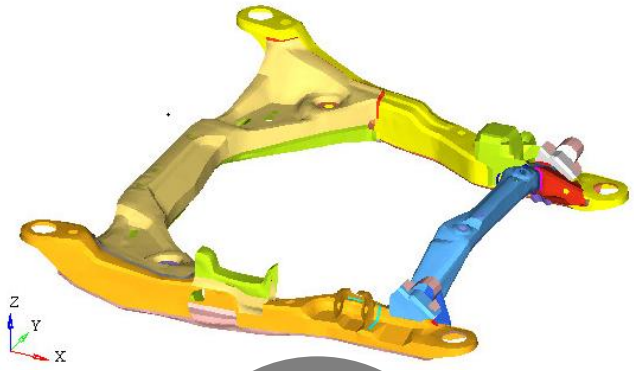
ANALYSIS AND OPTIMIZATION OF AN AUTOMOTIVE CRADLE USING SINGLE FINITE ELEMENT MODEL WITH MULTIPLE ATTRIBUTES I.E. NVH, STRENGTH AND FATIGUE

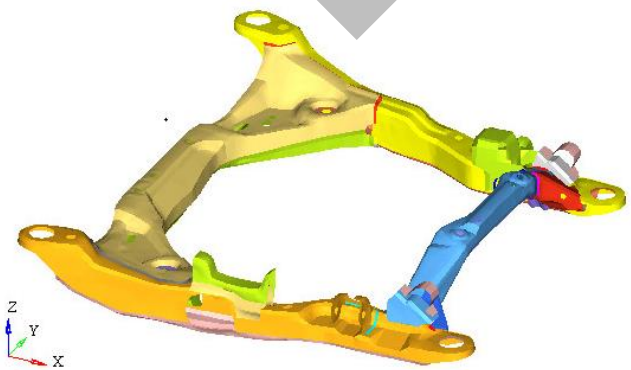
Presenter's Name; Prashant Hiremath*, Linus Fernandes and Balaji Kumar

Presenter's; Altair Engineering Inc.

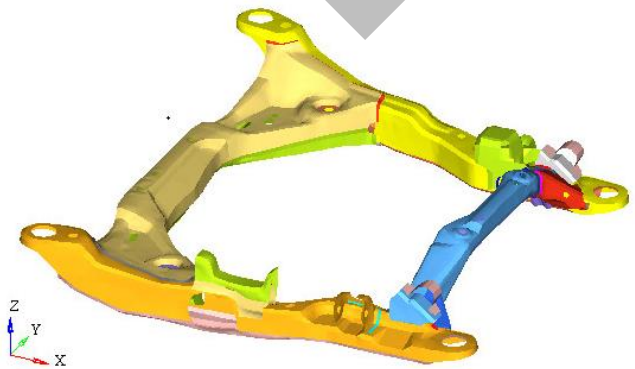
Time Consuming and inefficient workflows



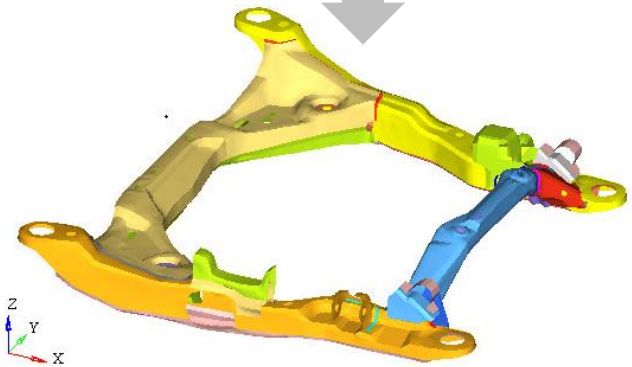
- Multiple models, solvers and formats
- Model conversions
- Error-prone
- Model version management
- Increased optimization complexity



Linear/NVH
Solver A
Format A



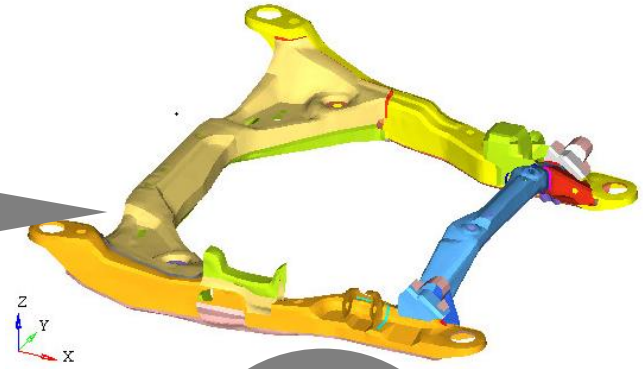
Nonlinear (Strength)
Solver B
Format B



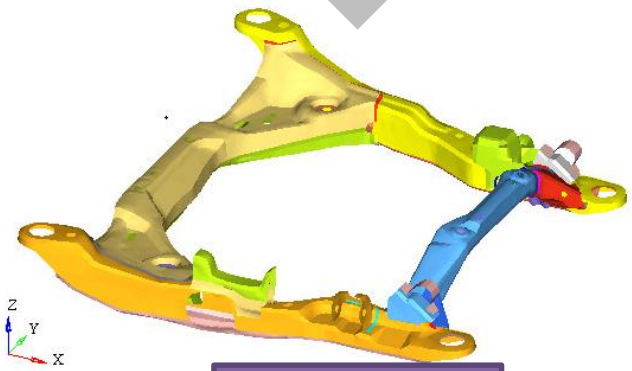
Fatigue
Solver C
Format C + D

Single Model Multi-Attribute Design workflow

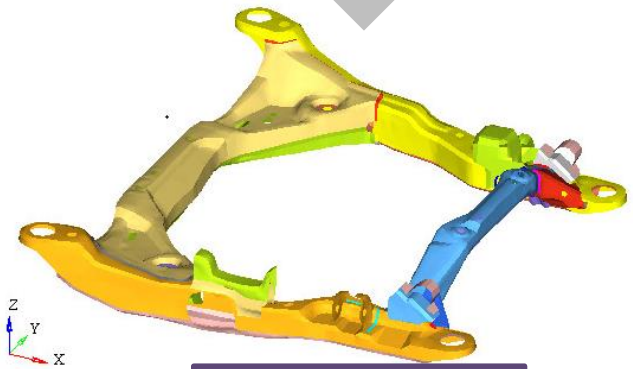
Subcase 1
… NVH
Subcase 2
…Nonlinear
Subcase 3
…Fatigue



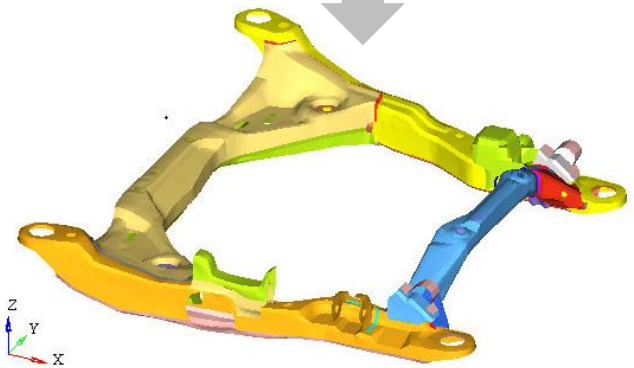
- Single model, solver and format
- Model conversions
- Error-prone
- Model version management
- Optimization-ready



Linear/NVH
OptiStruct



Strength Analysis
Nonlinear Implicit
OptiStruct

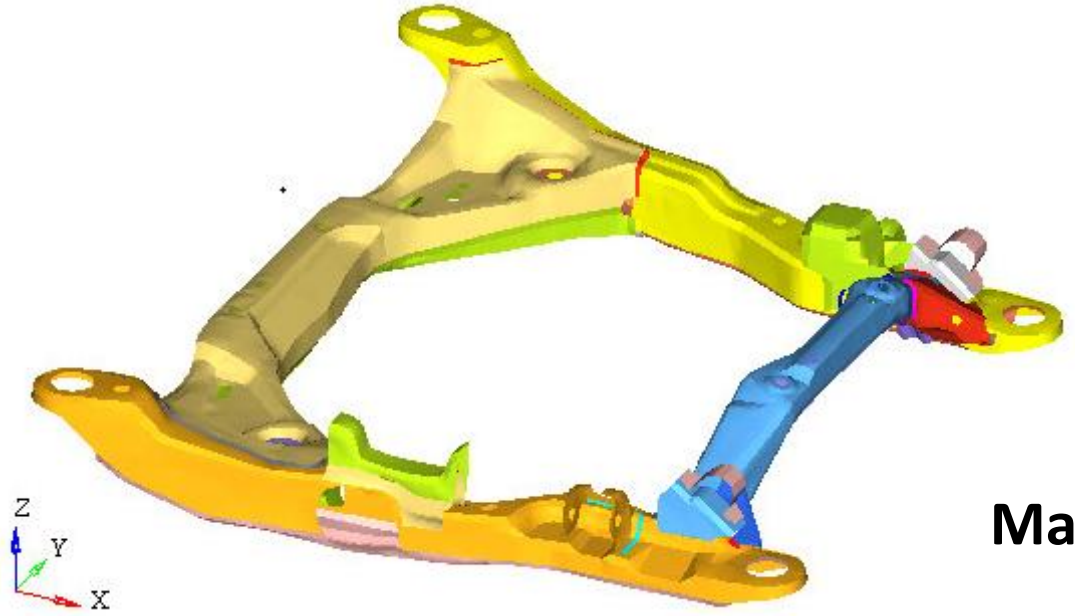


Fatigue
OptiStruct

Objective

To perform analysis and optimization of a multi-attribute model i.e. Linear NVH, Strength Analysis (Permanent set) and Durability(Weld Fatigue) using a single model

SL.No.	Model Attributes	Performance targets
1	Linear NVH (FRF at 2 Engine Mount locations, N/mm)	Node ID 13933527 X > 3508, Y > 1216, Z > 850 Node ID 13933595 X > 6250, Y > 2398, Z > 3508
2	Strength Analysis (Permanent set at LCA mount)	Permanent set < 0.5mm
3	Durability(Weld Fatigue)	Damage < 1



Cradle model from Ford Taurus crash model (courtesy)

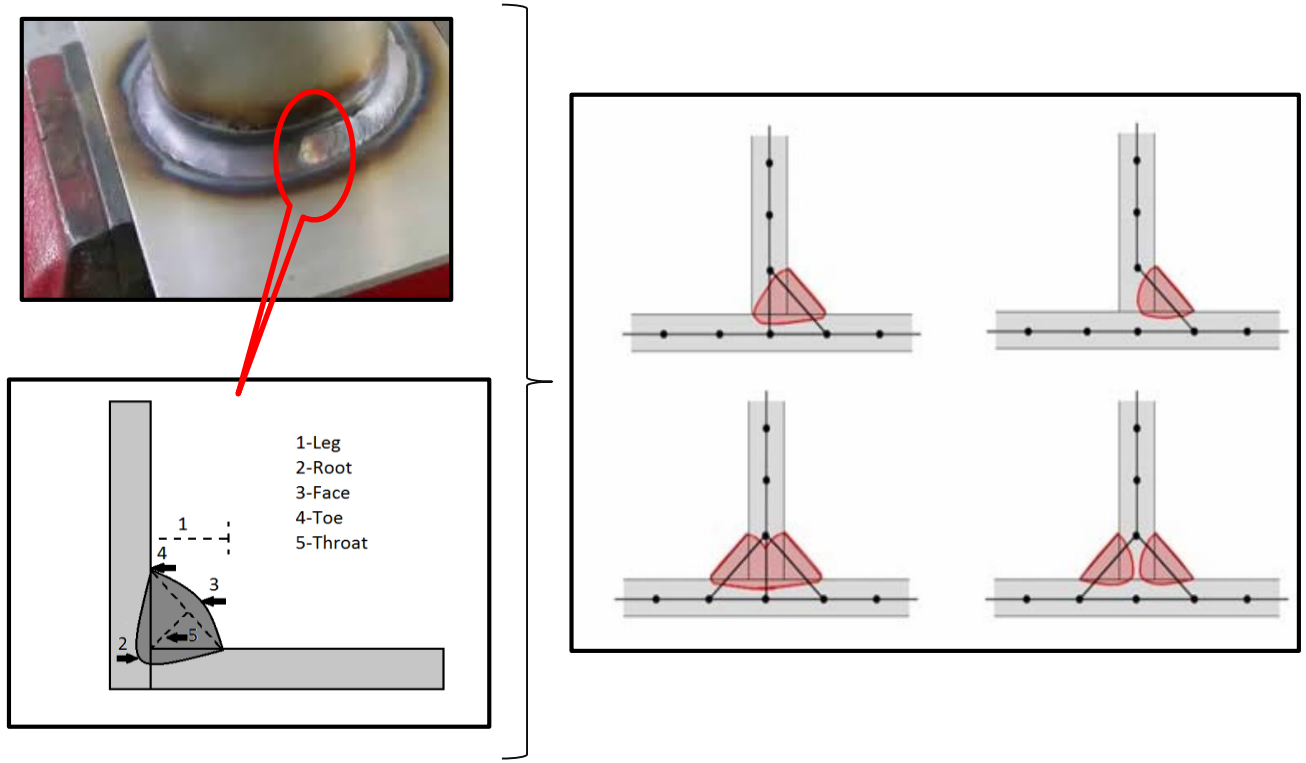
Mass Baseline Design 46.88 Kgs

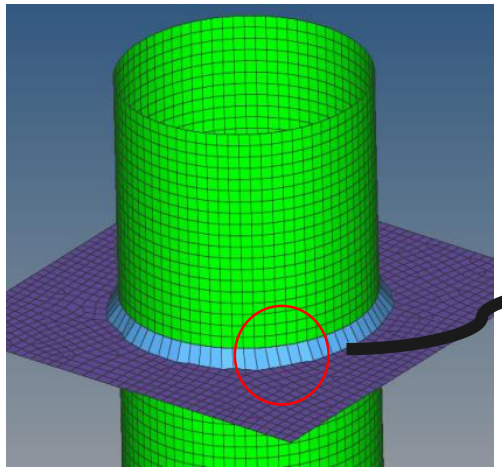
Baseline Analysis

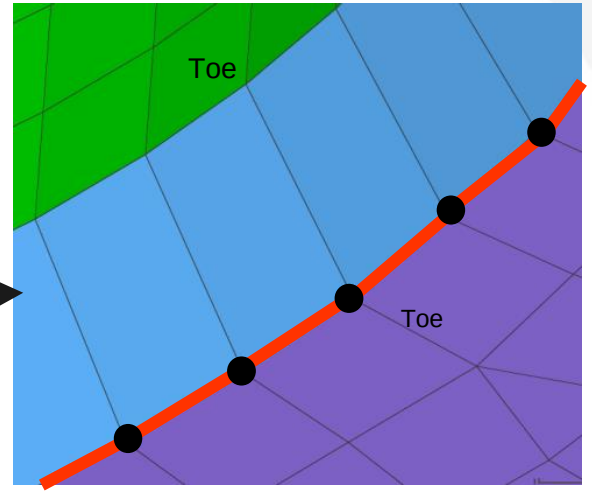
Fatigue set-up

Fatigue Analysis

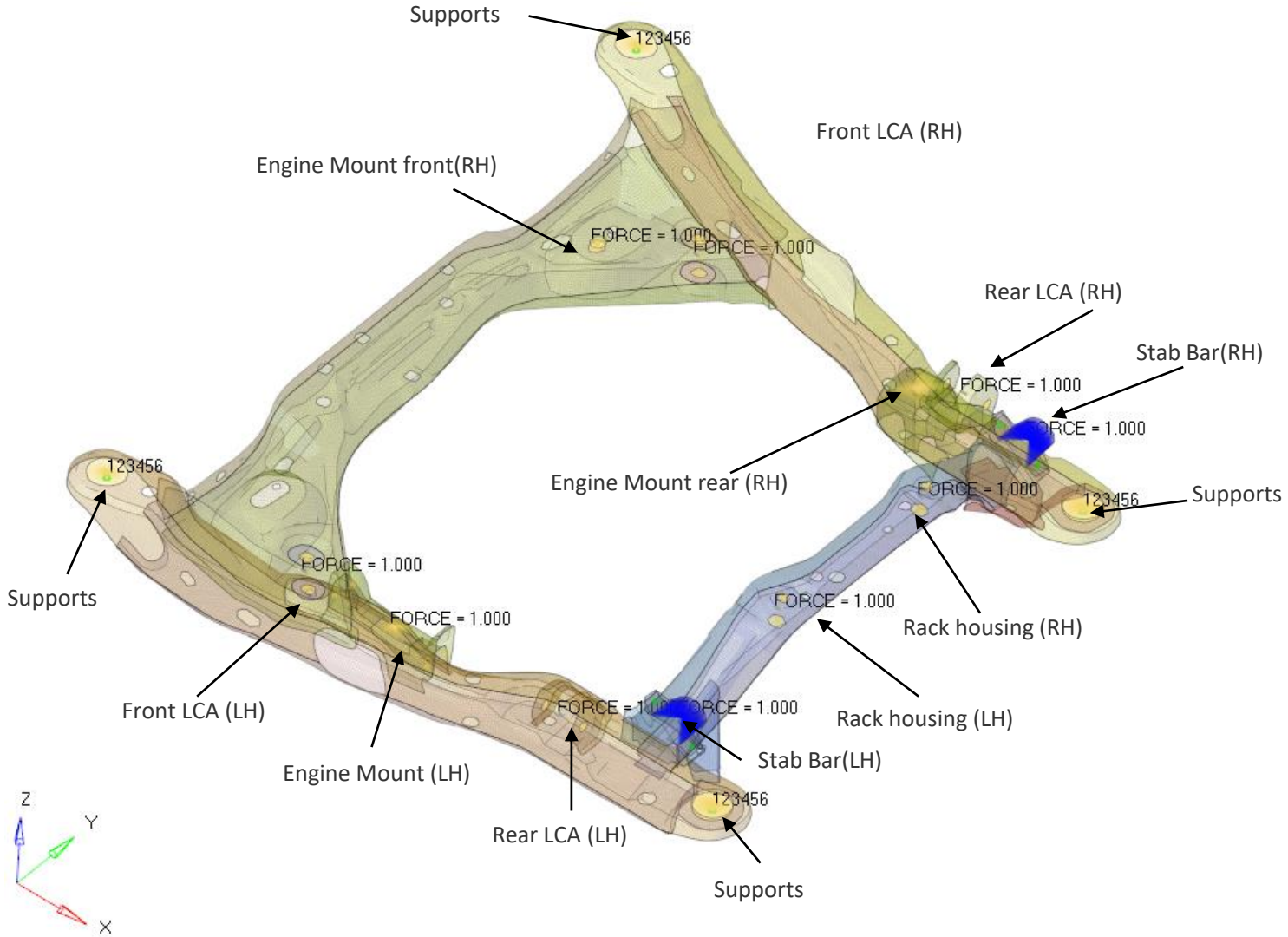
- We can perform parent material fatigue and seam/spot weld fatigue
- S-N (Stress Life), E-N (Strain Life) and Dang Van Criterion (fos) approaches
- Linear superposition of multiple static load cases
- In this study we are doing a seam weld fatigue analysis
  - Modeling seam welds uses a CQUAD4 element formulation
  - “Volvo Method” or “Hot Spot” Stress approach is used to calculate the hot spot stress from the nodal force at weld line.
  - Force equilibrium at weld line holds true regardless of weld shape





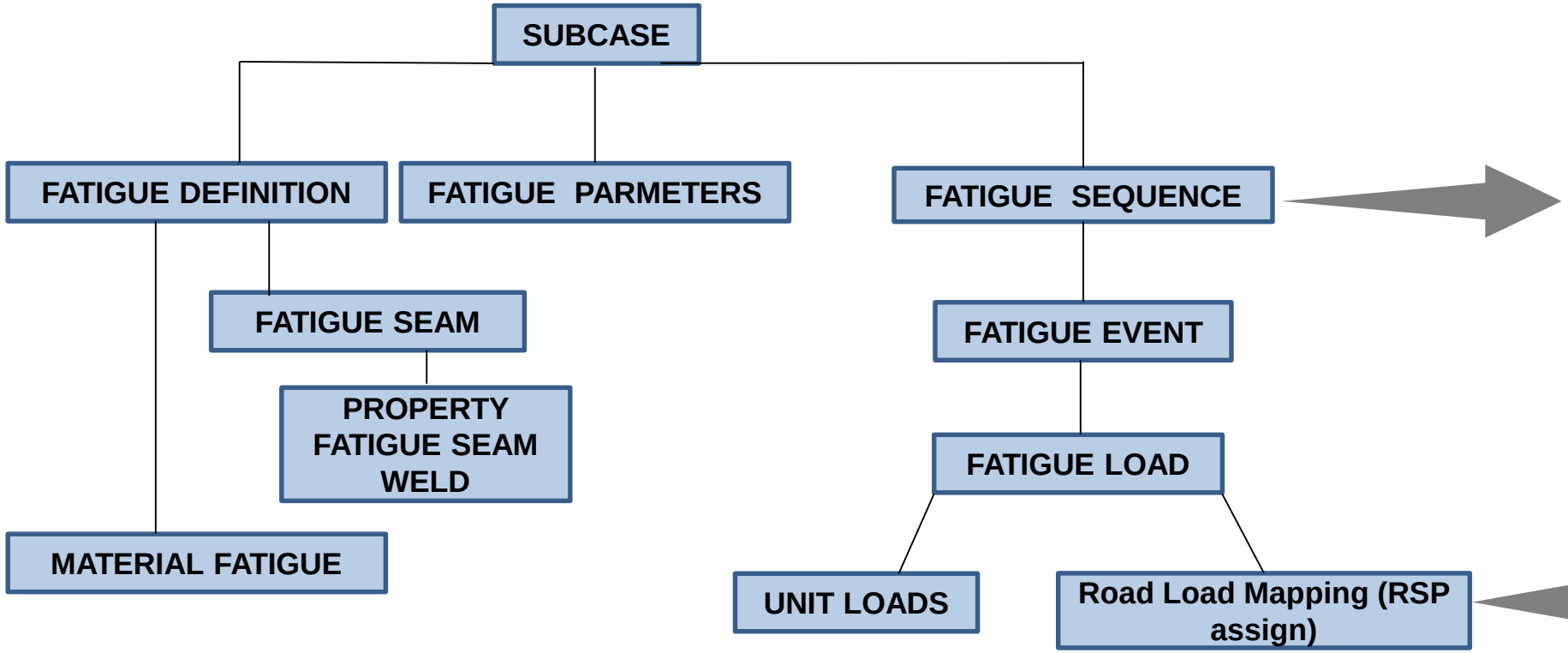


Fatigue set-up (loading locations)



- **Unit loads at 10 locations in X,Y AND Z**

Fatigue set-up (Work flow)



Events	Repeat/Occurance
EngMntX	2000/1
EngMntY	2000/1
EngMntZ	15000/1
Braking	600/1
ForeAft1	87/1
ForeAft2	87/1
ForeAft3	360/1
ForeAft4	60/1
Corner	600/1
Jounce1	58/1
Jounce2	58/1
Jounce3	2200/1
Jounce4	120/1
TieRod1	500/1
TieRod2	500/1
Rebound	300/1

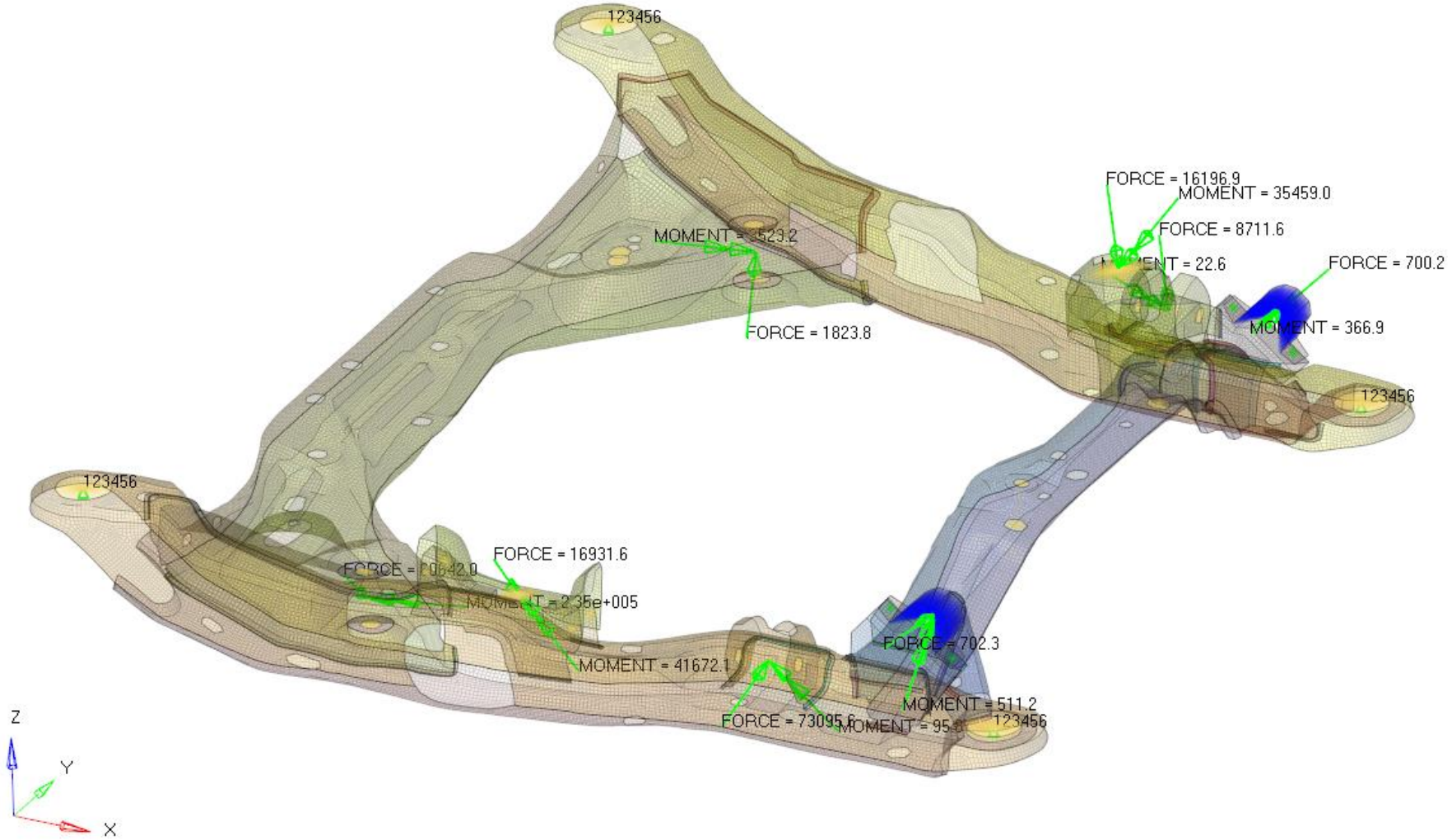
```
$$
$$ Optistruct Input Deck Generated by HyperMesh Version  : 2017.2.4-HWDesktop
$$ Generated using HyperMesh-Optistruct Template Version : 2017.2.4_hotfix-HWDesktop
$$
$$   Template:  optistruct
$$
$$
$$ optistruct
$
ANALYSIS ONLY
$
ASSIGN ,RPC,1,1st_event.rsp
ASSIGN ,RPC,2,2nd_event.rsp
ASSIGN ,RPC,3,3rd_event.rsp
ASSIGN ,RPC,4,4th_event.rsp
ASSIGN ,RPC,5,5th_event.rsp
ASSIGN ,RPC,6,6th_event.rsp
ASSIGN ,RPC,7,7th_event.rsp
ASSIGN ,RPC,8,8th_event.rsp
ASSIGN ,RPC,9,9th_event.rsp
ASSIGN ,RPC,10,10th_event.rsp
ASSIGN ,RPC,11,11th_event.rsp
ASSIGN ,RPC,12,12th_event.rsp
ASSIGN ,RPC,13,13th_event.rsp
ASSIGN ,RPC,14,14th_event.rsp
ASSIGN ,RPC,15,15th_event.rsp
ASSIGN ,RPC,16,16th_event.rsp
```

- Fatigue calculation parameters defined for – Rainflow counting, Stress combination, Stress influence (etc).
- FATDEF card identifies element set for fatigue analysis
- MATFAT tied to MAT1 card defines S-N curve data
- FATSEAM to identify seam weld strip (elements) and the type of weld
- PFATSMW to identify the seam weld properties for fatigue analysis
- Fatigue Subcase

- Unit load created for all the 30 load cases
- Loading time history can be read through assign statement using RPC/RSP/DAC file
- Fatigue load associates static subcase to load-time history
- Fatigue events identifies one or more fatigue loads
- Fatigue loading sequence defines combinations, scalers and repetitions of fatigue events

Non-linear

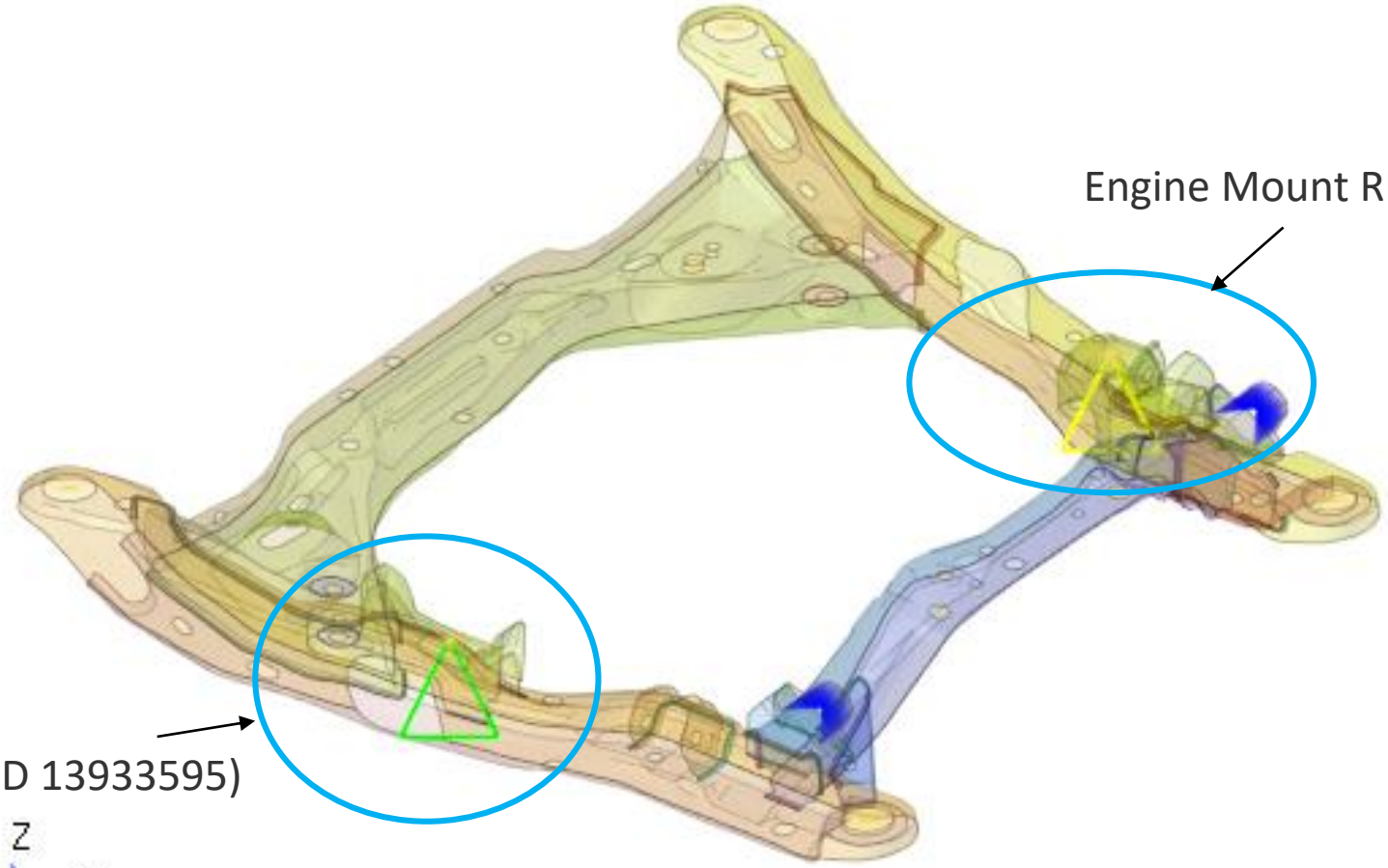
Strength Analysis set-up (Permanent set)



- **Loads for Pot hole event**
- **Model has geometry and material non-linearity**

NVH set-up

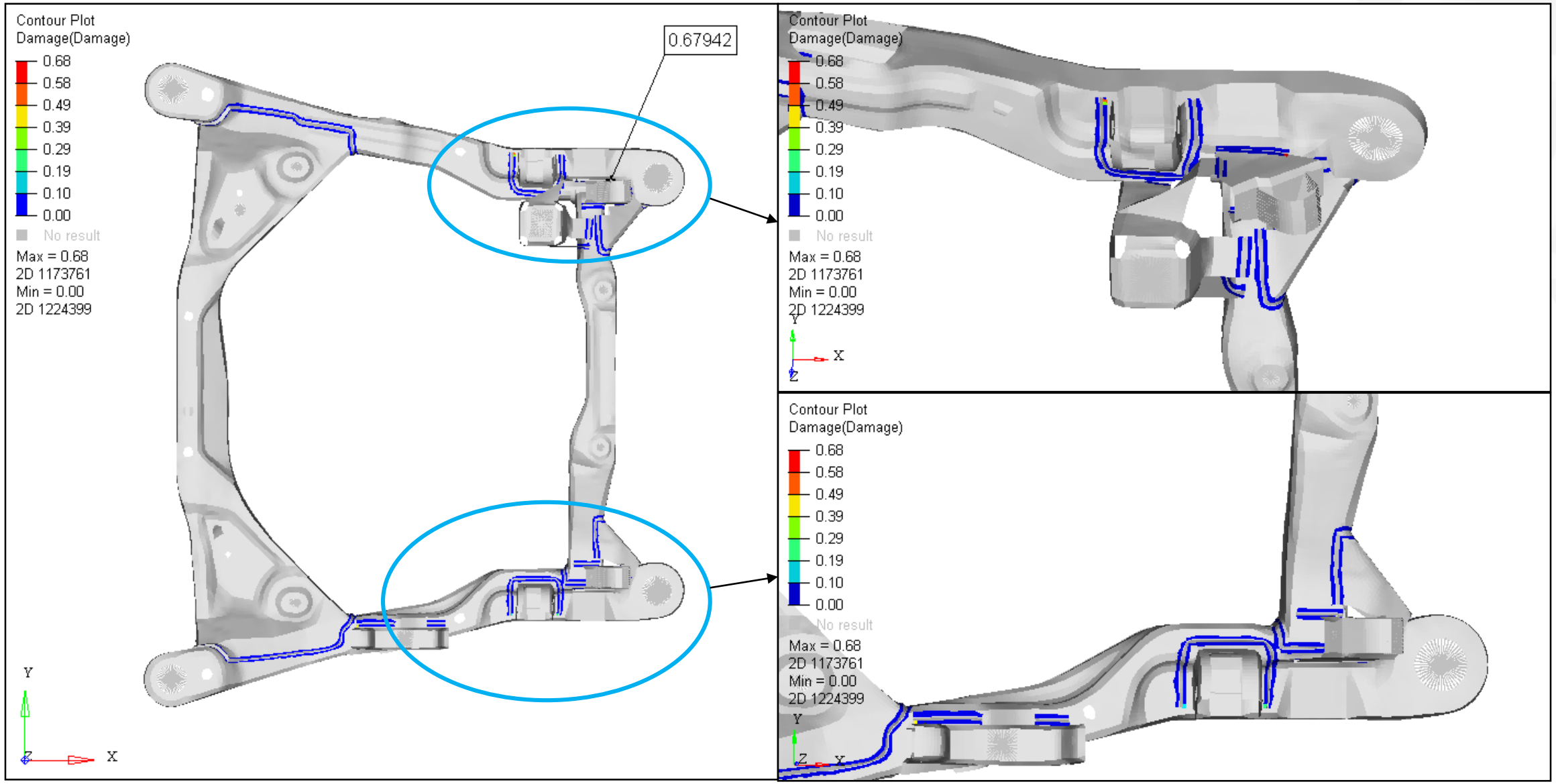
FRF Setup



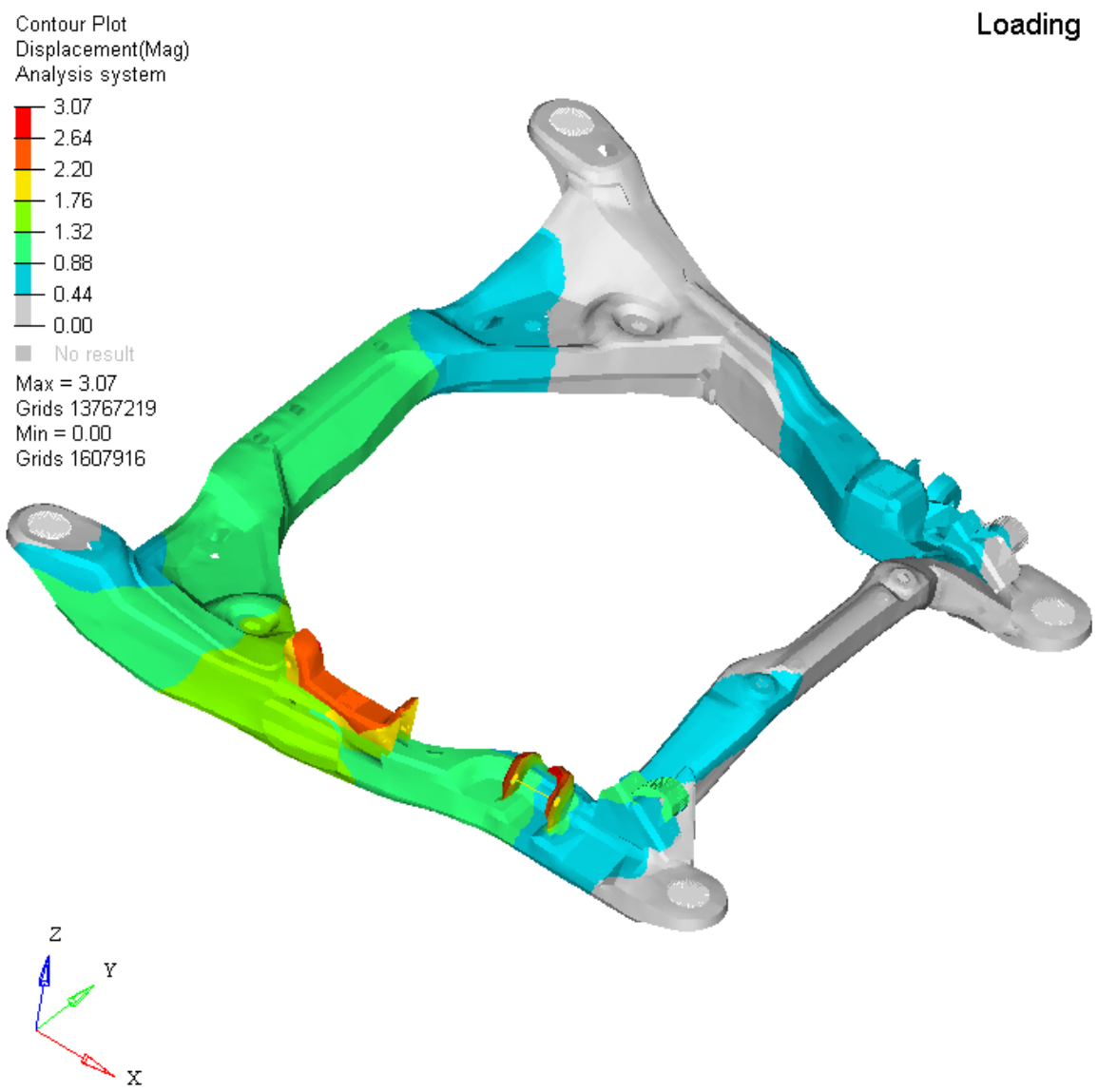
- **Local Dynamic stiffness of the cradle is calculated by applying a unit load excitation at the two Engine mount location of the cradle**
- **Frequency range upto 400 Hz is studied**

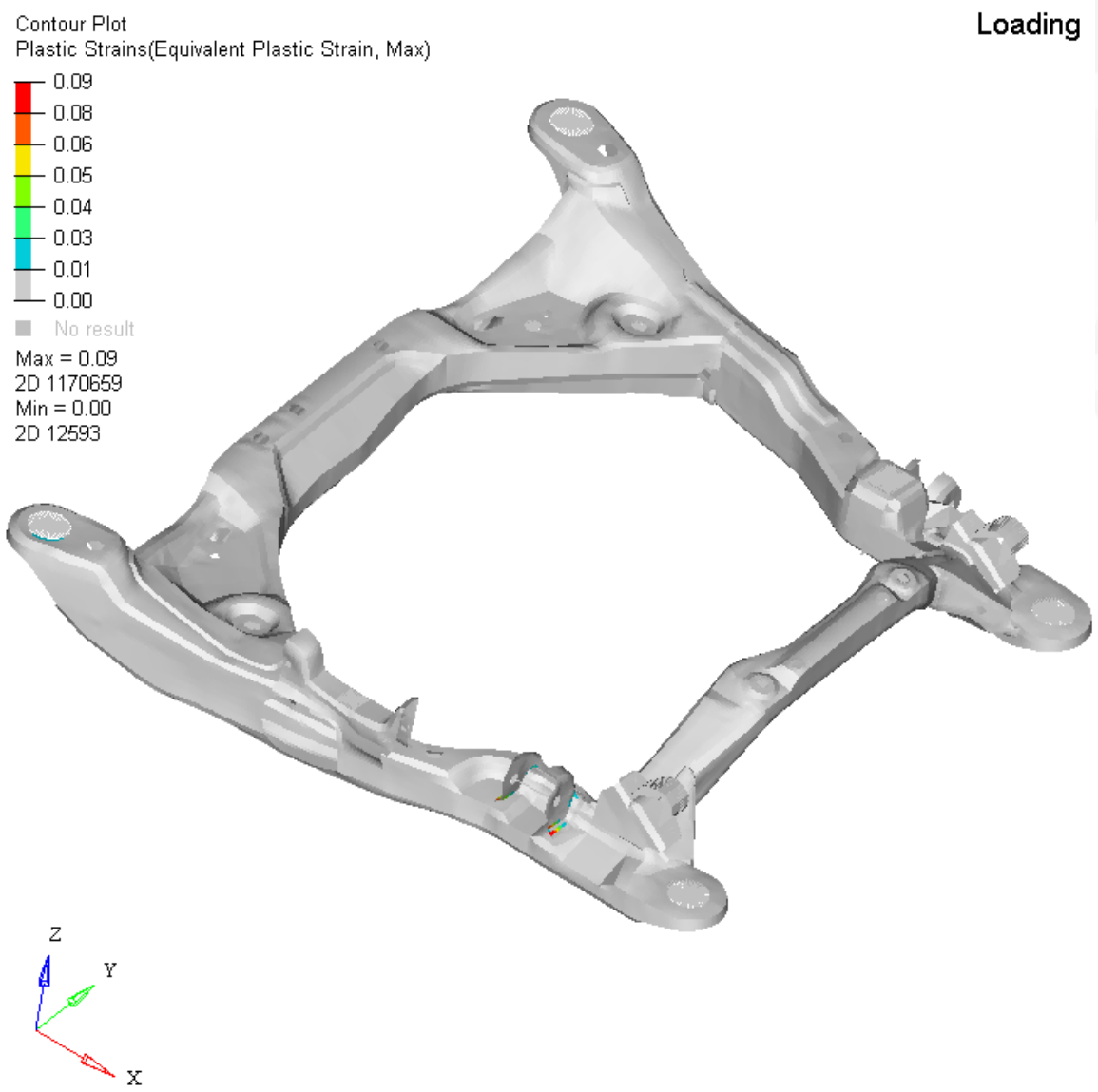
Baseline analysis Results

Fatigue

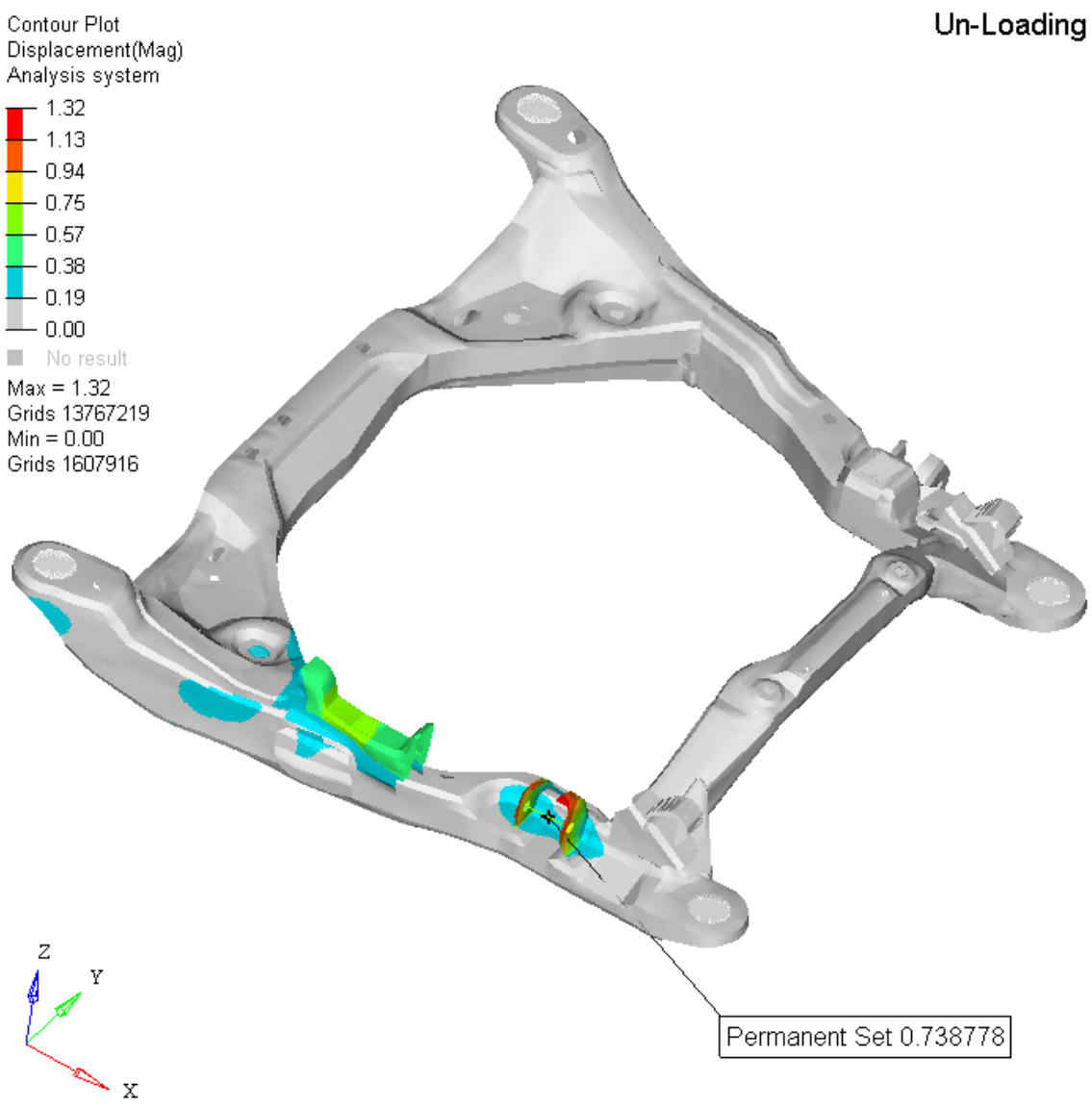

Contour Plot
Damage(Damage)
0.68
0.58
0.49
0.39
0.29
0.19
0.10
0.00
No result
Max = 0.68
2D 1173761
Min = 0.00
2D 1224399
0.67942
Y
Z
X
Contour Plot
Damage(Damage)
0.68
0.58
0.49
0.39
0.29
0.19
0.10
0.00
No result
Max = 0.68
2D 1173761
Min = 0.00
2D 1224399
Y
X
Z
Contour Plot
Damage(Damage)
0.68
0.58
0.49
0.39
0.29
0.19
0.10
0.00
No result
Max = 0.68
2D 1173761
Min = 0.00
2D 1224399
Y
Z
X

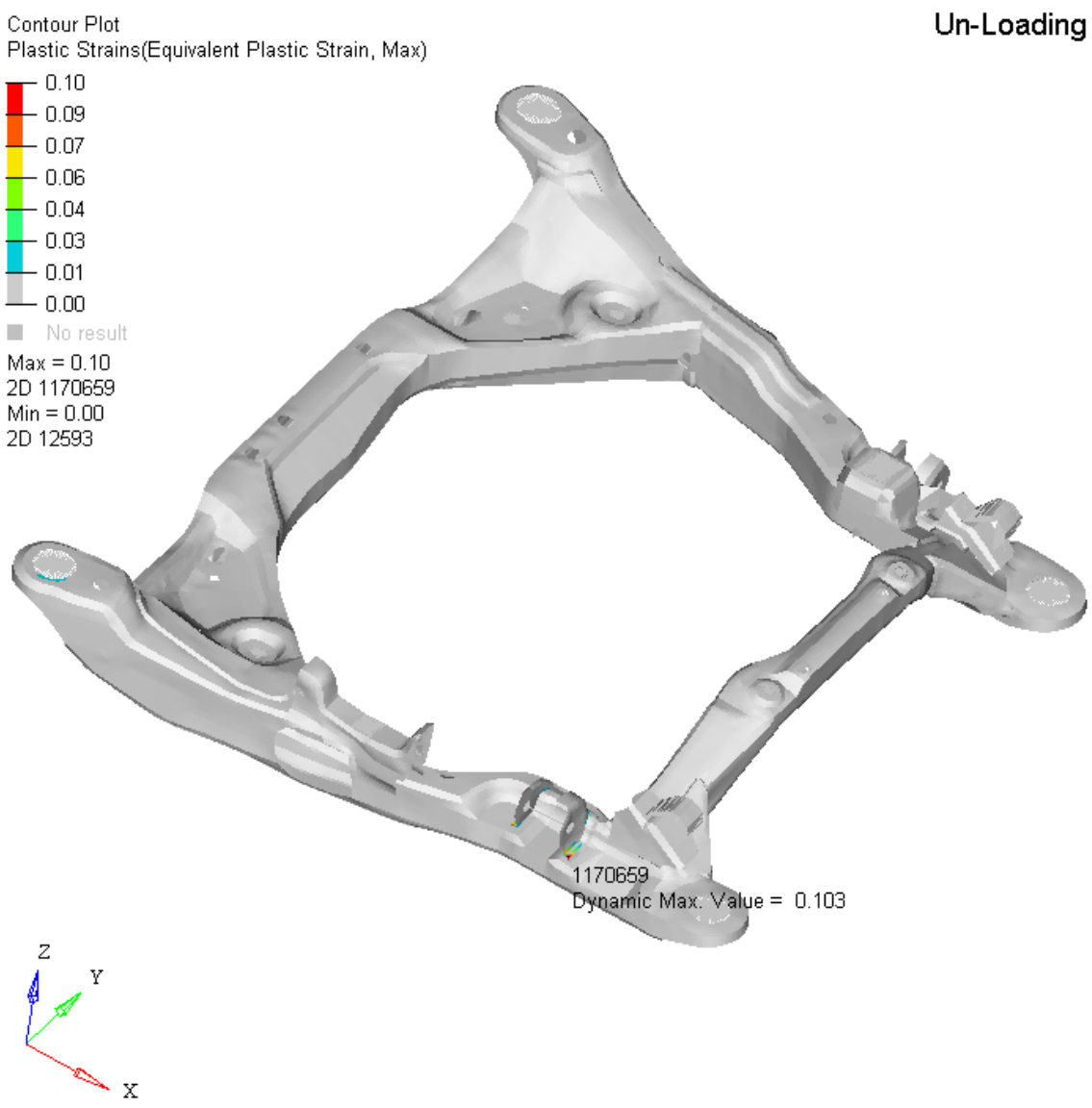
Permanent set



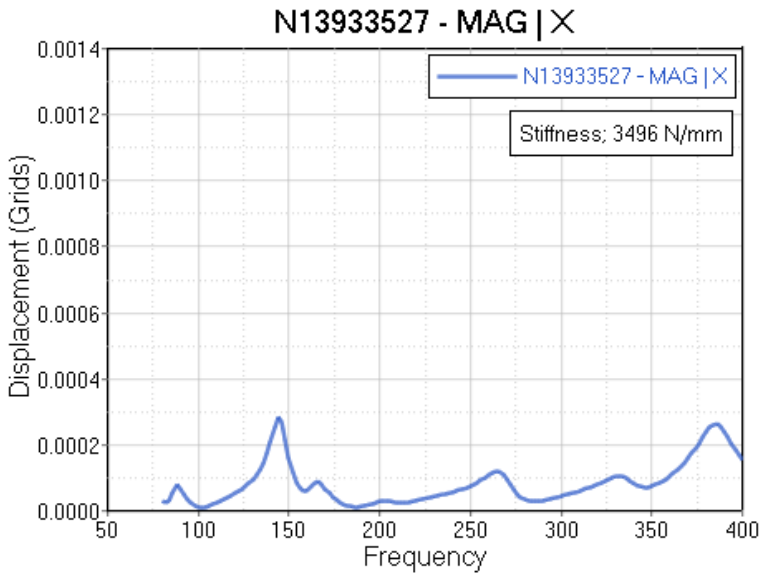


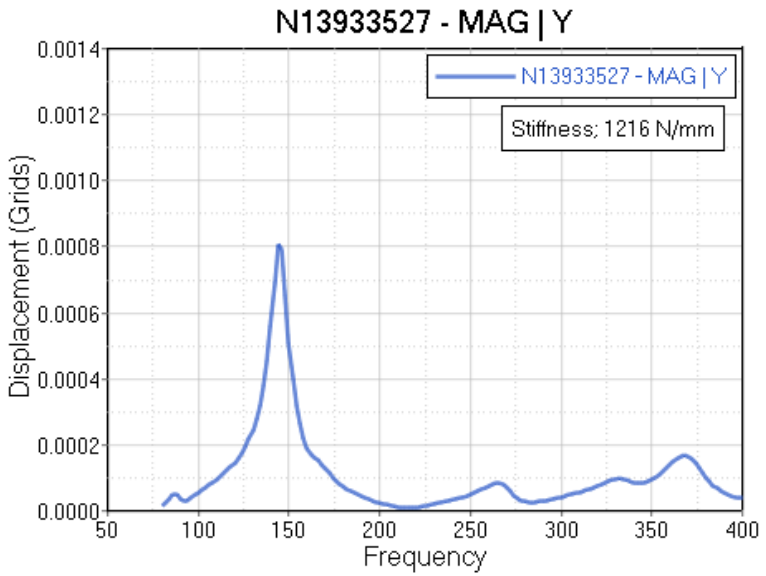
Permanent set

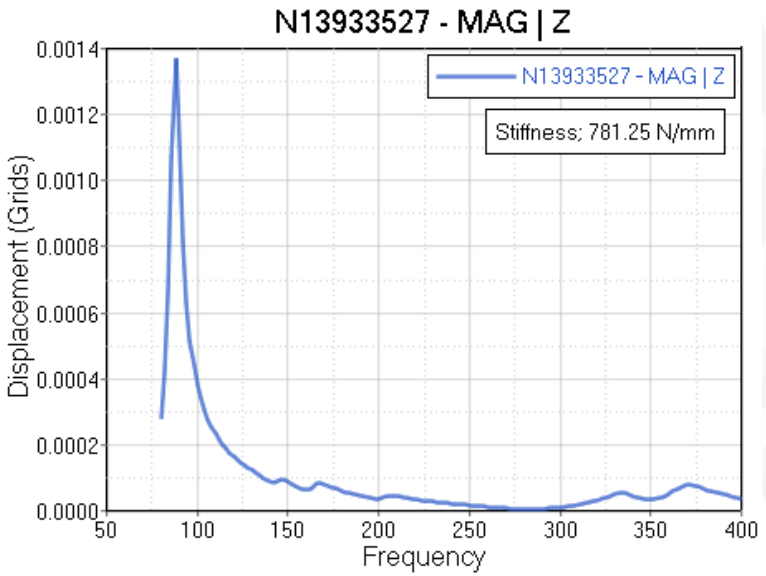


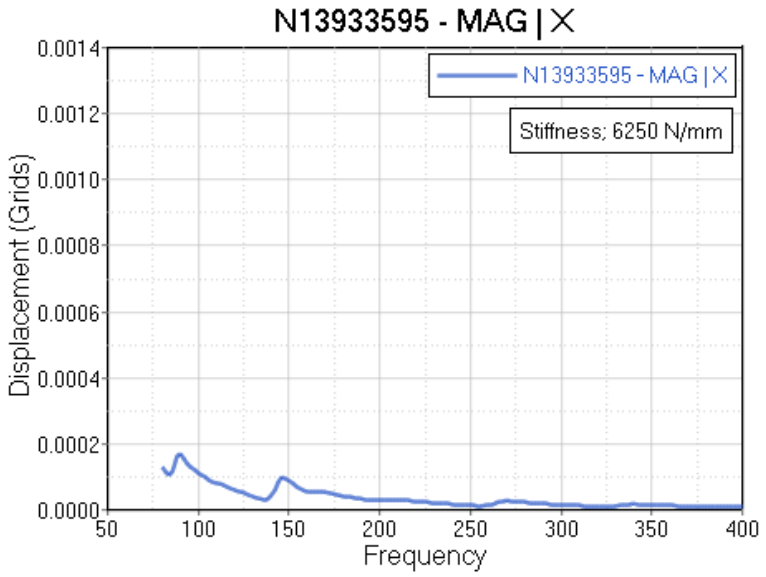


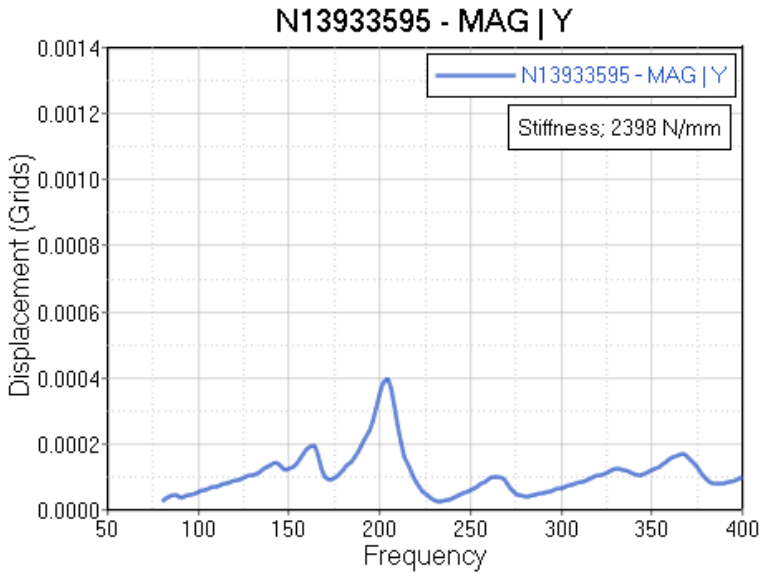
FRF Displacement

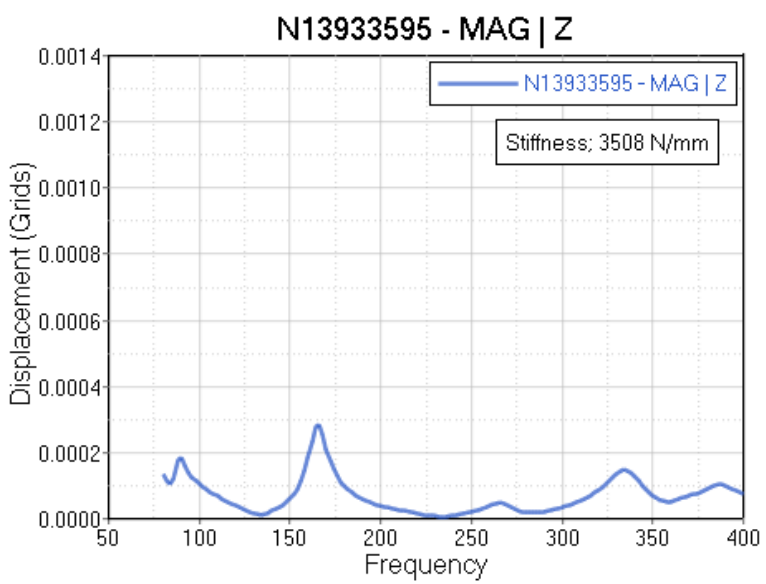










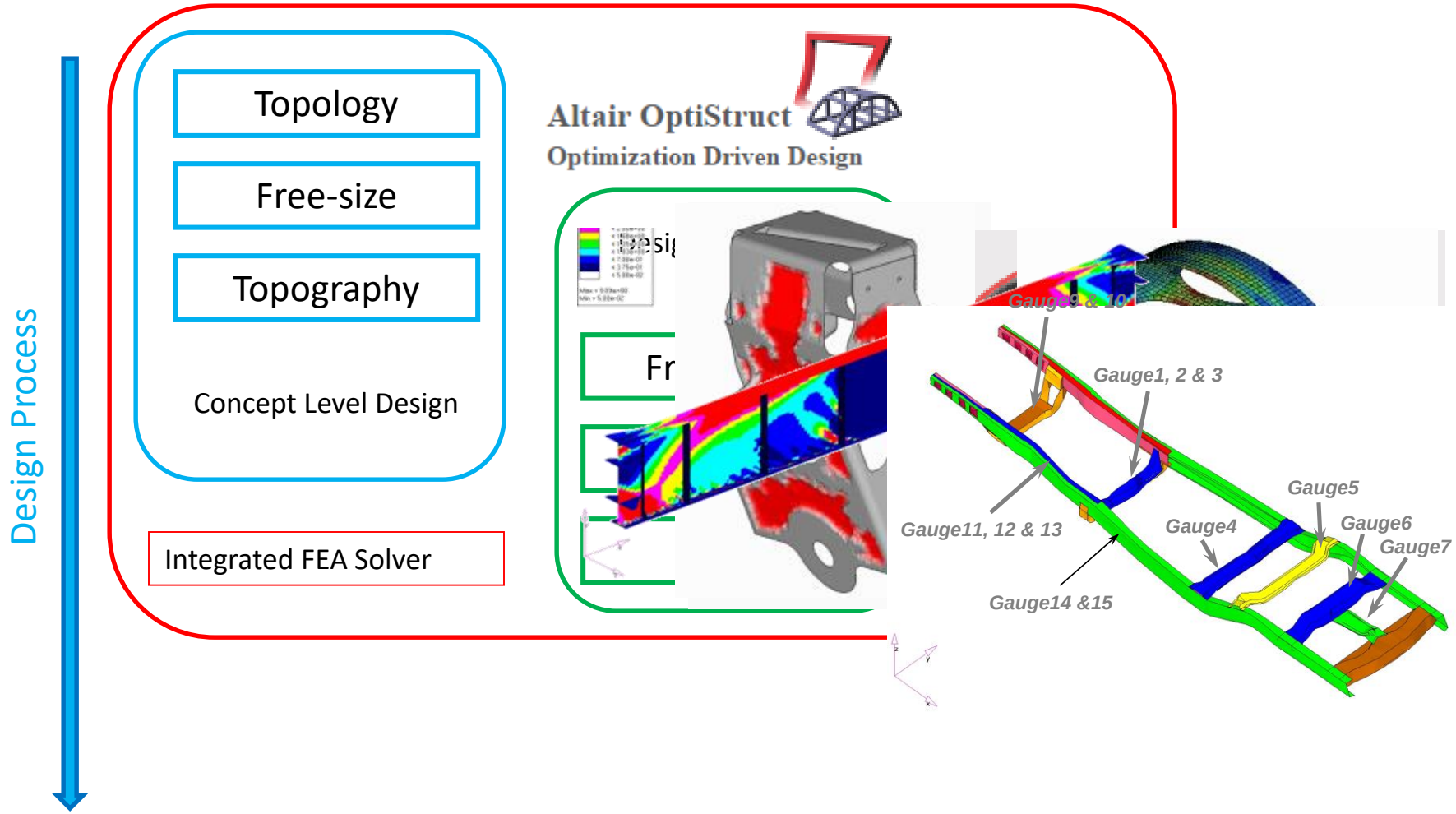


Baseline Analysis Results

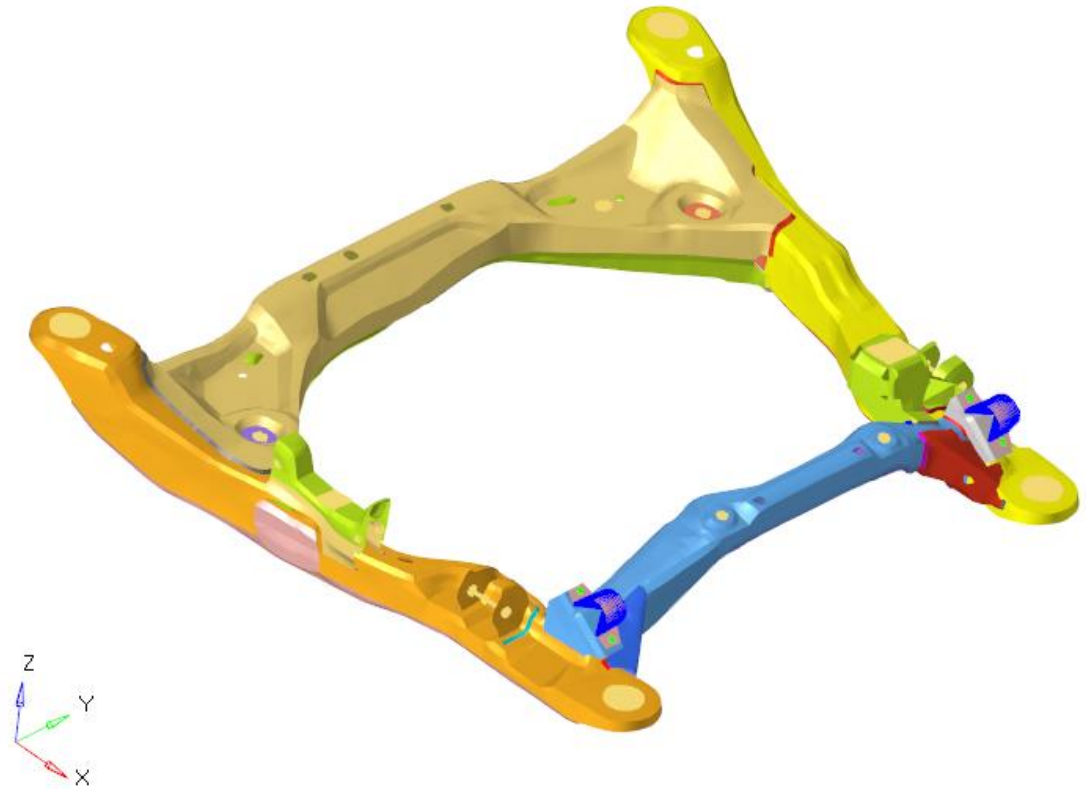
SL.No.	Model Attributes	Performance targets	Baseline design
1	Linear NVH (FRF at 2 Engine Mount locations, N/mm)	Node ID 13933527 X > 3508, Y > 1216, Z > 850 Node ID 13933595 X > 6250, Y > 2398, Z > 3508	Node ID 13933527 X = 3496, Y = 1216, Z = 781 Node ID 13933595 X = 6250, Y = 2398, Z = 3508
2	Strength Analysis (Permanent set)	Permanent set < 0.5mm	0.738 mm
3	Durability(Weld Fatigue)	Damage < 1	0.68
4	Mass		46.88 Kgs

Optimization Set-up

Types of Optimization in OptiStruct



Optimization setup



Gauge Optimization

Mass Baseline 46.88 Kgs

Design Variable: Thickness of all the members in Cradle

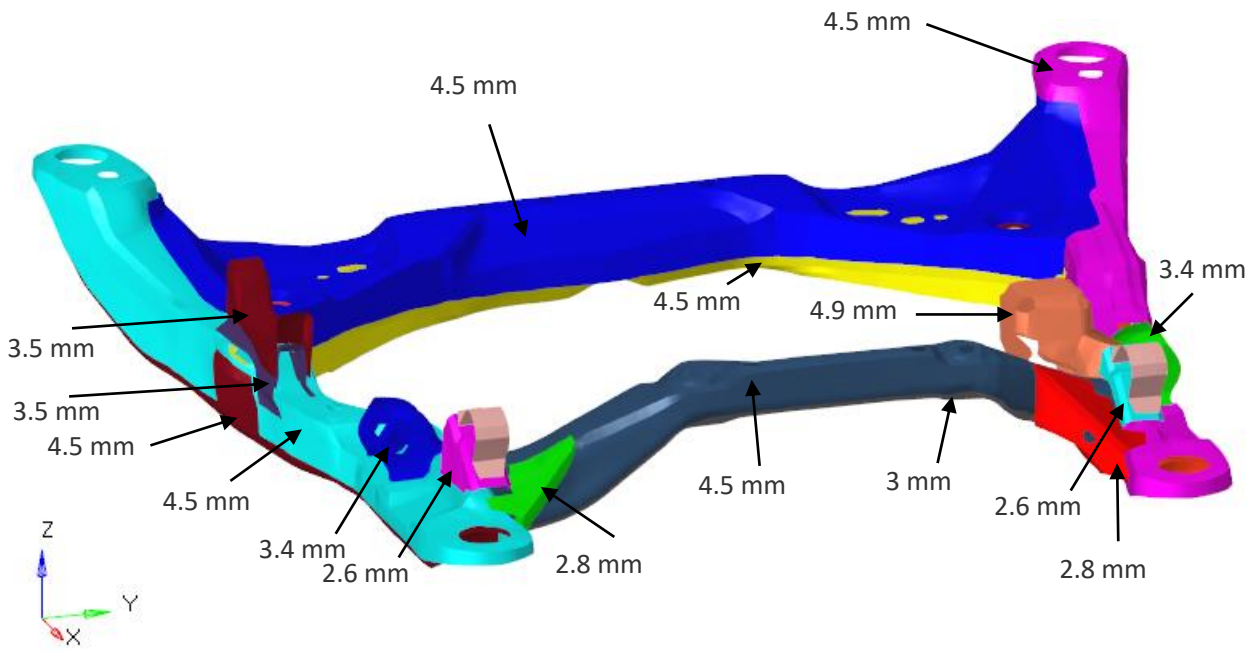
Objective: Minimize Mass

Constraints: FRF stiffness targets (N/mm) at **Node ID 13933527** X > 3508, Y > 1216, Z > 850 **Node ID 13933595** X > 6250, Y > 2398, Z > 3508

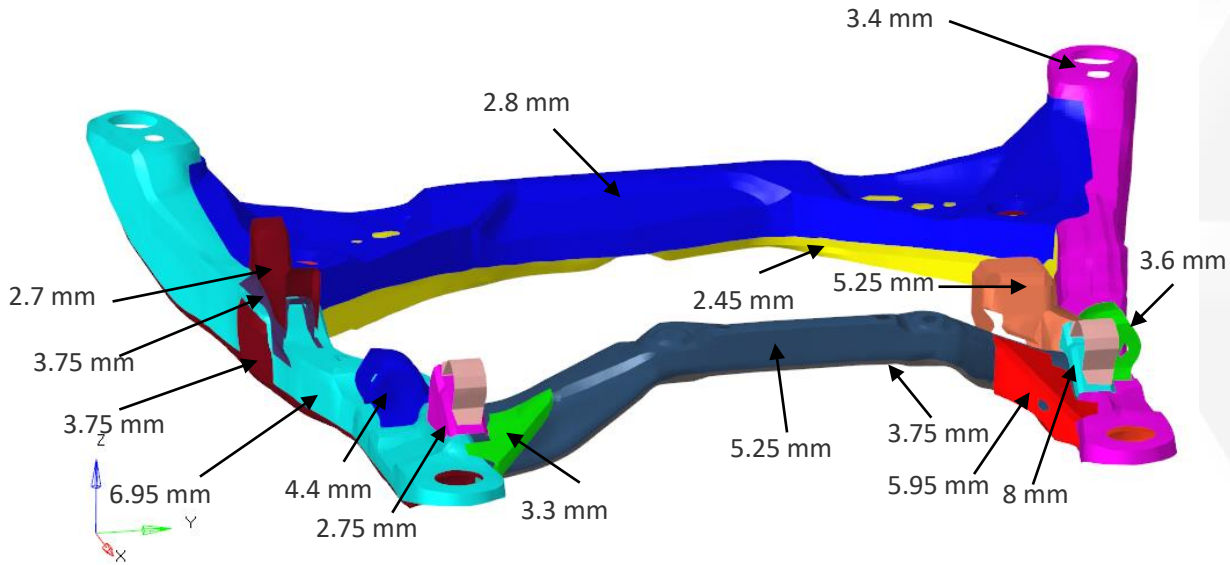
Damage < 1

Static strain (Neuber correction) < 2 % (To reduce the permanent set which is above limit)

Optimization result



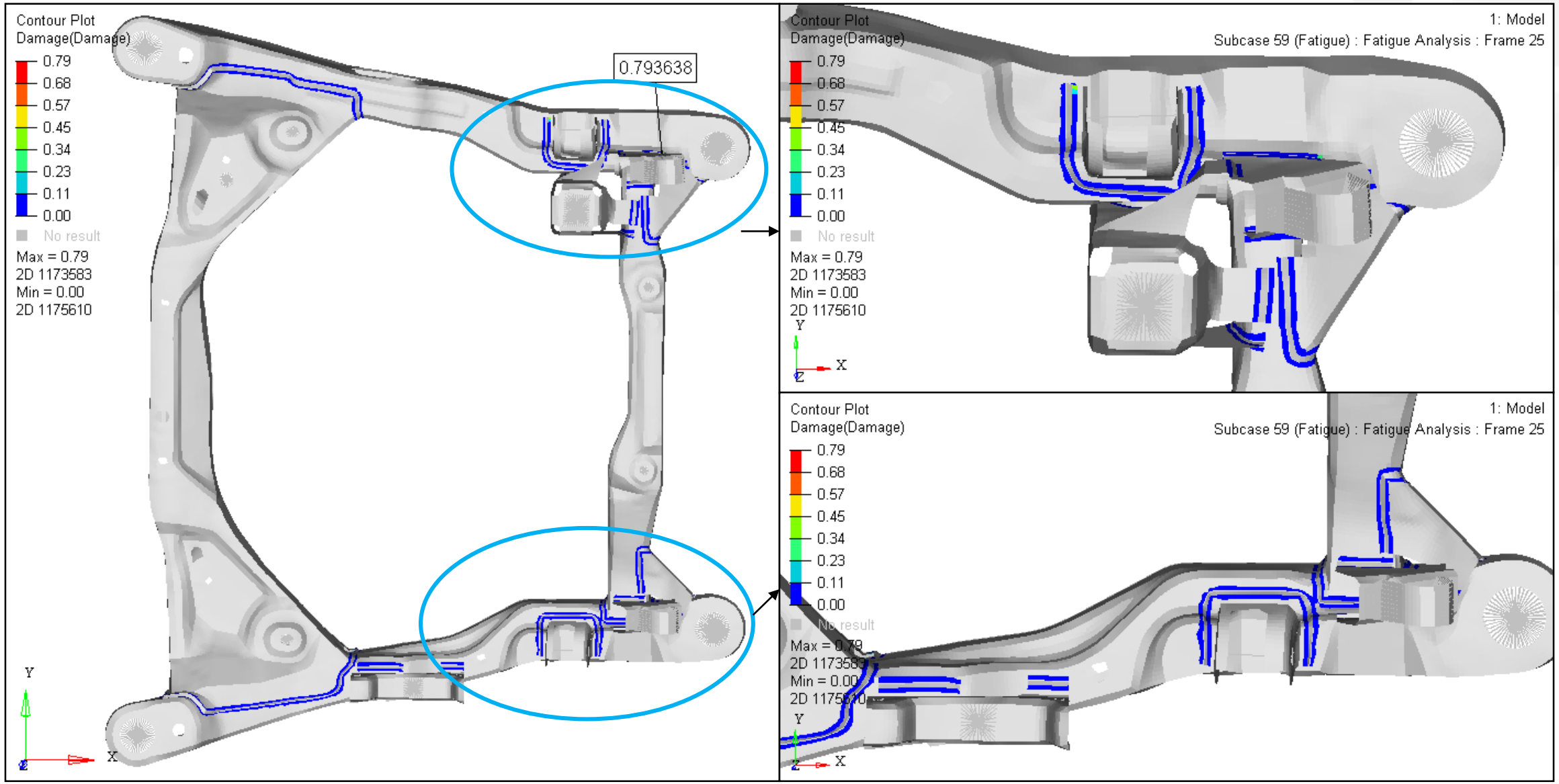
Mass Baseline Design 46.88 Kgs



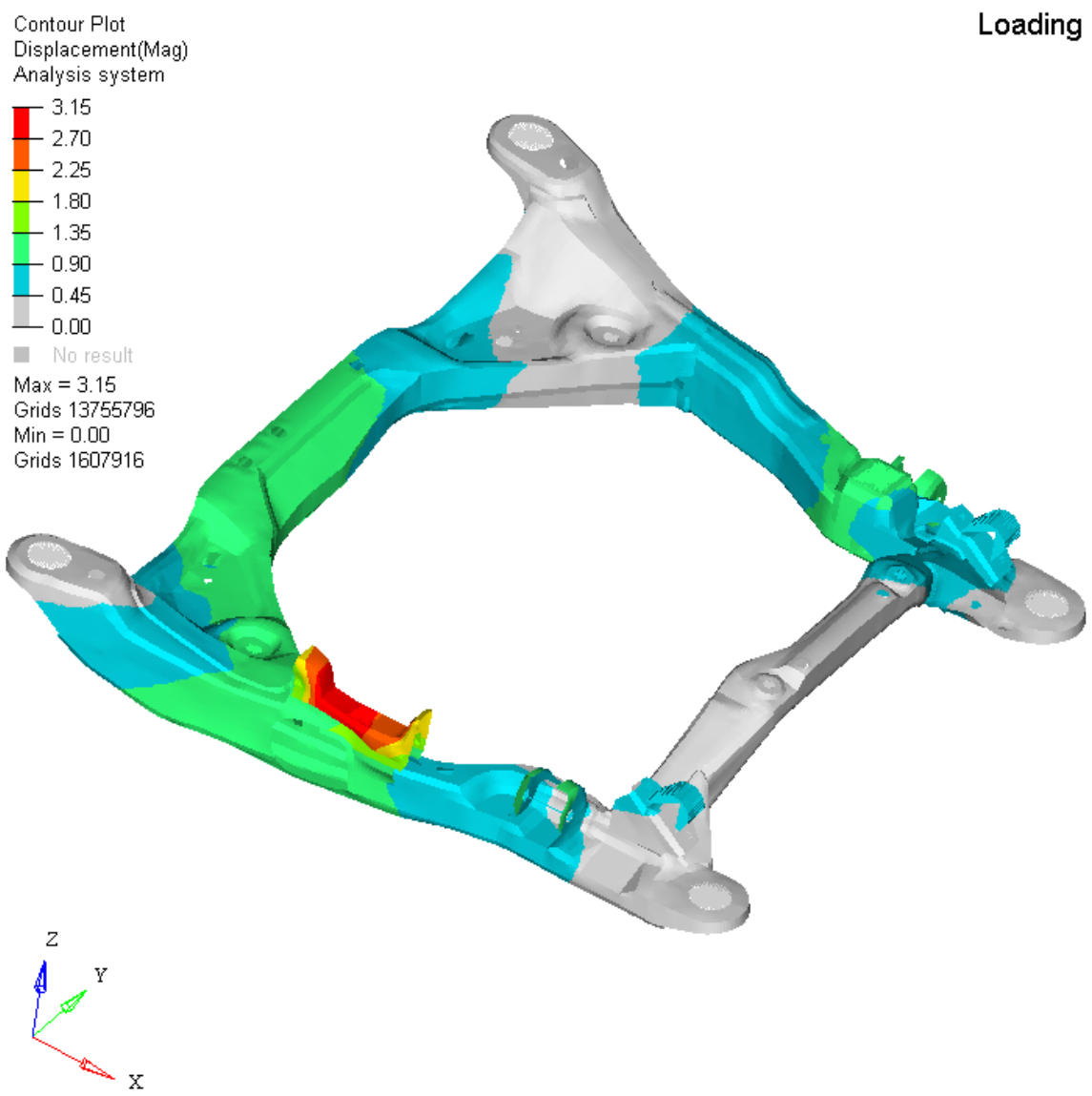
Mass Optimized Design 43.8 Kgs

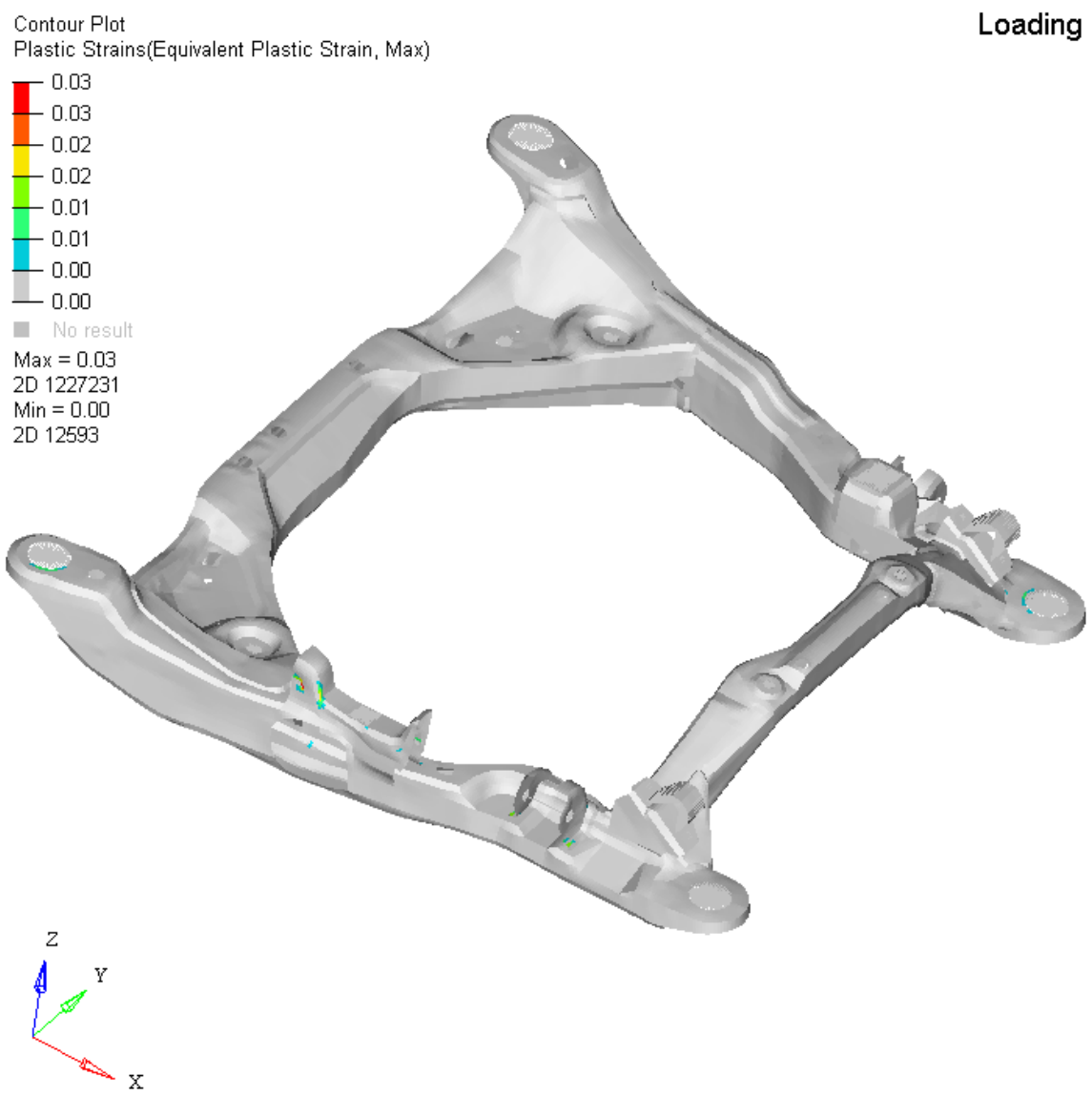
Optimized Design Results

Fatigue

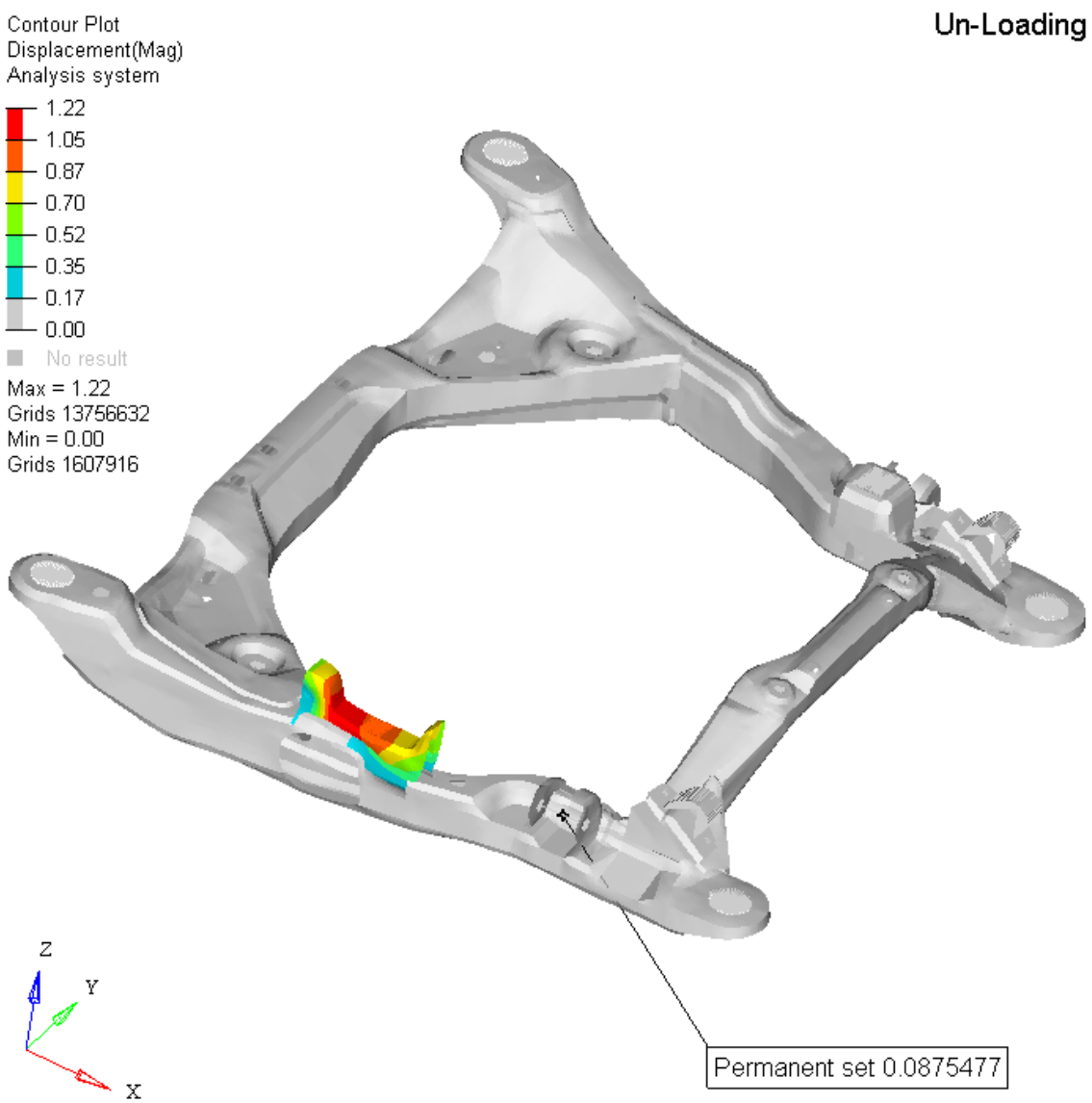

Contour Plot
Damage(Damage)
0.79
0.68
0.57
0.45
0.34
0.23
0.11
0.00
No result
Max = 0.79
2D 1173583
Min = 0.00
2D 1175610
0.793638
Y
X
Contour Plot
Damage(Damage)
1: Model
Subcase 59 (Fatigue) : Fatigue Analysis : Frame 25
0.79
0.68
0.57
0.45
0.34
0.23
0.11
0.00
No result
Max = 0.79
2D 1173583
Min = 0.00
2D 1175610
Y
X
Contour Plot
Damage(Damage)
1: Model
Subcase 59 (Fatigue) : Fatigue Analysis : Frame 25
0.79
0.68
0.57
0.45
0.34
0.23
0.11
0.00
No result
Max = 0.79
2D 1173583
Min = 0.00
2D 1175610
Y
X

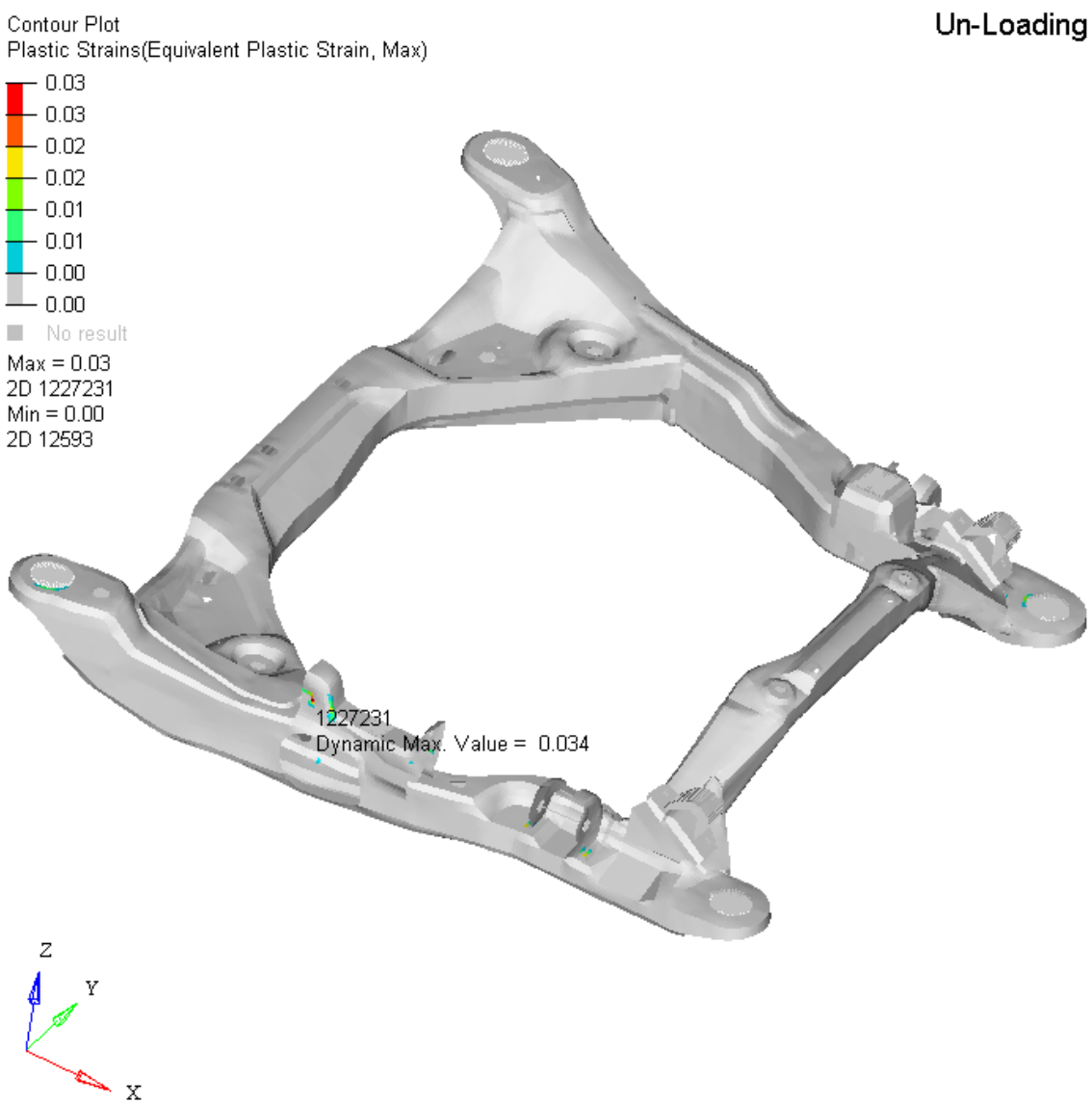
Permanent set



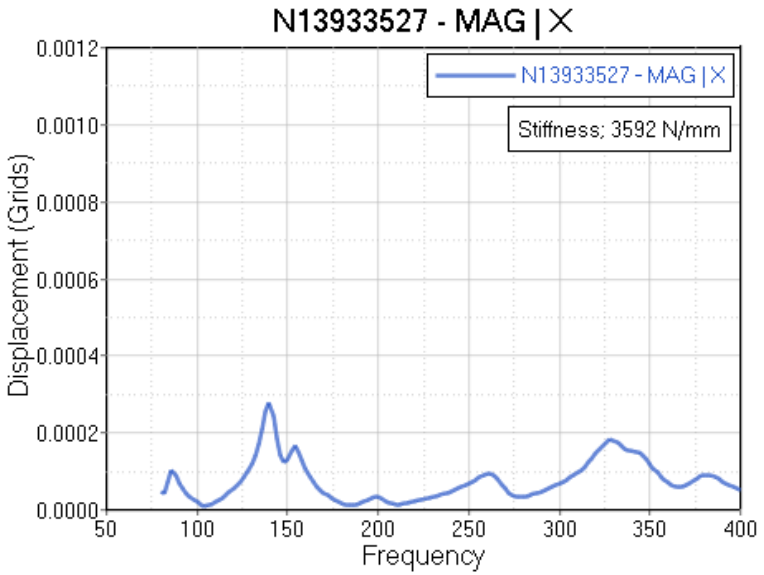


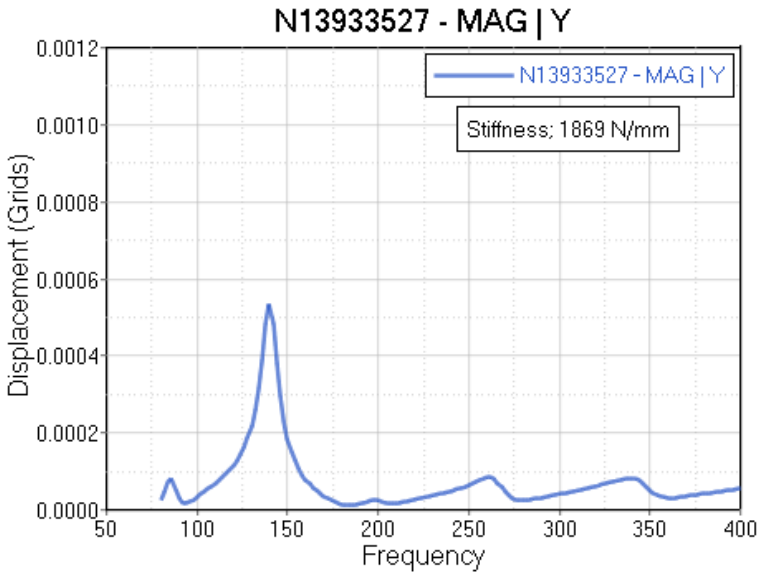
Permanent set

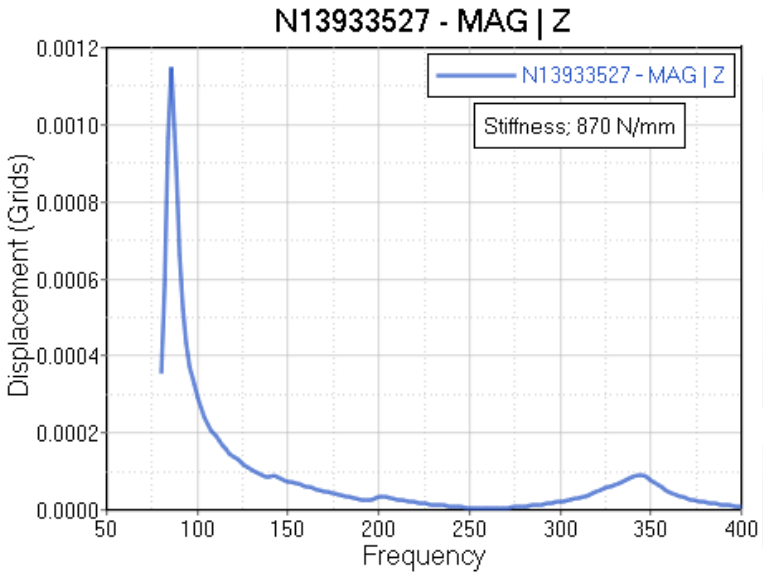


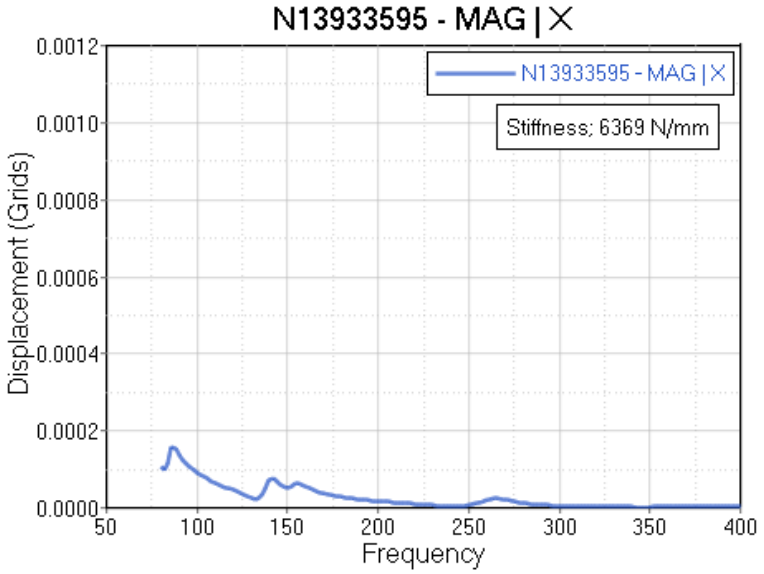


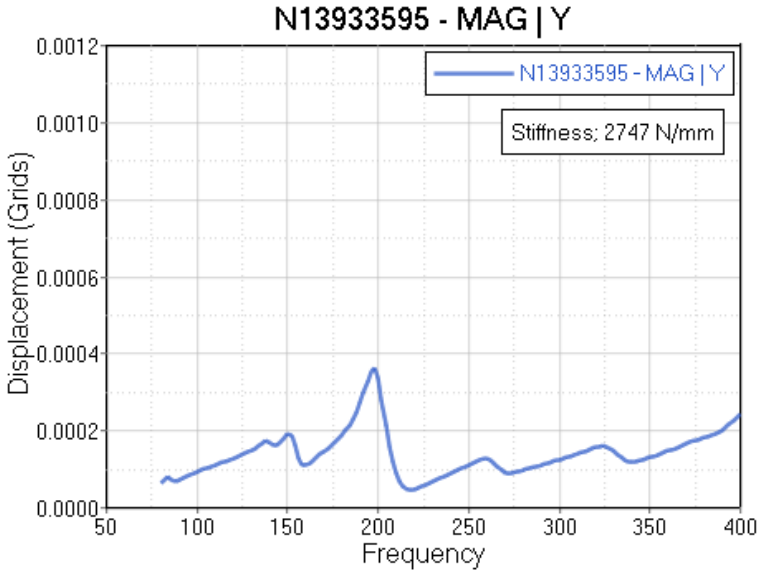
FRF Displacement

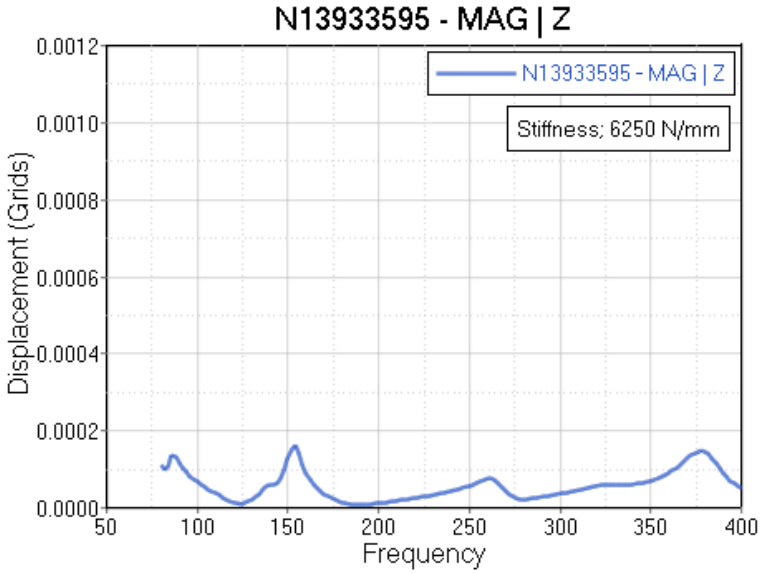






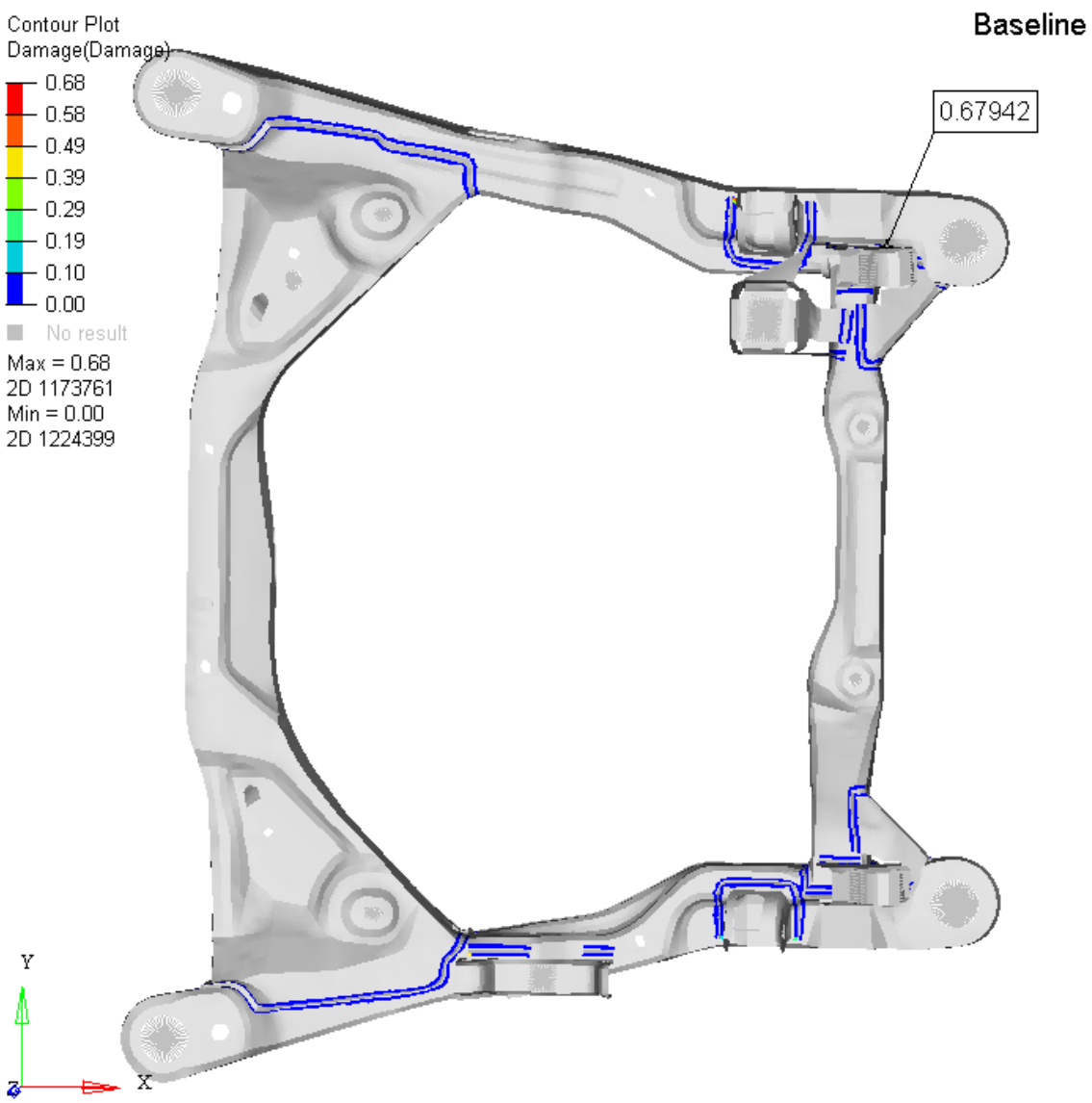


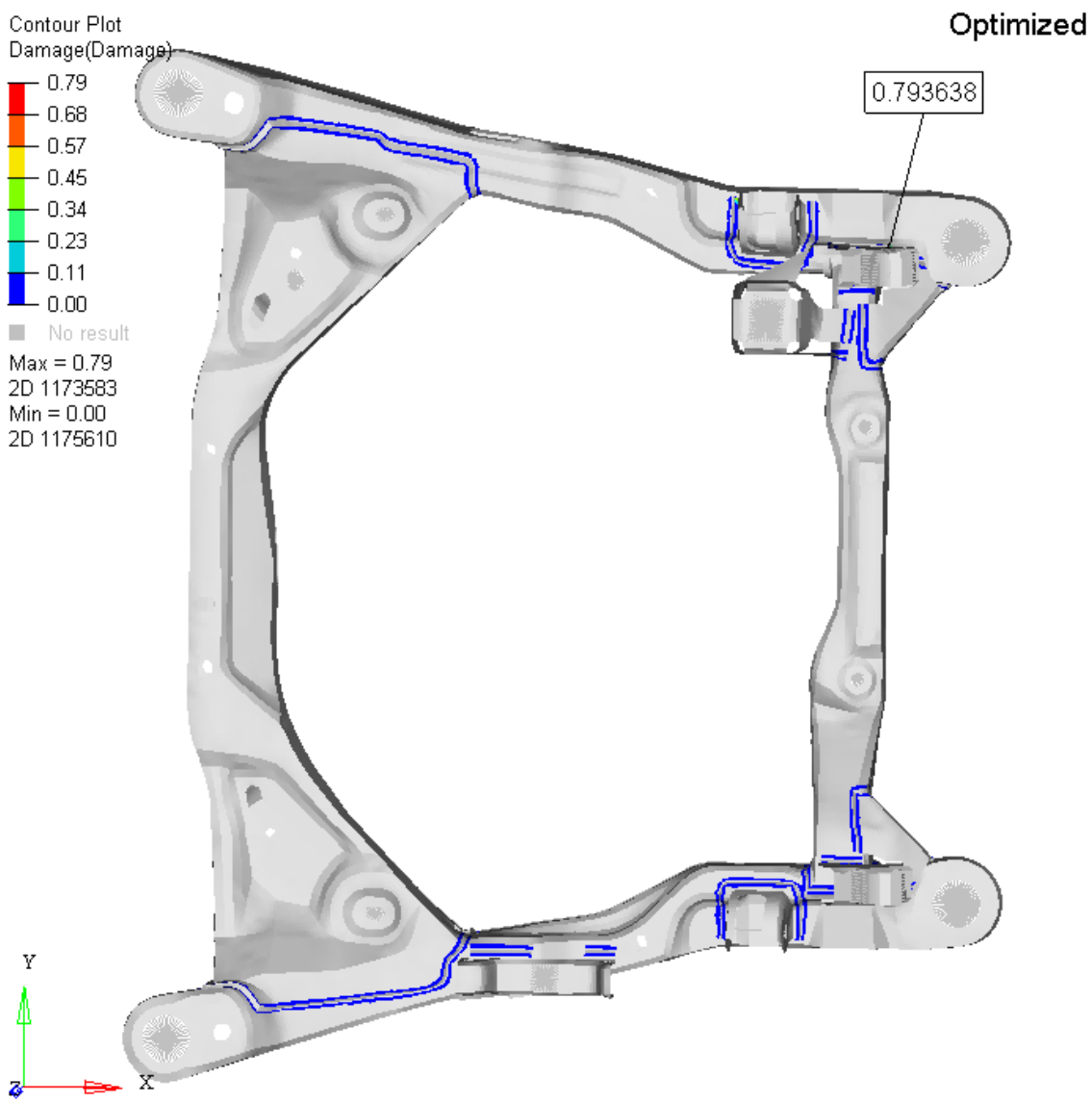




Comparison

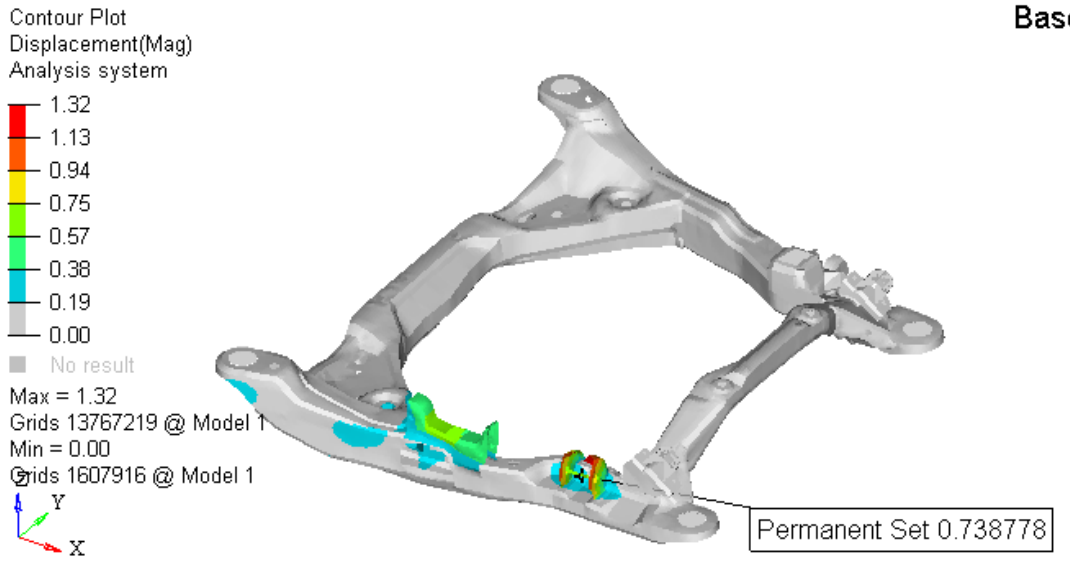
Damage Comparison



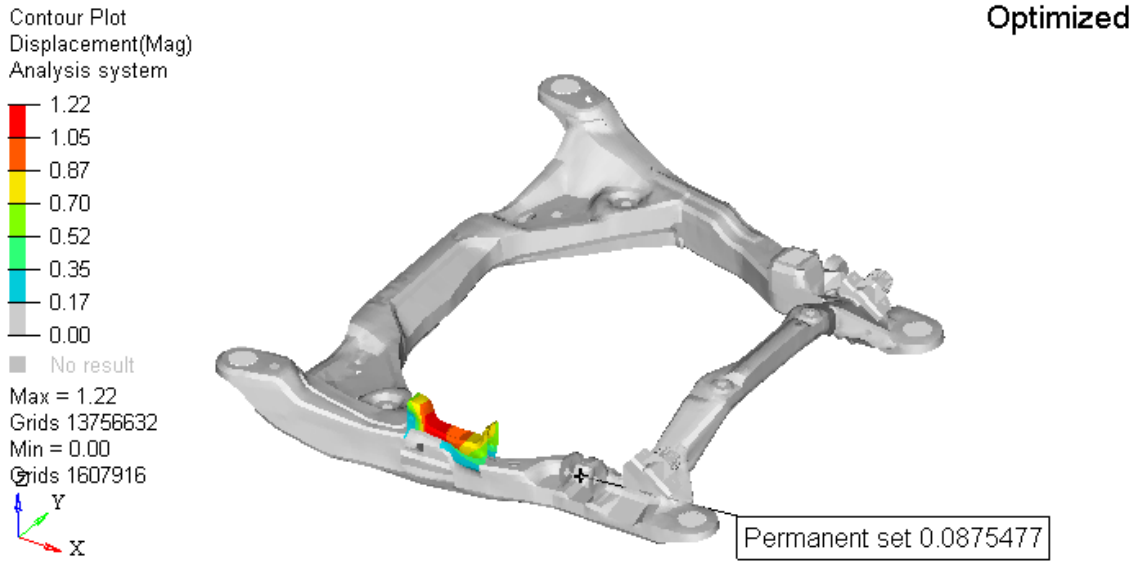


Permanent set - Comparison

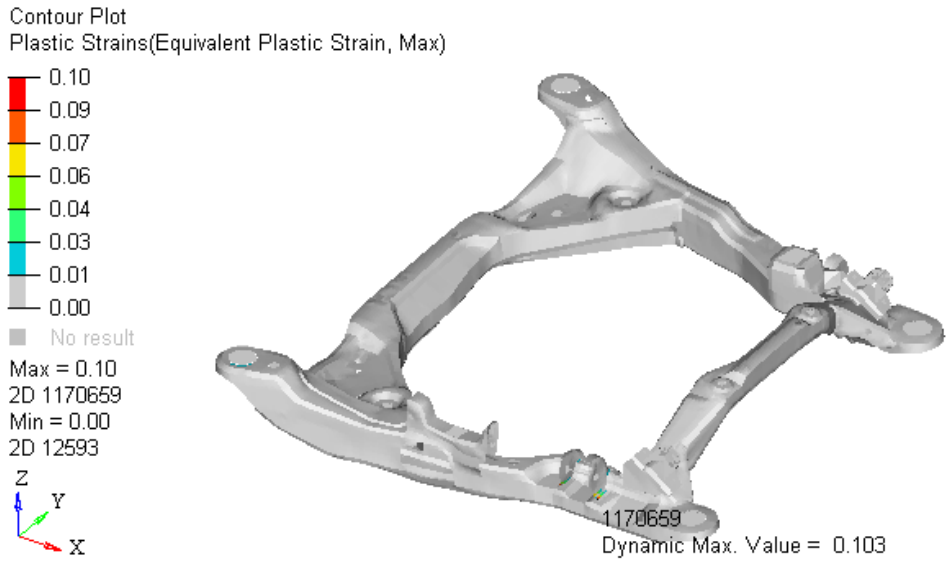
Baseline



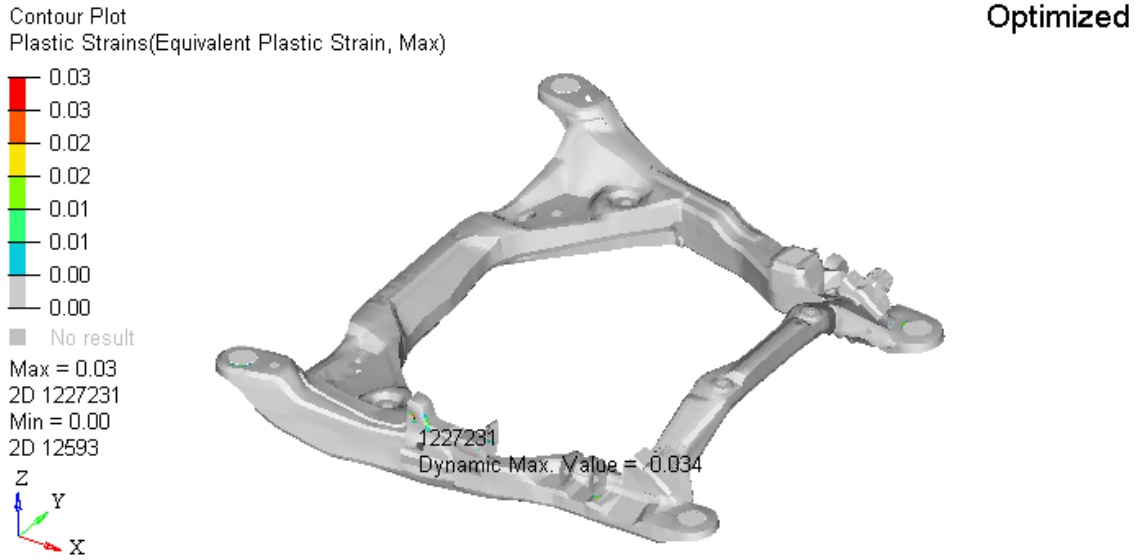
Optimized



Baseline

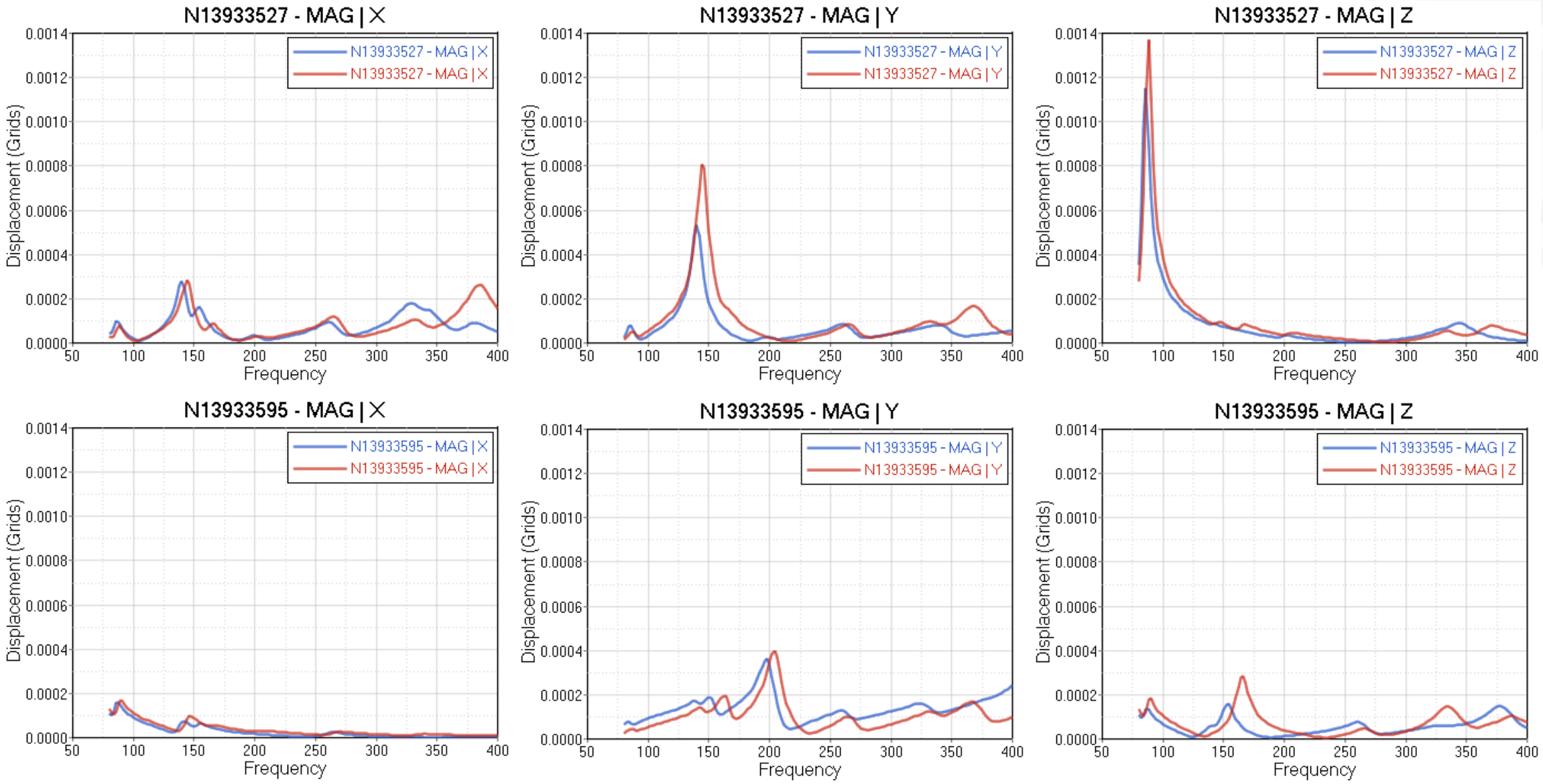


Optimized



FRF Displacement - Comparison

Baseline **Optimized**



Results & discussion

- All the performance targets have been attained using a single model
- The performance seems to have significantly improved with mass reduction of 6.5 %

SL.No.	Model Attributes	Performance targets	Baseline design	Optimized design
1	Linear NVH (FRF at 2 Engine Mount locations, N/mm)	Node ID 13933527 X > 3508, Y > 1216, Z > 850 Node ID 13933595 X > 6250, Y > 2398, Z > 3508	Node ID 13933527 X = 3496 , Y = 1216, Z = 781 Node ID 13933595 X = 6250, Y = 2398, Z = 3508	Node ID 13933527 X = 3592, Y = 1869, Z = 870 Node ID 13933595 X = 6369, Y = 2747, Z = 6250
2	Strength Analysis (Permanent set)	Permanent set < 0.5mm	0.73 mm	0.08 mm
3	Durability(Weld Fatigue)	Damage < 1	0.68	0.79
4	Mass		46.8 Kgs	43.8 Kgs

Thank You!

prashant@altair.com