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The Derivation of Appropriate Laboratory Vibration Test Durations and Number of Shocks Hits from Non-Stationary Field Test Data*

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Outline

- Purpose of Study
- Description of Field Test
- Maximum Predicted Environment Models
- Power Law Fatigue Model (Minor's Rule)
- Vibration Damage Model
- Vibration Test Results
- Shock Damage Model
- Shock Test Results
- Using Test Specification as Reference

Purpose of Study

- A series of field tests were recently conducted with the goal of establishing the Maximum Predicted Environment (MPE)
  - Using the total measured durations and/or number hits with the MPE spectra to define a test is overly conservative
- The purpose of this study was to derive the optimal durations / # of hits for use when testing with the MPE spectra

Description of Field Test

- The field test consisted of two phases
  - A long distance road test (60+ hours of data)
  - A series of short distance in-house handling operations using forklifts and motorized carts (minutes of data)
- Ensembles of vibration and shock acceleration histories were collected and grouped by test configuration
  - Skyline plots were used to separate shocks from vibration
  - Vibration data are presented as Acceleration Spectral Densities (ASDs)
  - Shock data are presented as Shock Response Spectra (SRS)

Description of Field Test

- The number of measured vibration events were defined based on the analysis segment duration (30 seconds)
  - A 720 minute test have 1440 events
- The number of measured shock events were taken directly from the skyline analysis

Maximum Predicted Environment (MPE)

- The P99/90 MPE responses were generated from the measured field data
- For large sample sets a Distribution Free Tolerance Limit (DFTL) model was used
  - Simple rank ordering of the ensemble
  - Bootstrap realizations were used to increase confidence
- For small sample sets a Lognormal Tolerance Limit model (NASA 7005) was used

$$Y = log(X)$$

$$Y_{MPE} = \mu + k\sigma$$

$$X_{MPE} = 10^{Y_{MPE}}$$

Power Law Fatigue Damage Model

- Many references document the use of a power law fatigue damage model (Minor's Rule) to shorten the duration associated with a vibration environment

$$(G2/G1) = (T1/T2)^{b}$$

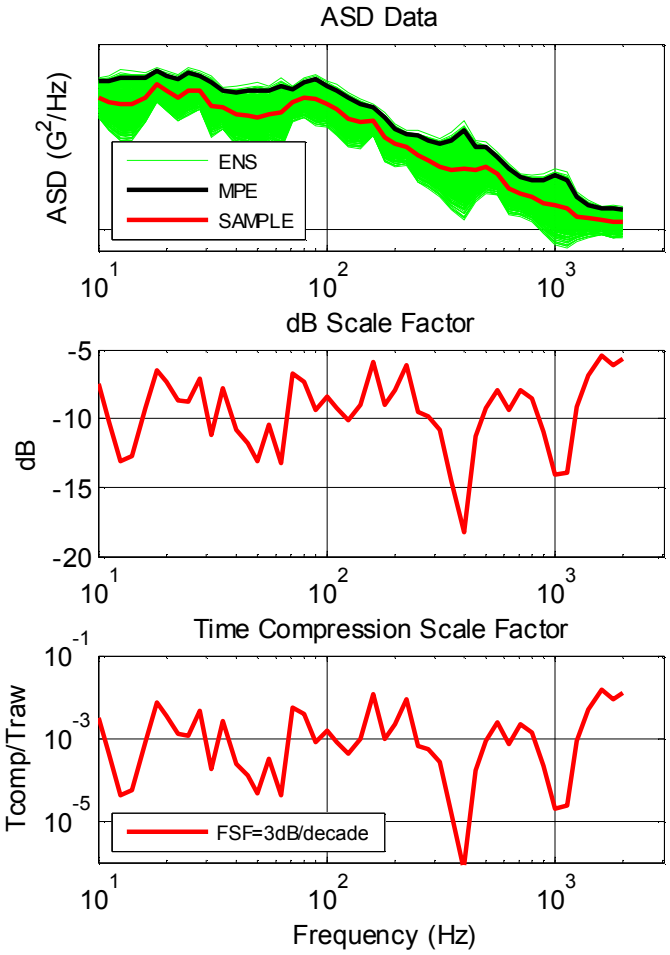
Vibration Damage Model

- For each random vibration event use the MPE ASD, *Smpe*, and the individual ASD, *Si*, to compute the compressed time, *Tc*, from the baseline time, *Ti*

$$log\left(\frac{Smpe}{Si}\right) = 2b * log(\frac{Ti}{Tc})$$

- The definition of dB is simply left hand side of this equation multiplied by 10
- The scaling is applied frequency by frequency

Frequency Dependent Compression Example



- Compute dB ratio for MPE and sample ASDs
- Compute compressed time using fatigue scale factor
  - 3dB/decade
- Sum by frequency for each curve in the ensemble
  - The final duration is the maximum of the frequency specific sums

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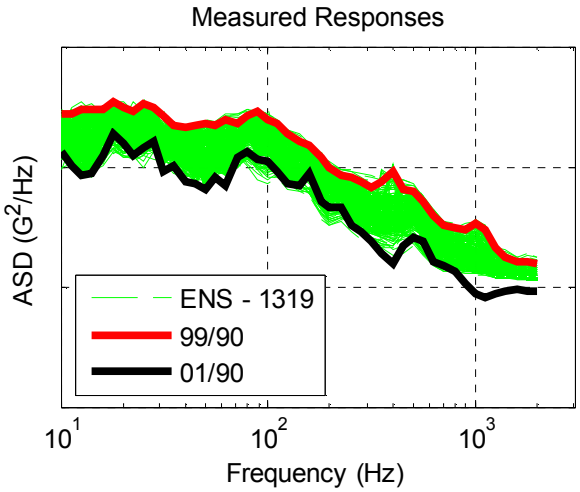
Vibration Damage Model Ensembles

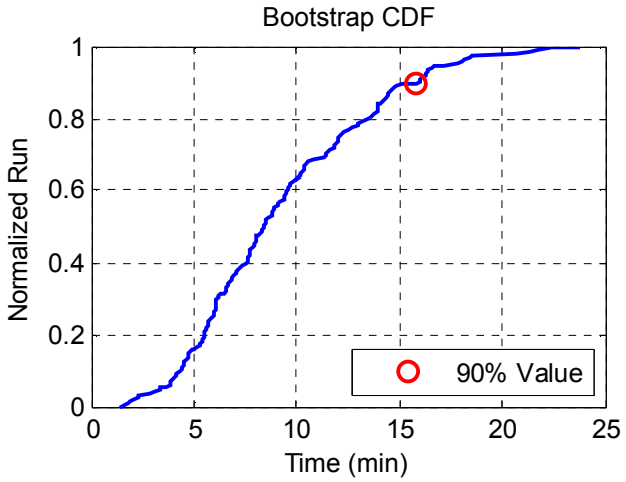
- Even for cases where there were hundreds of data points there is no guarantee that the ensemble is statistically significant
- The solution was to generate ensembles based on the sample statistics
  - The mean, μ, was computed from the "as measured" data
  - The standard deviation, σ, was computed based on the fact that the P99/90 spectra is $\approx$ equal to $\mu + 2.33\sigma$
  - The desired # of events was defined by multiplying the measured # of events by the ratio of the desired duration divided by the measured duration
- This approach was used for both dense and sparse data sets

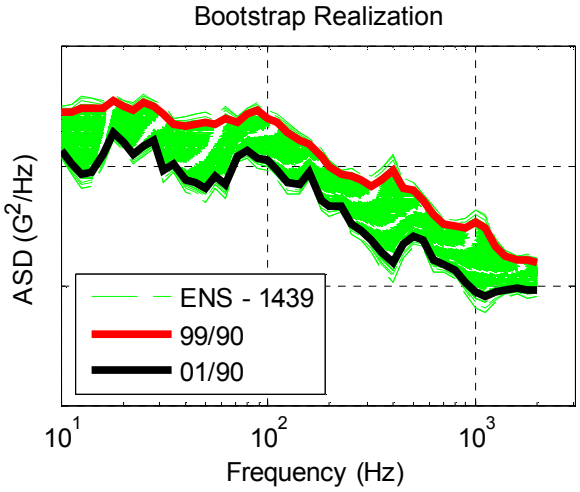
Vibration Damage Model Confidence

- The compressed duration for a single ensemble does not provide sufficient confidence in the results
- Bootstrap sampling was used to generate multiple realizations of the desired ensemble
  - The resulting collection of compressed durations are then ranked in ascending order
  - The 90% highest value is used to define the worst case duration

Example for Large Vibration Sample Set







Field Duration: 720 min
Compressed Duration: 15.5 min

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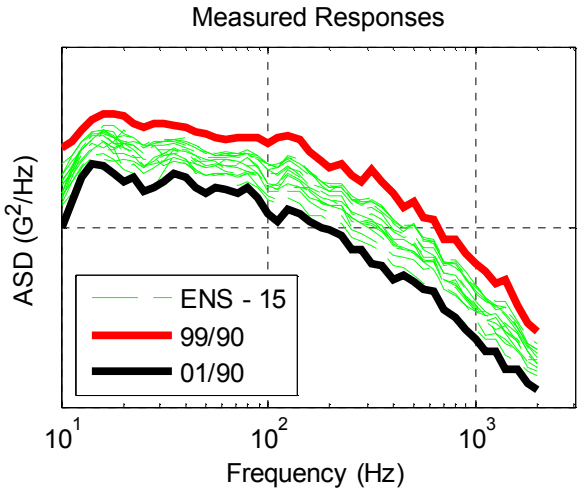
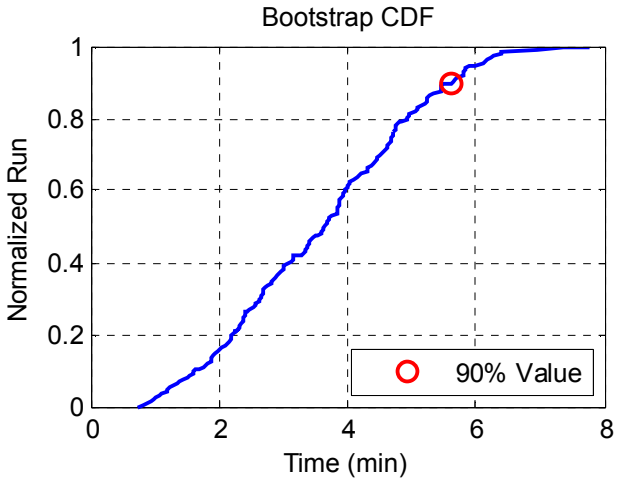
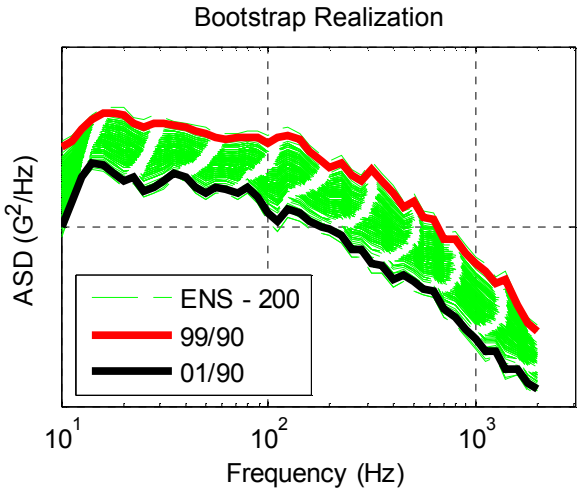
Example for Small Vibration Sample Set







Field Duration: 100 min
Compressed Duration: 5.7 min

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Shock Damage Model

- Transportation and handling shocks tend to be oscillatory in nature and comparable in magnitude to the background vibration
- This allows us to treat the shocks as just another portion of a large cycle fatigue environment

Shock Damage Model

- Use the MPE SRS, *Gmpe*, and the individual SRS, *Gi*, to compute the compressed time, *Tc*, from the baseline time, *Ti*

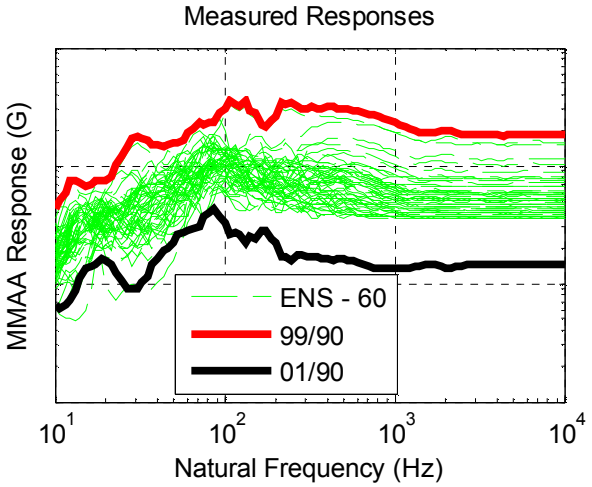
$$log\left(\frac{Gmpe}{Gi}\right) = b * log(\frac{Ti}{Tc})$$

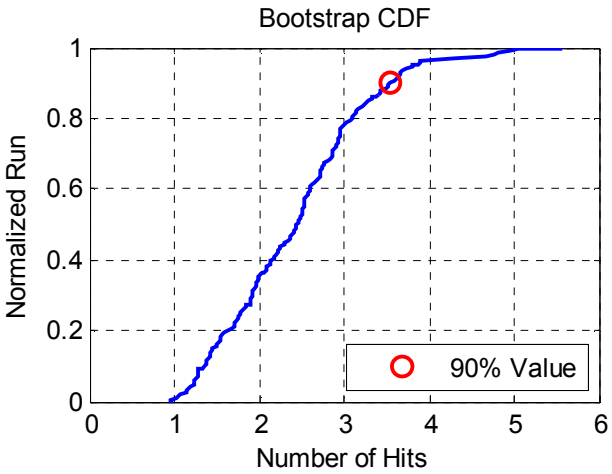
- The scaling is applied frequency by frequency

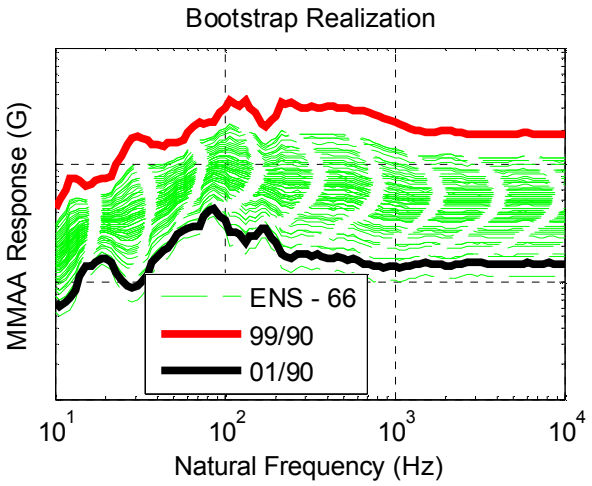
Shock Damage Model
Ensembles and Confidence

- Just as was done for the vibration ensembles, SRS ensembles were generated using the sample statistics
  - The desired # of field hits, N, were defined as the measured number of hits multiplied by the ratio of the desired field duration divided by the measured field duration
  - The compressed number of hits were computed as the maximum of the frequency specific hit totals for the ensemble
- Bootstrap realizations were used to generate the 90% confidence number of compressed hits

Example for Shock Sample Set







Field Hits: 66 hits
Compressed Hits: 3.5 hits
(round up to 4)

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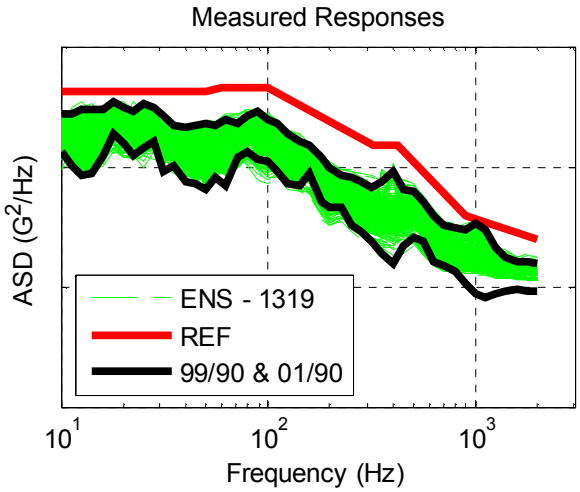
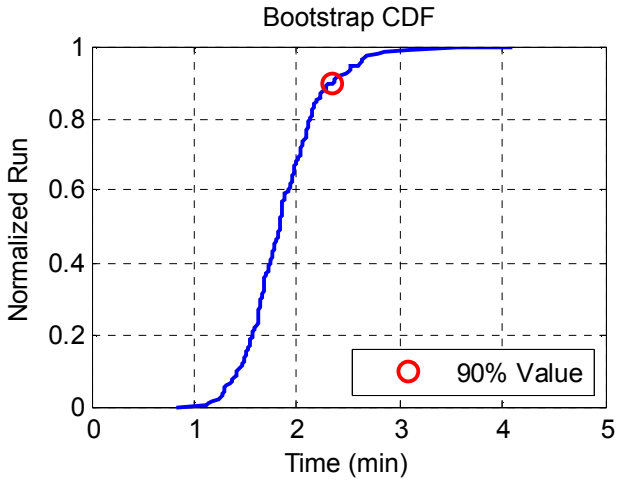
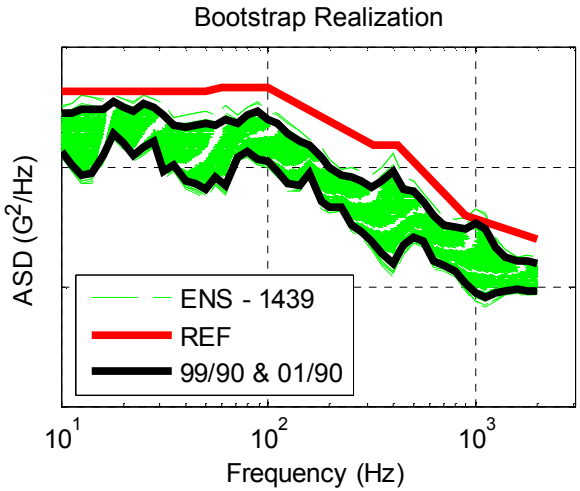
Using Test Specifications as the Reference

- Until now all of the examples have used the P99/90 MPE spectra as the basis for computing the compressed durations and number of hits
- Often the actual test specification is higher (enveloping other environments, etc.)
  - Allows for greater time compression

Example of Test Specification Reference







Duration (Re: MPE): 15.5 min
Duration (Re: Spec): 2.5 min

Observations

- The compression rates for the same road type varied based on tie down scheme
  - More loosely tied down packages exhibited more variation and hence higher MPE responses
  - This actually resulted in higher compression rates
- The long haul road compression rates are higher than defined in Mil-Std 810
  - 40:1 for this test
  - 16:1 for Mil-Std 810
  - We believe that this is at least partly due to the fact that we were shipping light weight, loosely constrained packages

Summary

- The methodology described in this presentation can be used to identify the appropriate vibration duration and/or number of shock hits associated with using the MPE spectra to define a test