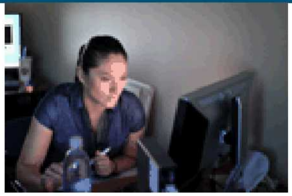
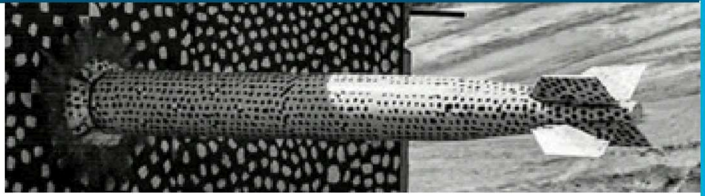
SAND2018-7451PE

MEC/MHK Load Characterization and Measurements



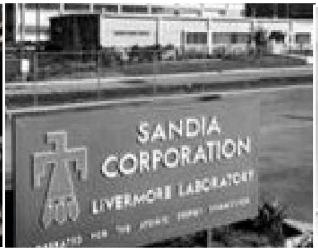


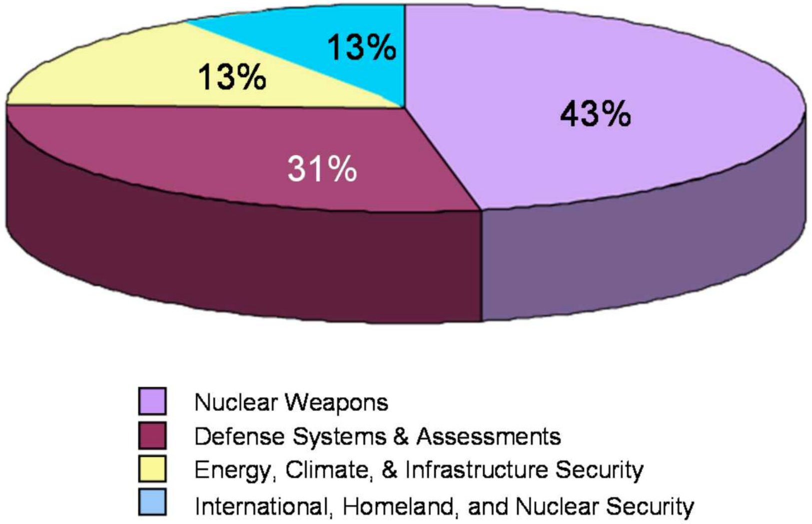
PRESENTED BY

Budi Gunawan

bgunawa@sandia.gov

Sandia National Labs





- Federally funded research and development center
- On-site workforce: 12,001 (10,715 NM, 1,286 CA)
- FY16 Budget: $3 Billion
- Renewable Energy Programs: Solar, Wind, Water, Geothermal, Biomass

Advanced Materials Program – Load Characterization & Measurements

Motivations:

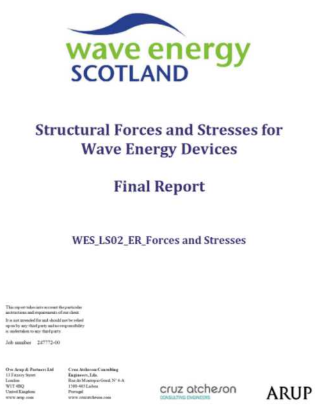
1. **MEC/MHK design load**
    - Provide characteristic/design loads for material performance studies
2. **Industry needs for structural and mechanical load measurements**
    - Ability to measure loads on device, as a short-term need (MHK Composites Workshop 2015)
    - "In the current IEC TC 114 Strategic Business Plan, Load measurement and verification is identified as the highest priority standard for development based on input and agreement from the National Committees"
    - …immediate need of the MHK industry for inexpensive and reliable means of accurately measuring structural loads in real time during ocean trials of WEC and TEC devices (Resolute)
    - Load data during field operation to validate structural and hydrodynamic models, provide confidence in system reliability (ORPC)

Objectives:

1. Provide design/realistic load for material performance testing
2. Advance the scientific understanding of load measurements and sensor response on composite materials

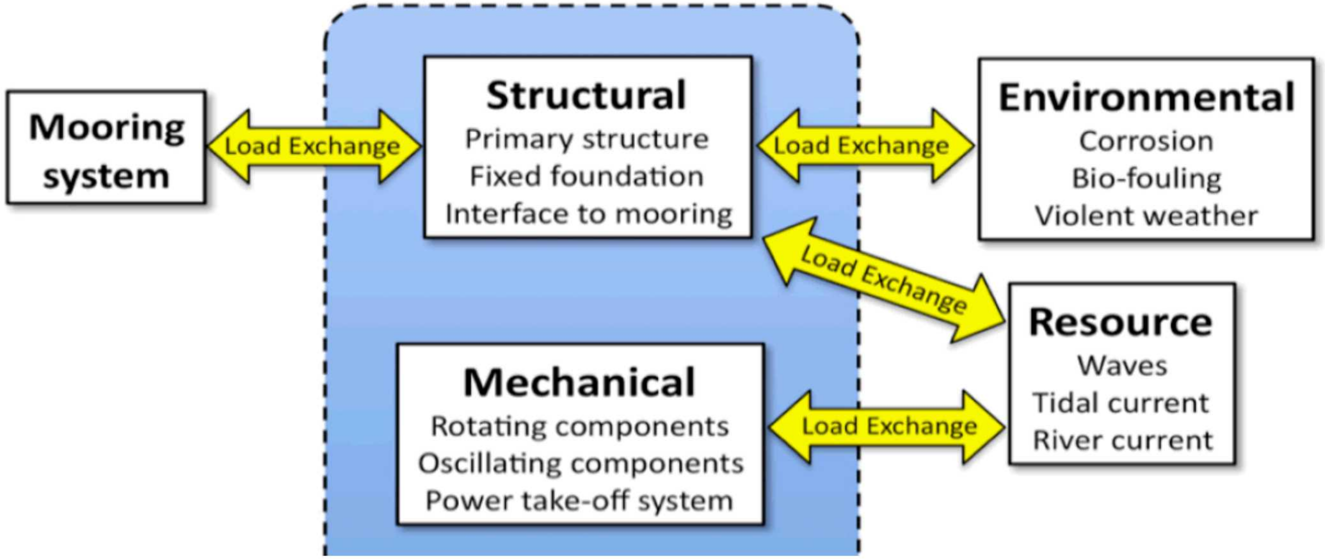
Load design requirements

IEC TS 62600 -2 ED2 (2018) Marine energy - Wave, tidal and other water current converters - Part 2: Design requirements for marine energy systems



Structural forces and stresses for wave energy devices. Wave Energy Scotland Report (2016)

Load exchanges on structural and mechanical components



IEC TS 62600 -2 ED2 (2018)

Design load < **Material's strength**

$$F_d = \gamma_f F_k$$

where:

F_d is the design value for loads acting on the MEC for the given design load case

γ_f is the partial safety factor for loads

F_k is the characteristic value for the load

$$f_d = \frac{f_k}{\gamma_m}$$

where:

f_d is the design values for materials

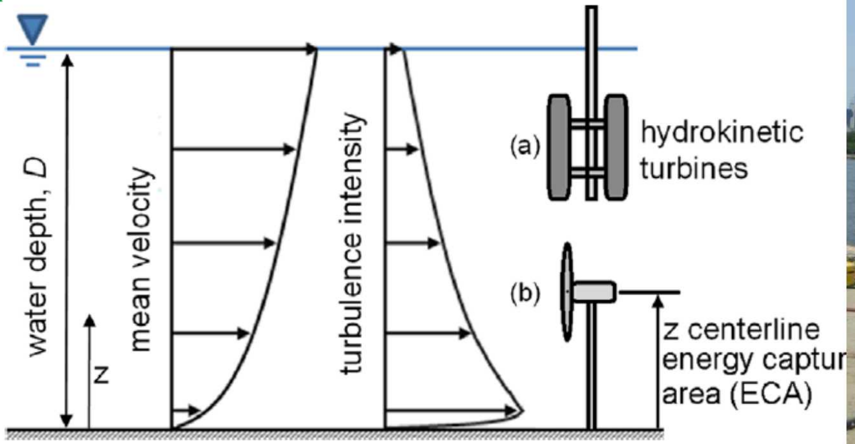
γ_m is the partial safety factors for materials

f_k is the characteristic values of material properties

Ensure material's strength exceed design loads

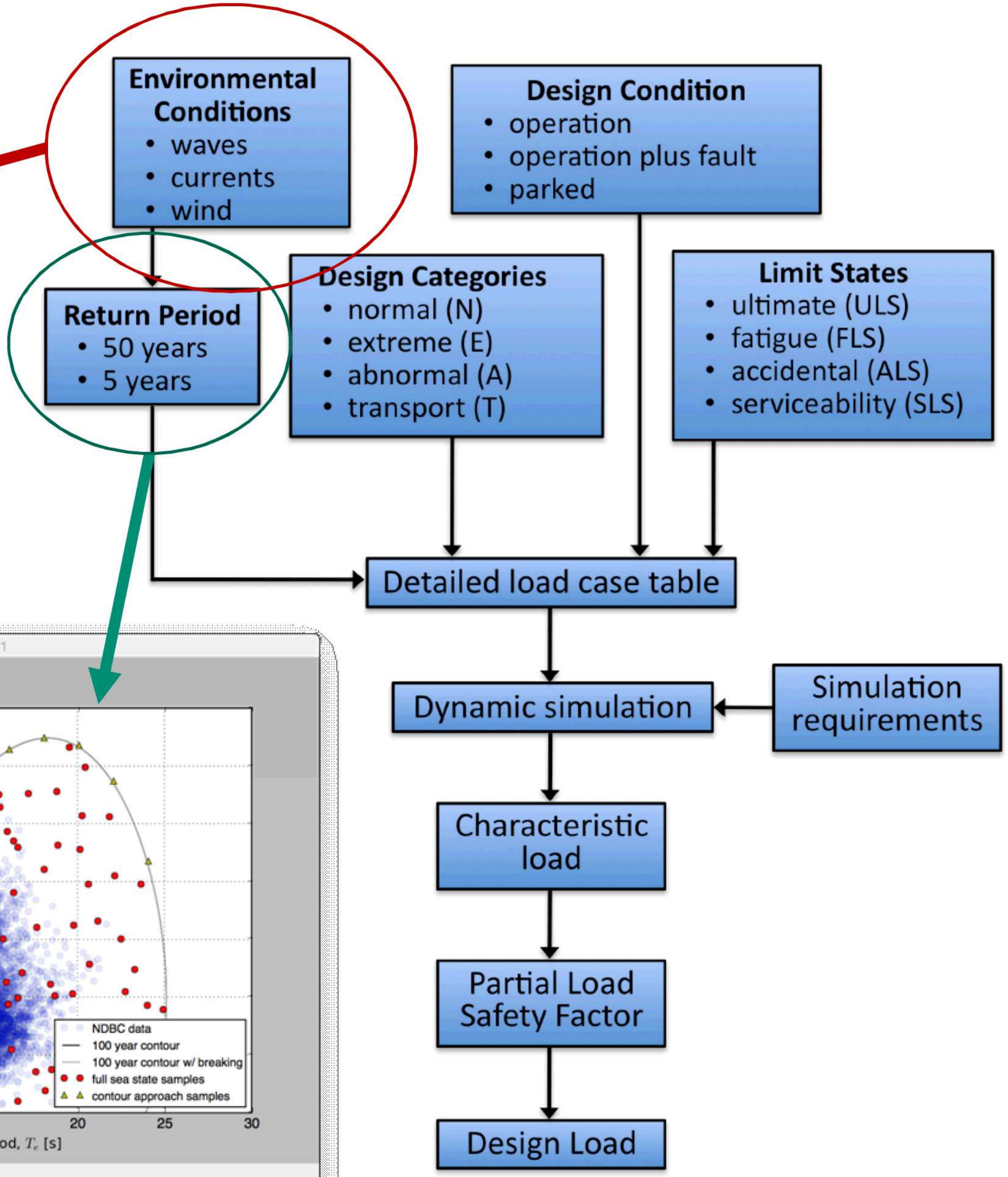
IEC design load

A



Neary et al. 2013, *Renewable and Sustainable Energy Reviews*

B



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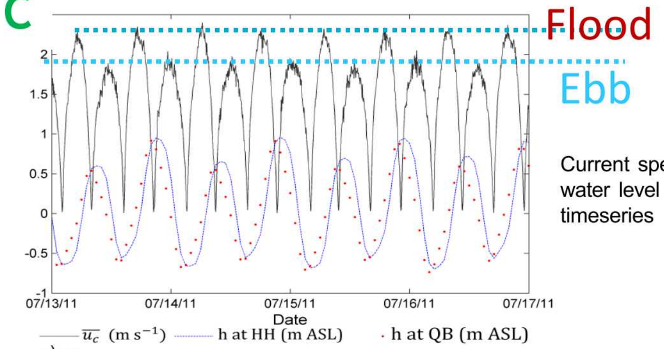
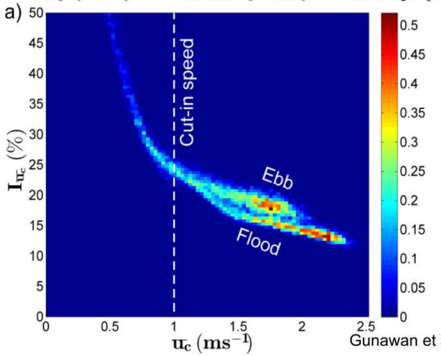


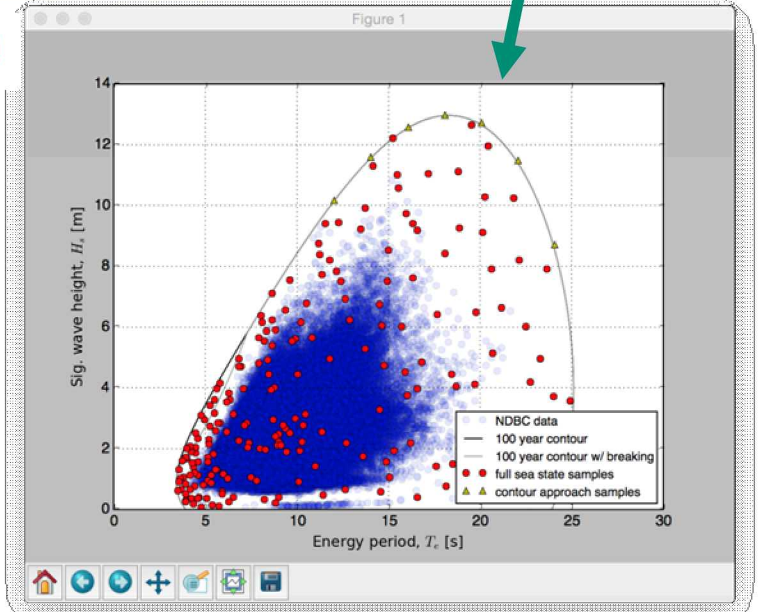
Current speed & water level timeseries



Turbulence intensity Vs. current speed

Gunawan et al. 2013, *Renewable Energy*

D



Wave design response toolbox

s for determining design loads via load cases

IEC TS 62600 -2 ED2 (2018)

IEC design load

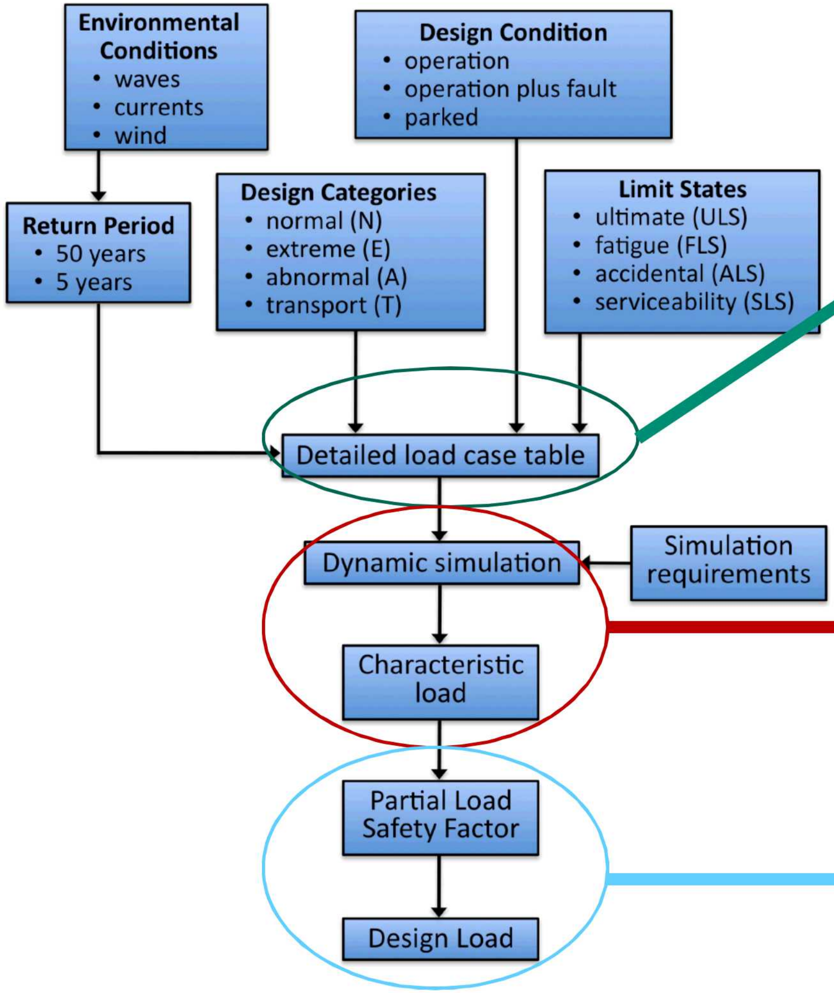


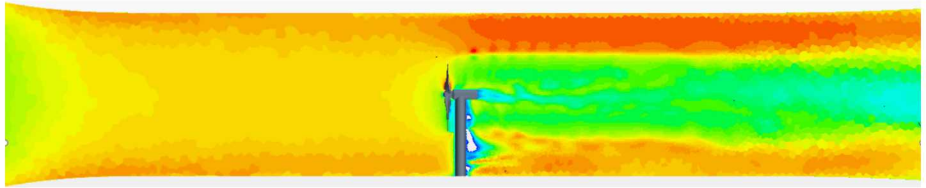
Figure 7-1. Process for determining design loads via load cases

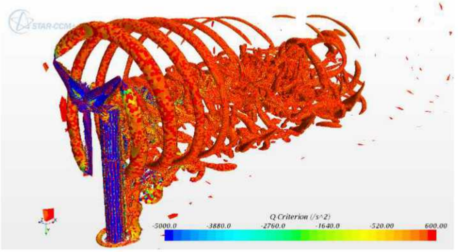
IEC TS 62600 -2 ED2 (2018)

Table 7-5. Design load cases for WEC

Design condition	DLC	Partial safety factor (limit state)	Wave conditions	Current conditions	Water level	Other conditions	Design category
1) Normal operation	1.1	1,35 (ULS) 1,00 (FLS) 1,00 (SLS)	NSS $H_{s,in} \leq H_s \leq H_{s,out}$	NCM $U=U_1$	NWLR		
	Ice	1,35 (ULS) 1,00 (FLS)	No waves	NCM $U_{in} \leq U \leq U_{out}$	NWLR	Ice	
6) Parked/survival conditions	6.1	1,35(ULS) 1,00 (SLS)	ESS $H_s=H_{s50}$	ECM $U=U_5$	EWLR	Wind: EWM ($V=V_5$)	

ECM extreme current model (see 6.2.2.5)
ESS extreme stochastic sea state (see 6.2.1.3)
NCM normal steady current model (see 6.2.2.4)
NSS normal stochastic sea state (see 6.2.2.1)





Design load < Material's strength

$$F_d = \gamma_f F_k \qquad f_d = \frac{f_k}{\gamma_m}$$

Real-time load measurements – Instream Energy System testing

A

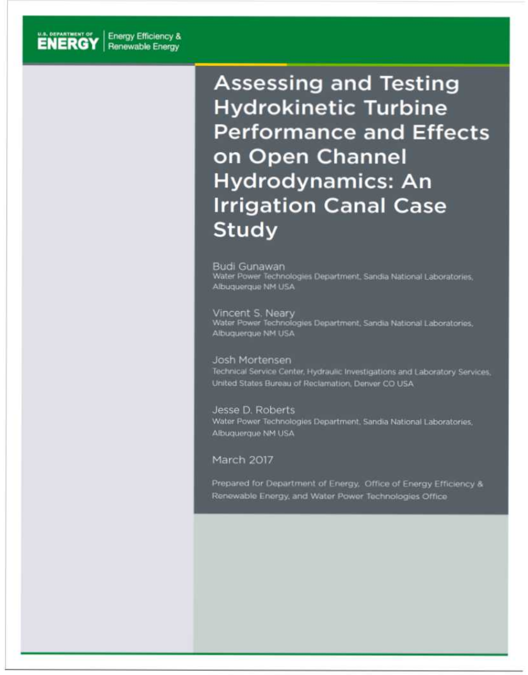
B

C

Torque sensor

D

Drag/thrust load sensor



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Assessing and Testing Hydrokinetic Turbine Performance and Effects on Open Channel Hydrodynamics: An Irrigation Canal Case Study

Budi Gunawan
Water Power Technologies Department, Sandia National Laboratories, Albuquerque NM USA

Vincent S. Neary
Water Power Technologies Department, Sandia National Laboratories, Albuquerque NM USA

Josh Mortensen
Technical Service Center, Hydraulic Investigations and Laboratory Services, United States Bureau of Reclamation, Denver CO USA

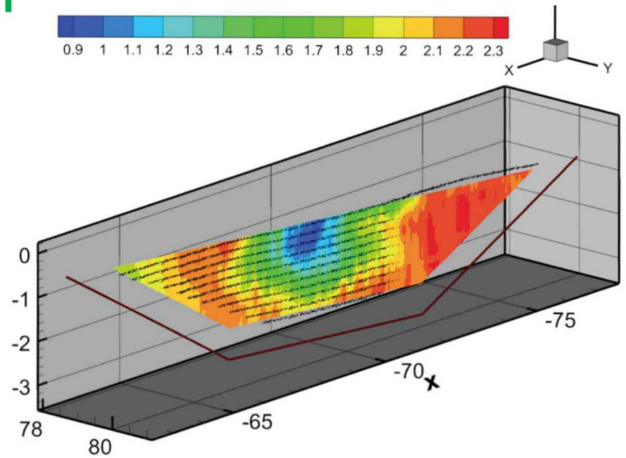
Jesse D. Roberts
Water Power Technologies Department, Sandia National Laboratories, Albuquerque NM USA

March 2017

Prepared for Department of Energy, Office of Energy Efficiency & Renewable Energy, and Water Power Technologies Office

E

F



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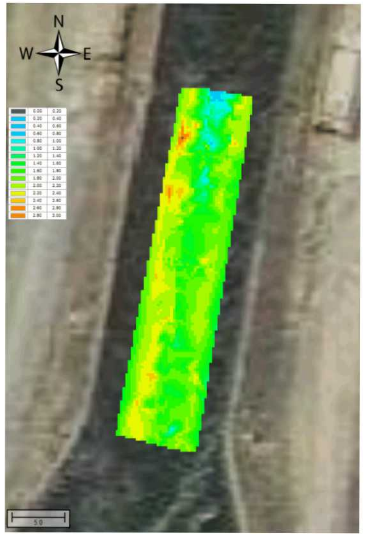
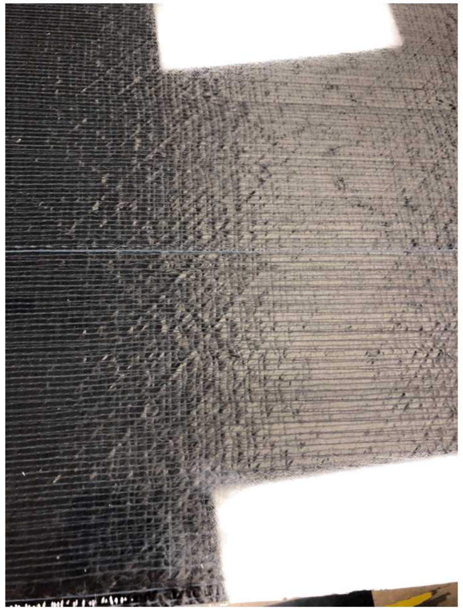
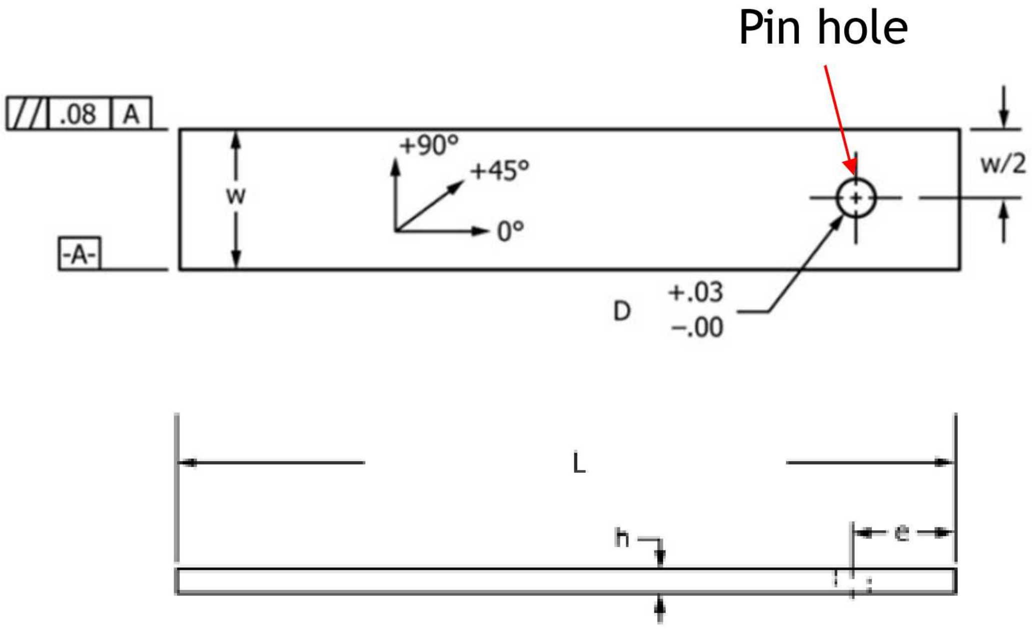


FY18 work: bolted joint testing

Bolted joint testing - ASTM D5961

ASTM D5961: Standard Test Method for Bearing Response of Polymer Matrix Composite Laminates





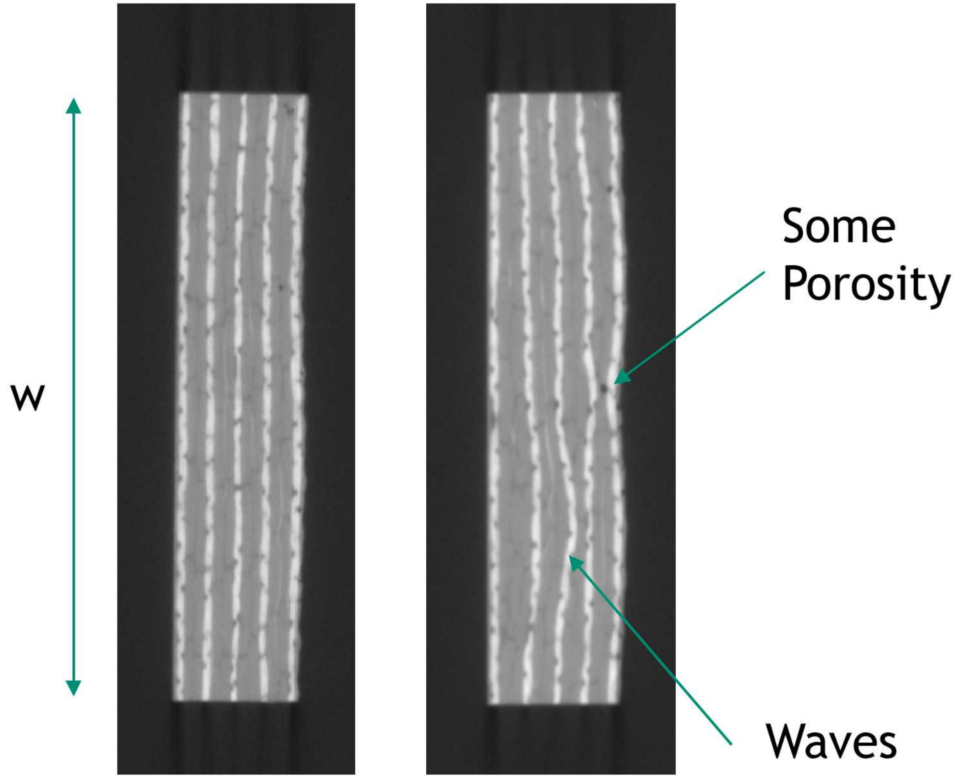
Parameter	Standard Dimension, mm
fastener or pin diameter, d	6 + 0.00/−0.03
hole diameter, D	6 + 0.03/−0.00
thickness range, h	2-4
length, L	135
width, w	36 ± 1
edge distance, e	18 ± 1
countersink	none

FIG. 1 Double-Shear and Single-Shear One-Piece Test Specimen Drawing (SI)

ASTM D5961

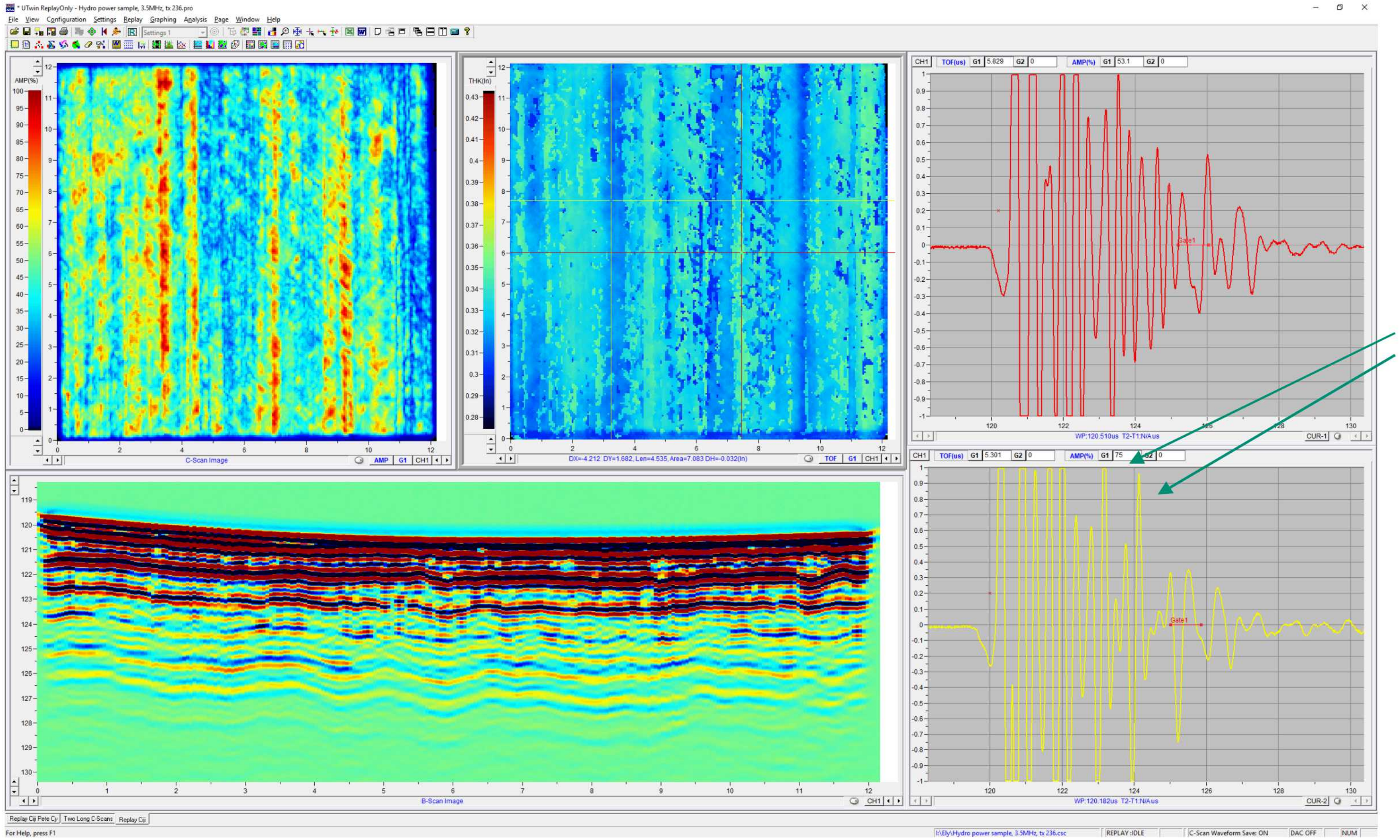
Non Destructive Inspection – CT Scanning

NDI team: Ray Ely, Ciji Nelson, Eddie Moffitt, Dennis Roach

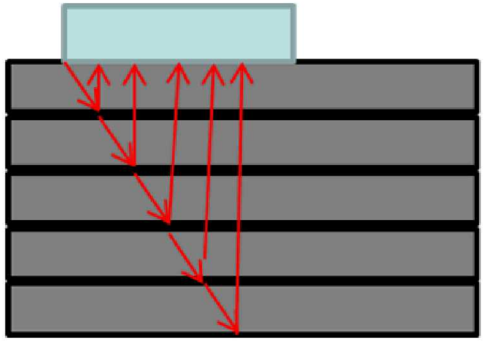


- CT Scans will identify such as porosity and wave, contributed to premature failures
- Overall the specimens appear fairly “clean”, with some occasional porosity and waves
- Due to its high accuracy CT Scans can be used as a reference method for quantifying the effectiveness of other NDI techniques
- CT Scanning may not be the most cost effective solution for performing QA inspections on an ongoing basis

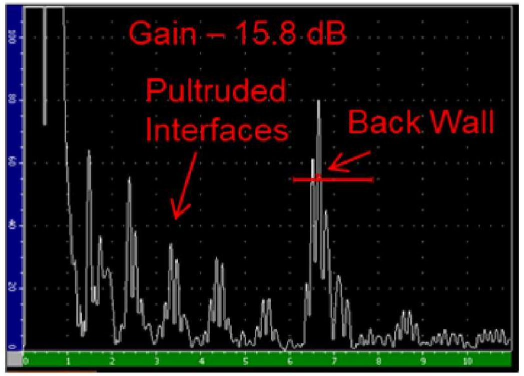
Non Destructive Inspection – Ultrasonic Immersion Testing



Multiple Reflections at Interfaces



Signal return schematic of pulturded sheet interfaces shown on A-Scan

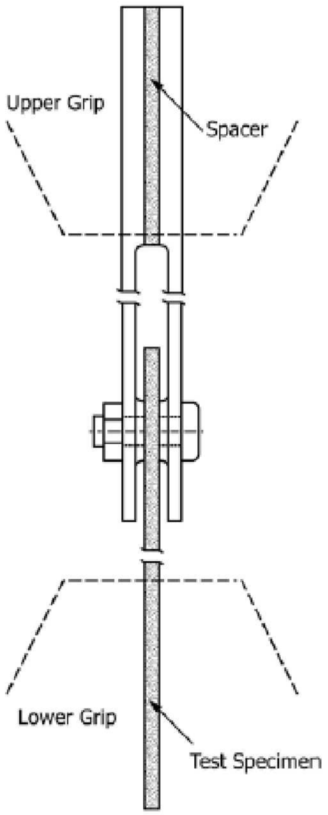


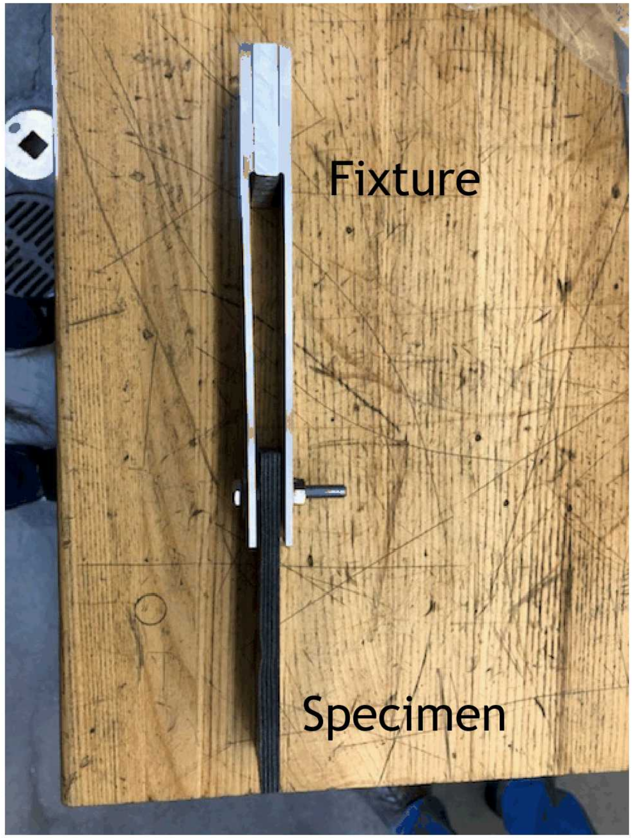
- Ultrasonic immersion testing was performed on a 12” x 12” section cut from the panel as the tensile coupons
- Initial scans showed multiple signal reflections at the alternating carbon/glass interfaces, which result in significant signal attenuation
- Similar results as previous work with multiple layers of pultruded carbon

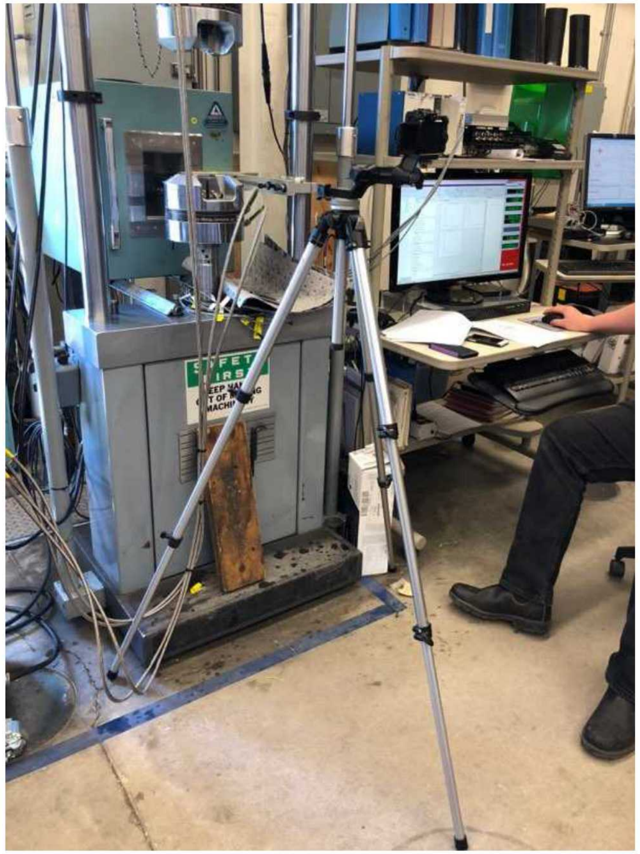
Bearing Response Testing – Test setup

Tensile test team: Mathew Ingraham, James Nicholas, Mariana Castenada, Budi, Bernie

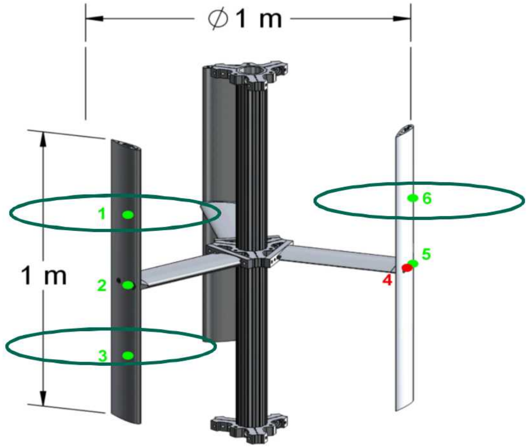
Data output rate: 20 Hz
Measurement time: a few minutes per specimen



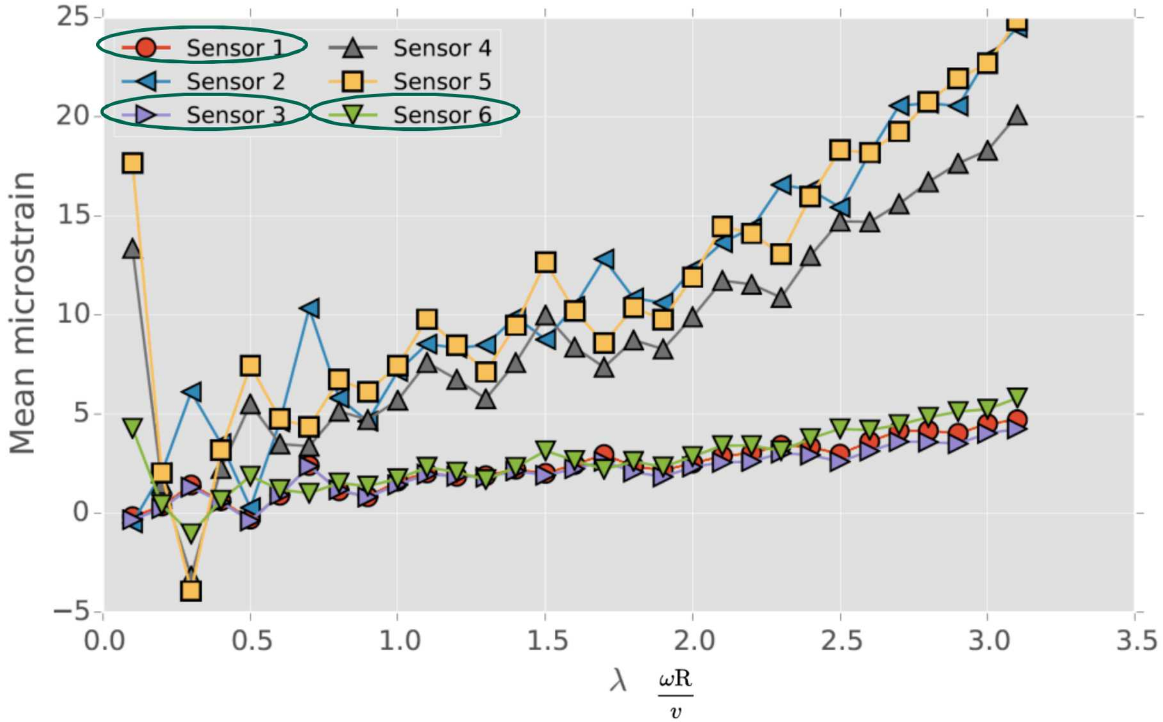




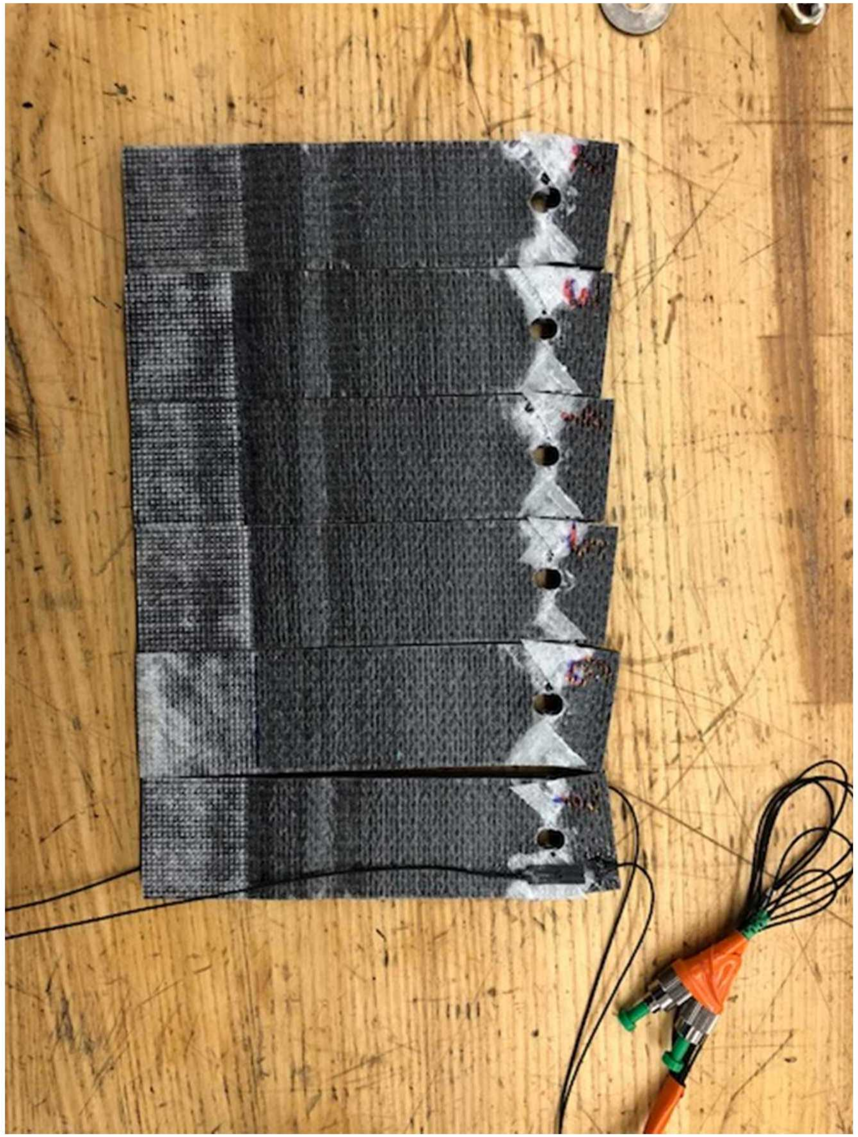
Fiber optic sensor for strain measurement

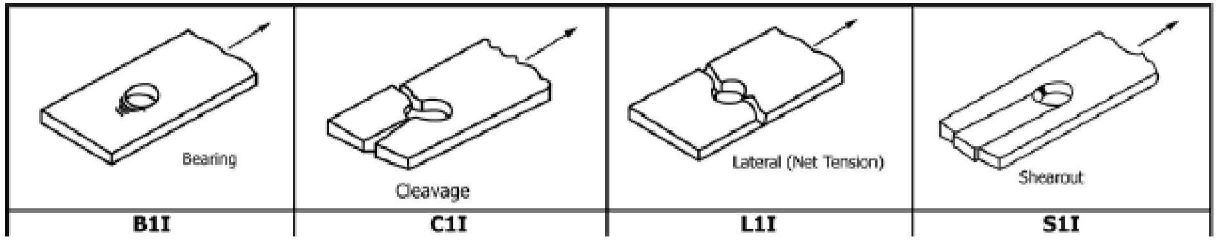


FBG sensor:
- Low noise (immune to EMI)
- Waterproof
- Small in size
- Rapidly becoming an instrument of choice for wind energy



Bearing Response Testing – Failure

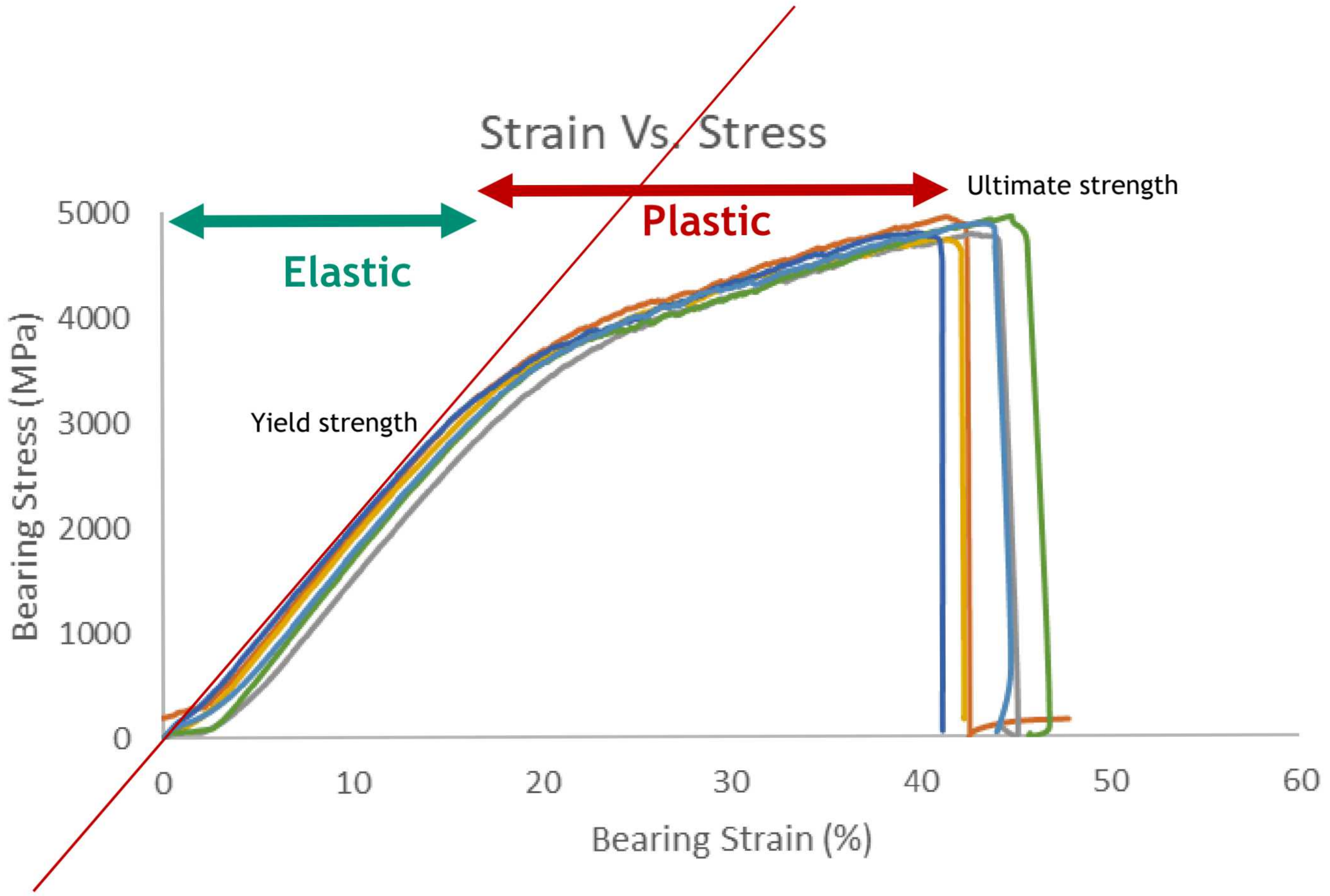




Bearing Test Failure Codes With Illustrations of Common Modes

ASTM D5961

FY18 work: NDI results



(D'-D)/ D in percent

Next steps

Load and sensor

- Continue testing for bolted joint panels, for wet samples and fatigue testing
- Determine design loads for large subcomponent to be tested in FY19
- Instrument subcomponent with load sensors
- Open water testing of subcomponent at PNNL's Marine Science Lab

Non destructive inspection

- Better understand inspection needs (e.g., interply delaminations vs. bondline inspections may drive different inspection methods and optimization)
- Optimize inspections, which may include changes in probe frequency, gate changes and application of Time Corrected Gain (TCG) to account for the signal attenuation
- Evaluate additional inspection methods, such as Phased Array Ultrasonics, and Resonance

Feedback and Participation

Feedback and recommendation are more than welcome!

Bernadette Hernandez-Sanchez
Sandia National Laboratories
baherna@sandia.gov

or

Budi Gunawan
Sandia National Laboratories
bgunawa@sandia.gov