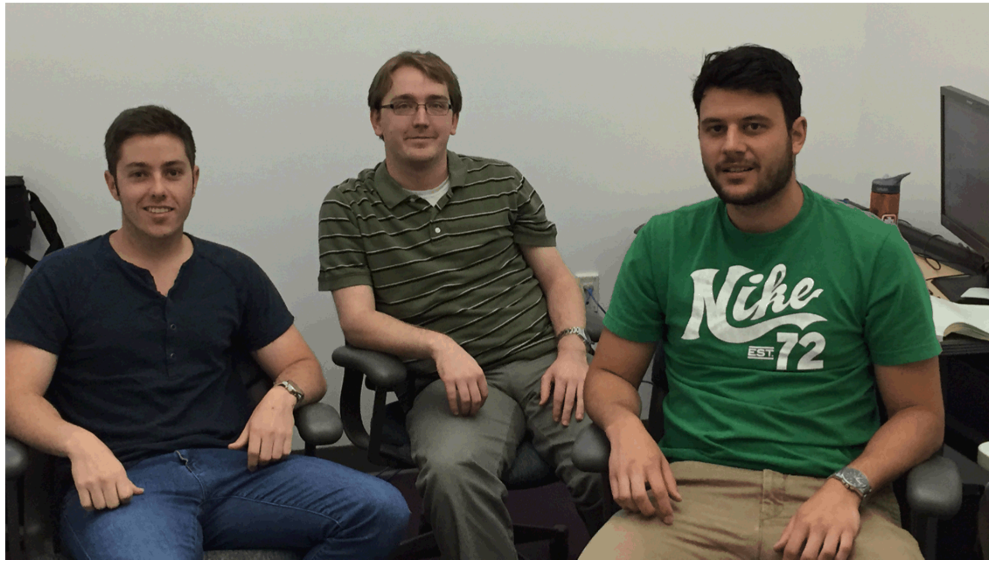
SAND2015-6044D

Project 3: Quantification of Uncertainty in Lap Joints



- **Students:**

Matthew S Bonney – University of Wisconsin

Brett A Robertson– Arizona State University

Fabian Schempp – University of Stuttgart

- **Mentors:**

Matthew Brake – Sandia National Labs

Marc Mignolet – Arizona State University

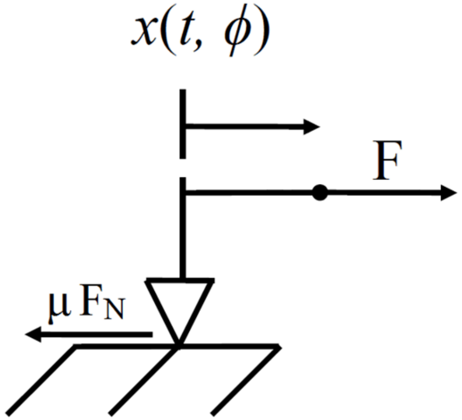
Matt Allen – University of Wisconsin

Motivation

- The dynamics in physical joints is still mostly unknown; However, joints have a great influence on the energy dissipation and vibration characteristics of structures.
- Great effort has been put into creating models which capture the dynamic behavior in joints accurately.
- The scope of this project within the summer research institute is to deduce parameters for those models from experimental results and to quantify the uncertainty.
- The system used is the Brake-Reuß beam, which contains a lap joint fixed together by three bolts.
- Friction models that are investigated: Coulomb friction, Jenkins element, and Iwan friction model.

Coulomb Friction

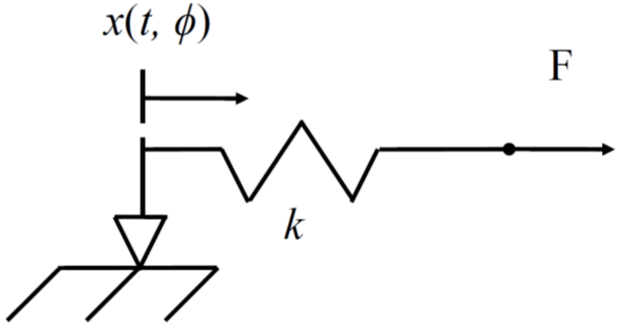
- Parameters: μ
- The coulomb friction model describes the relation between tangential force and the applied normal force as a function of displacement.
- μ may have different values for static and dynamic friction.
- Assumptions: Amontons' friction laws and Coulomb's friction law



$$F_f = \mu \, F_N$$

Jenkins Element

- Parameters: k , μ
- ϕ is the maximum distance the spring can elongate without the slider slipping.
- For a force equal to μF_N, the coulomb element will slip.
- Located at a single point.
- Fundamental element for Iwan and other friction models.
- Assumptions: Coulomb Friction, Linear spring



$$F(t) = \begin{cases} k\,x(t,\phi) & \quad\quad Stick \\ \mu\,F_N & \quad\quad Slip \end{cases}$$

Iwan Element

- The Iwan model is a parallel connection of multiple Jenkins elements with different slip thresholds.
- Distribution of sliders given by:

$$\rho(\phi) = \boldsymbol{R}\,\phi^{\chi}[H(\phi) - H(\phi - \phi_{\mathbf{max}})] + \boldsymbol{S}\delta(\phi - \phi_{\mathbf{max}})$$

Converted to physical parameters

$\{R, \chi, \phi_{\text{max}}, S\} \rightarrow \{F_S, K_T, \chi, \beta\}$

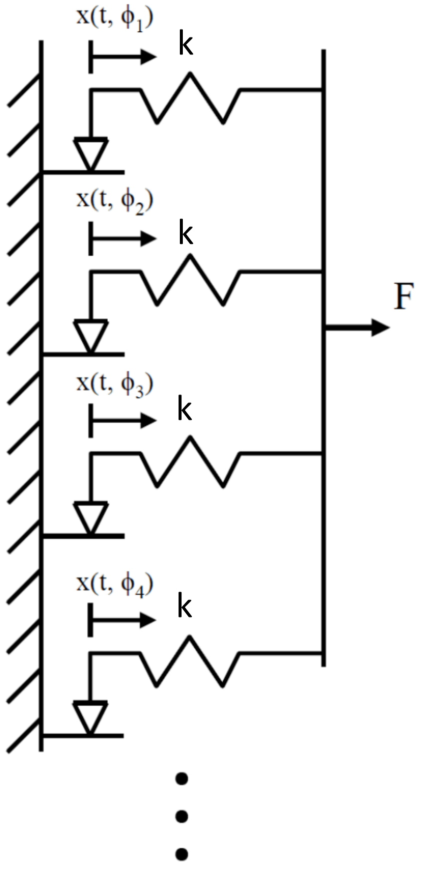
- Parameters:

F_s: Force where macroslip first occurs

K_t: Interface stiffness

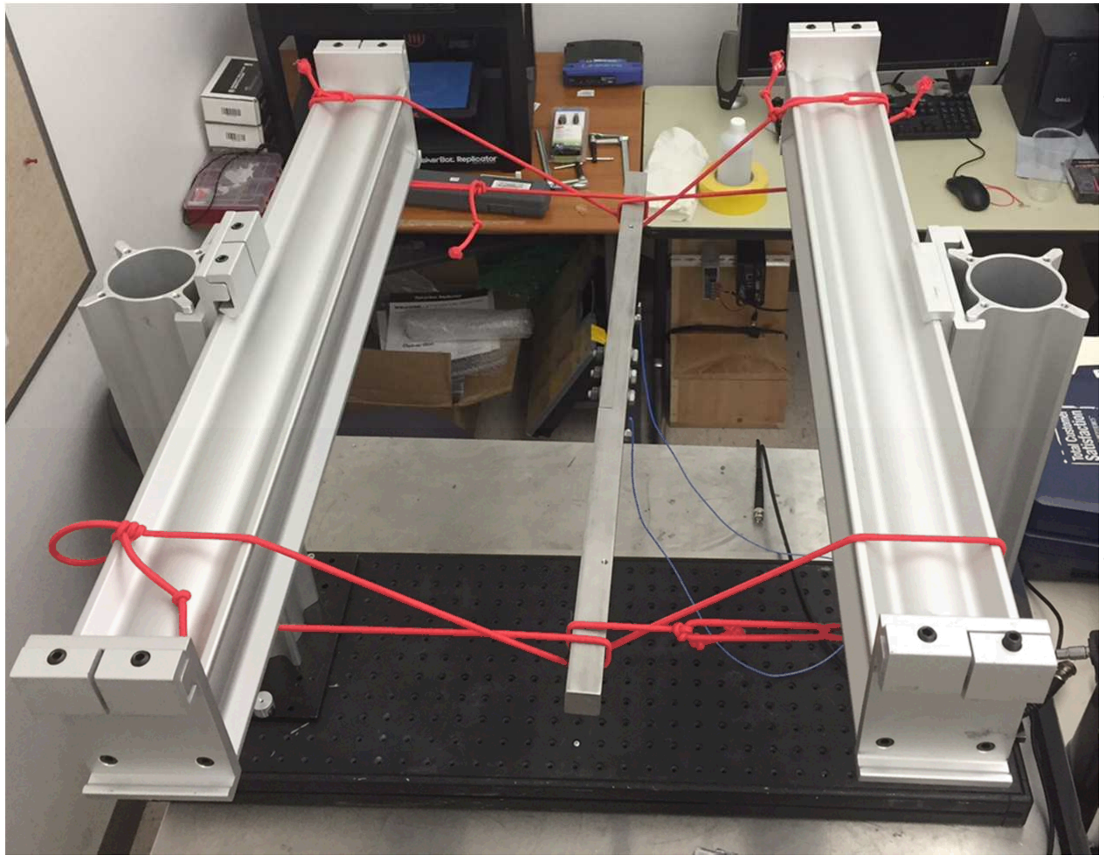
χ: Power law exponent

β: Mathematical correction factor



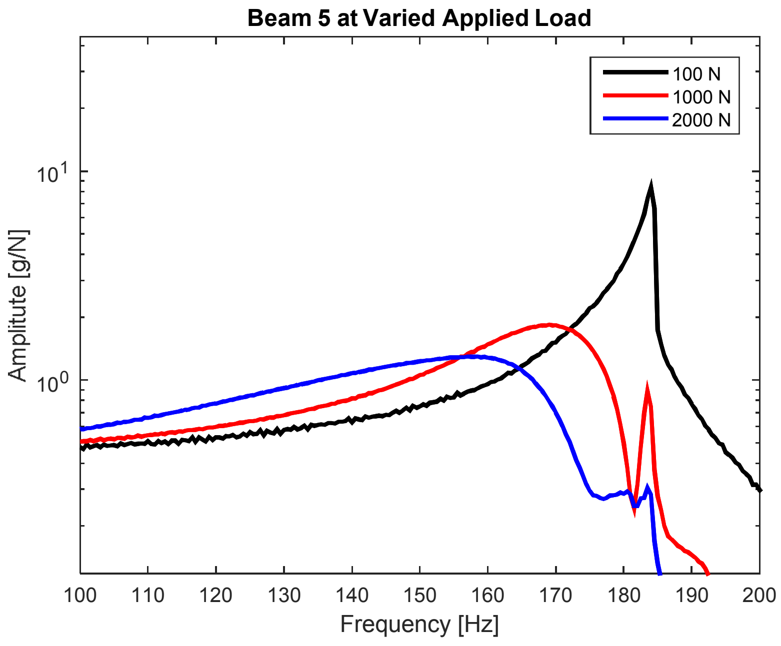
$$F(t) = \int_0^{\infty} \rho\left(\tilde{\phi}\right) k[x(t) - \tilde{x}(t, \widetilde{\phi})]\, d\tilde{\phi}$$

Experimental Setup

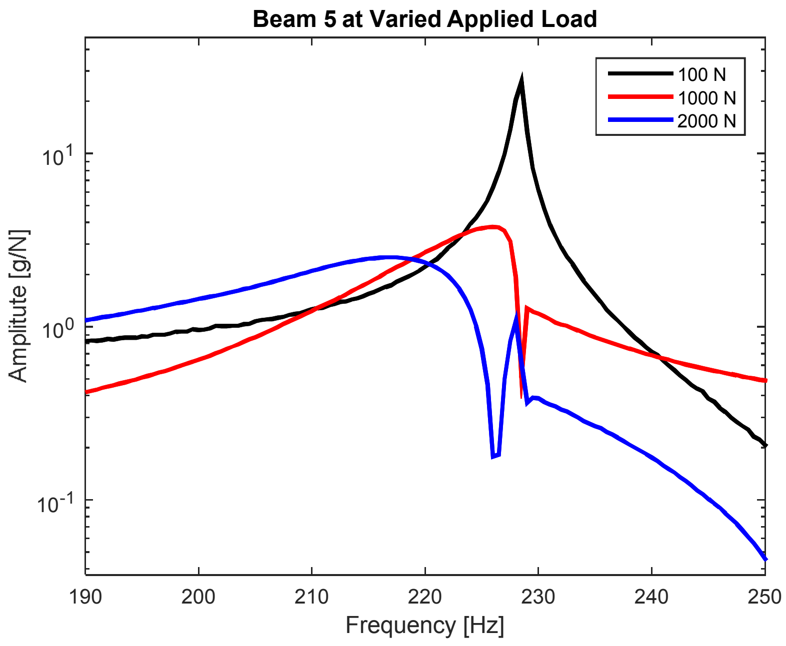


- Test Parameters:
  - Beam Interface Finish (Rough -> Mirror)
  - Bolt Torque (3, 5, 7, 10, 15 N-m)
  - Impact Level (100, 1000, 2000, 4000, >8000 N)
- 4 total bungee loops used to hold beam in place, while also simulating free-free boundary conditions.

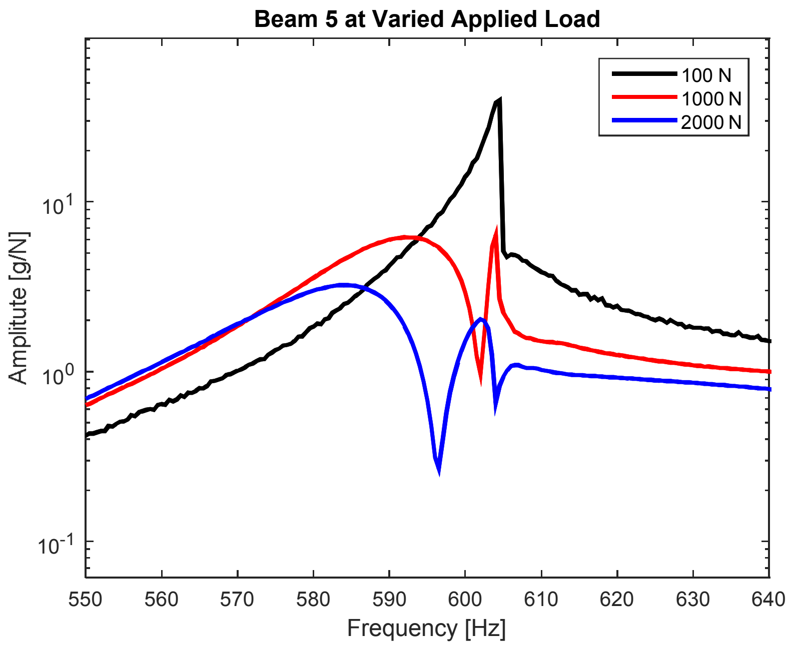
FRF for Varying Load Level



Mode 1

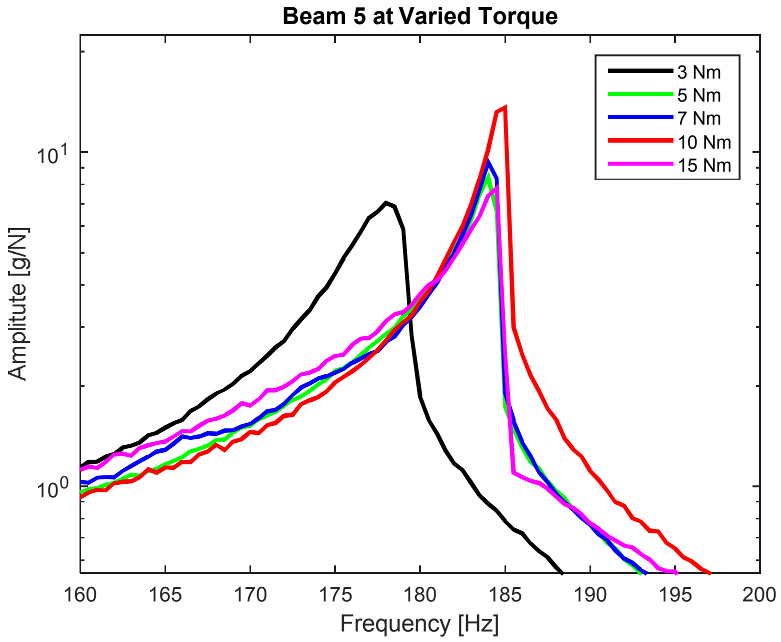


Mode 2

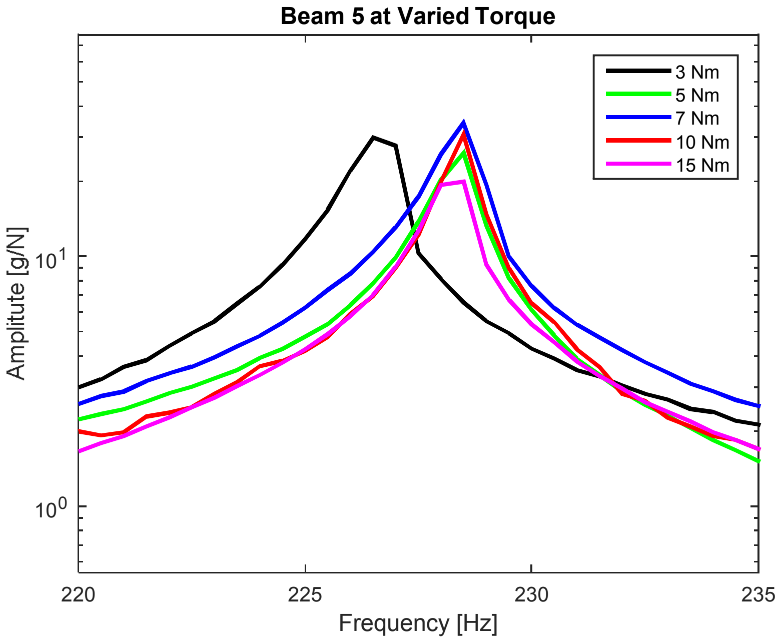


Mode 3

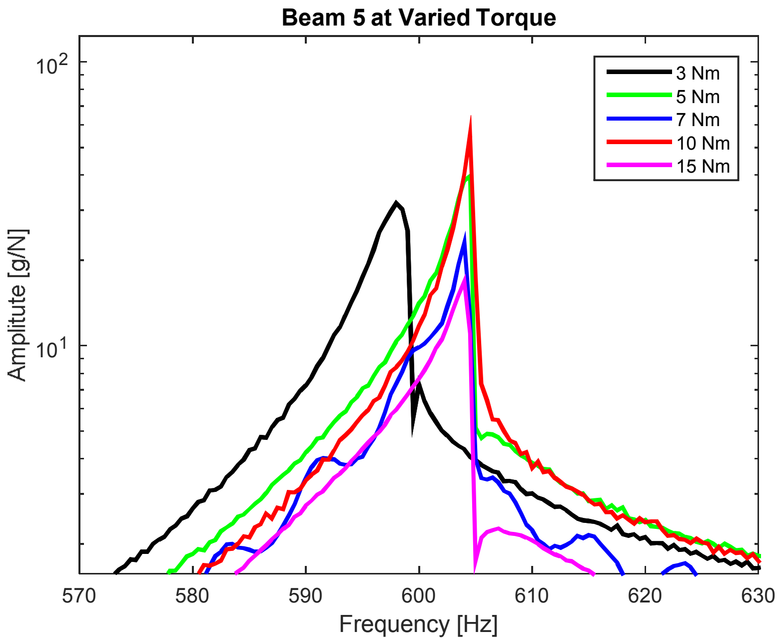
FRF for Varying Torque Level



Mode 1



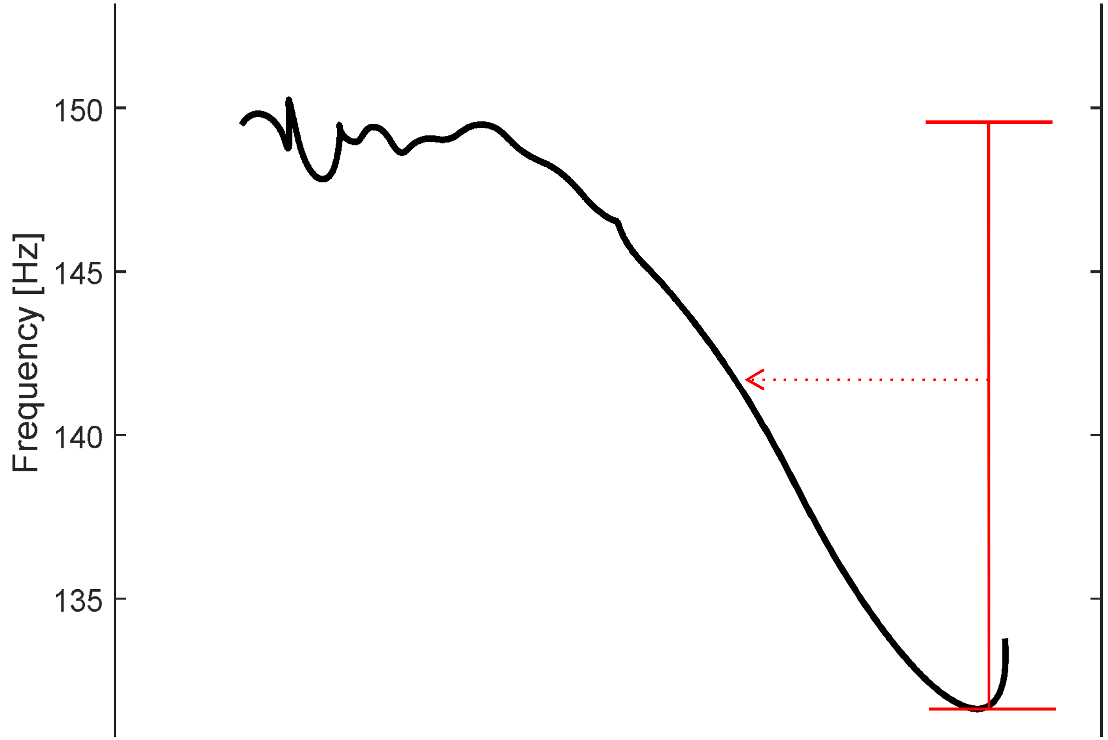
Mode 2



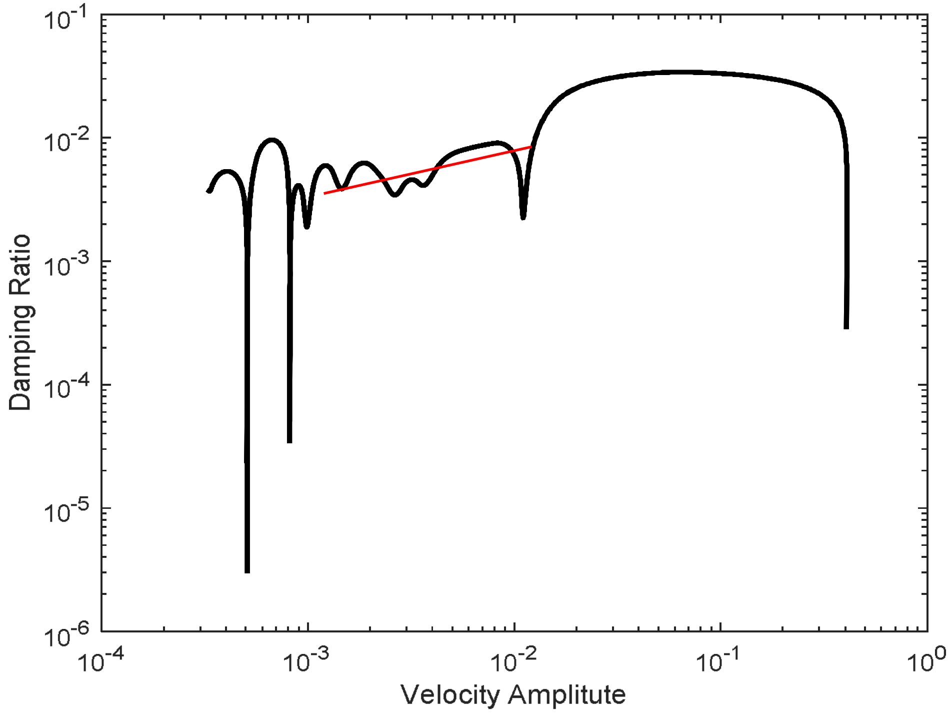
Mode 3

Deducing Iwan Parameters

- Hilbert Transform of time history
  - Get frequency, damping, and velocity amplitudes
- Choose linear fit of damping vs. velocity amplitude - Slope = χ
  - Also obtain standard error of χ
- Determine Kt by difference in linear frequency and macroslip saturation frequency (using frequency vs. velocity amplitude plot)
- Determine $\Phi_{\max}$ by choosing half the difference between linear and macroslip frequencies and obtaining velocity at that point, then transferring into displacement by dividing by ω
- Assume a distribution for β
- Use sampling methods to determine distribution of F_s using all other parameters found

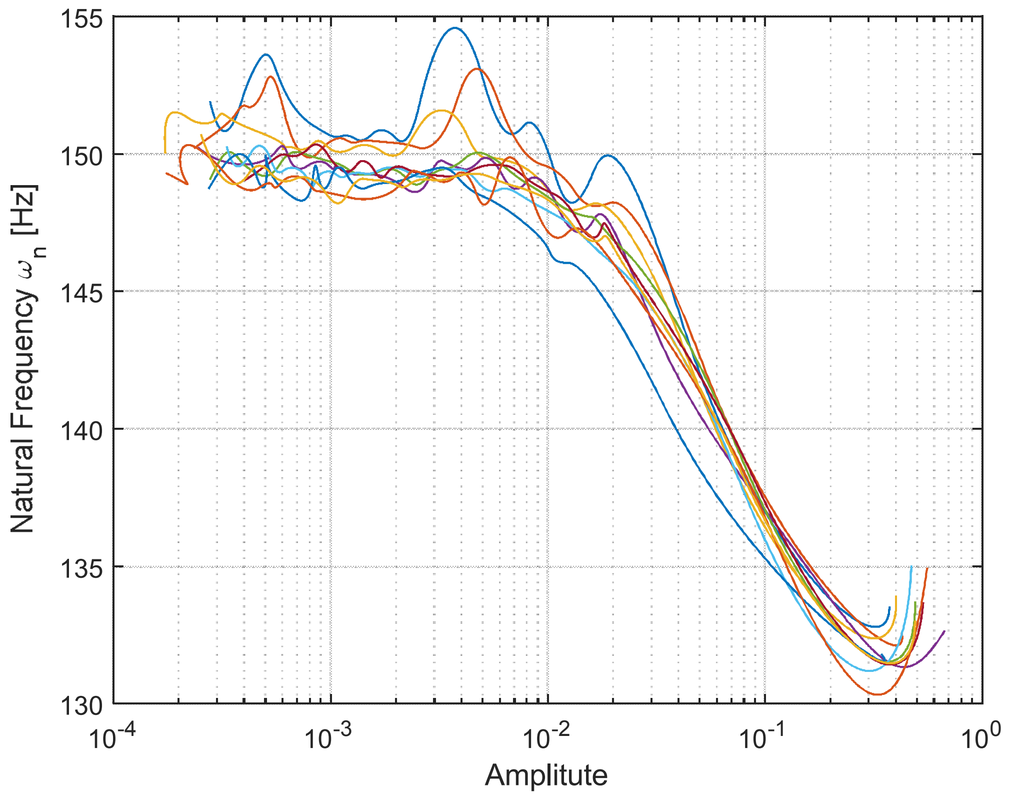


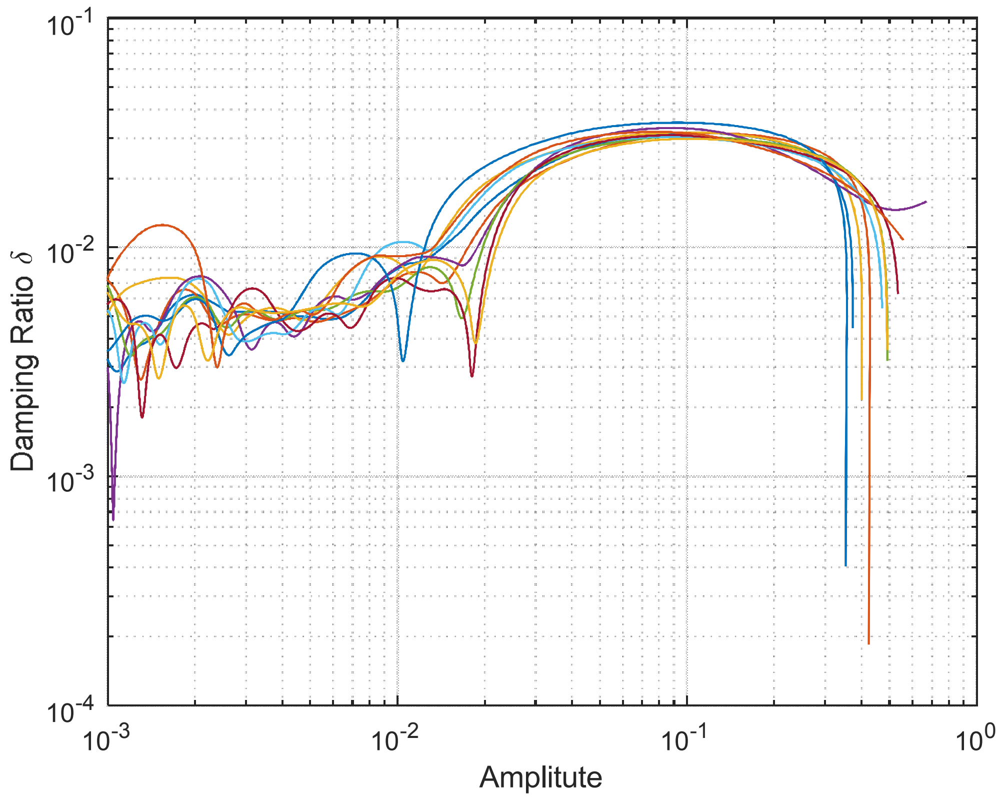
Frequency vs. Amplitude



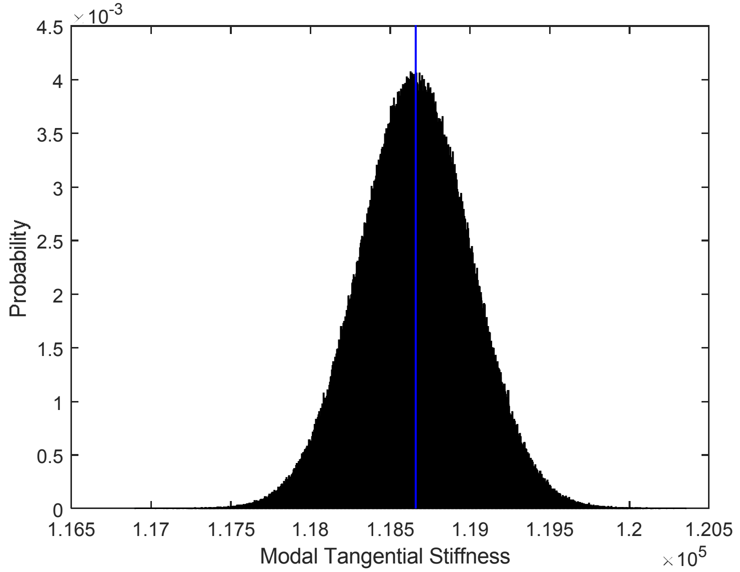
Damping Ratio vs. Amplitude

Hilbert Transform of Data
(Forcing Level > 8000 N)

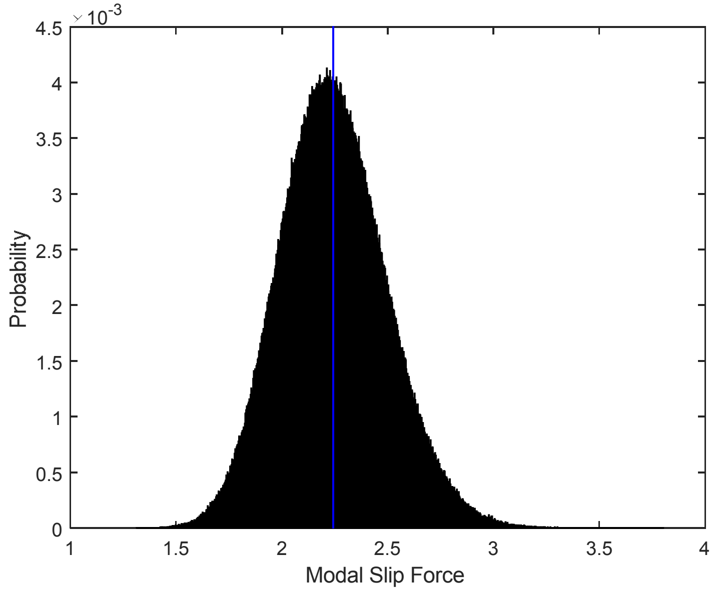




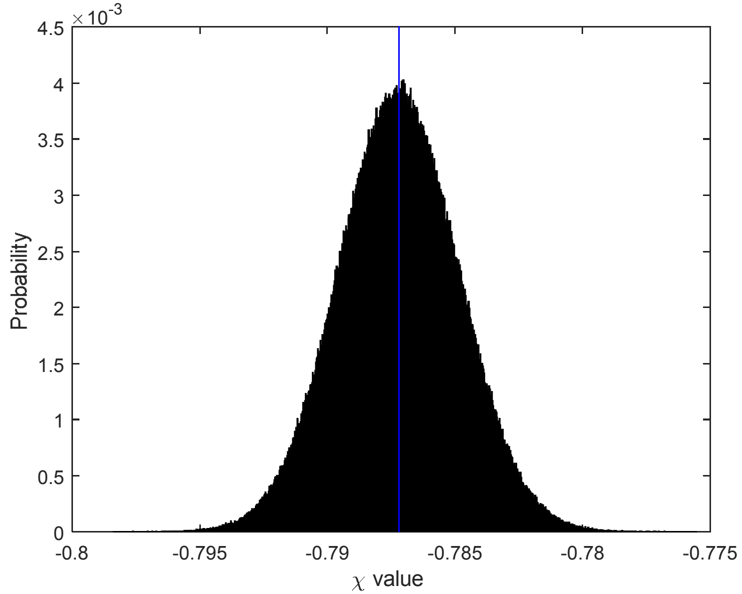
Iwan Parameter Distributions (Beam 1,Torque 15 N-m, Mode 1)



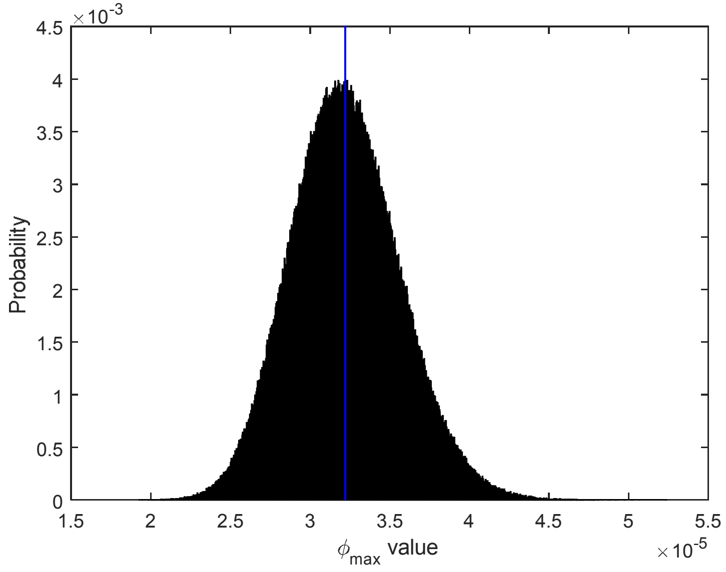
$$K_T \sim \Gamma(\alpha_K, 1)$$



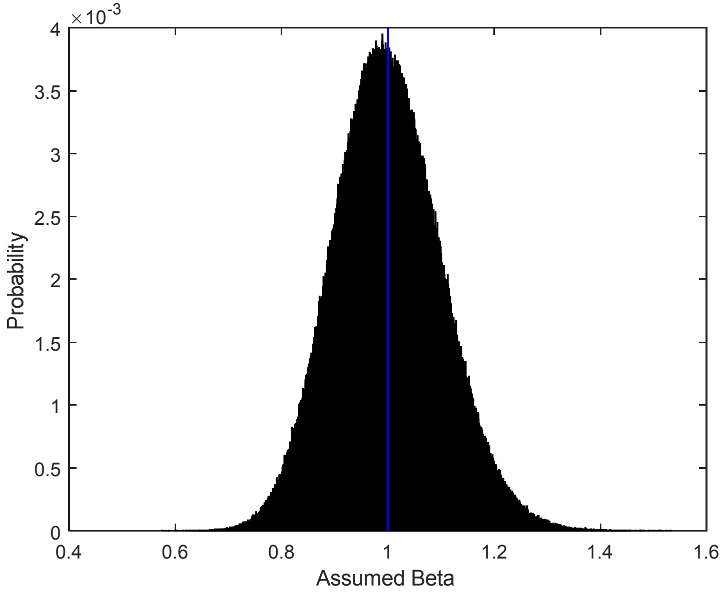
$$F_S \sim \Gamma(\alpha_F, \beta_F)$$



$$\chi \sim \beta(\alpha_\chi, \beta_\chi) - 1$$



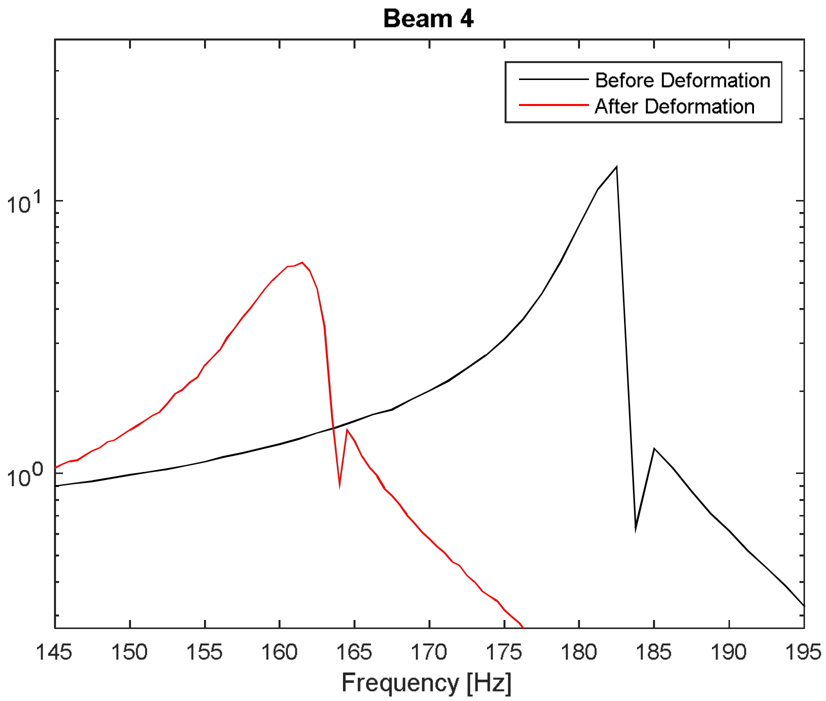
$$\phi_{max} \sim \Gamma(\alpha_{\phi}, \beta_{\phi})$$



$$B \sim \Gamma(100, .01).....(Assumption)$$

Plasticity Effect #1

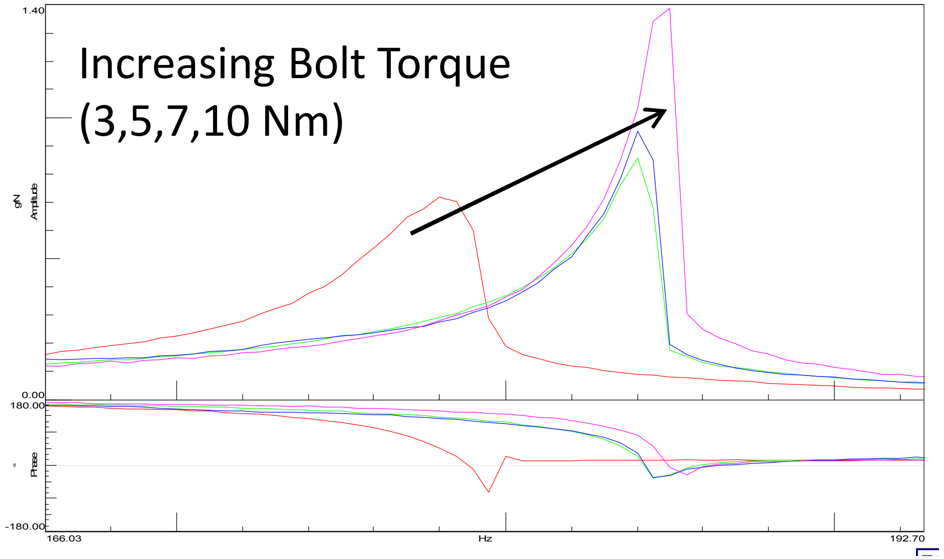
- **Problem:** Permanent change in fundamental frequency of beam 4
- **Tests:** New bolts; took out middle bolt; Mixed beams 3 and 4
- **Results:** All attempts showed same results, can conclude that beam 4 has permanent deformation at the interface and is no longer valid for comparison



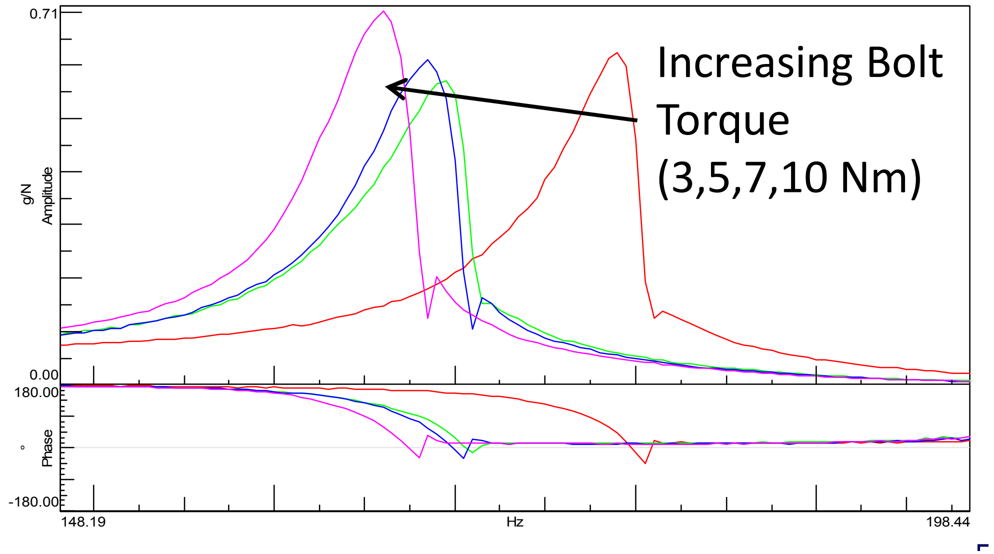
Beam 4 (left)
Beam 3 (right)

Plasticity Effect #2

- **Problem:** As bolt tightness was increased, the fundamental frequency was decreasing (counterintuitive as tighter bolts create stiffer interface)
- **Test:** Tested beams 1:5 (we only used 3 and 4 previously)
- **Results:** Only 3 and 4 decrease. 1, 2, and 5 increase as expected



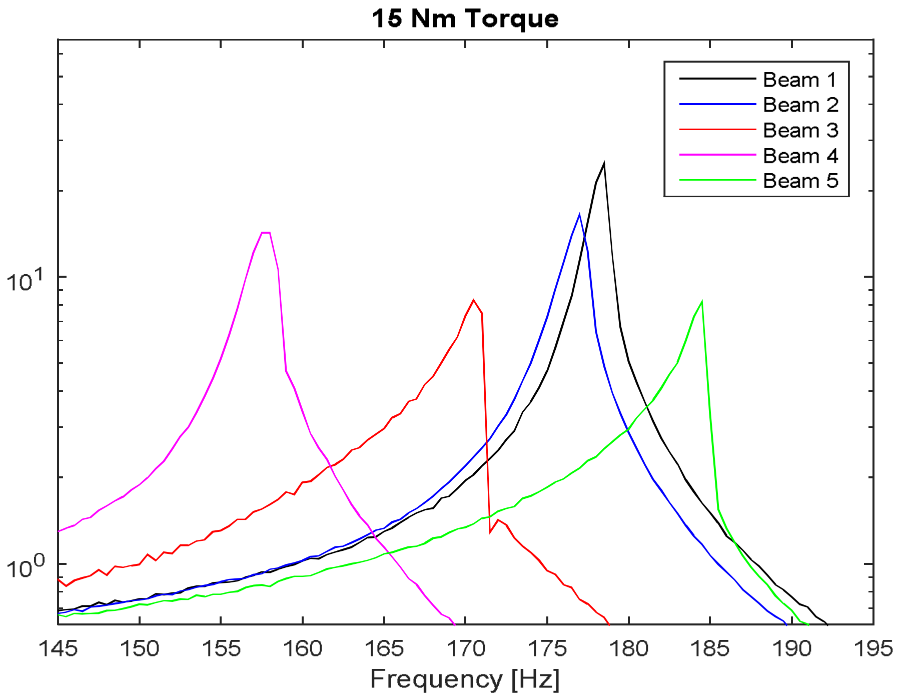
Beam 5

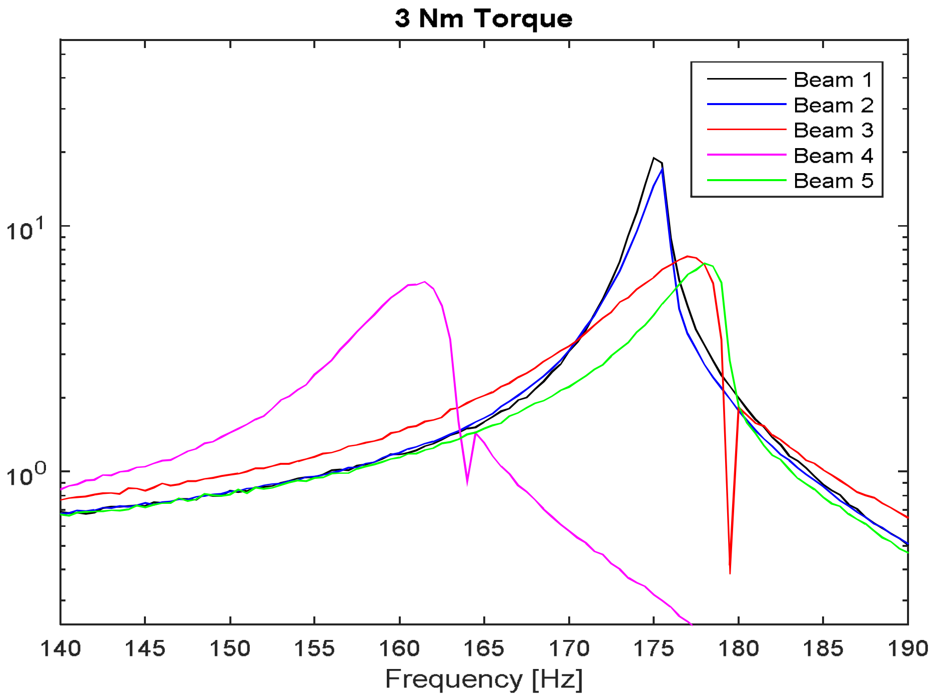


Beam 3

Plasticity Effect #3

- **Problem:** As beams go from rough to smooth, the fundamental frequency was decreasing
- **Test:** Tested beams 1:5 (we were comparing 1 with 4 previously)
- **Results:** Rough beams have fundamental frequency ~178 Hz and smooth beams have fundamental frequency ~184 Hz (Disregarding beams 3 and 4)





References

- B. Robertson and M. Bonney, et al. “Quantifying Epistemic and Aleatoric Uncertainty in the Ampair 600 Wind Turbine”, Proceedings of IMAC 2015, February 2015.
- C, Soize, "Generalized probabilistic approach of uncertainties in computational dynamics using random matrices and polynomial chaos decompositions." *International Journal for Numerical Methods in Engineering* 81.8 (2010): 939-970.
- L. Gaul and R. Nitsche, “The Role of Friction in Mechanical Joints”, Applied Mechanics Review, vol. 54, no. 2, pp. 93-105, 2001.
- D. J. Segalman, “A Four-Parameter Iwan Model for Lap-Type Joints”, ASME Journal of Applied Mechanics, vol. 72, pp.752-760, September 2005.
- M. Mignolet, P. Song, X.Q. Wang, “A stochastic Iwan-type model for joint behavior variability modeling”, Journal of Sound and Vibration, Volume 349, 4 August 2015, Pages 289-298, ISSN 0022-460X,
- M. Mayer, “Zum Einfluss von Fügestellen aud das dynamische Verhalten zusammengesetzter Strukturen”, Bericht aus dem Institut für Angewandte und Experimentelle Mechanik 2007/1, Der Andere Verlag
- M. Allen, “Introduction to Iwan Models and Modal Testing for Structures with Joints”, Presentation at the Nonlinear Mechanics and Dynamics Summer Research Institute

ASU

University of Stuttgart
Germany

Slide 1 Title		
	Slide 2 Motivation	
Slide 9 Deducing Iwan Parameters	Slide 3 4 5 Friction Models	Slide 14 Plasticity 1
Slide 10 Deducing Iwan Parameters	Slide 6 7 8 Setup/FRF‘s	Slide 15 Plasticity 2
Slide 11 Hilbert Transform Data	Slide 12 13 Iwan Parameter Distributions	Slide 16 Plasticity 3
Slide 18 Logos	Slide 17 References	

Recommended Layout