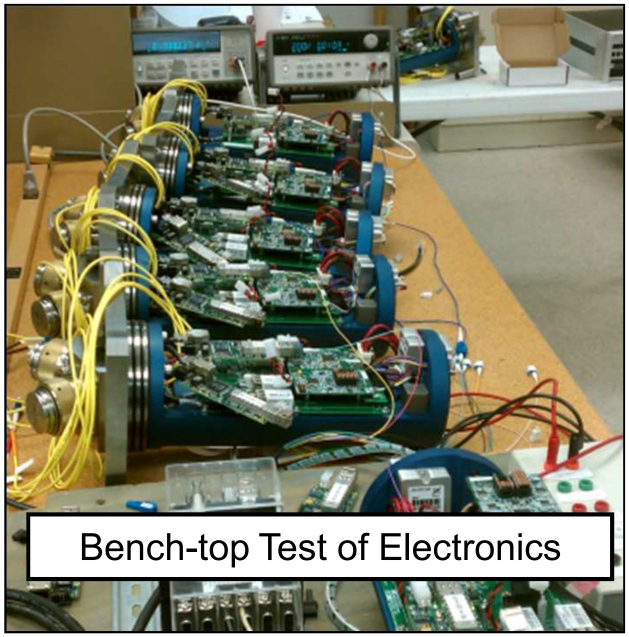
SES SYSTEM ADVANTAGES: HARDWARE DESIGN, TESTING, DATA ANALYSIS AND VALIDATION

SES System Advantages

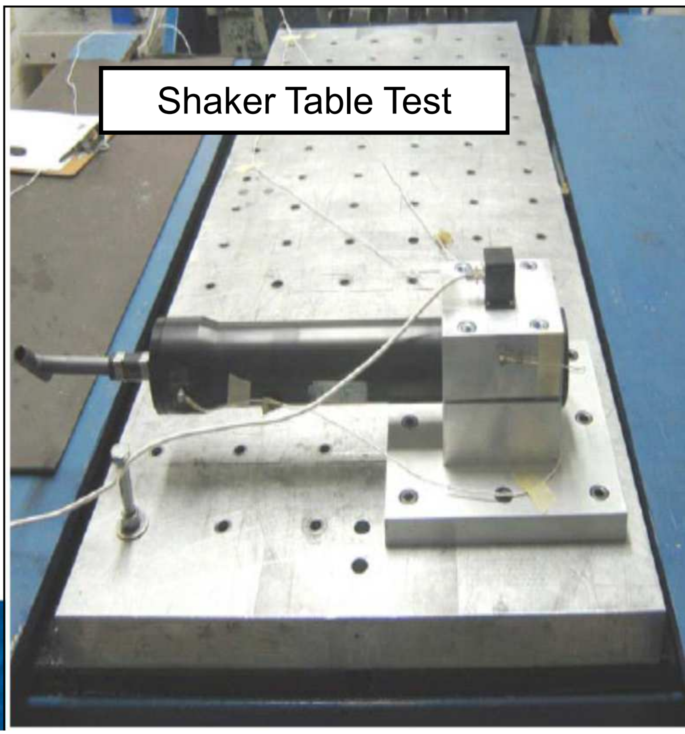
- Our measurement quality is better
  - Better sensor quality, resolution, and accuracy
  - Better analog electronics and filtering
  - Better digital resolution
  - Better oversampling capability
  - Fully configurable, programmable measurement parameters
  - Sensors specs suitable for individual applications
- We understand structures and dynamics and signal processing. We implement robust algorithms to extract information from measured data and determine structural integrity.
- All hardware designs undergo rigorous testing
- All algorithms undergo rigorous verification
- *We will use, analyze, and interpret the data we measure, so we must ensure that it is good!*

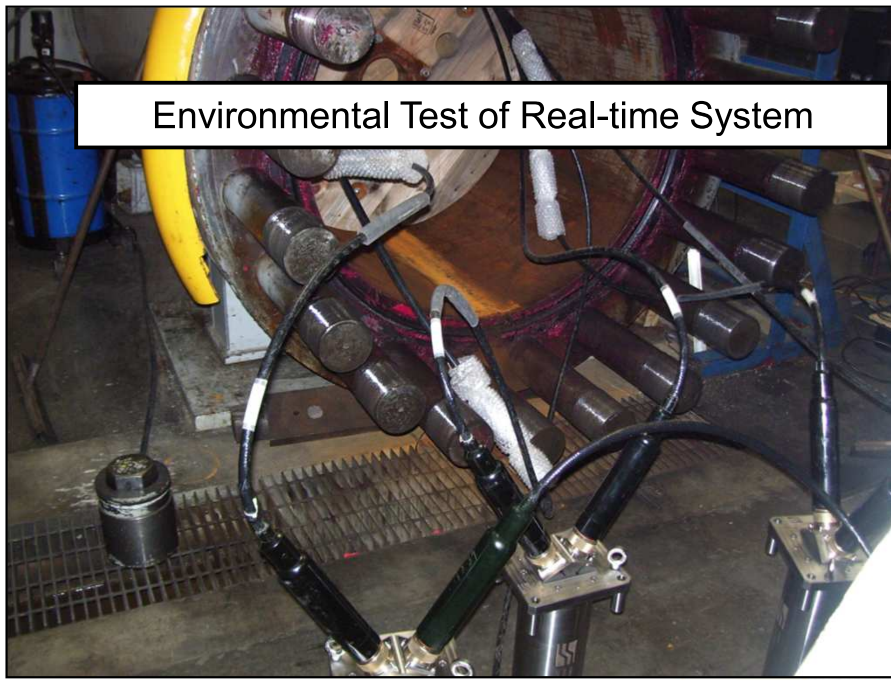
SES Hardware Designs Have Been Thoroughly Tested

- Bench-top testing of electronics and software
  - Amplifiers
  - Filters
  - Analog-to-digital converter
  - On-board firmware, interface software
- Environmental test
  - Simultaneous pressure (10,000 FSW), temperature (34°F), vibration (±0.8g)
- Shaker table test
  - Dynamic characterization
  - Workmanship (6.8 g_{rms})
- Calibration
- Battery life tests
  - Ambient and cold (34°F) temperatures

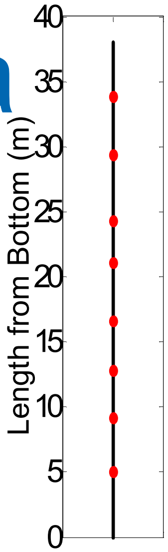

Bench-top Test of Electronics


Environmental Test of Stand-alone SVDL

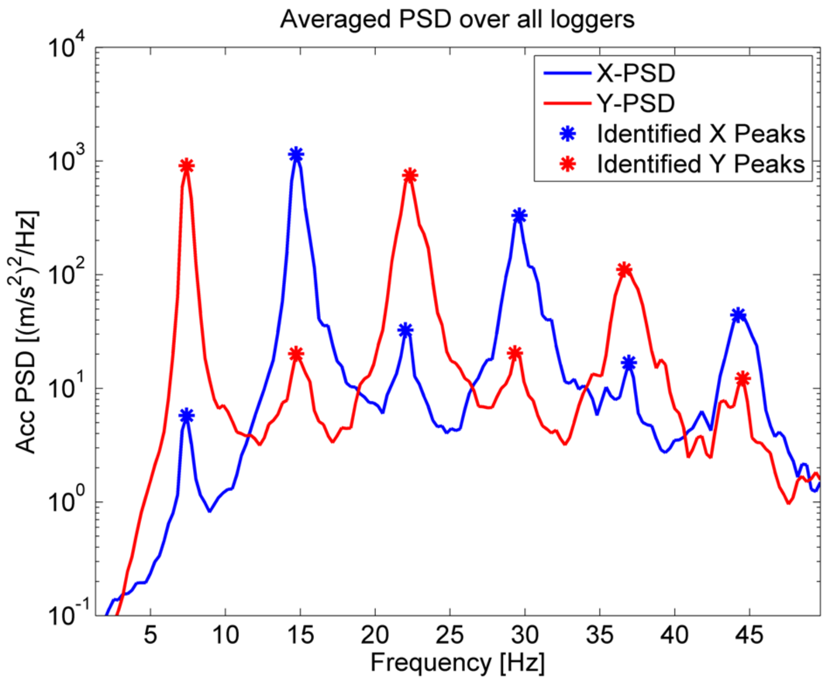

Shaker Table Test


Environmental Test of Real-time System

MDR Validation: NDP 2120 Data

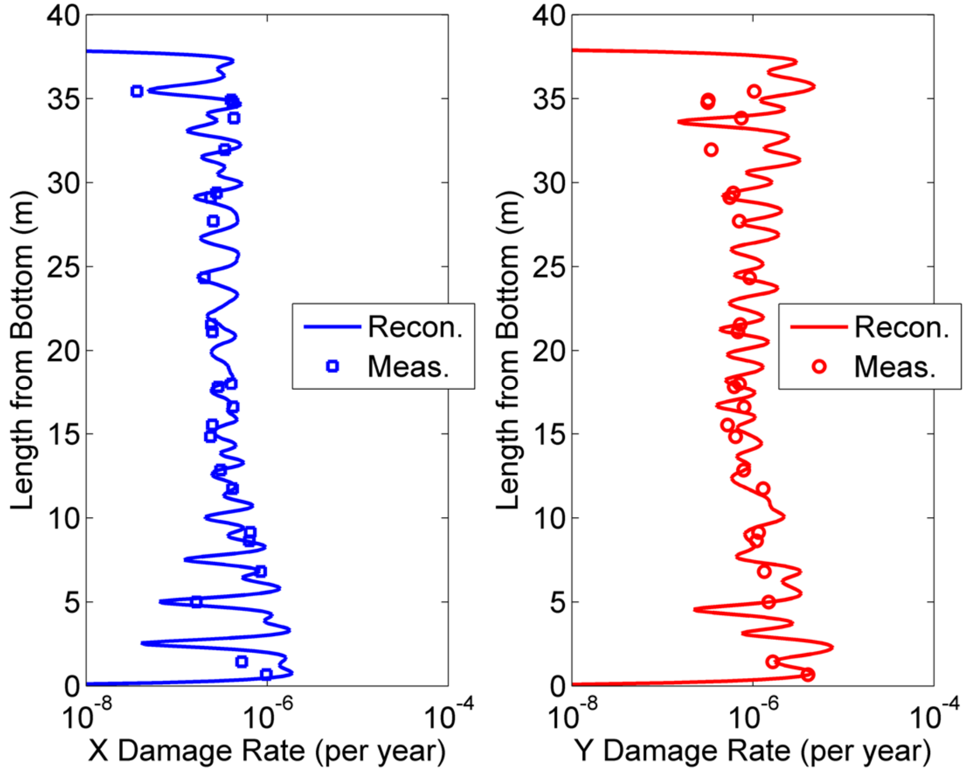


- Riser
  - 38 meter long bare riser, D = 32 mm, L/D ~ 1200
  - **Uniform current (dataset 2120) of 1.4 m/s**
- Measurements
  - Acceleration measurements at 8 locations
  - Strain measurements at 24 locations



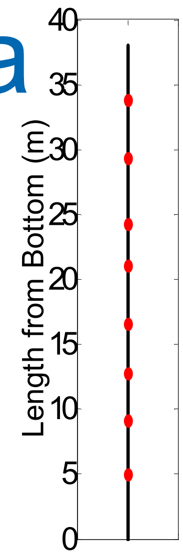
Validation cases appear in:
OMAE2011-49469

MDR Validation: NDP 2120 Data

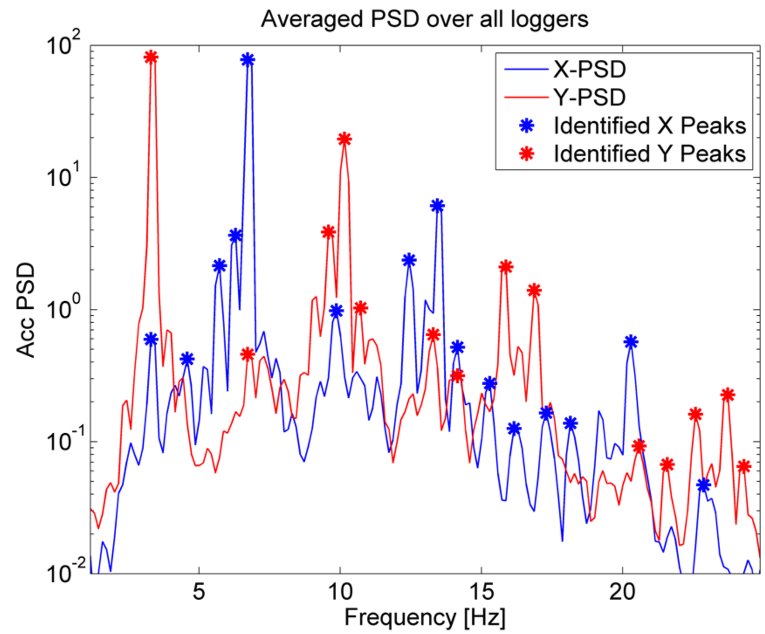


Comparison of reconstructed ("Recon.") fatigue damage using data from 8 accelerometers with measured ("Meas.") damages at 24 strain gages for uniform current test NDP2120

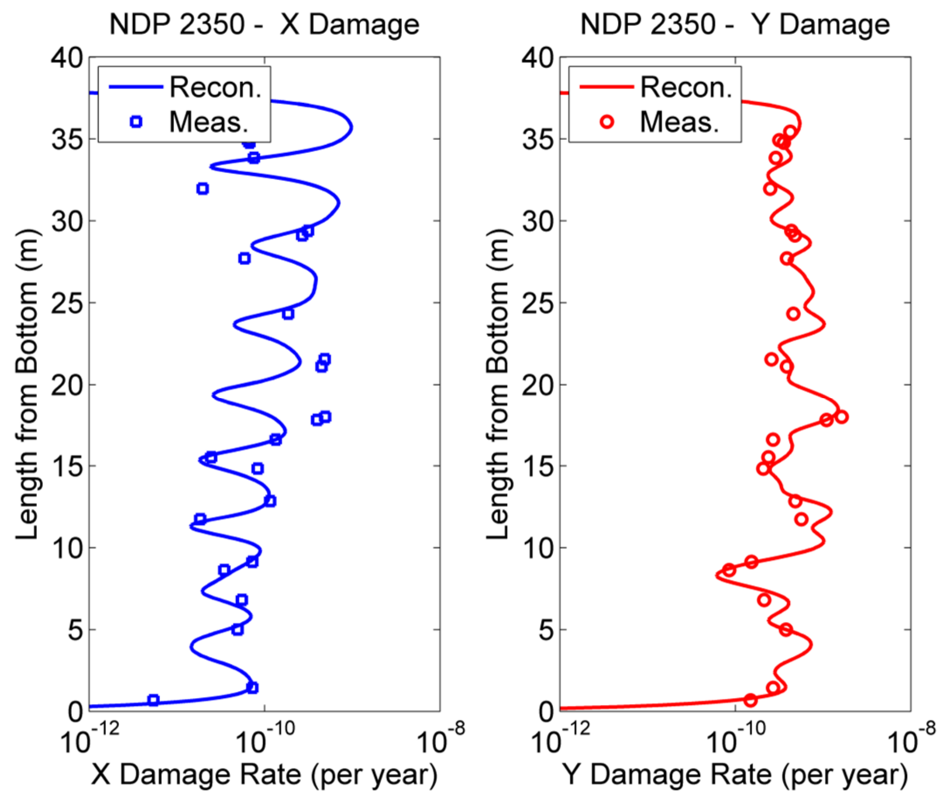
MDR Validation: NDP 2350 Data



- Riser
  - 38 meter long bare riser, D = 32 mm, L/D ~ 1200
  - Linearly sheared current (dataset 2350) from 0.7 m/s
- Measurements
  - Acceleration measurements at 8 locations
  - Strain measurements at 24 locations



MDR Validation: NDP 2350 Data



Comparison of reconstructed ("Recon.") fatigue damage using data from 8 accelerometers with measured ("Meas.") damages at 24 strain gages for sheared current test NDP2350

Performed a battery of similar tests to validate the algorithm

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