



Essential Random Vibration Fatigue for Structural Dynamic Applications

Giovanni de Moraes

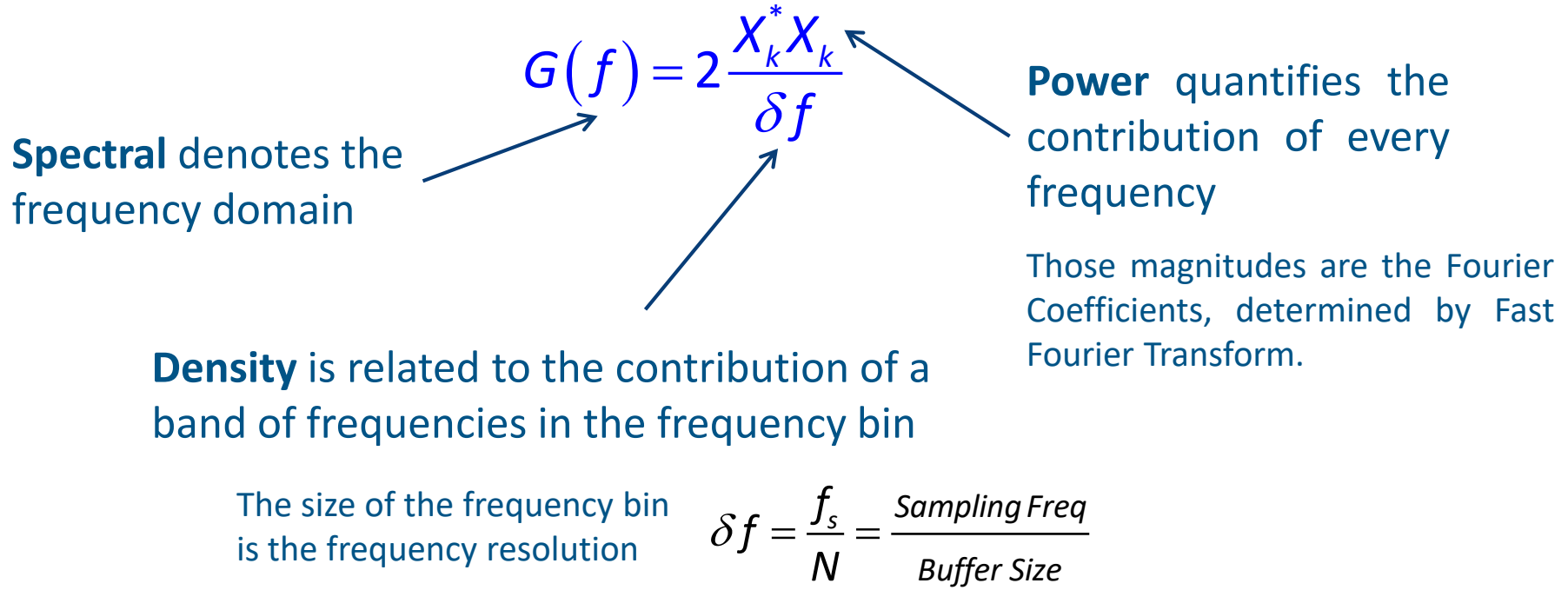
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3DEXPERIENCE®

What are we talking about Today?

- The extent of fe-safe Random Vibration Solution
- The underpinning assumptions
- Workflows
- Multiple Channels Example
- Fatigue Methods

What is Power Spectral Density?

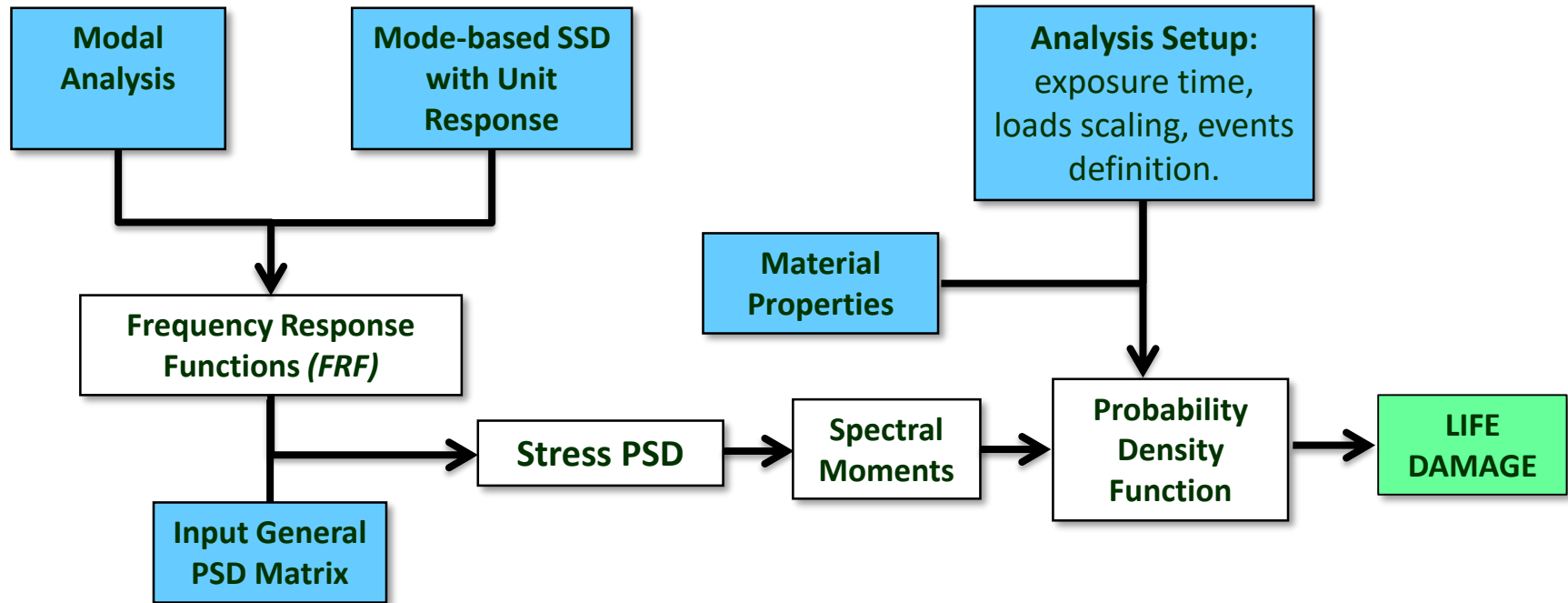


What is Random?

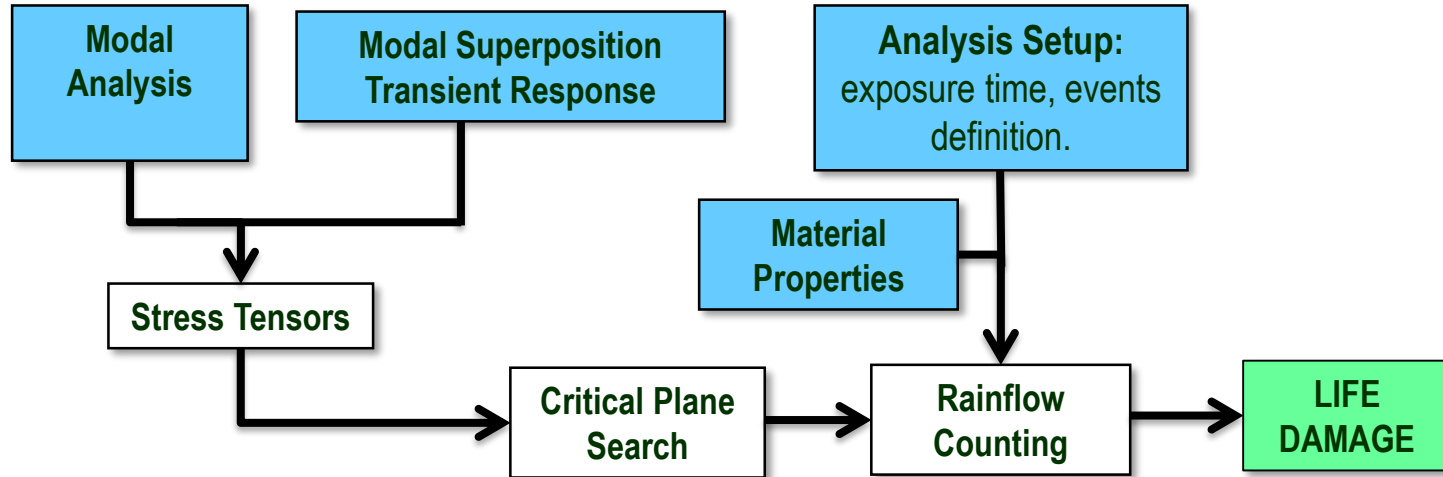
- **Randomness** is associated with **Uncertainty**.
- The precise value of a variable can not be forecast but the space of possible outcomes.
- In fe-safe “Random Vibration Fatigue” the **randomness** is in the **loading**. The input statistically represents the loads.
- The output ***is not*** Random.

Frequency Domain and Time Domain **Workflows**

Fatigue Analysis Flowchart (Frequency Domain)

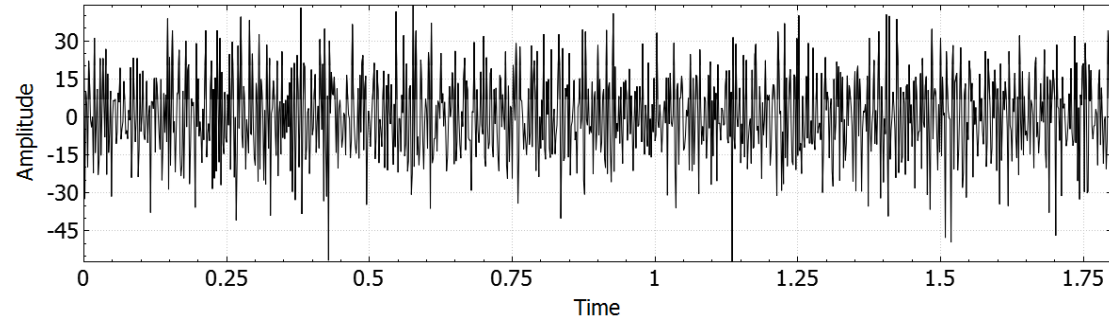


Fatigue Analysis Flowchart (Time Domain)

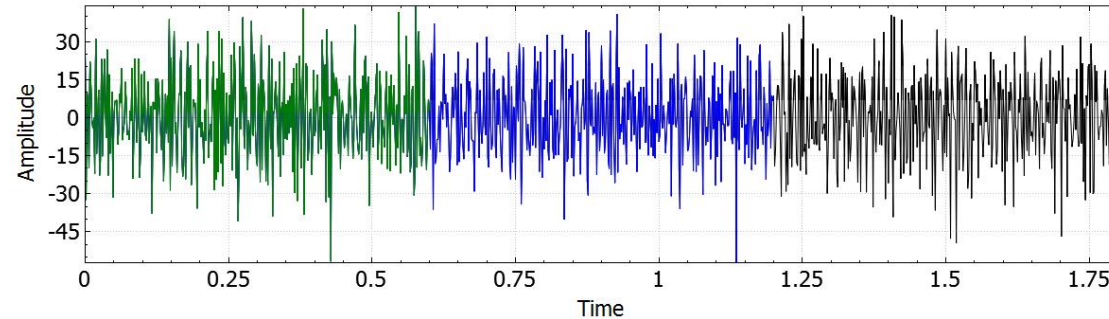


How fe-safe evaluates PSDs?

A given signal



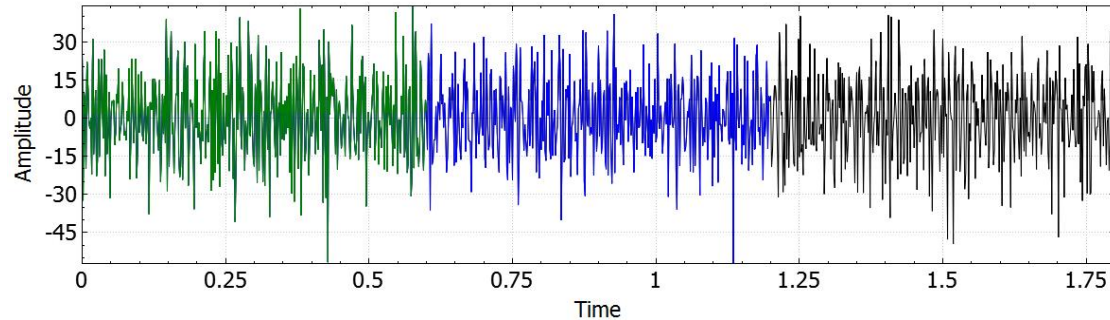
is divided in a number of segments



Since you can't perform the FFT of the given signal in just one go.

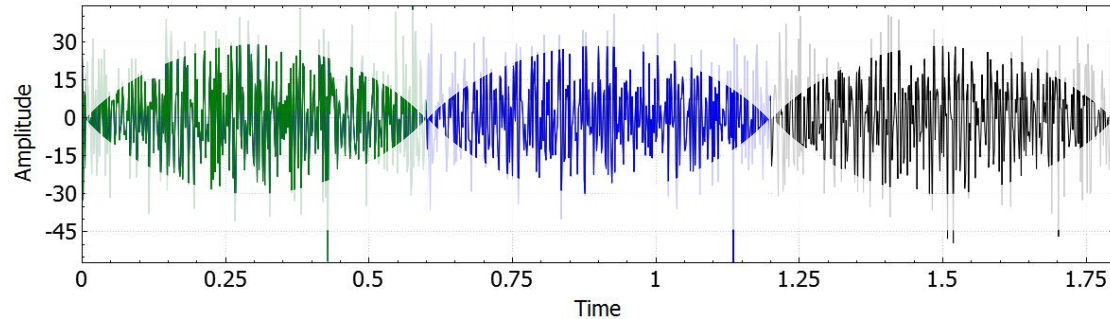
How fe-safe evaluates PSDs?

These segments are not periodic!



Buffer = 2^n

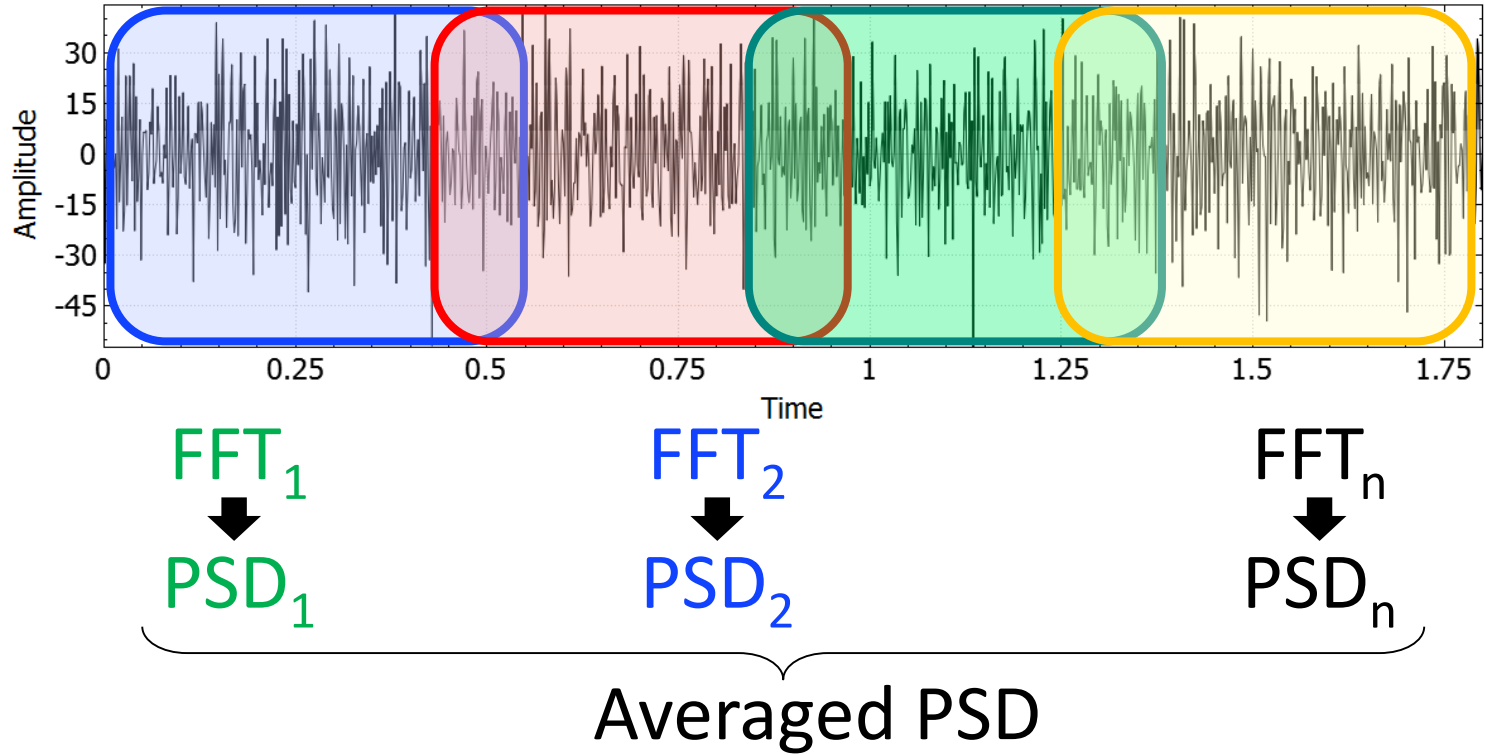
What about these ones?



Then we artificially reduce their amplitudes near the ends using an appropriate function.

Overlapping

fe-safe adopts 10% Overlap



The Modal Superposition Technique

Global Coordinates $[M]\{\ddot{z}\} + [C]\{\dot{z}\} + [K]\{z\} = \{F\}$

Eigen Analysis



Generalized or Modal Masses Generalized or Modal Stiffness

$$[\underline{M}] = [X]^T [M] [X] \quad [\underline{K}] = [X]^T [K] [X]$$

Generalized or Modal Damping

$$[\underline{C}] = [X]^T [C] [X]$$

$$\{Q\} = [X]^T \{F\} \quad \text{Generalized or Modal Forces}$$

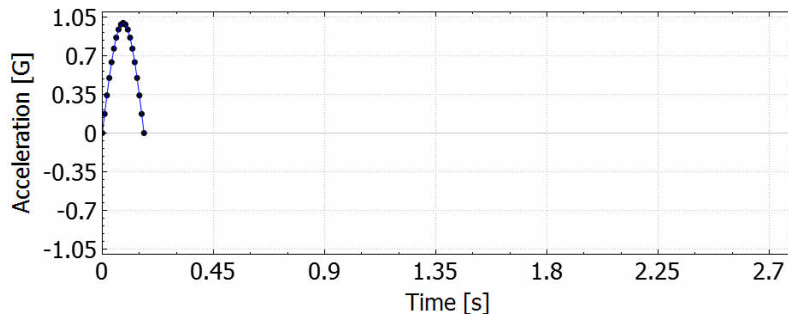
$$\{z\} = [X] \{q\} \quad \text{Generalized Displacements}$$

$$\{\sigma\} = [X] \{q\} \quad \text{Stress Recovery}$$

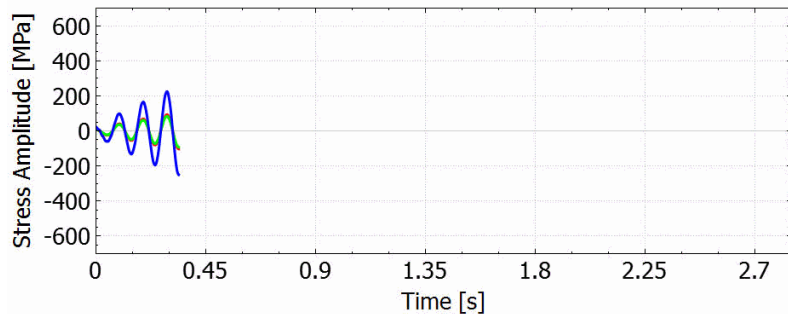
Modal Coordinates $[\underline{M}]\{\ddot{q}\} + [\underline{C}]\{\dot{q}\} + [\underline{K}]\{q\} = \{Q\} \quad \text{set of uncoupled equations}$

Steady State Dynamics vs. Transient

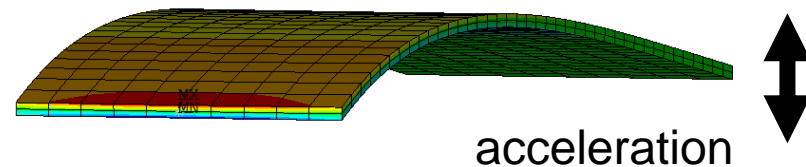
Unit Acceleration Load



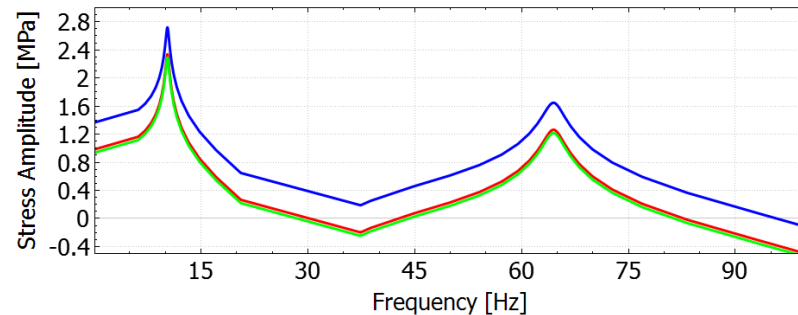
Modal Superposition Transient Analysis



Stress Response in a Vibrating Beam



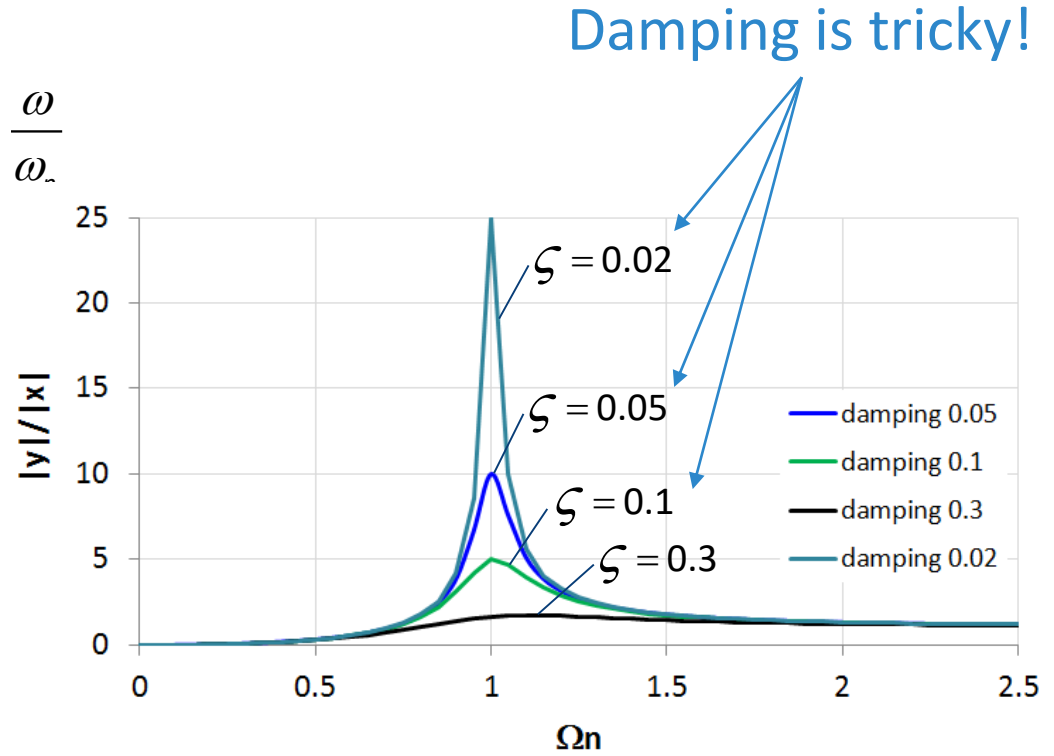
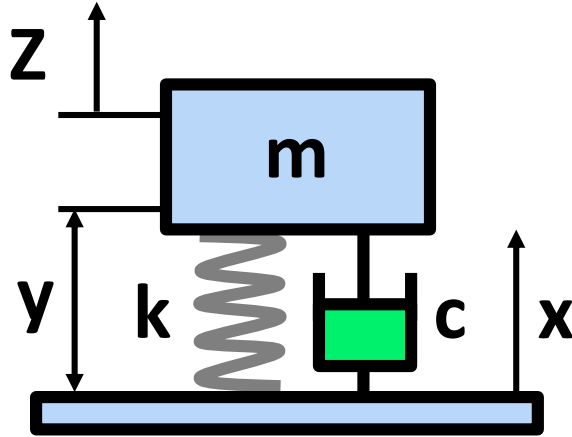
Steady State Dynamic Analysis



Linear Transfer Function

$$\frac{|y|}{|x|} = \frac{\Omega^2}{\left[(1 - \Omega^2)^2 + (2\Omega\zeta)^2 \right]^{1/2}}$$

$$\Omega = \frac{\omega}{\omega_n}$$



Linear Transfer Function

$$Q^T \cdot G_L \cdot Q = G^\sigma$$

Input PSD Transfer Function Output PSD

$$\frac{G^2}{Hz} \quad \times \quad \left(\frac{MPa}{G} \right)^2 \quad = \quad \frac{MPa^2}{Hz}$$

Dynamic Response Matrix

The first step towards critical planes approach is to assemble the Transition Coefficient Matrix or Dynamic Response Matrix

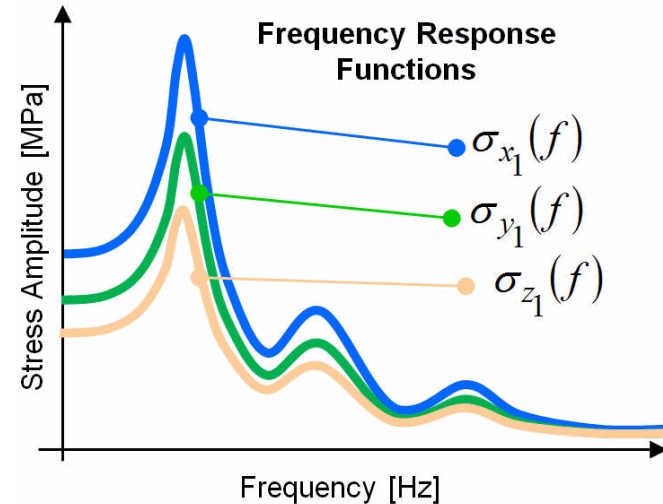
$$Q(f) = \begin{bmatrix} \sigma_{x1} & \sigma_{y1} & \cdots & \sigma_{xz1} \\ \sigma_{x2} & \sigma_{y2} & & \sigma_{xz2} \\ \vdots & & & \vdots \\ \sigma_{xN} & \sigma_{yN} & \cdots & \sigma_{xZN} \end{bmatrix}_{N \times 6}$$

Order of the stress/strain tensor

Number of loading channels

Channel 1

Channel N



Dynamic Response Matrix

The first step towards critical planes approach is to assemble the Transition Coefficient Matrix or Dynamic Response Matrix

$$Q(f) = \begin{bmatrix} \sigma_{x1} & \sigma_{y1} & \cdots & \sigma_{xz1} \\ \sigma_{x2} & \sigma_{y2} & & \sigma_{xz2} \\ \vdots & & & \vdots \\ \sigma_{xN} & \sigma_{yN} & \cdots & \sigma_{xzN} \end{bmatrix}_{N \times 6}$$

Channel 1

Channel N

$[Q(f)]_{N \times 6}$

Order of the stress/strain tensor

Number of loading channels

Linear Transfer Function

Input PSD matrix

$$G_L = \begin{bmatrix} PSD_{11} & \dots & CPSD_{1N} \\ \vdots & \ddots & \vdots \\ CPSD_{N1} & \dots & PSD_{NN} \end{bmatrix}_{N \times N}$$

Transfer Function

$$Q = \begin{bmatrix} \sigma_{x_1} & \sigma_{y_1} & \sigma_{z_1} & \sigma_{xy_1} & \sigma_{yz_1} & \sigma_{xz_1} \\ \vdots & & & & & \vdots \\ \sigma_{x_N} & \sigma_{y_N} & \sigma_{z_N} & \sigma_{xy_N} & \sigma_{yz_N} & \sigma_{xz_N} \end{bmatrix}_{N \times 6}$$

Output Stress PSD

$$G^\sigma = \begin{bmatrix} G_{11} & \dots & G_{61} \\ \vdots & \ddots & \vdots \\ G_{16} & \dots & G_{66} \end{bmatrix}_{6 \times 6}$$

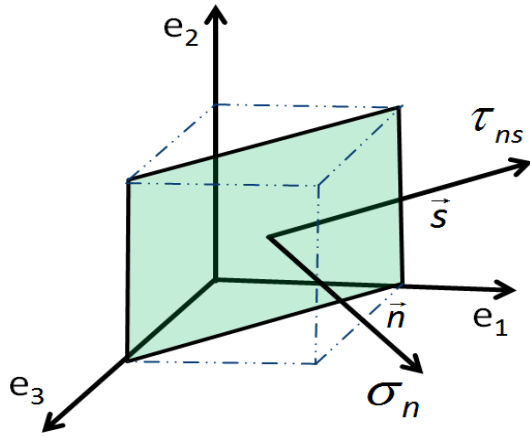
Von Mises Stress PSD

$$G_{Mises}^{\sigma} = Trace \left\{ A \cdot G^{\sigma} \right\}$$

Von Mises PSD Matrix

$$A = \begin{bmatrix} 1 & -1/2 & -1/2 & & & \\ -1/2 & 1 & -1/2 & & & \\ -1/2 & -1/2 & 1 & & & \\ & & & 3 & & \\ & & & & 3 & \\ & & & & & 3 \end{bmatrix}$$

Critical Plane Approach



$$G_n^\sigma = d_n^T \cdot G^\sigma \cdot d_n$$

$$G_s^\sigma = d_s^T \cdot G^\sigma \cdot d_s$$

$$\vec{n} = \frac{e_{1x} + e_{3x}}{\sqrt{2}} \vec{i} + \frac{e_{1y} + e_{3y}}{\sqrt{2}} \vec{j} + \frac{e_{1z} + e_{3z}}{\sqrt{2}} \vec{k}$$

$$\vec{s} = \frac{e_{1x} - e_{3x}}{\sqrt{2}} \vec{i} + \frac{e_{1y} - e_{3y}}{\sqrt{2}} \vec{j} + \frac{e_{1z} - e_{3z}}{\sqrt{2}} \vec{k}$$

$$d_s = \begin{bmatrix} \frac{(e_{1x}^2 - e_{3x}^2)}{2} & \frac{(e_{1y}^2 - e_{3y}^2)}{2} & \frac{(e_{1z}^2 - e_{3z}^2)}{2} & (e_{1x}e_{1y} - e_{3x}e_{3y}) & (e_{1y}e_{1z} - e_{3y}e_{3z}) & (e_{1x}e_{1z} - e_{3x}e_{3z}) \end{bmatrix}^T$$

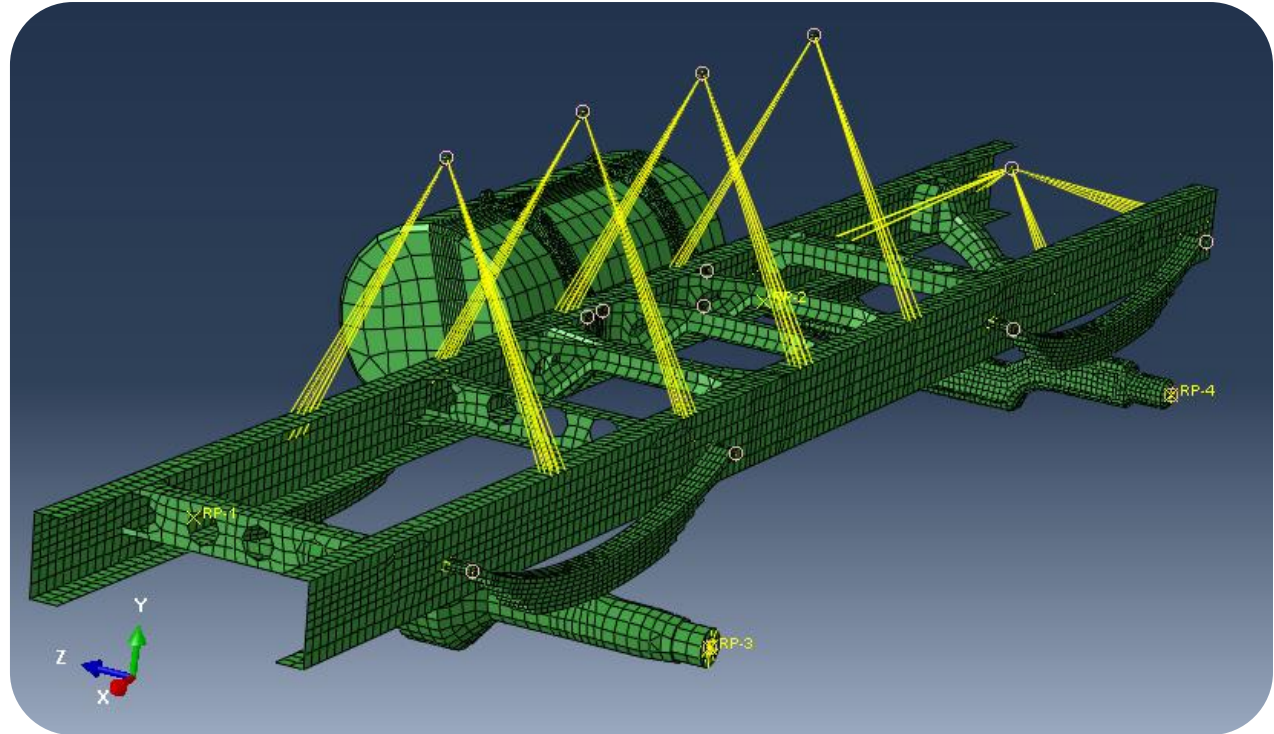
$$d_n = \begin{bmatrix} \frac{(e_{1x} + e_{3x})^2}{2} & \frac{(e_{1y} + e_{3y})^2}{2} & \frac{(e_{1z} + e_{3z})^2}{2} & (e_{1x} + e_{3x})(e_{1y} + e_{3y}) & (e_{1y} + e_{3y})(e_{1z} + e_{3z}) & (e_{1x} + e_{3x})(e_{1z} + e_{3z}) \end{bmatrix}^T$$

Multiple Channels

Truck Chassis Example

The Truck Chassis Model

- inpdeck_vX8
 - Parts (1)
 - Materials (6)
 - Calibrations
 - Sections (9)
 - Profiles
 - Assembly
 - Steps (6)
 - Initial
 - frqExtrac
 - mySSD_01
 - mySSD_02
 - mySSD_03
 - mySSD_04
 - Field Output Requests (1)
 - History Output Requests (1)
 - Time Points
 - ALE Adaptive Mesh Constraints
 - Interactions
 - Interaction Properties
 - Contact Controls
 - Contact Initializations
 - Contact Stabilizations



Initial Boundary Conditions

The image illustrates the steps to set initial boundary conditions in ANSYS Workbench:

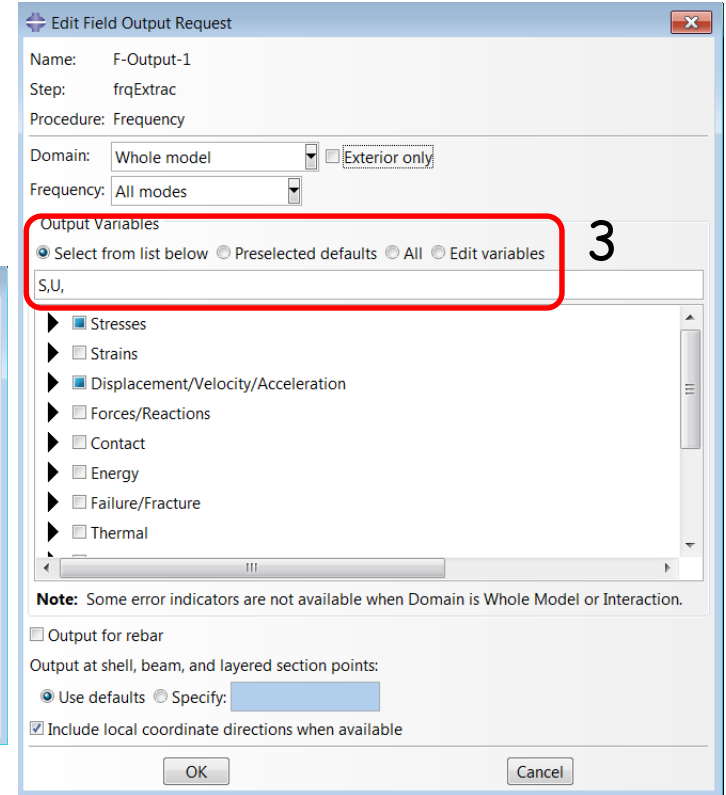
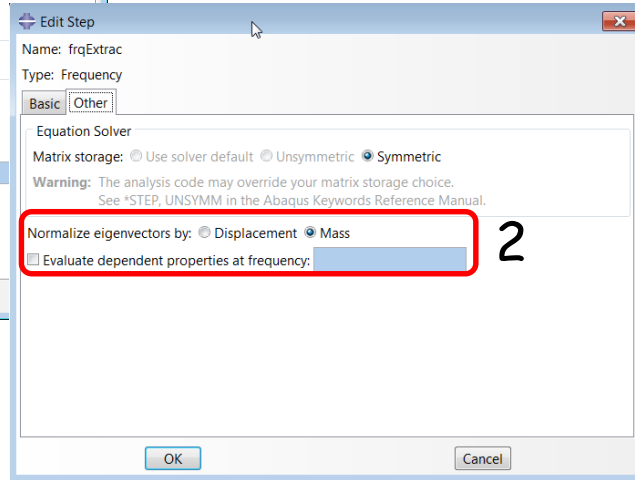
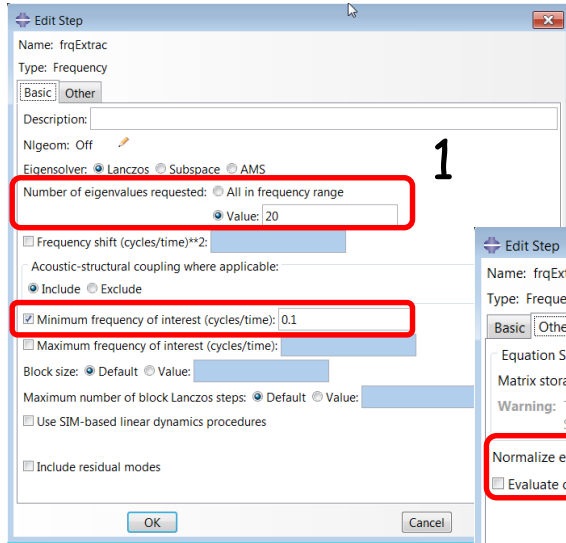
- 1**: In the Project Tree on the left, the **Initial** step under **Steps (6)** is selected and highlighted with a red box.
- 2**: In the **Steps (6)** pane, the **Interactions** folder is expanded, and the **BCs (4)** sub-folder is highlighted with a red box. It contains four entries: **BC_chn_01 (Created)**, **BC_chn_02 (Created)**, **BC_chn_03 (Created)**, and **BC_chn_04 (Created)**.
- 3**: The **Edit Boundary Condition** dialog box is open, showing the configuration for **BC_chn_01**. The **U1** checkbox is checked and highlighted with a red box. The **U3**, **UR1**, **UR2**, and **UR3** checkboxes are also checked and highlighted with a red box.

The **Edit Boundary Condition** dialog box shows the following details:

- Name:** BC_chn_01
- Type:** Displacement/Rotation
- Step:** Initial
- Region:** Set-60
- CSYS:** (Global)
- U1:** ☒
- U2:** ☐
- U3:** ☒
- UR1:** ☒
- UR2:** ☒
- UR3:** ☒

Note: The displacement value will be maintained in subsequent steps.

Frequency Extraction Step



Frequency Extraction Step

frqExtrac

- Field Output Requests (1)
- History Output Requests
- ALE Adaptive Mesh Constraints
- Interactions
- Loads
- BCs (8)
 - BC_SECBASE_01 (Created)
 - BC_SECBASE_02 (Created)
 - BC_SECBASE_03 (Created)
 - BC_SECBASE_04 (Created)
 - BC_chn_01 (Propagated from base state)
 - BC_chn_02 (Propagated from base state)
 - BC_chn_03 (Propagated from base state)
 - BC_chn_04 (Propagated from base state)
- Predefined Fields
- Load Cases

Edit Boundary Condition

Name: BC_SECBASE_01
Type: Secondary base
Step: frqExtrac (Frequency)

Constrained Degrees-of-freedom

	Region	U1	U2	U3	UR1	UR2	UR3
1	Set-64	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

1

Edit Boundary Condition

Name: BC_chn_01
Type: Displacement/Rotation
Step: frqExtrac (Frequency)
Region: Set-60

CSYS: (Global)

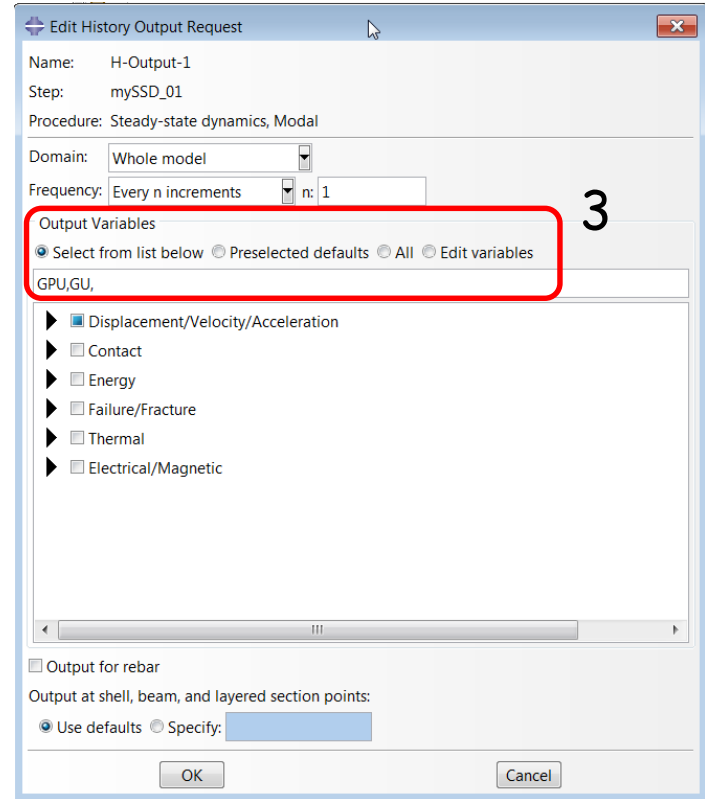
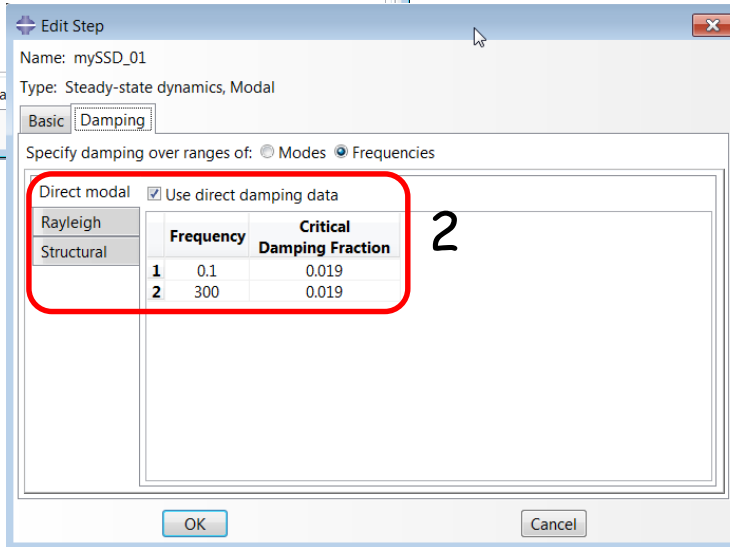
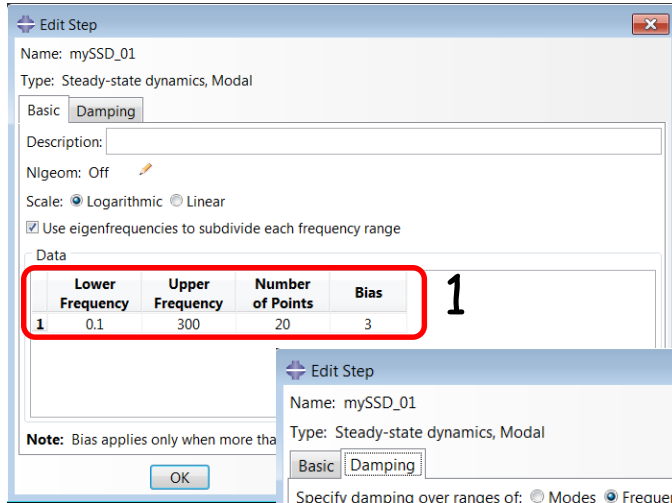
- ☒ U1
- ☐ U2
- ☒ U3
- ☒ UR1
- ☒ UR2
- ☒ UR3

2

Note: The displacement value will be maintained in subsequent steps.

OK Cancel

Steady State Dynamics



Steady State Dynamics

- mySSD_01
 - Field Output Requests
 - History Output Requests (1)
 - H-Output-1 (Created)
 - ALE Adaptive Mesh Constraints
 - Interactions
 - Loads
 - BCs (9)
 - BC_ACC_01 (Created)
 - BC_SECBASE_01 (Built into modes)
 - BC_SECBASE_02 (Built into modes)
 - BC_SECBASE_03 (Built into modes)
 - BC_SECBASE_04 (Built into modes)
 - BC_chn_01 (Built into modes)
 - BC_chn_02 (Built into modes)
 - BC_chn_03 (Built into modes)
 - BC_chn_04 (Built into modes)
 - Predefined Fields
 - Load Cases
- mySSD_02
- mySSD_03
- mySSD_04

Channel 1

Edit Boundary Condition

Name: BC_ACC_01

Type: Acceleration base motion

Step: mySSD_01 (Steady-state dynamics, Modal)

Basic Correlation

Degree-of-freedom: ☐ U1 ☒ U2 ☐ U3 ☐ UR1 ☐ UR2 ☐ UR3

☒ Secondary base: BC_SECBASE_01

Amplitude: AmpGravity

Amplitude scale factor: 1

Center of rotation: (0, 0, 0)

☐ Define imaginary (out-of-phase) portion given by amplitude

OK Cancel

Channel 2

Edit Boundary Condition

Name: BC_ACC_02

Type: Acceleration base motion

Step: mySSD_02 (Steady-state dynamics, Modal)

Basic Correlation

Degree-of-freedom: ☐ U1 ☒ U2 ☐ U3 ☐ UR1 ☐ UR2 ☐ UR3

☒ Secondary base: BC_SECBASE_02

Amplitude: AmpGravity

Amplitude scale factor: 1

Center of rotation: (0, 0, 0)

☐ Define imaginary (out-of-phase) portion given by amplitude

OK Cancel

Edit Amplitude

Name: AmpGravity

Type: Tabular

Time span: Step time

Smoothing: ☒ Use solver default

☐ Specify:

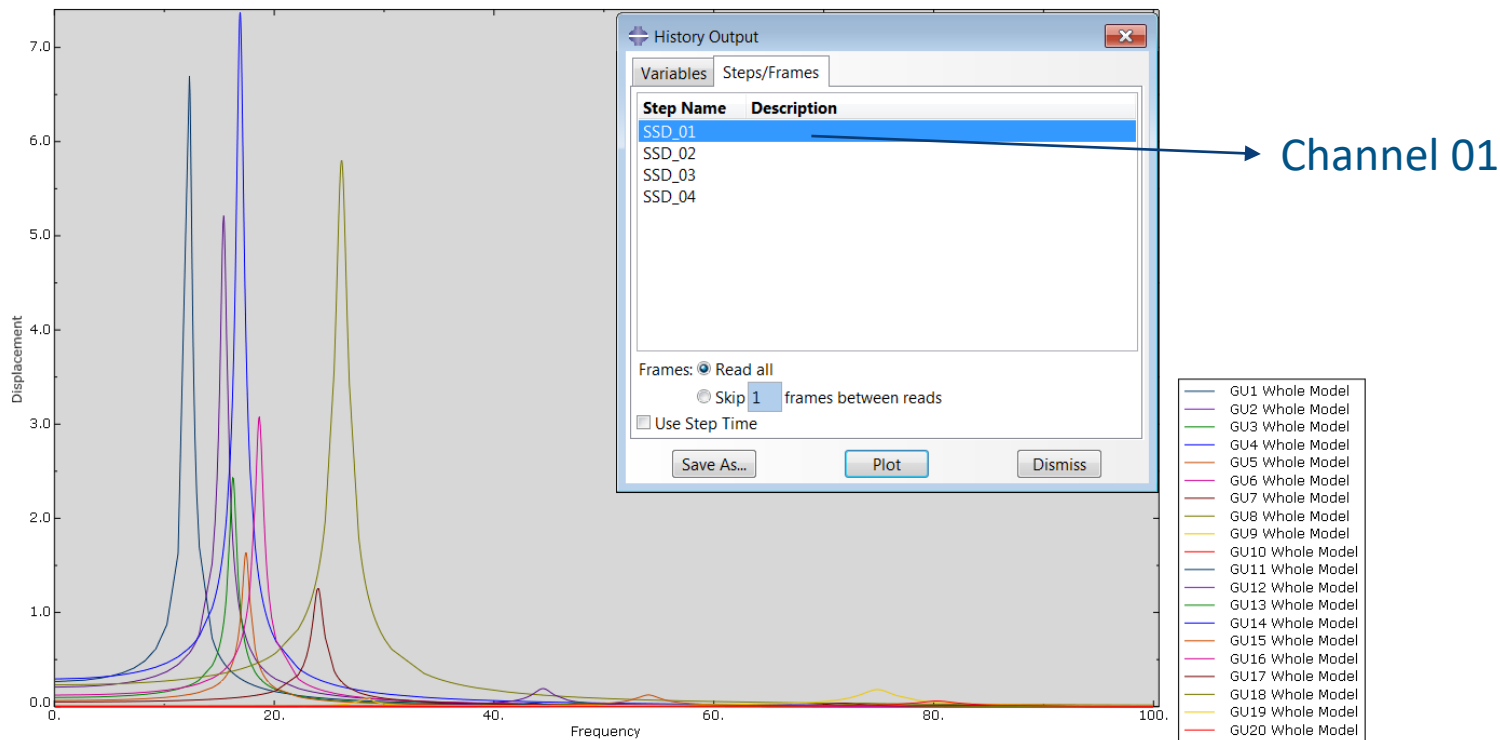
Amplitude Data Baseline Correction

	Time/Frequency	Amplitude
1	0.1	9800
2	300	9800

OK Cancel

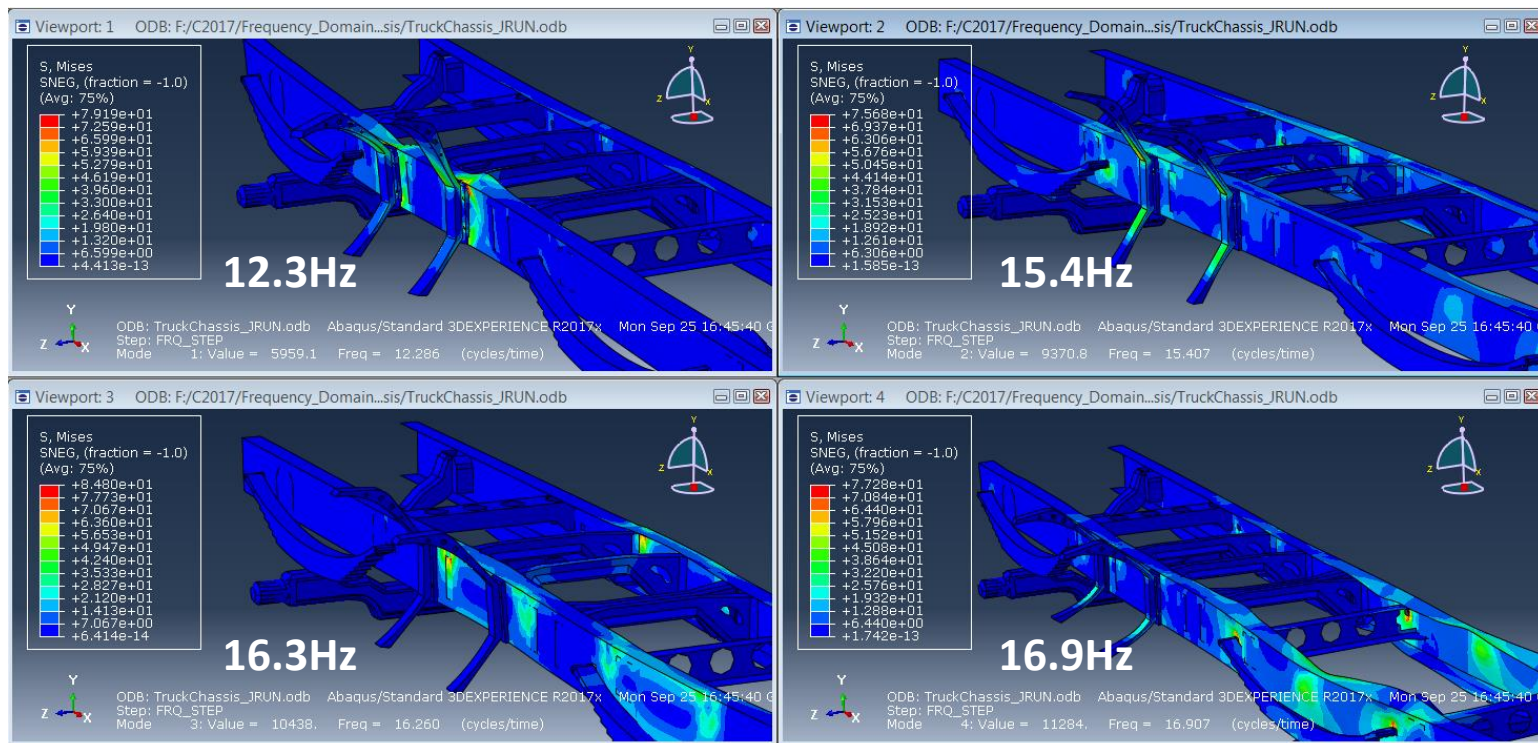
ABAQUS Results

Modal Coordinates or Generalized Displacements

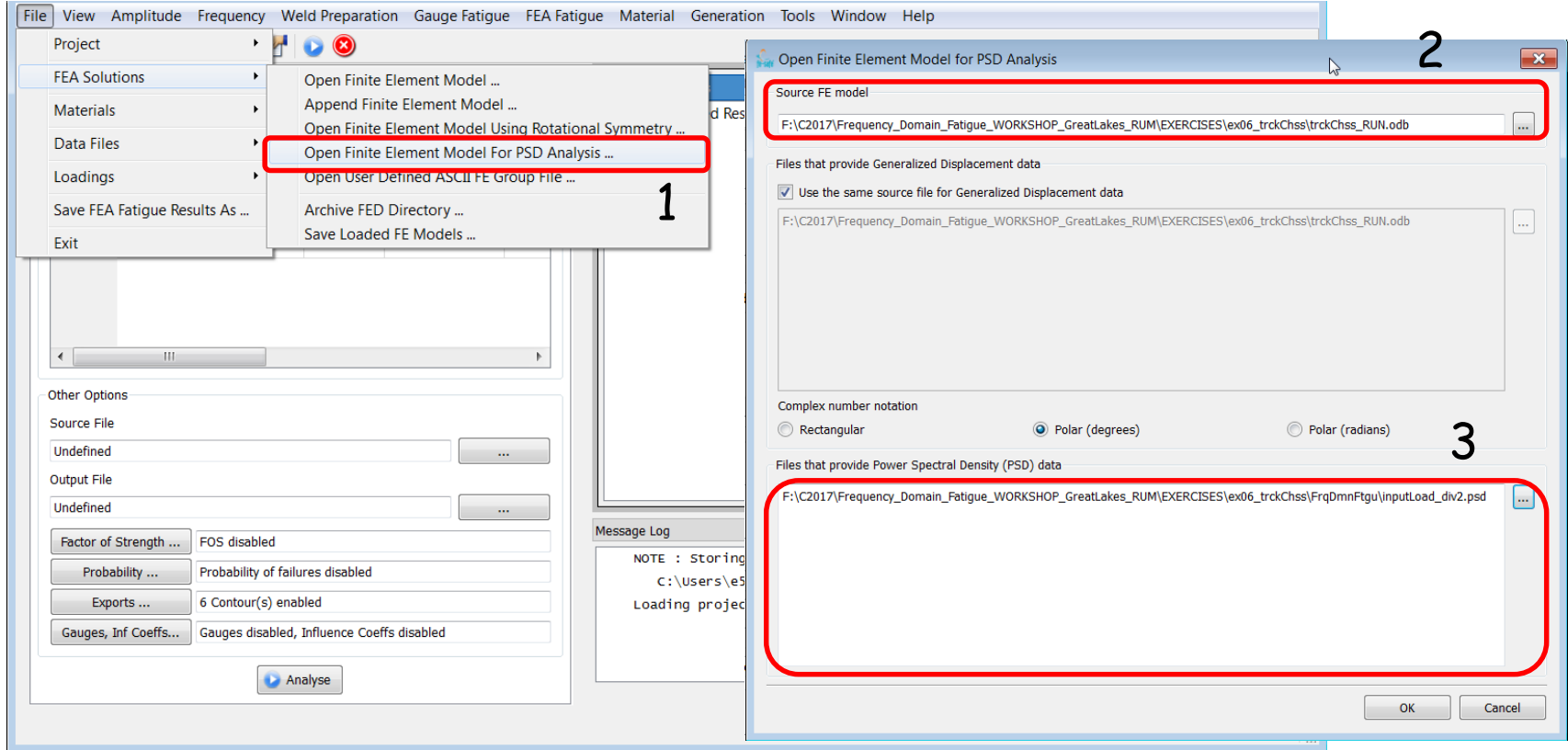


ABAQUS Results

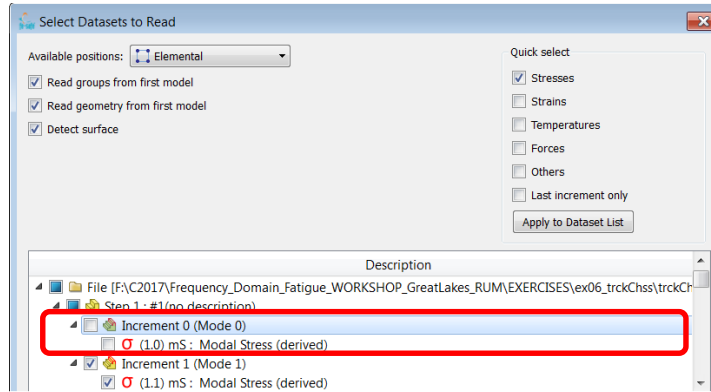
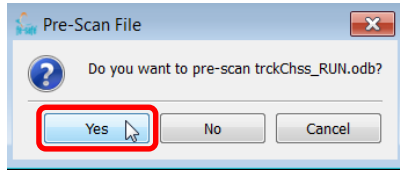
Modal Stresses



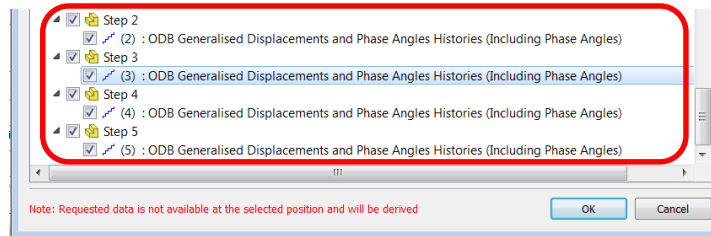
fe-safe Random Vibration



Pre-scanning selections

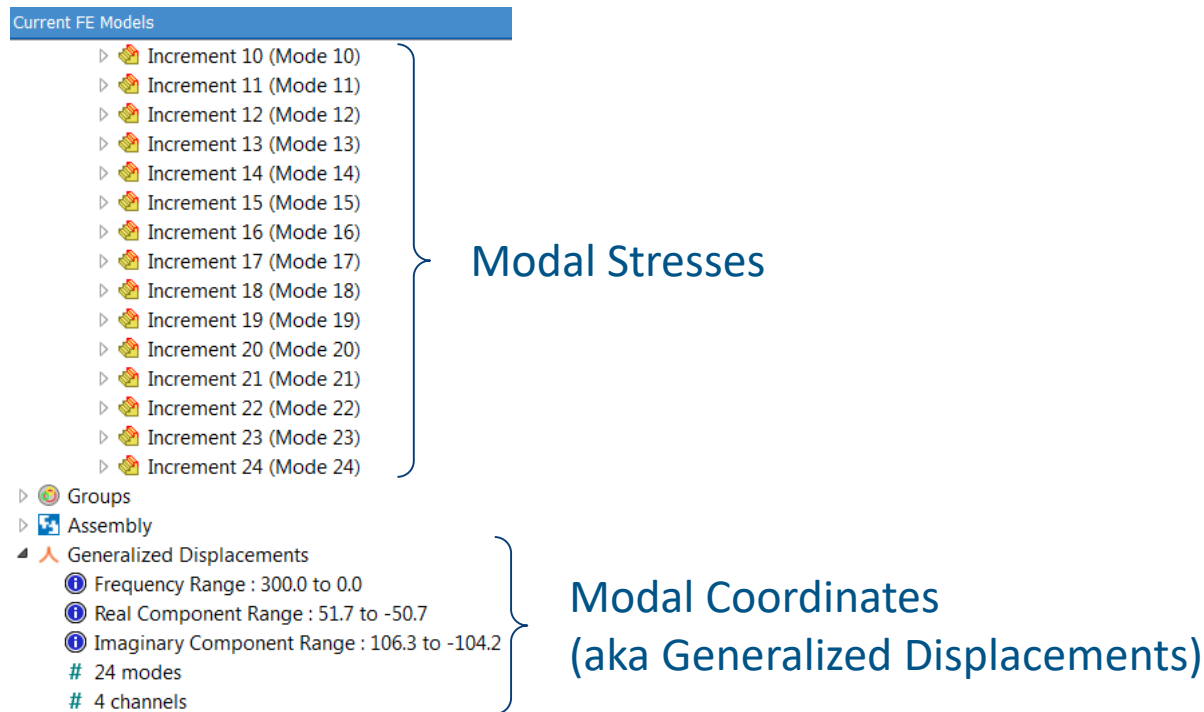


Make sure Mode 0 is unselected.

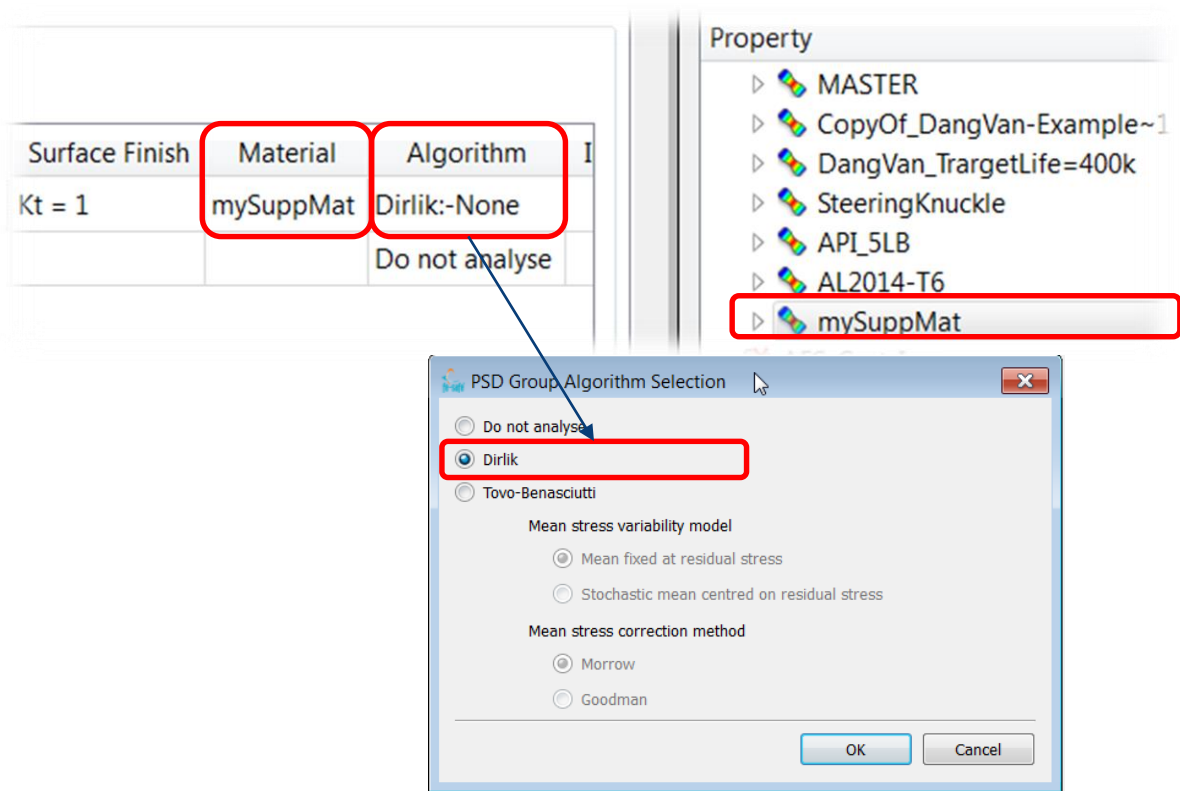


Select the steps that contain the Generalized Displacements

The data loaded in fe-safe



Material and Methods



Material and Methods

fe-safe Random Vibration is a Stress-Based Approach

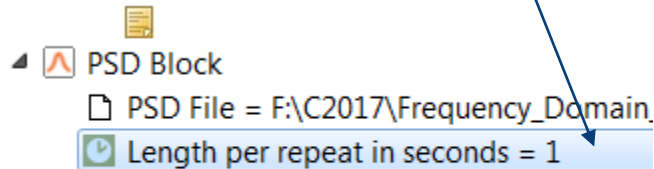
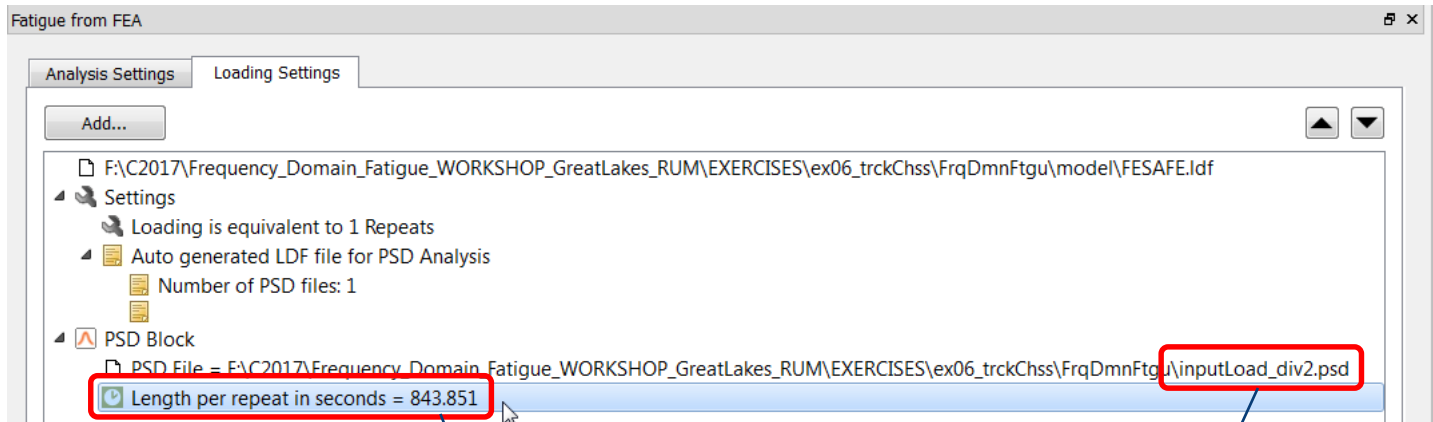
N Values/S Values (MPa)

	Nf	S (0 degC)
1	10000	479
2	1e+06	309.3
3		
4		
5		
6		
7		
8		
9		

Populate OK Remove Cancel

gi : n-Comp	undefined
gi : SWT Life Curve Coeff (MPa)	undefined
gi : SWT Life Curve Exponent	undefined
sn curve : N Values (nf)	10000, 1E6
sn curve : R Ratios	undefined
sn curve : S Values (MPa)	479, 309.299988
walker : gamma@R<0	undefined
walker : gamma@R>=0	undefined
weibull : Min QMUF	0.25
weibull : Slope BF	3
buch : Proof Stress 0.2% (MPa)	634.299988

Loading Block Definition



Set the length to 1 sec

If the loads change you point to the new file that contemplates the changes. No need to run ABAQUS again.

Interpreting the Input PSD File

Input PSD File

```
1 Number of channels = 4
2 #Input sample rate = 598.802
3 #Input signals' length = 505300
4 Exposure time(seconds) = 843.851
5
6 #Input #0: file F:/C2017/Frequency_Domain_Fatigue_W
7 #Input #1: file F:/C2017/Frequency_Domain_Fatigue_W
8 #Input #2: file F:/C2017/Frequency_Domain_Fatigue_W
9 #Input #3: file F:/C2017/Frequency_Domain_Fatigue_W
10
11 #PSD_0_0_frq      PSD_0_0_real
12 1.16954 0.000112501
13 2.33907 0.000128473
14 3.50861 0.000104452
15 4.67814 0.000171993
16 5.84768 0.000232986
17 7.01722 0.00042747
18 8.18675 0.000990825
19 9.35629 0.0015742
```

...

Number of Load Channels

Exposure Time

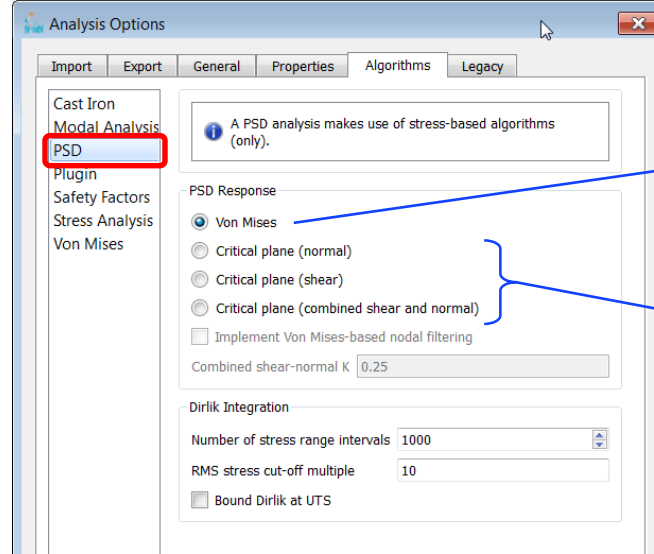
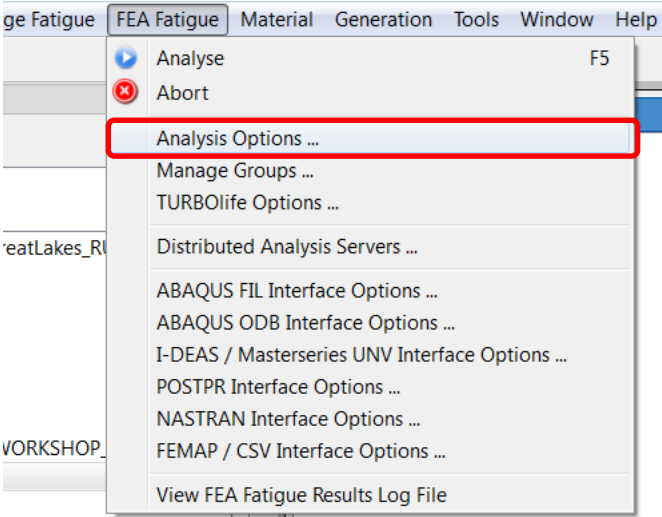
Auto PSDs

Cross PSDs

...

#CPSD_0_2_frq	CPSD_0_2_real	CPSD_0_2_imag
1.16954	0.000103774	3.0678e-07
2.33907	0.000125386	-2.08408e-06
3.50861	6.50101e-05	-1.40455e-05
4.67814	7.82215e-05	-2.2799e-05
5.84768	9.09092e-05	-5.5179e-05
7.01722	9.89627e-05	-0.000138587
8.18675	5.43902e-05	-0.000401876
9.35629	0.000288409	-0.000289905
10.5258	0.00026273	-9.75707e-05
11.6954	-0.000389818	0.00025891
12.8649	-0.000826054	0.00105563

Fatigue Methods

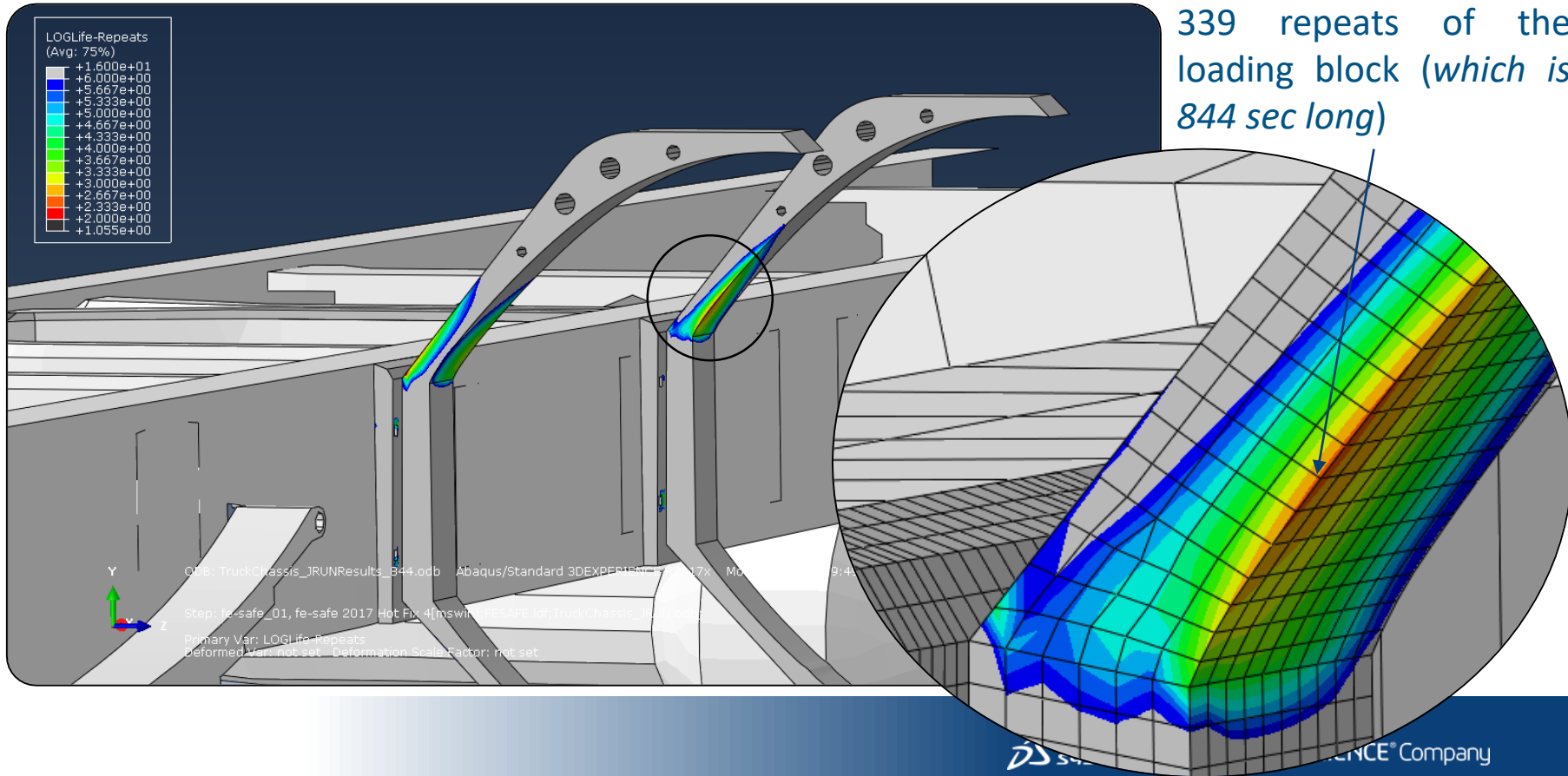


Invariant Method

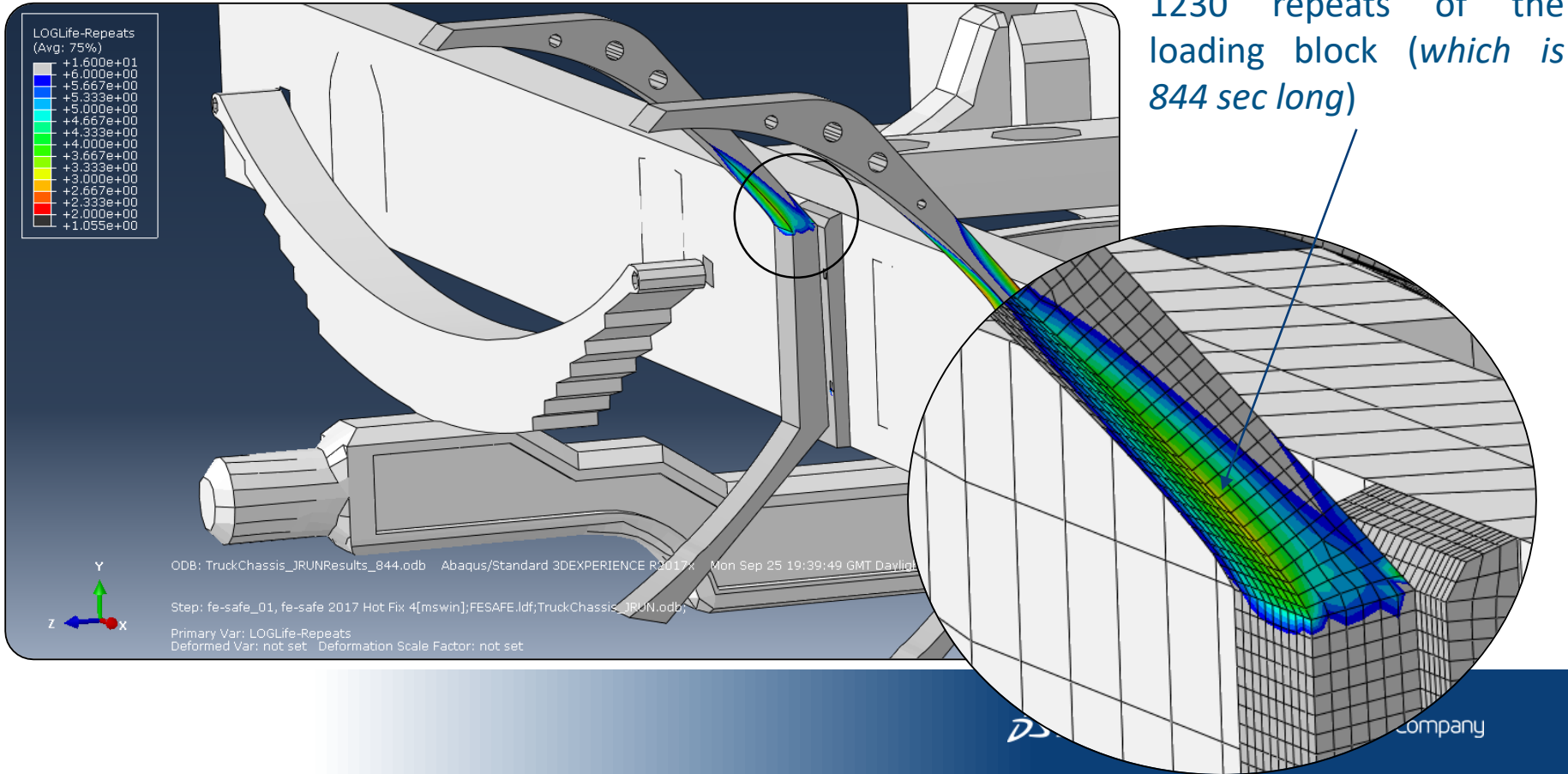
Critical plane methods

Ready to RUN!

Fatigue Life



Fatigue Life



Fatigue Methods

Narrow Band Approach

Bendat

$$D_{BEN} = \frac{n_0^+ T}{k} \left(\sqrt{2m_0} \right)^b \Gamma \left(1 + \frac{b}{2} \right)$$

$$\lambda_{2/b} = \int_0^\infty \omega^{2/b} G(\omega) d\omega$$

$$N\sigma_a^b = k$$

Single Moment
Lutes and Larsen

$$D_{LAR} = \frac{T}{2\pi k} \left(2\sqrt{2} \right)^b \Gamma \left(1 + \frac{b}{2} \right) \left(\lambda_{2/b} \right)^{b/2}$$

$$n_0^+ = \sqrt{\frac{m_2}{m_0}}$$

Ortiz and Chen

$$D_{ORT} = \frac{1}{\gamma} \left(\sqrt{\frac{m_2 m_Q}{m_0 m_{Q+2}}} \right)^m D_{NB}$$

$$\gamma = \sqrt{\frac{m_2^2}{m_0 m_4}}$$

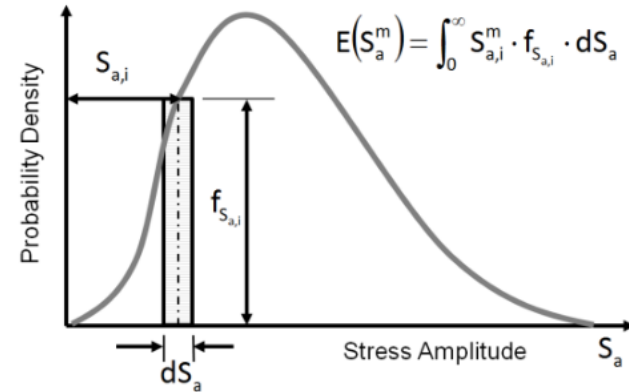
Steinberg
3-Band Method

$$D_{STEIN} = (1/k) n_0^+ T \left[0.683 \left(2\sqrt{m_0} \right)^b + 0.271 \left(4\sqrt{m_0} \right)^b + 0.043 \left(6\sqrt{m_0} \right)^b \right]$$

The Dirlik's Method

$$D_{DIR} = \frac{E[P]T}{k} \sum_0^{\infty} s_r^b p(s_r) ds_r$$

$$p(s_r) = \frac{1}{2\sqrt{m_0}} \left[\frac{D_1}{Q} e^{\frac{-Z}{Q}} + \frac{D_2 Z}{R^2} e^{\frac{-Z^2}{2R^2}} + D_3 Z e^{\frac{-Z^2}{2}} \right]$$



$$Z = \frac{S_r}{2\sqrt{m_0}}$$

$$D_1 = \frac{2(x_m - \gamma^2)}{1 + \gamma^2}$$

$$D_2 = \frac{1 - \gamma - D_1 + D_1^2}{1 - R}$$

$$D_3 = 1 - D_1 - D_2$$

$$E[P] = \sqrt{\frac{m_4}{m_2}}$$

$$x_m = \frac{M_1}{M_0} \sqrt{\frac{M_2}{M_4}}$$

$$R = \frac{\gamma - x_m - D_1^2}{1 - \gamma - D_1 + D_1^2}$$

$$Q = \frac{1.25(\gamma - D_3 - D_2 R)}{D_1}$$

The Dirlik's Method

$$D_{DIR} = \frac{E[P]T}{k} \sum_0^{\infty} S_r^b p(S_r) dS_r$$

$$p(S_r) = \frac{1}{2\sqrt{m_0}} \left[\frac{D_1}{Q} e^{\frac{-Z}{Q}} + \frac{D_2 Z}{R^2} e^{\frac{-Z^2}{2R^2}} + D_3 Z e^{\frac{-Z^2}{2}} \right]$$

$$Z = \frac{S_r}{2\sqrt{m_0}} \quad D_1 = \frac{2(x_m - \gamma^2)}{1 + \gamma^2} \quad D_2 = \frac{1 - \gamma - D_1 + D_1^2}{1 - R} \quad D_3 = 1 - D_1 - D_2 \quad \gamma = \sqrt{\frac{m_2^2}{m_0 m_4}}$$

$$E[P] = \sqrt{\frac{m_4}{m_2}} \quad x_m = \frac{m_1}{m_0} \sqrt{\frac{m_2}{m_4}} \quad R = \frac{\gamma - x_m - D_1^2}{1 - \gamma - D_1 + D_1^2} \quad Q = \frac{1.25(\gamma - D_3 - D_2 R)}{D_1}$$

The Building Blocks

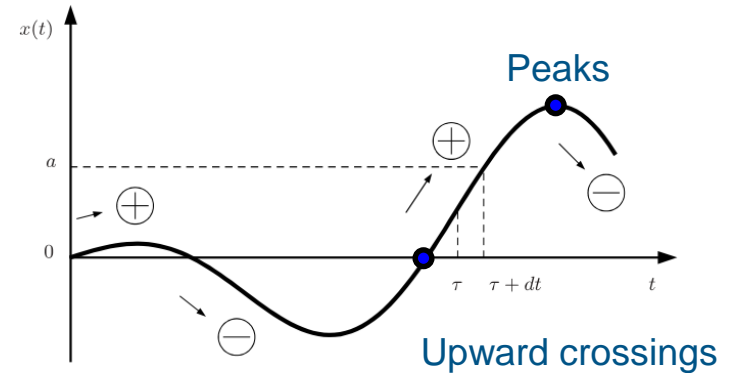
$$m_n = \sum_{k=1}^N f_k^n \cdot PSD(k) \cdot \Delta f$$

$\sqrt{m_0}$ Standard deviation

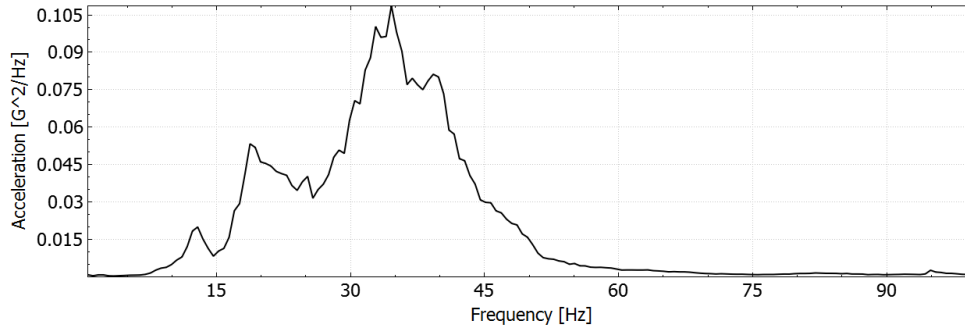
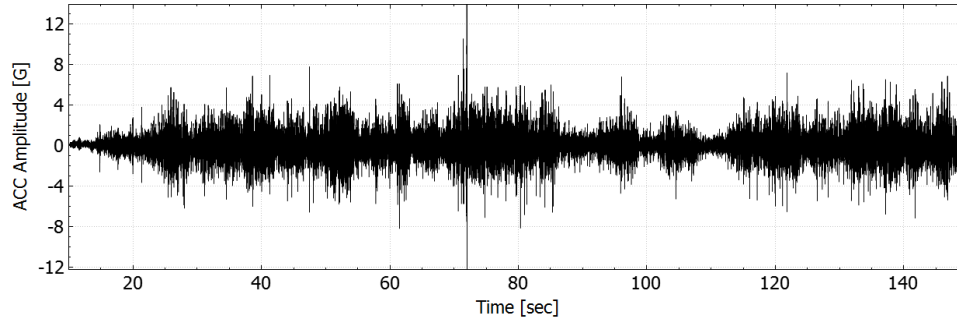
$E[P] = \sqrt{\frac{m_4}{m_2}}$ Peaks per second

$E[0] = \sqrt{\frac{m_2}{m_0}}$ Upward crossings per second

$\gamma = \sqrt{\frac{m_2^2}{m_0 m_4}}$ bandwidth



Long Signal Example



Final Time = 842.165 sec

Moment_0 = 2.00314

Moment_1 = 70.9763

Moment_2 = 3171.05

Moment_4 = 2.76368e+007

Number Of Peaks/Second = 93

Number Of Zero Crossings/Second = 40

Irregularity Factor = **0.43 (1 = Narrow Band)**

TB Method

according to **Tovo & Benasciutti** Method

$$D_{RFC} = bD_{NB} + (1 - b_{app})D_{RC}$$

Narrow band contribution
to the damage

Broad band contribution
to the damage

Spectral moments

$$\lambda_i = \int_0^{\infty} \omega^i S(\omega) d\omega$$

Weighting factor

Upward mean crossing per
second

$$v_+ = \frac{1}{2\pi} \sqrt{\frac{\lambda_2}{\lambda_0}} \quad \alpha_1 = \frac{\lambda_1}{\sqrt{\lambda_0 \lambda_2}}$$

Peaks per second

$$v_p = \frac{1}{2\pi} \sqrt{\frac{\lambda_4}{\lambda_2}} \quad \alpha_2 = \frac{\lambda_2}{\sqrt{\lambda_0 \lambda_4}}$$

Weighting coefficient

$$b_{app} = \frac{(\alpha_1 - \alpha_2) \left[1.112 (1 + \alpha_1 \alpha_2 - (\alpha_1 + \alpha_2)) e^{2.11 \alpha_2} + (\alpha_1 + \alpha_2) \right]}{(\alpha_2 - 1)^2}$$

Tovo & Benasciutti Method

Range Count Joint Distribution

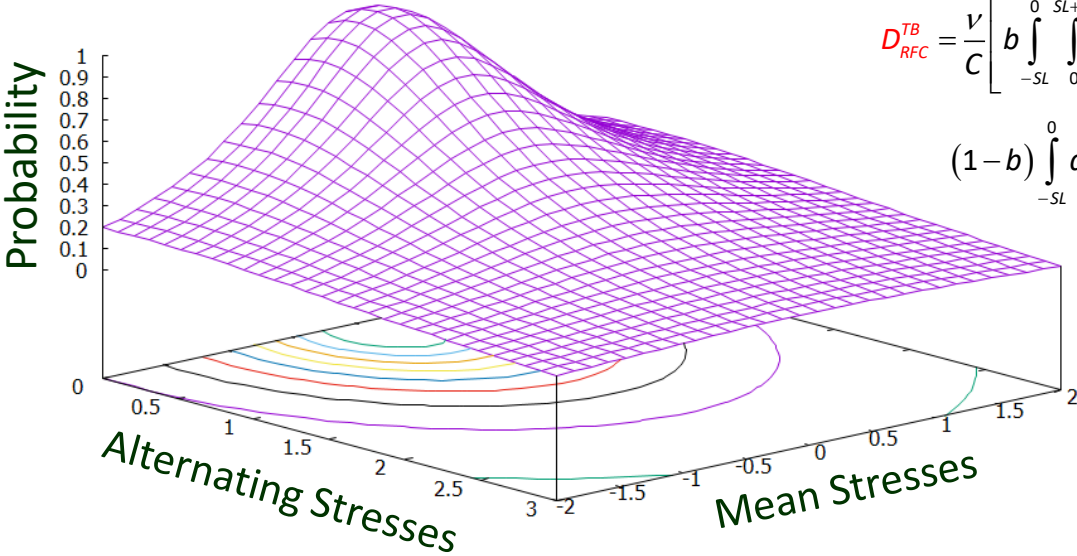


Figure 15

Range Count Probability Density Function

$$p_{a,m}^{RC}(s,m) = \frac{1}{\sqrt{2\pi\lambda_0(1-\alpha_2^2)}} e^{-\frac{(m-m_c)^2}{2\lambda_0(1-\alpha_2^2)}} \cdot \frac{s}{\lambda_0\alpha_2^2} e^{-\frac{s^2}{2\alpha_2^2\lambda_0}}$$

$$D_{RFC}^{TB} = \frac{V}{C} \left[b \int_{-SL}^0 \int_0^{SL+m} S^k p_{LC}(s,m) ds dm + b \int_0^{SL} \int_0^{SL-m} \left(\frac{S}{1-m/SL} \right)^k p_{LC}(s,m) ds dm + \right. \\ \left. (1-b) \int_{-SL}^0 dm \int_0^{SL+m} S^k p_{RC}(s,m) ds + (1-b) \int_0^{SL} \int_0^{SL-m} \left(\frac{S}{1-m/SL} \right)^k p_{RC}(s,m) ds dm \right]$$

Level Crossing PDF
Weighing Factor b
Range Count PDF

Level Crossing Probability Density Function

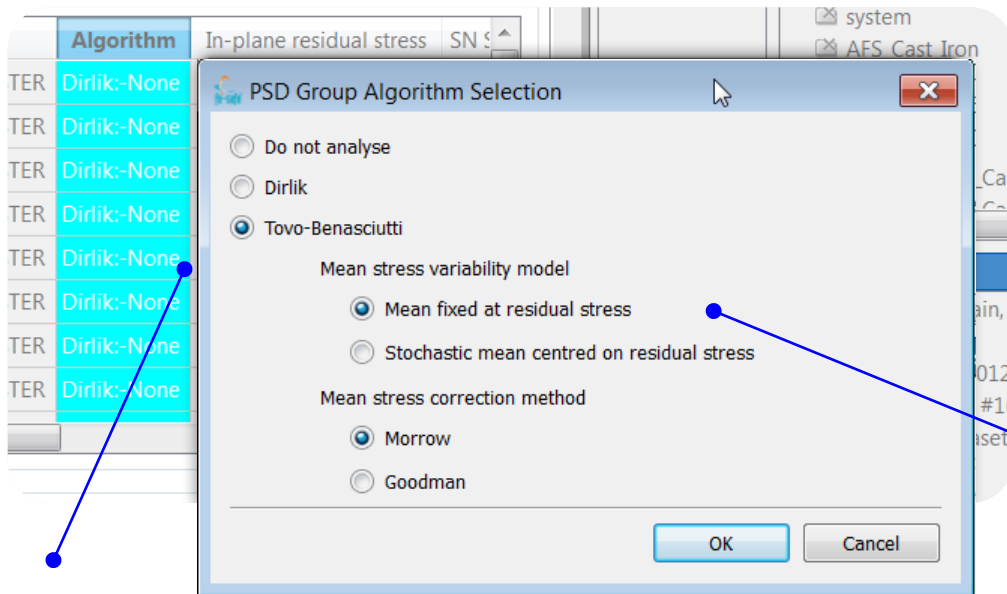
$$p_{LC}(s,m) = \begin{cases} [(p_p(s) - p_v(s))\delta(m - m_c) + p_v(m)\delta(s)] & \text{if } (s+m) > m_c \\ [p_p(m)\delta(s)] & \text{if } (s+m) \leq m_c \end{cases}$$

$$p_p(x) = \frac{\sqrt{1-\alpha_2^2}}{\sqrt{2\pi}\sigma_x} e^{-\frac{(x-m_c)^2}{2\sigma_x^2(1-\alpha_2^2)}} + \frac{\alpha_2(x-m_c)}{\sigma_x^2} e^{-\frac{(x-m_c)^2}{2\sigma_x^2}} \Phi\left(\frac{\alpha_2(x-m_c)}{\sigma_x\sqrt{1-\alpha_2^2}}\right)$$

$$p_v(x) = P_p(2m_c - x)$$

$$\Phi(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^x e^{-\frac{t^2}{2}} dt$$

Mean Stresses



The employed mean stress correction takes the Goodman form for positive mean m :

$$S'_a = S_a \left(1 - \frac{m}{S_L} \right)^{-1}$$

The limit stress can be set to either the stress which gives damage of 1 on the SN curve (Use SN curve intercept in MSC, the default) or the UTS (over conservative).

When the random mean form of Tovo-Benasciutti is used, then as well as integrating the expected damage over the Rayleigh distribution of stress, the (wide band) range counting component is also integrated over the Gaussian distribution of mean stresses. This will produce more damage than using a fixed mean.

Vibration fatigue

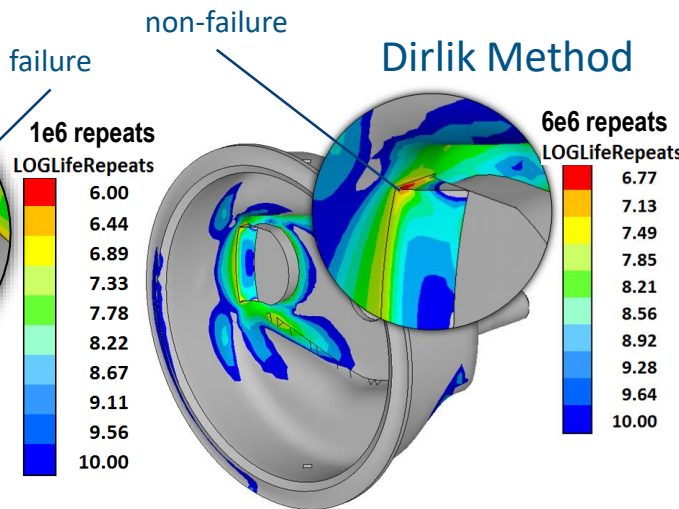
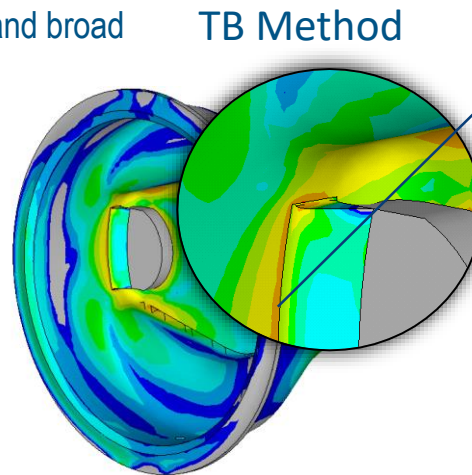
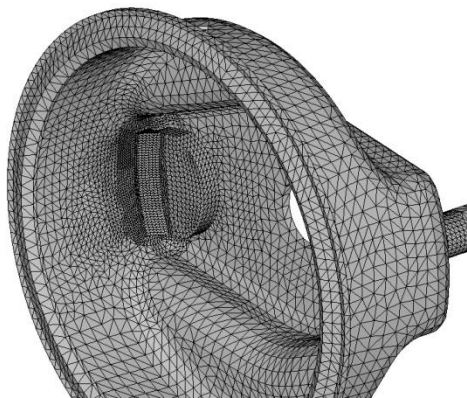
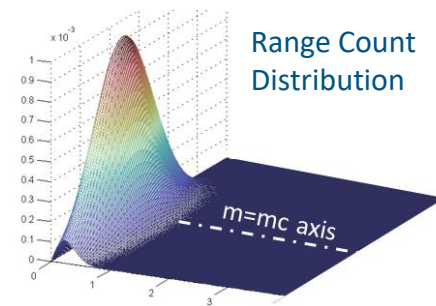
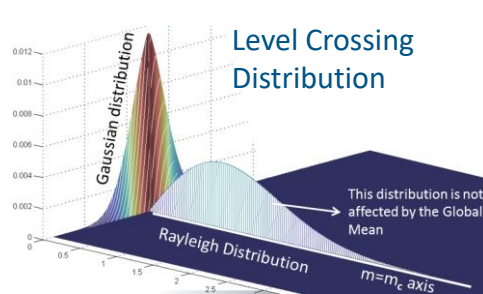
Frequency-Domain Fatigue Analysis

fe-safe 2016:

► Tovo and Benasciutti Method

- ▷ Addresses mean and residual stresses
- ▷ Weights damage evaluated by narrow and broad band distributions

$$D_{RFC} = bD_{NB} + (1 - b)D_{BB}$$



Fatigue Failure

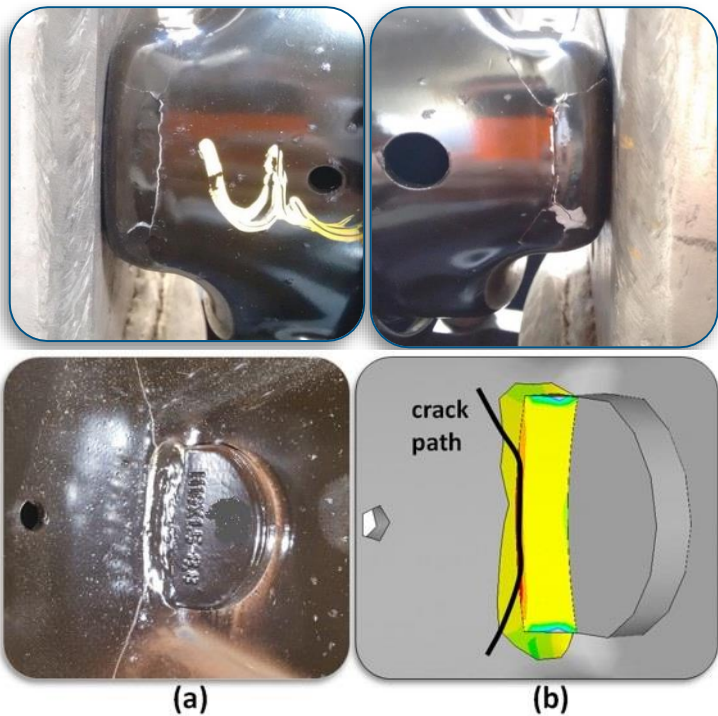


Figure 21

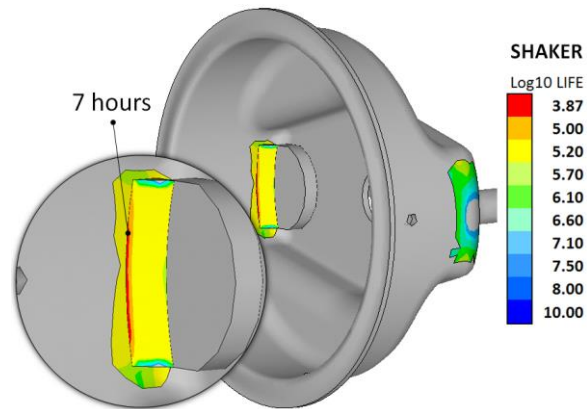


Figure 22

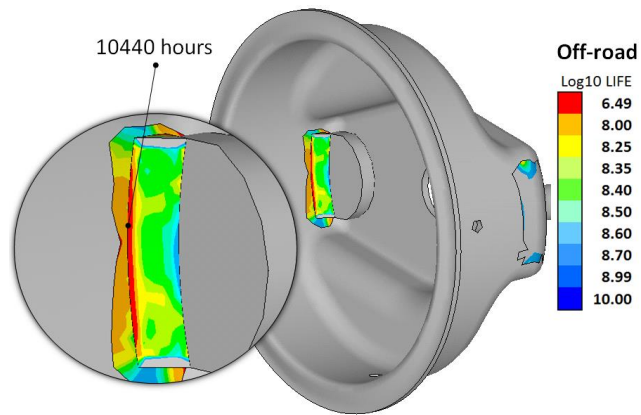


Figure 23

