Ansys TECHCON 2020

Random vibration fatigue analysis based on IGA model in LS-DYNA®

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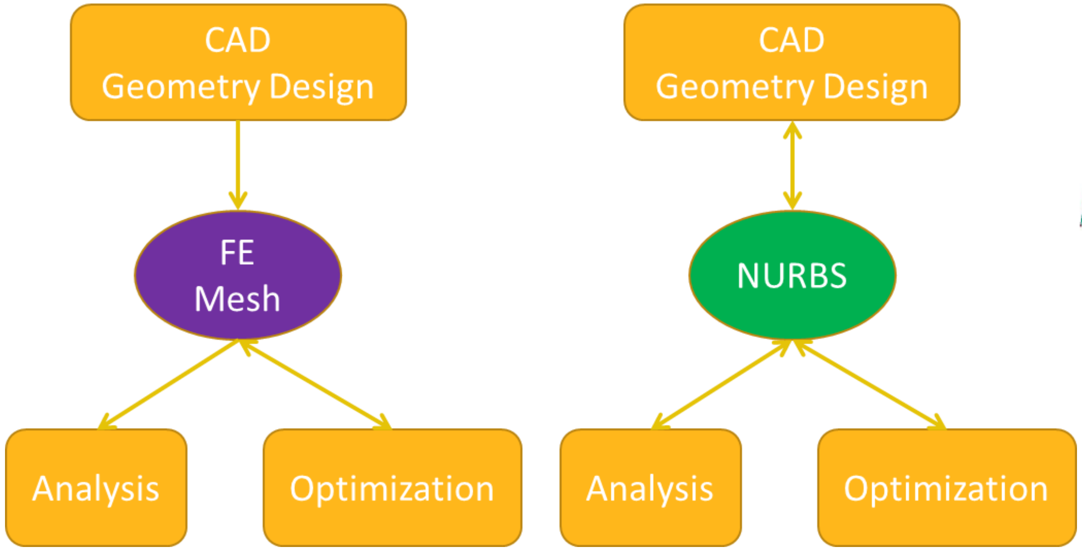
1. Introduction: IGA

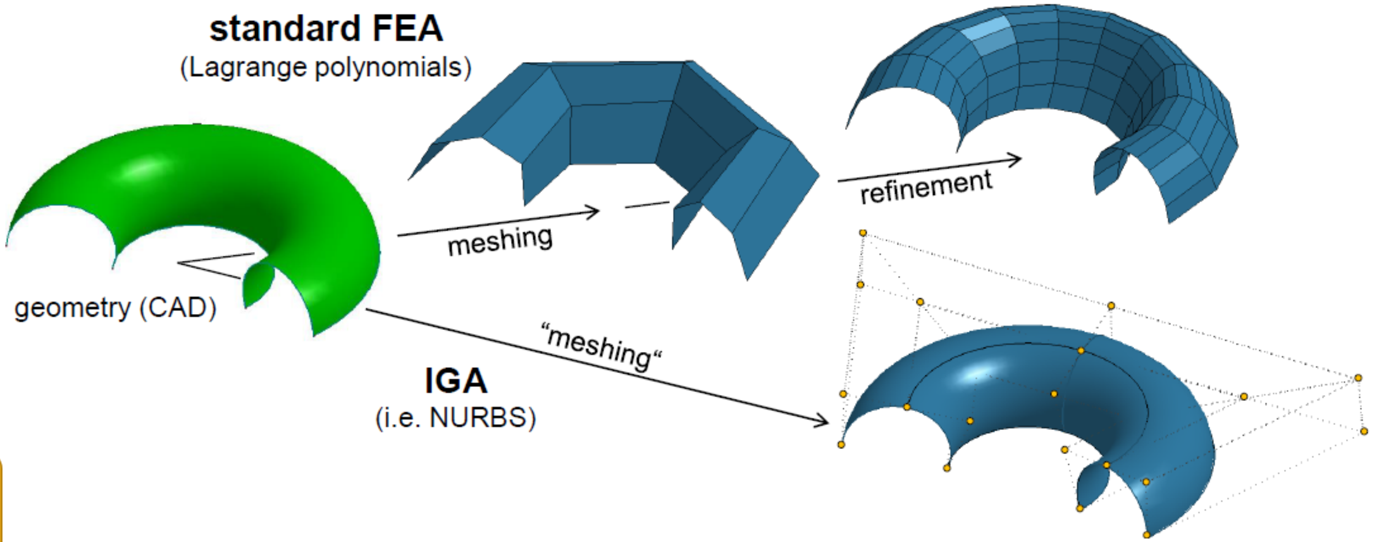
What is IGA

Same description of the geometry in the design (CAD) and the analysis

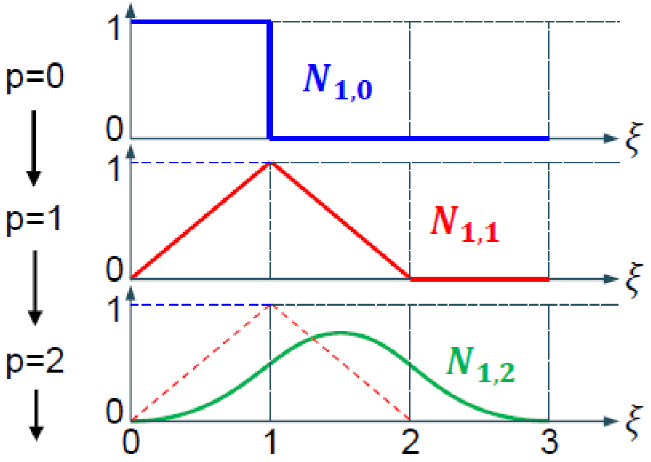
Why IGA

Reduce effort of geometry conversion from CAD into a suitable mesh for FEA





- B-Spline Basis Functions
  - Are constructed recursively

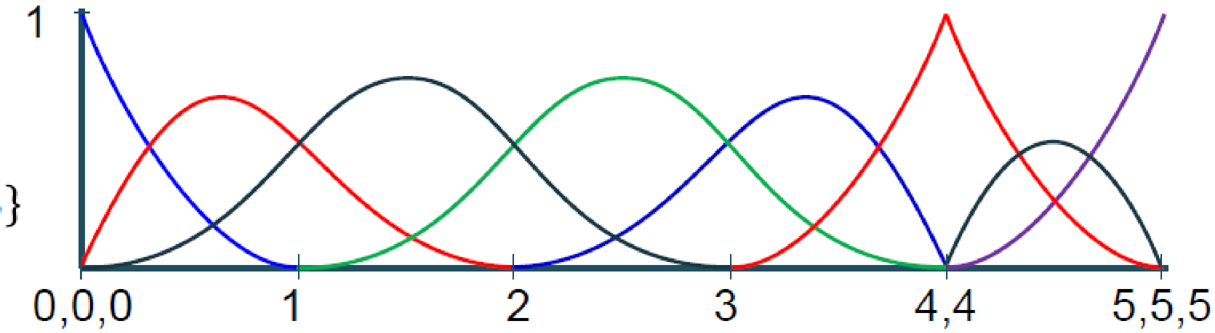


$$N_{i,0}(\xi) = \begin{cases} 1 & \text{if } \xi_i \le \xi < \xi_{i+1} \\ 0 & \text{otherwise} \end{cases}$$

$$N_{i,p}(\xi) = \frac{\xi - \xi_i}{\xi_{i+p} - \xi_i} N_{i,p-1}(\xi) + \frac{\xi_{i+p+1} - \xi}{\xi_{i+p+1} - \xi_{i+1}} N_{i+1,p-1}(\xi)$$

open, non-uniform knot vector

$\Xi = \{0,0,0,1,2,3,4,4,5,5,5\}$

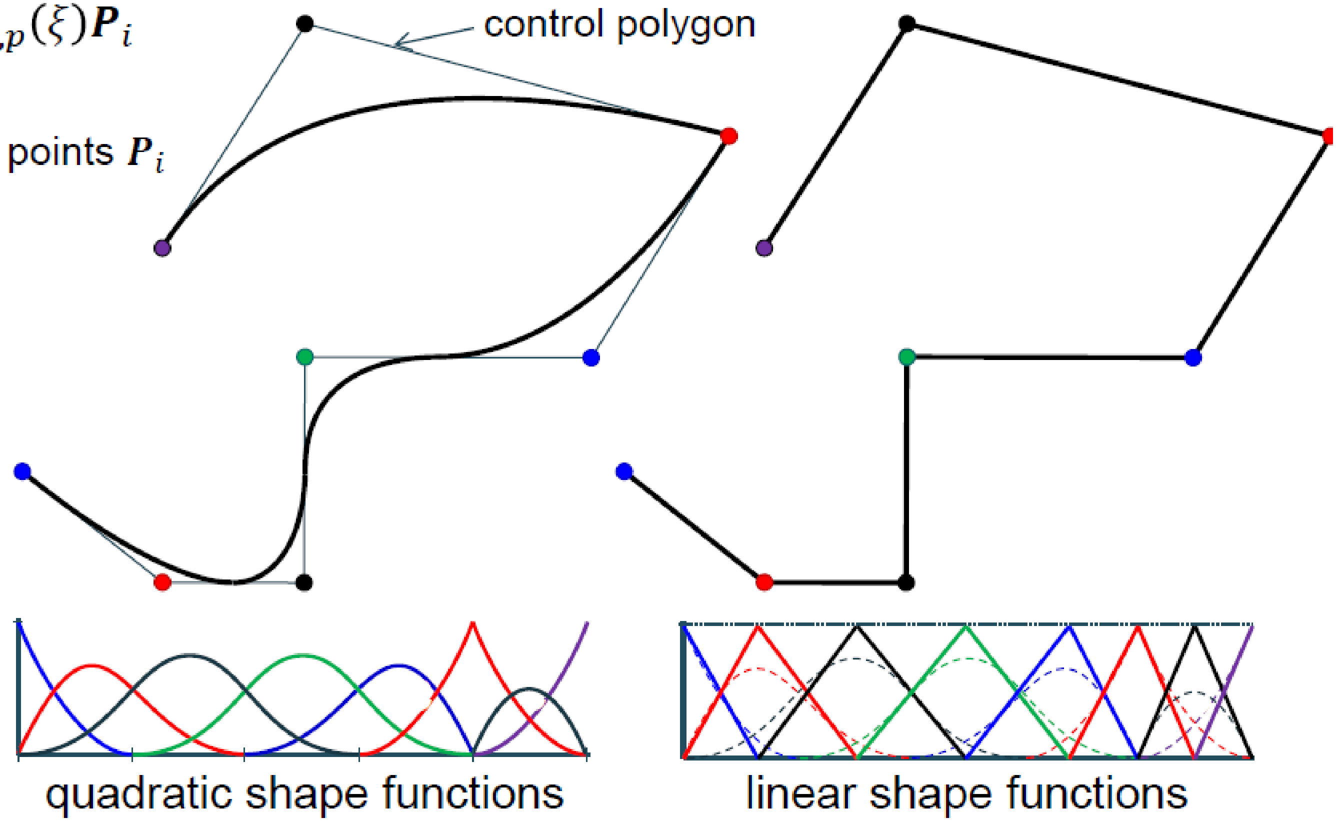


B-Spline - Curves

- Linear combination of B-Spline basis functions, just like in standard FEA

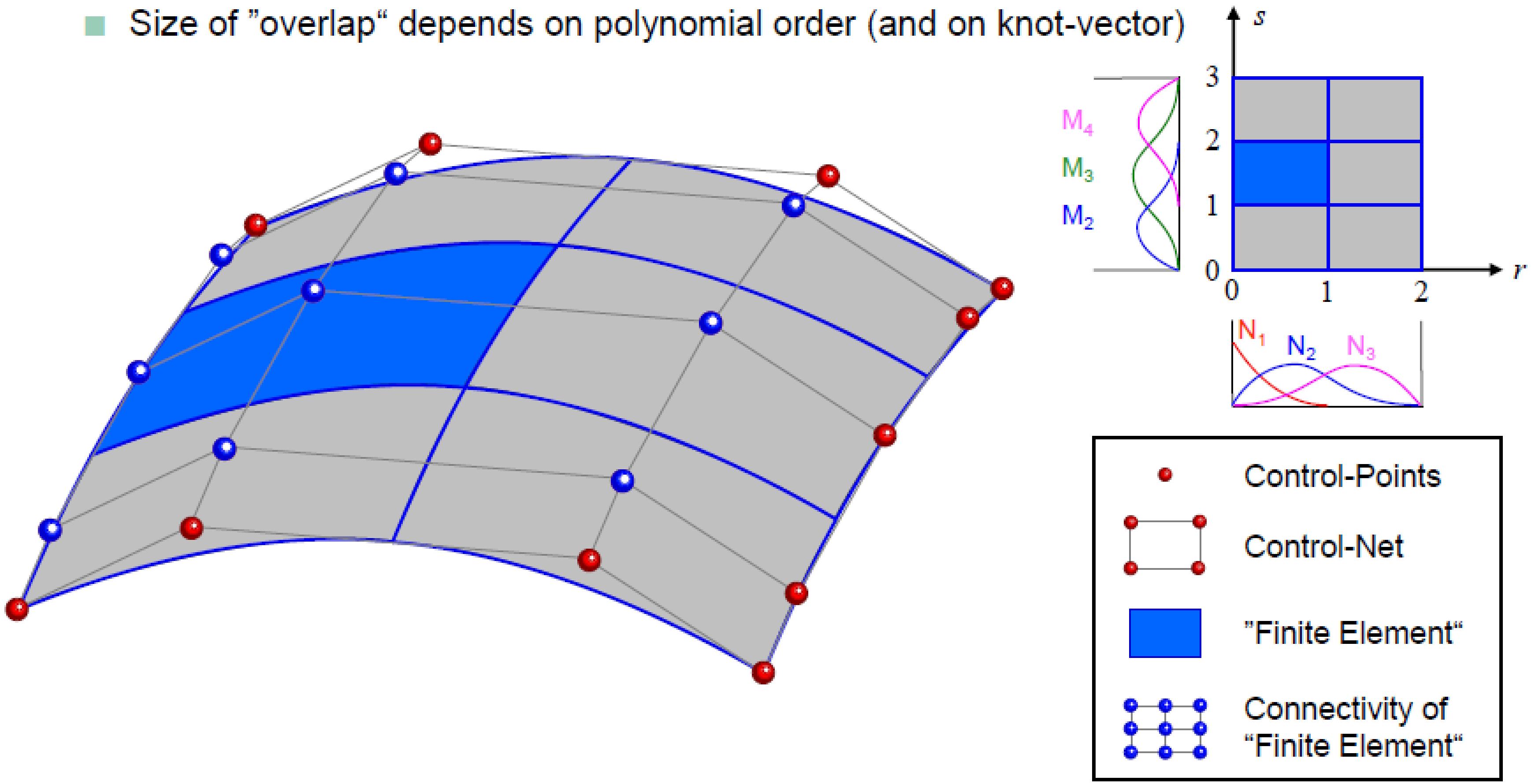
$$C(\xi) = \sum_{i=1}^{n} N_{i,p}(\xi) \boldsymbol{P}_i$$

- With the control points $\boldsymbol{P}_i$



Finite Element Analysis with NURBS

- A typical NURBS-Patch – Connectivity of elements
  - Possible ”overlaps“ (→ higher continuity!)
  - Size of ”overlap“ depends on polynomial order (and on knot-vector)



LS-DYNA keyword for NURBS-shells – 3

- **`*ELEMENT_SHELL_NURBS_PATCH`**

	1	2	3	4	5	6	7	8
Card 1	NPID	PID	NPR	PR	NPS	PS		
Card 2	WFL	FORM	INT	NISR	NISS	IMASS		IDFNE
Card A	RK1	RK2	RK3	RK4	RK5	RK6	RK7	RK8
Card B	SK1	SK2	SK3	SK4	SK5	SK6	SK7	SK8
Card C	N1	N2	N3	N4	N5	N6	N7	N8
Card D	W1	W2	W3	W4	W5	W6	W7	W8

- RKi: values of univariate knot-vector in local r-direction
  → #of Card A: $ceil[(NPR + PR + 1)/8]$
- SKi: values of univariate knot-vector in local s-direction
  → #of Card B: $ceil[(NPS + PS + 1)/8]$
- Ni: control point IDs (defined via **`*NODE`**) to define the control-net
  → two dimensional table of NPS rows and NPR columns
  → per column requires #of Card C: $ceil[(NPR)/8]$
  → total #of Card C: $\mathrm{NPS} \times ceil[(NPR)/8]$
- Wi: weights at control points (optional, only if WFL=1)
  → identical order as Ni (Card C)

2. Introduction: random vibration fatigue analysis

Why we need to run random vibration analysis?

- The loading on a structure is not known in a definite sense
- Vibration environments are not related to a specific driving frequency (input from multiple sources)
- To be precise, all vibration is random (due to all kinds of disturbance)
- Examples:
  - Wind load on wind-turbine
  - Air flow over a wing or past a car body
  - Earthquake ground motion
  - Tires running over a rough road
  - Ocean wave loads on offshore platforms

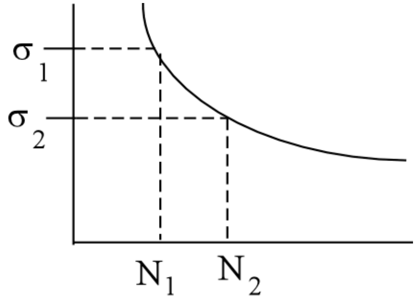
What is fatigue?

- Fatigue is a process in which damage accumulates due to repetitive application of loads that may be well below the yield point.
- Fatigue is a complex process involving many steps, but it can be broken down into initiation and propagation of fatigue cracks.
- For many years, fatigue has been a significant and challenging problem for engineers, especially for those who design structures such as aircrafts, railroad vehicles, automotive, bridges, pressure vessels, and cranes.
- Fatigue analysis can be performed in time domain and frequency domain.

Overview of random vibration fatigue analysis in LS-DYNA

- Keyword *FREQUENCY_DOMAIN_RANDOM_VIBRATION_*FATIGUE*
- Calculate fatigue life of structures under random vibration
- Based on S-N fatigue curve
- Based on probability distribution & Miner's Rule of Cumulative Damage Ratio

$$R = \sum_i \frac{n_i}{N_i}$$



Typical SN (or Wöhler) curve

- Schemes:
  - ✓ *Steinberg's Three-band technique considering the number of stress cycles at the 1σ, 2σ, and 3σ levels.*
  - ✓ *Dirlik method based on the 4 Moments of PSD.*
  - ✓ *Narrow band method*
  - ✓ *Wirsching method*
  - ✓ …

PDF
(*probability density function*)

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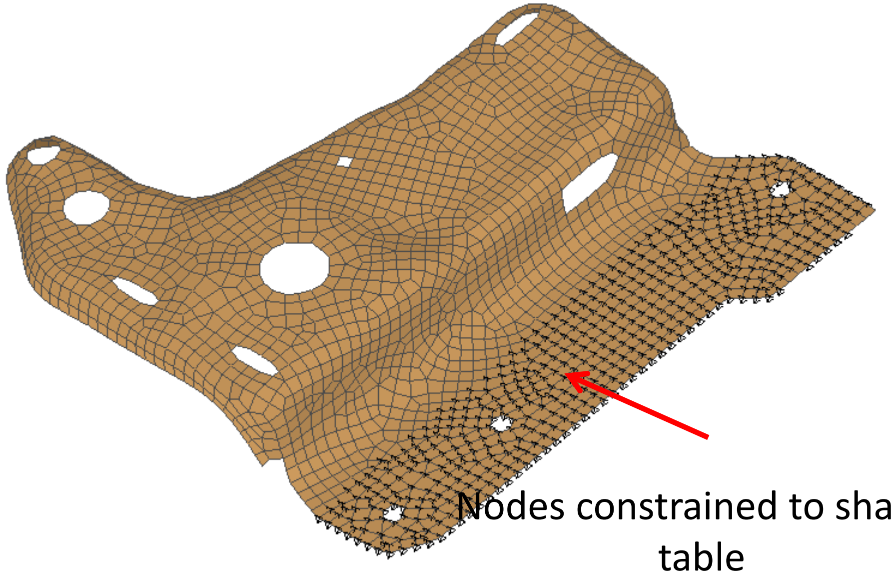
Keywords to run random vibration fatigue analysis

```
*FREQUENCY_DOMAIN_RANDOM_VIBRATION_FATIGUE
$#   mdmin     mdmax     fnmin     fnmax    restrt    unused    restrm
         1         0       0.0       0.0         0                   0
$#   dampf     lcdam     lctyp    dmpmas    dmpstf    dmptyp
     0.035         0         0       0.0       0.0         0
$#  vaflag    method      unit      umlt     vapsd     varms     napsd     ncpsd
         1         1         0       0.0         0         0         1         0
$#   ldtyp   ipanelu   ipanelv    temper    unused    ldflag   icoarse   bcoarse
         0         0         0       0.0                   0         0       0.1
$#     sid     stype       dof     ldpsd     ldvel     ldflw     ldspn       cid
         0         0         3         1         0         0         0         0
$#    mftg      nftg    sntype    texpos     strsf     inftg
         2         1         0      12.0       2.0         0
$#     pid      lcid     ptype     ltype         a         b    sthres    snlimt
         1         2         0         1       0.0       0.0       0.0         0
```

```
*DATABASE_FREQUENCY_BINARY_D3FTG
$#  binary
         1
*DATABASE_FREQUENCY_BINARY_D3PSD
$#  binary
         1
$#    fmin      fmax     nfreq    fspace    lcfreq
      0.01     400.0      3999         0         0
*DATABASE_FREQUENCY_BINARY_D3RMS
$#  binary
         1
```

Example: an aluminum bracket



Nodes constrained to shaker table

Aluminum 2014 T6

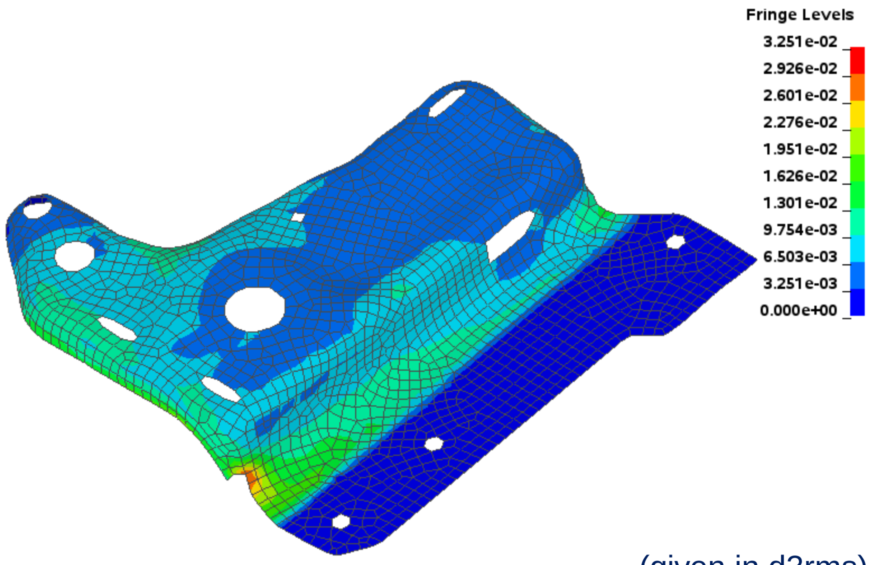
ρ = 2800 kg/m^3

E = 72,400 MPa

ν = 0.33

Time of exposure: 4 hours

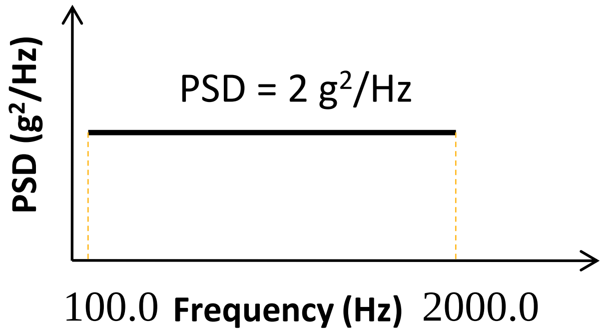
Method: Steinberg's method

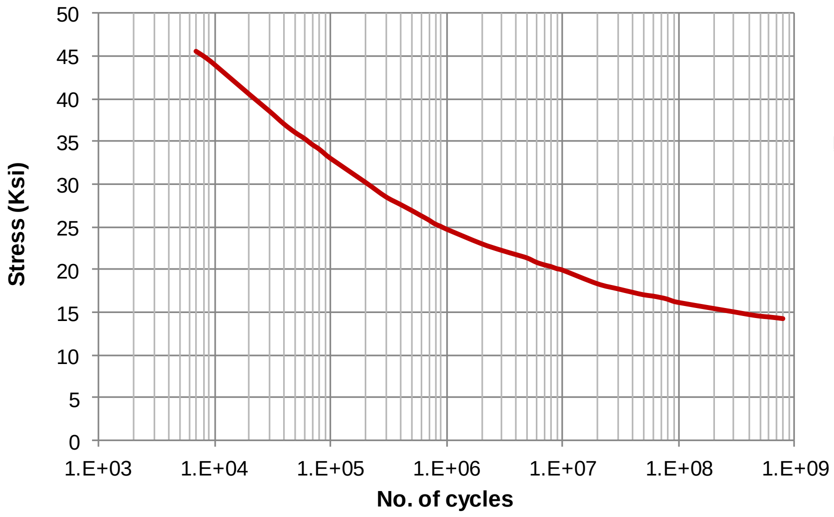


(given in d3rms)

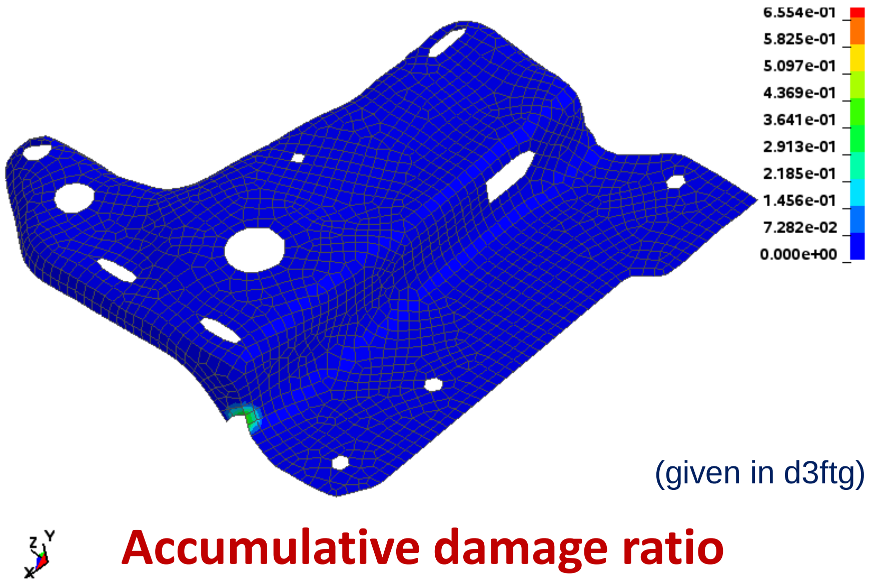
RMS of Von-Mises stress (unit: GPa)

Z-acceleration PSD





S-N fatigue curve



(given in d3ftg)

Accumulative damage ratio

3. Random vibration fatigue analysis based on IGA model

Flow chart for random vibration fatigue analysis using IGA model

Modal analysis with IGA

↓

Modal stress computation with IGA

↓

Eigenvectors and modal stress mapped to an interpolation elements

↓

Random vibration solver reads in eigenvectors and modal stress

↓

Random vibration and fatigue analysis

↓

Post processing: d3psd, d3rms, d3ftg

4. Example and preliminary results

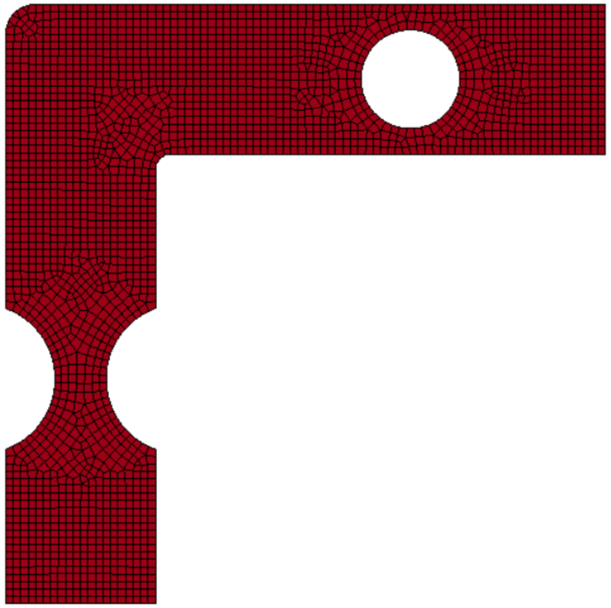
Courtesy of Shubiao Wang, INSA Rouen, France

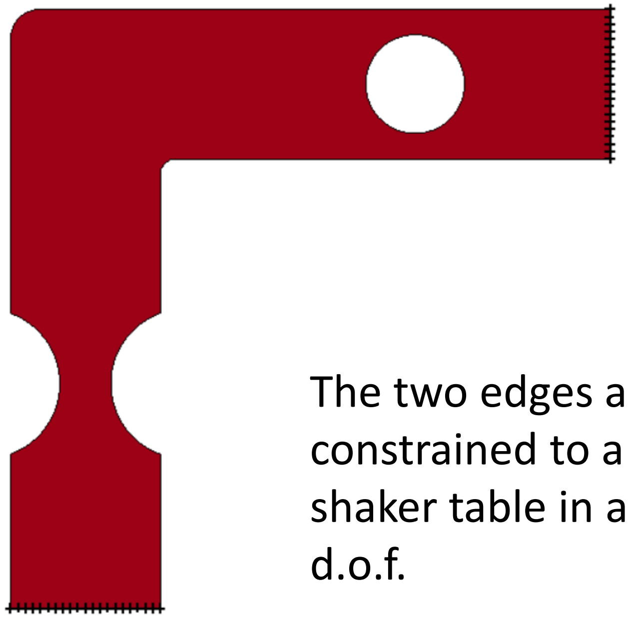
<u>FEM information</u>

No. of nodes: 2601
No. of shell elements: 2427

<u>Material properties</u>

Mass density: 3810 kg/m^3)
Young's modulus: 3.1e+11 Pa
Poisson ratio: 0.33



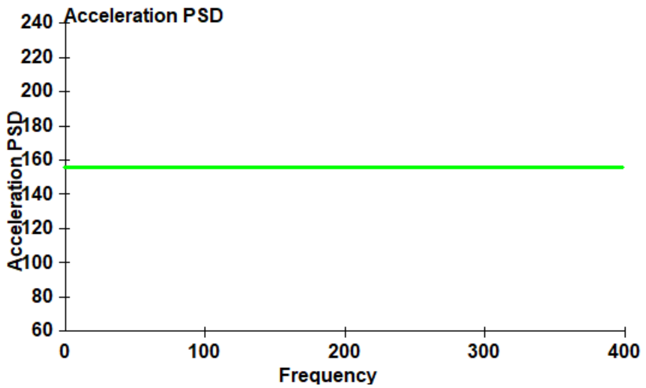


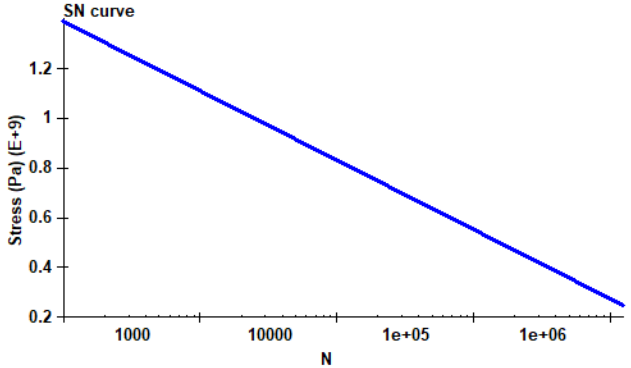
The two edges are constrained to a shaker table in all d.o.f.

A metal bracket (originally modelled by IGA) subject to base acceleration PSD

Keyword and loading condition

```
*FREQUENCY_DOMAIN_RANDOM_VIBRATION_FATIGUE
$#   mdmin     mdmax     fnmin     fnmax    restrt    unused    restrm
         1         0       0.0       0.0         0                   0
$#   dampf     lcdam     lctyp    dmpmas    dmpstf    dmptyp
     0.035         0         0       0.0       0.0         0
$#  vaflag    method      unit      umlt     vapsd     varms     napsd     ncpsd
         1         1         0       0.0         0         0         1         0
$#   ldtyp   ipanelu   ipanelv    temper    unused    ldflag   icoarse   bcoarse
         0         0         0       0.0                   0         0       0.1
$#     sid     stype       dof     ldpsd     ldvel     ldflw     ldspn       cid
         0         0         3         1         0         0         0         0
$#    mftg      nftg    sntype    texpos     strsf     inftg
         2         1         0      12.0       2.0         0
$#     pid      lcid     ptype     ltype         a         b    sthres    snlimt
         1         2         0         1       0.0       0.0       0.0         0
```



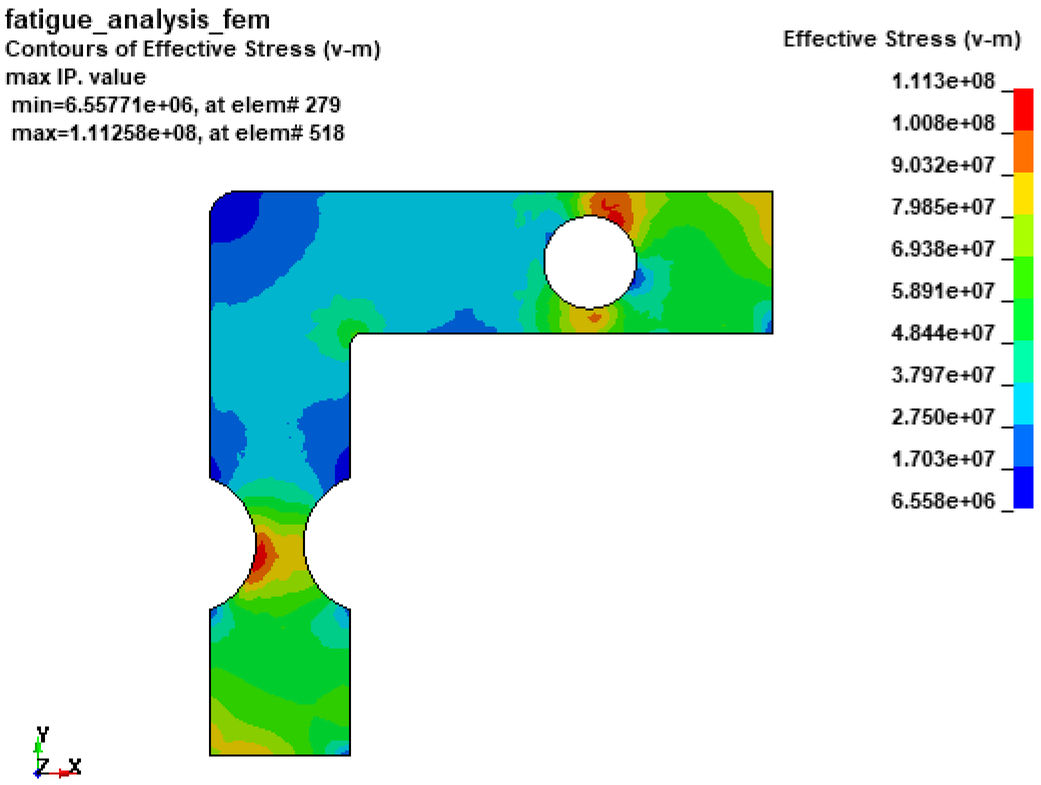


Loading and other computation conditions

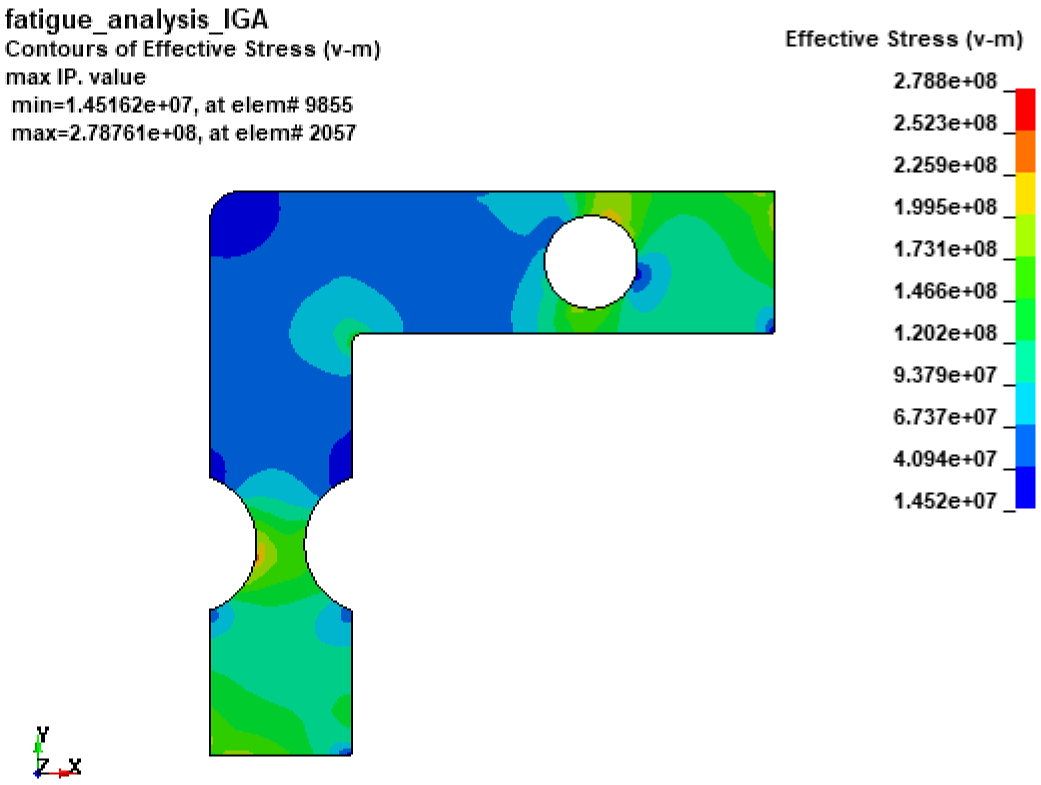
1. Base acceleration PSD (constant for whole range of frequency 1-400 Hz)
2. Use mode 1 only
3. Constant modal damping ratio 0.035
4. Dirlik method is used for fatigue analysis (mftg = 2)

Stress results from random vibration analysis

FEM

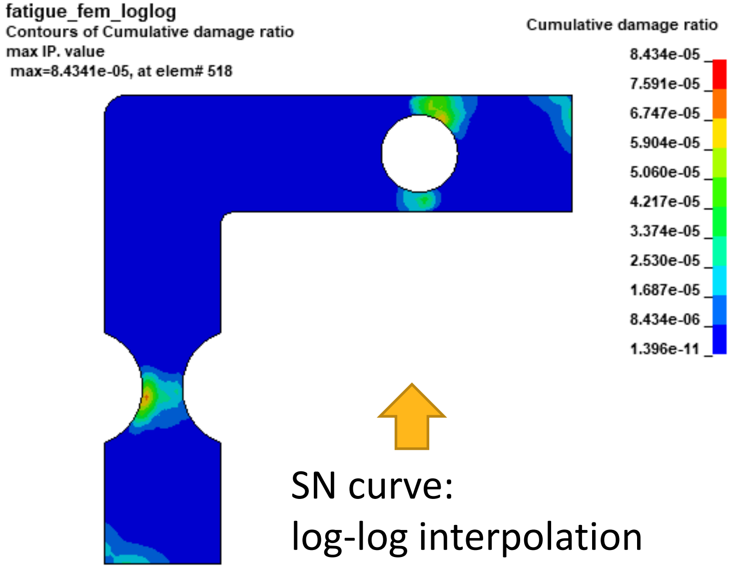


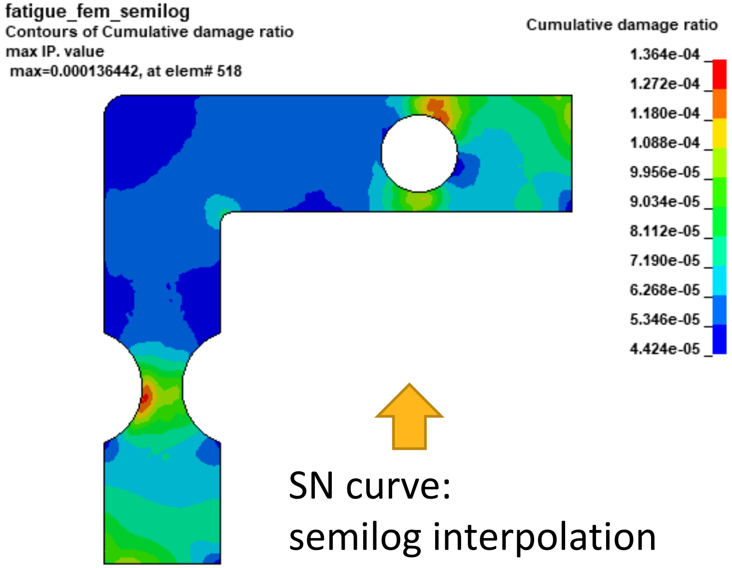
IGA

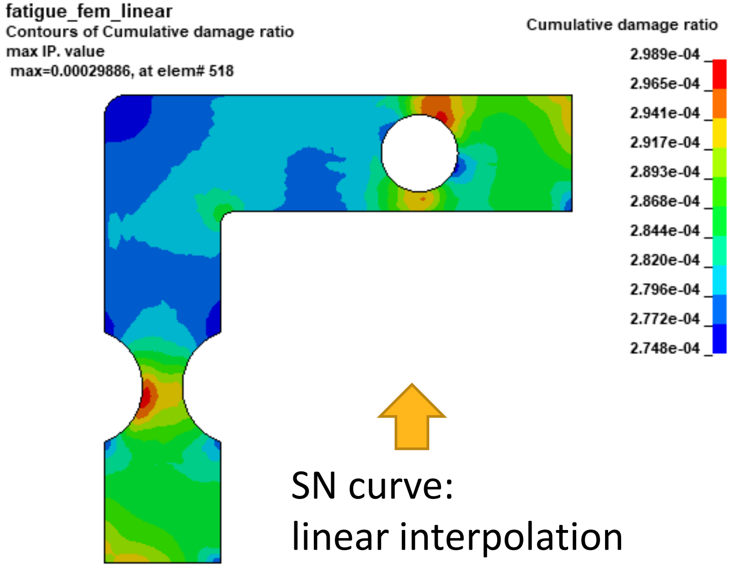


Fatigue analysis results

FEM





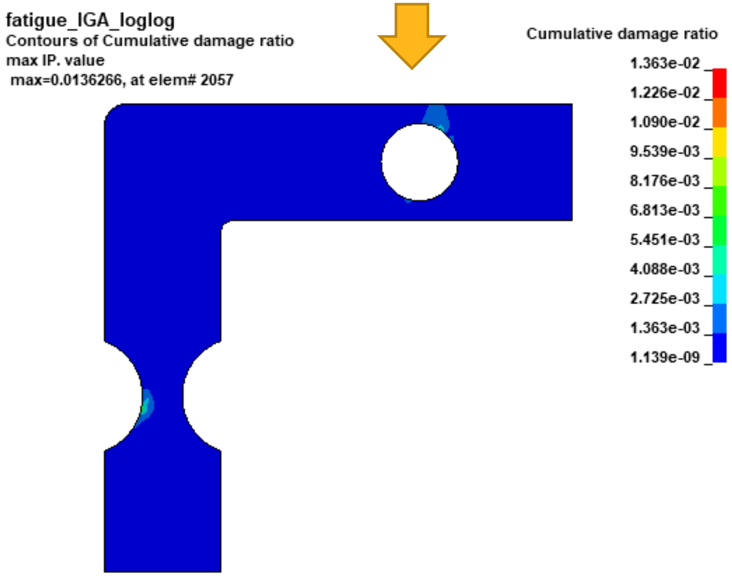


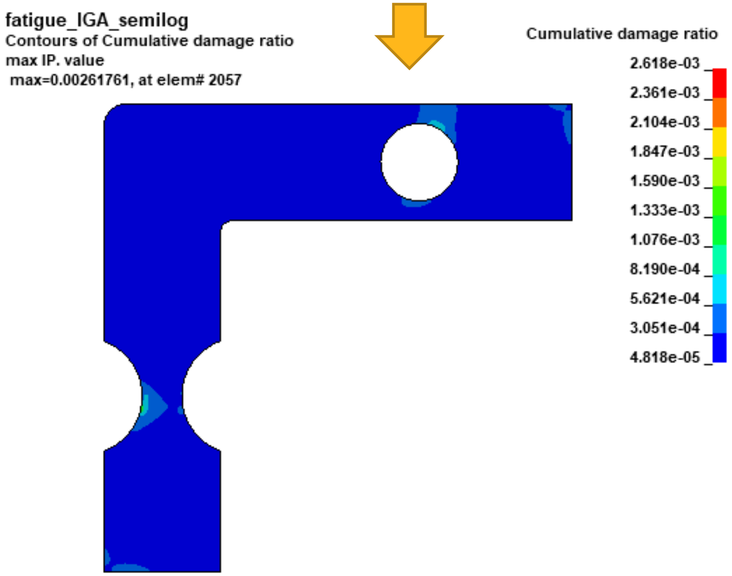
SN curve:
log-log interpolation

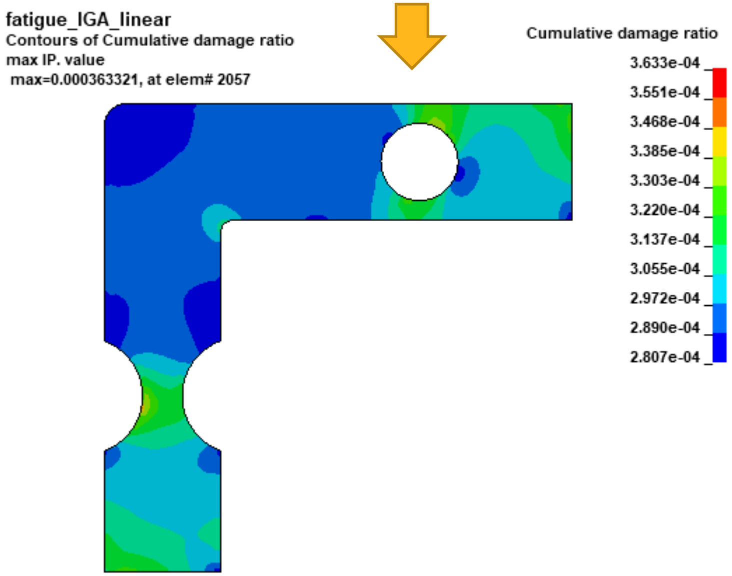
SN curve:
semilog interpolation

SN curve:
linear interpolation

IGA







Comments

Max values from FEM & IGA

		FEM	IGA
Von Mises Stress (Pa)		1.113e+8	2.788e+8
Cumulative damage ratio	log-log	8.434e-5	1.363e-2
	semilog	1.364e-4	2.618e-3
	linear	2.989e-4	3.633e-4

- There are some difference in stress and fatigue damage results (actually, it's big difference for cumulative damage ratio results, when using log-log interpolation on SN curves);
- The stress results from IGA are higher than those given by FEM, as IGA can essentially capture the stress concentration better;
- Consequently the cumulative damage ratios from IGA are higher;
- The location of max stress / cumulative damage ratio is consistent for FEM and IGA.

5. Future work

- Refine the FEM mesh to see if a better match in stress and cumulative damage ratio by IGA model and FEM model can be reached;
- For random vibration module, get the modal stress from IGA integration points directly, without using the interpolation elements;
- Run random vibration and fatigue analysis on integration points of IGA directly;
- Update the post-processing tool to show vibration and fatigue results on integration points of IGA directly.
- Time domain fatigue analysis based on IGA.
- Suggestions from users …

Acknowledgement

We would like to thank Shubiao Wang of INSA Rouen of France for permitting us to use his model as an example.

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