Texas A&M Transportation Institute

Using Machine Learning Based Surrogate Models, Nonlinear Finite Element Analysis and Optimization Techniques to Design Road Safety Hardware

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OUTLINE

- Background
- Objective
- Design Space
- Optimization: Topology
- Optimization: Meta-Modeling
- Simulation verification
- Conclusion

BACKGROUND

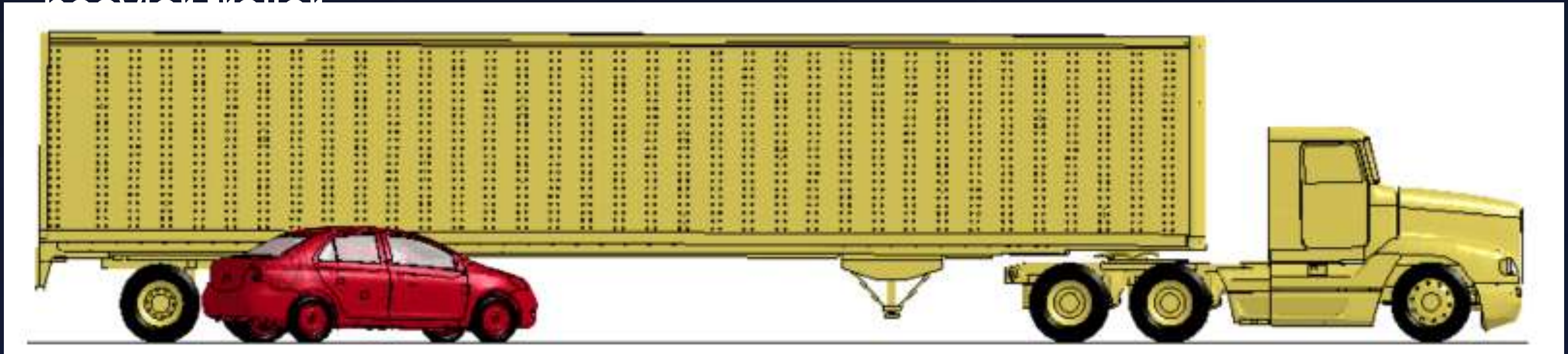
- *“In 2015, 301 of the 1,542 passenger vehicle occupants killed in two-vehicle crashes with a tractor- trailer died when their vehicles struck the side of a tractor-trailer, IIHS said, citing its own data. This total compares with 292 people who died when their passenger vehicles struck the rear of a tractor-trailer, according to the institute.”*

  IIHS : Insurance Institute for Highway Safety

- Source: *Transportation Topics (online edition), May 15, 2017*

BACKGROUND

- The disparity in the height between passenger cars and trailers edges puts the passenger cars at a serious disadvantage in the event of a crash with these heavier trailer.



"Computer modeling and evaluation of side underride protective device designs (Report No. DOT HS 812 522). Washington, DC: National Highway Traffic Safety Administration", April, 2018.

BACKGROUND

- Angular impacts represent the majority of side impacts with heavy truck.

Heavy-Vehicle Crash Data Collection and Analysis to Characterize Rear and Side Underride and Front Override in Fatal Truck Crashes, DOT HS 811 725, March 2013

https://www.nhtsa.gov/crashworthiness/truck-underride

OBJECTIVE

- Design a concept Side Underride Protective Device (SUPD) to redirect a passenger vehicle impacting at a speed of 50 mph and angle of 30 degrees while reducing the mass of the SUPD.

Design Space & Load Requirements

- Design Impact Conditions
  - Impact Speed
    - 50 mph
  - Impact Angles
    - 15, 22.5, and 30 degrees
  - Vehicle
    - Recent model passenger car
    - 2012 Toyota Camry
    - Curb Weight = 3,215 lbs.
    - 2 million elements

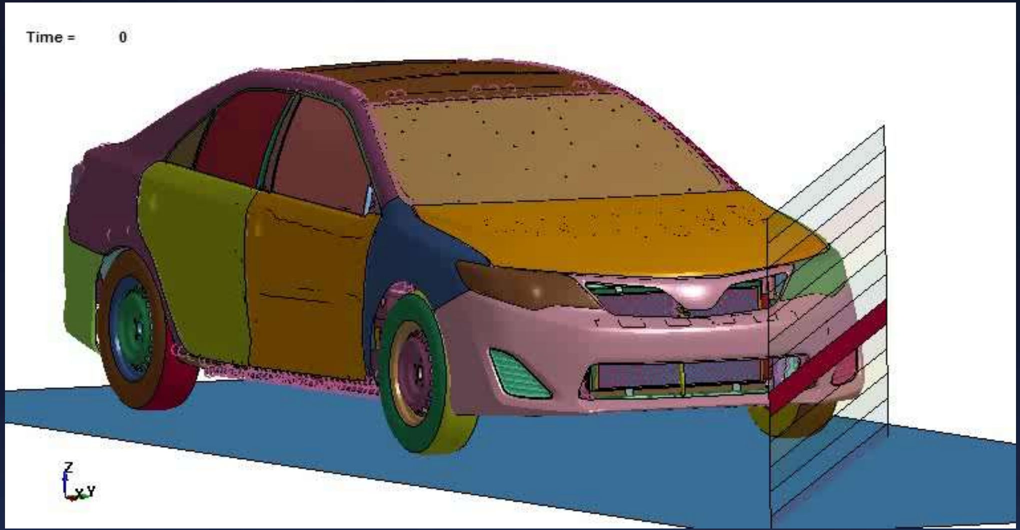
Design Space & Load Requirements

- Ground clearance of SUPD rail
  - 16-20 inches per FMVSS 581 Test Zone
  - 18 inches selected to provide good vehicle coverage
- Length of SUPD
  - Controlled by functional requirements of trailer
    - Movement of rear bogie, turning radius of rear tractor tandem, access to landing gear
  - 20 ft. length selected
- Traffic face of SUPD aligned with trailer edge
  - Behind aerodynamic side skirt

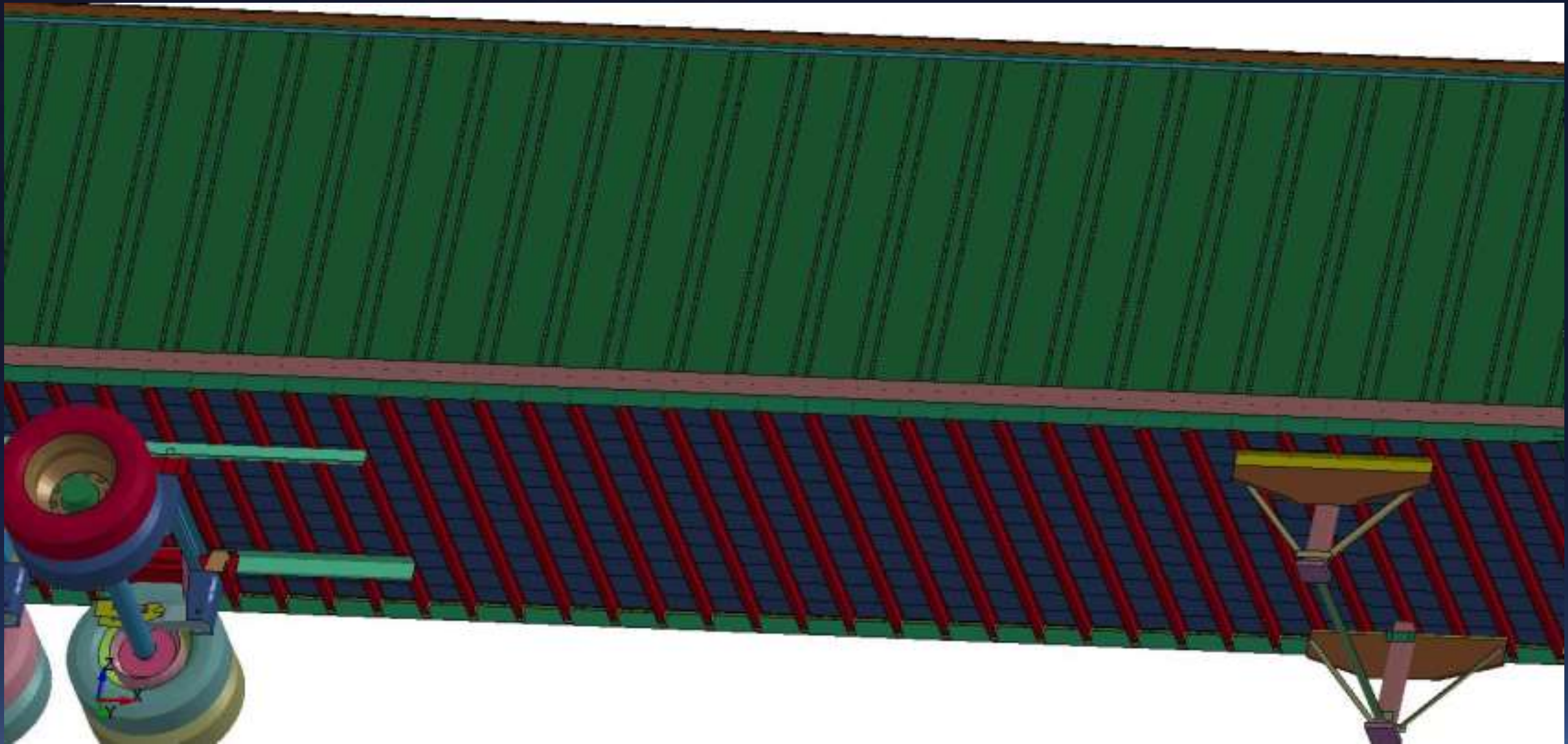
Design Space & Load Requirements

Simulation with Rigidized SUPD

- Evaluation of ground clearance & rail interface area

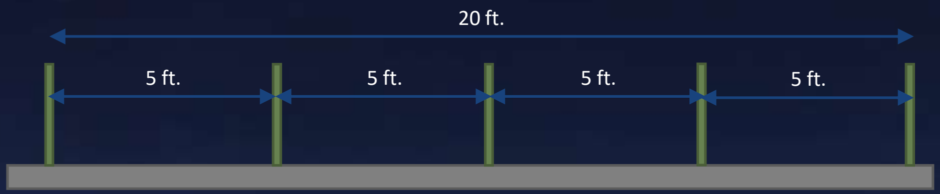


Design Space & Load Requirements



Design Space & Load Requirements

Initial Design Space/Constraints

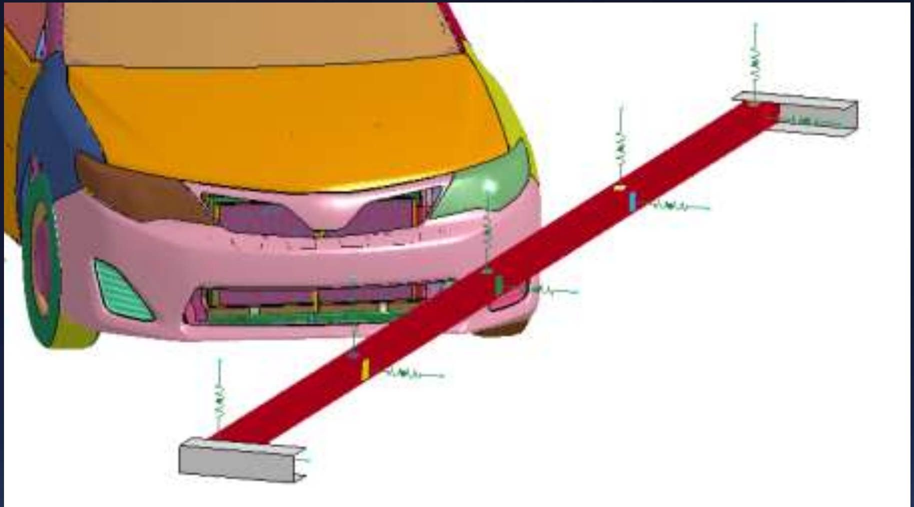


- 5-ft spacing selected
- Aligns with cross-members of trailer model

Design Space & Load Requirements

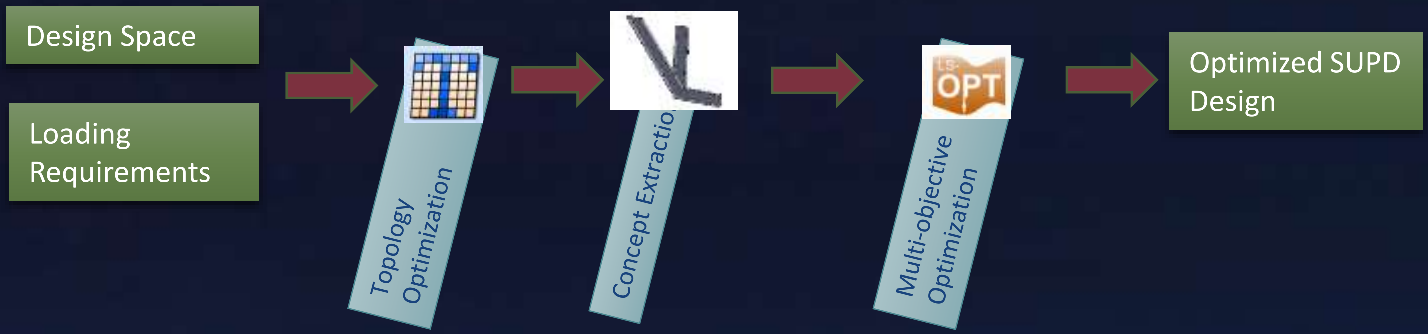
Deformable SUPD with Spring Braces

- Springs used to represent braces
- Obtain initial lateral and vertical design loads



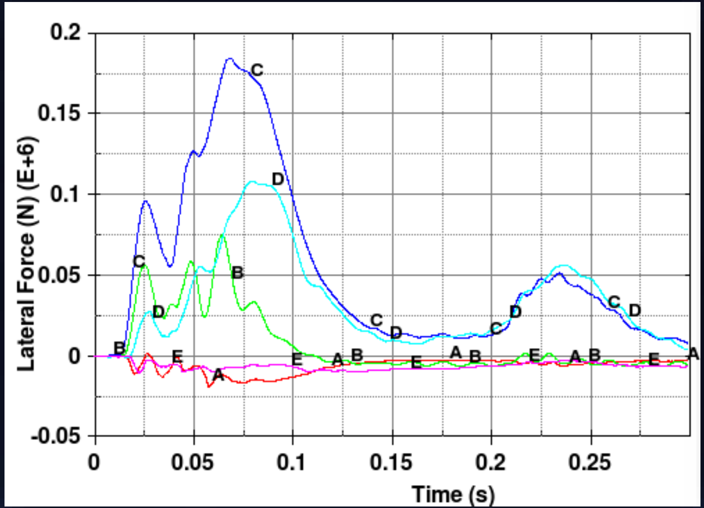
Brace Optimization

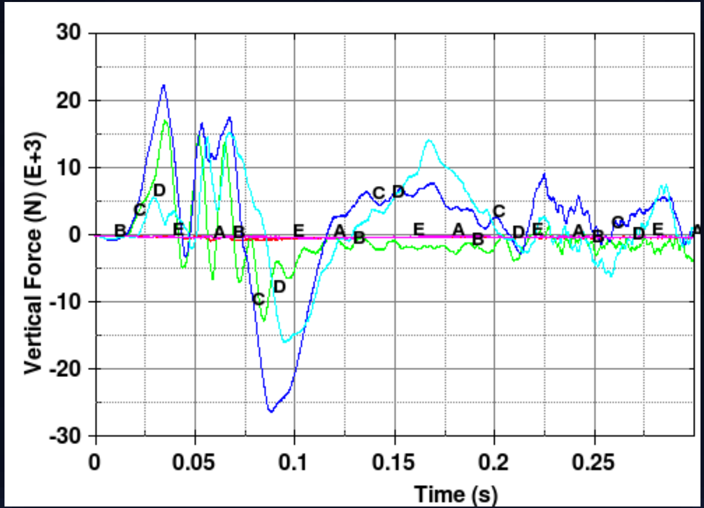
- Utilized numerical optimization technologies to develop optimized SUPD braces



Design Space & Load Requirements

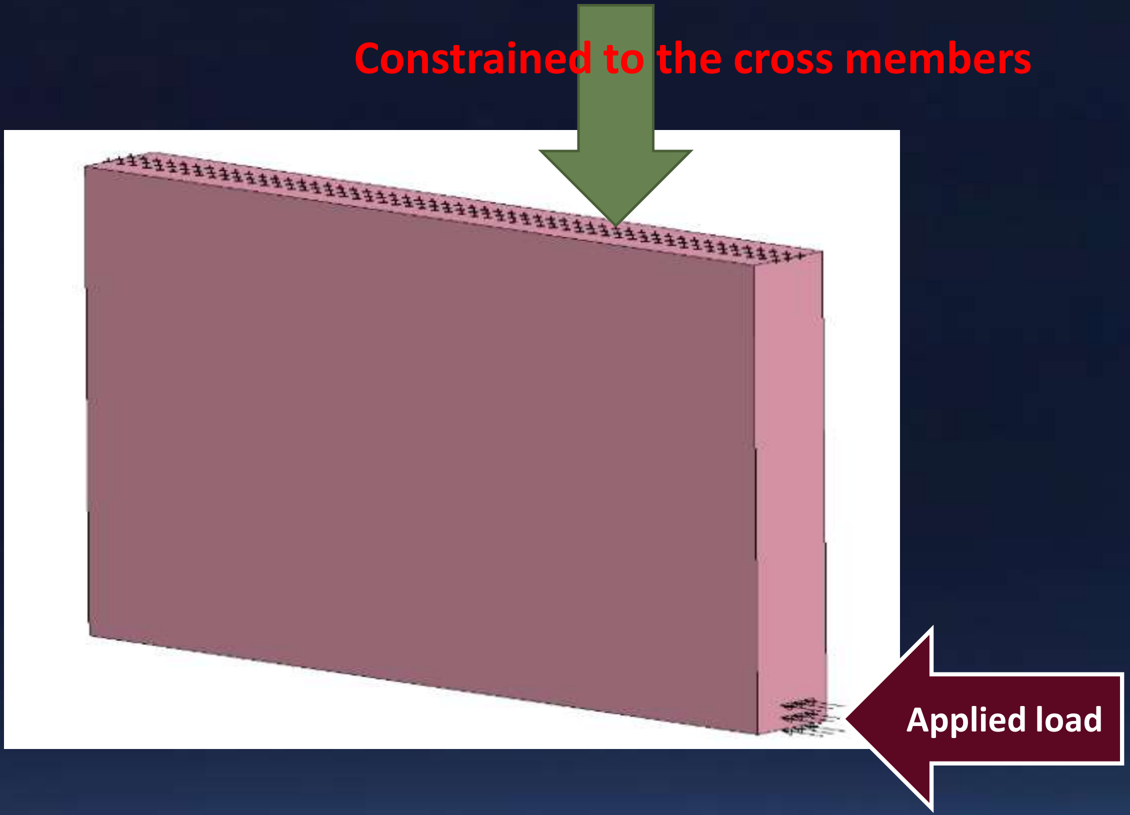
Deformable SUPD with Spring Braces





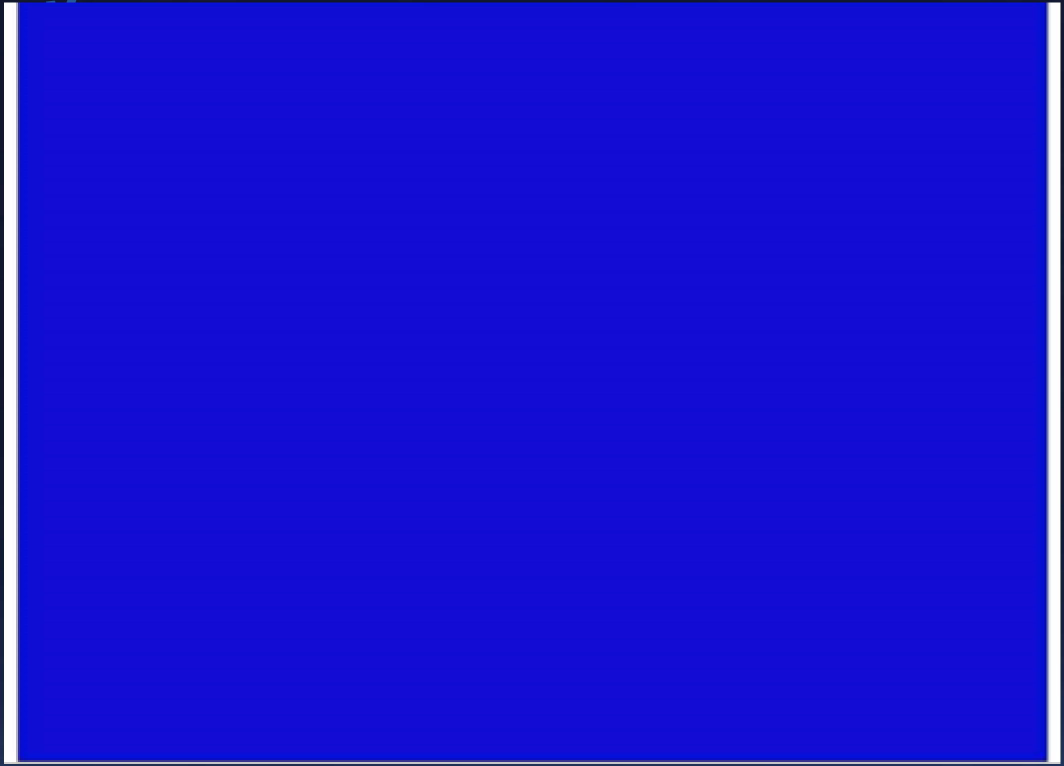
Optimization: Topology

- Design Space Block



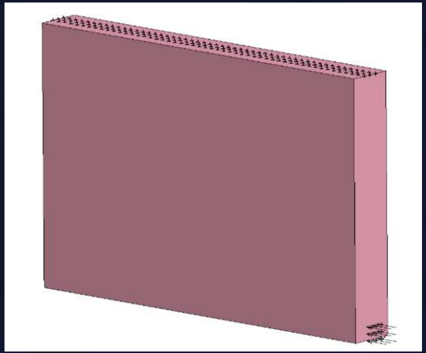
Optimization: Topology

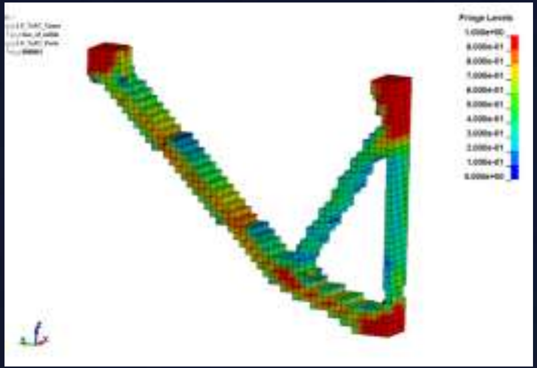
Topology Progression



Optimization: Topology

Topology Evolution

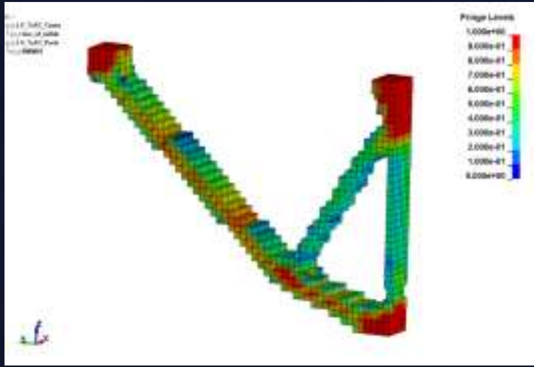




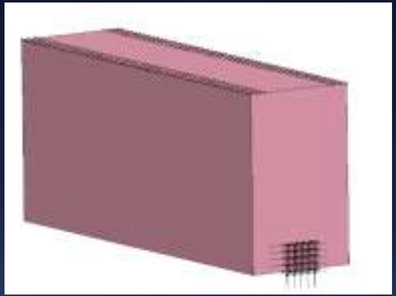
- *Design space aligned with trailer cross member*
- *Provides best mass distribution profile to resist applied load subject to defined deflection constraint*

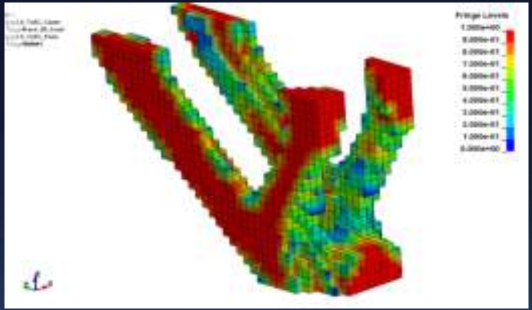
Optimization: Topology

Design space utilizing one trailer cross member



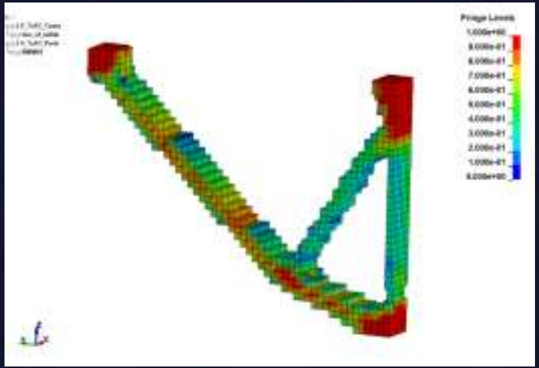
Design space utilizing two trailer cross members





Brace Optimization

Topology Shape Extraction

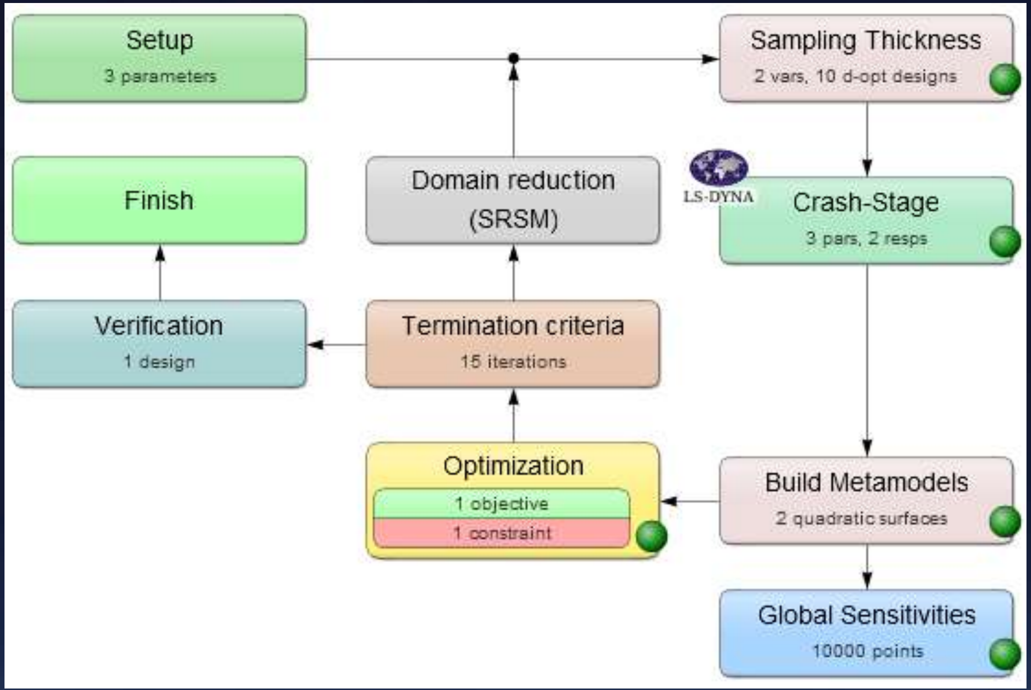


- *Extraction is based on capturing general geometry and comparable strength and stiffness based on mass distribution*
- *Accounted for critical cross-section and percent-utilization of material*

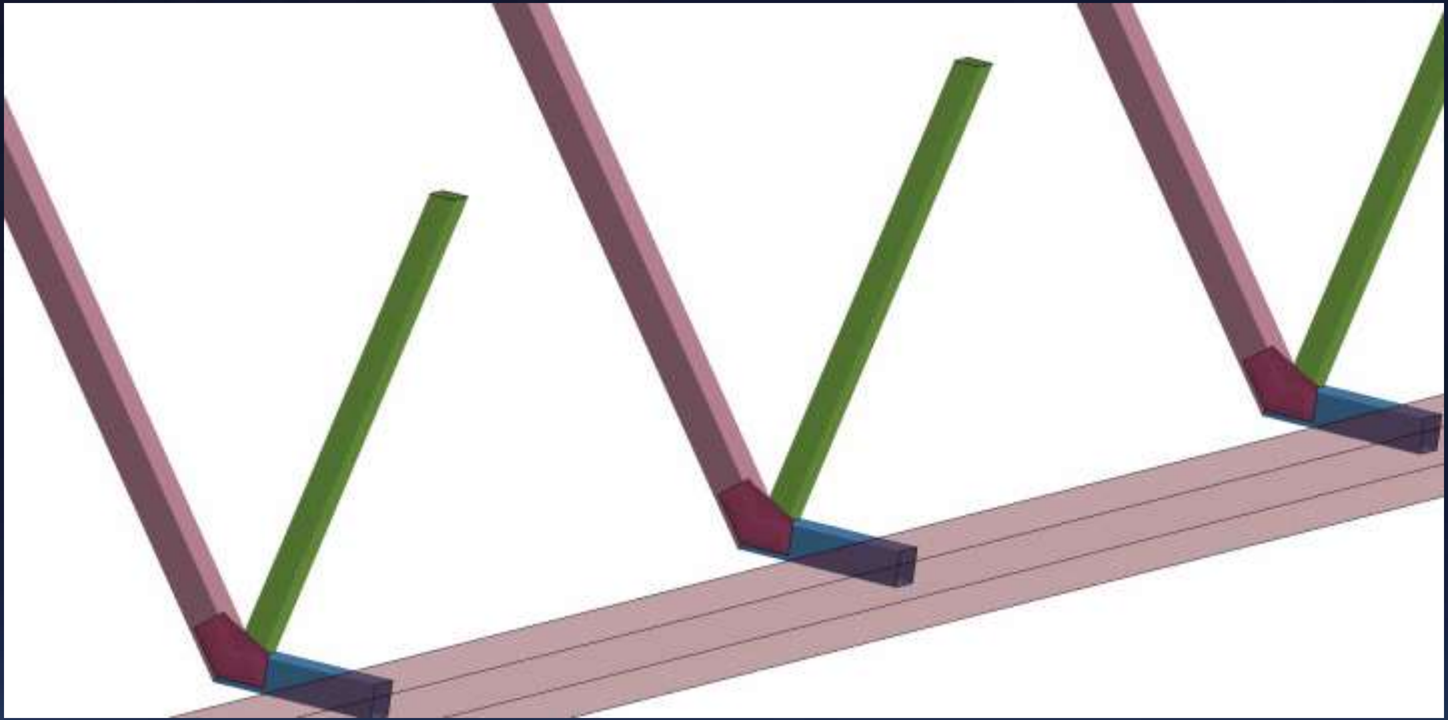
Optimization: Meta-Model

- Given the loading history profile from simple impact with representative spring
- Minimize the weight of the braces extracted from topology optimization
- Impose a maximum deflection of 100 mm at the middle brace-rail interface section
- Both polynomials based and RBF based meta-models were considered.

Optimization: Meta-Model



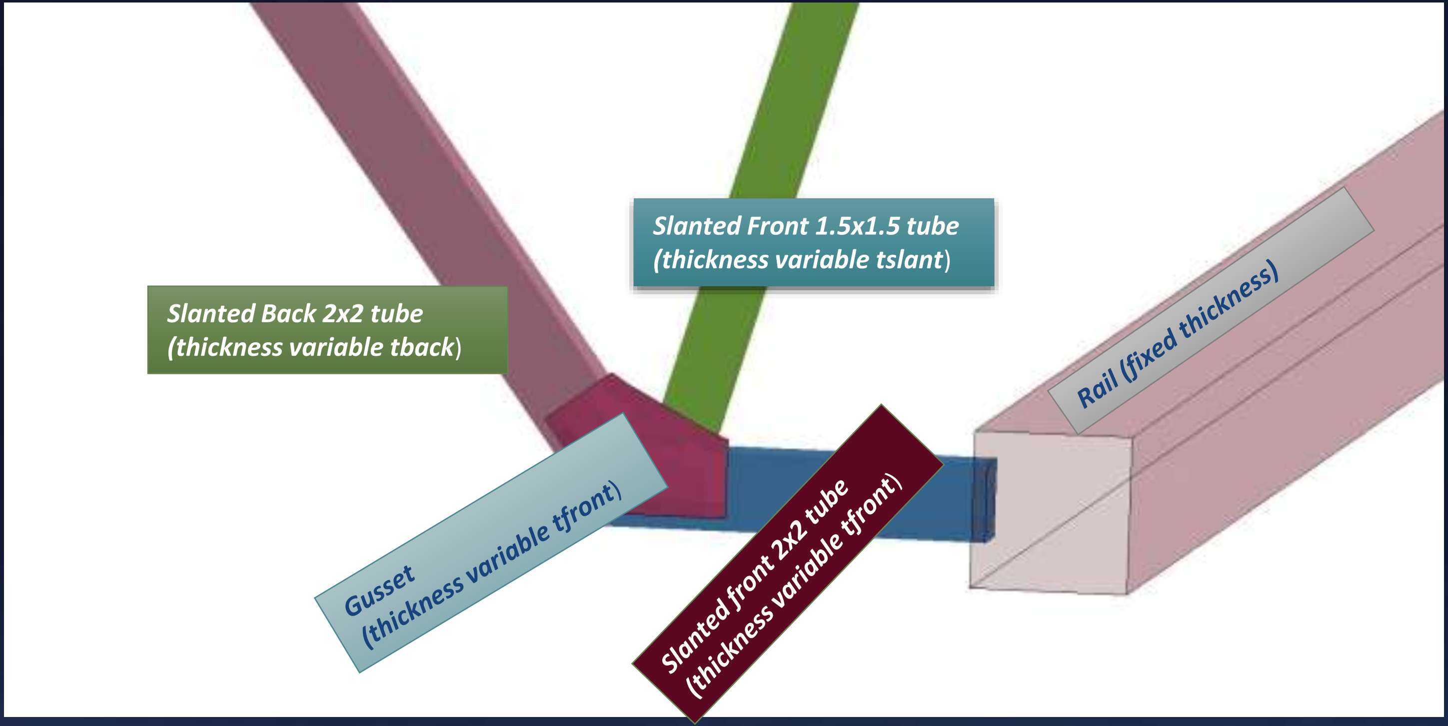
Tubular Aluminum Brace



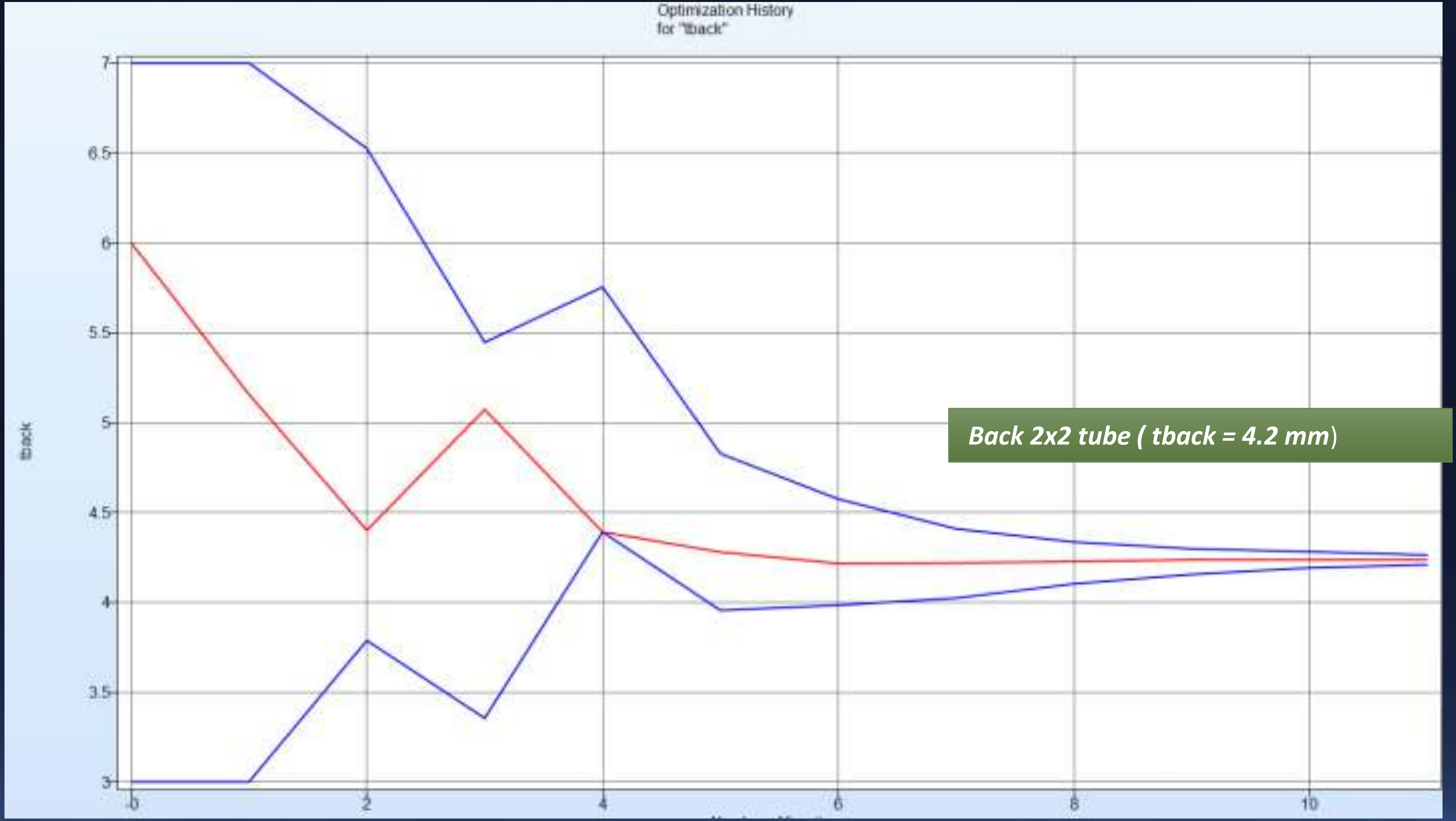
Tubular Aluminum Brace

- **Tubular Aluminum Brace (6061-T6)**
- 2 in by 2 back tube
- 2 in by 2 front horizontal short tube
- 1.5 in by 1.5 front slanted tube
- Gusset at the joint

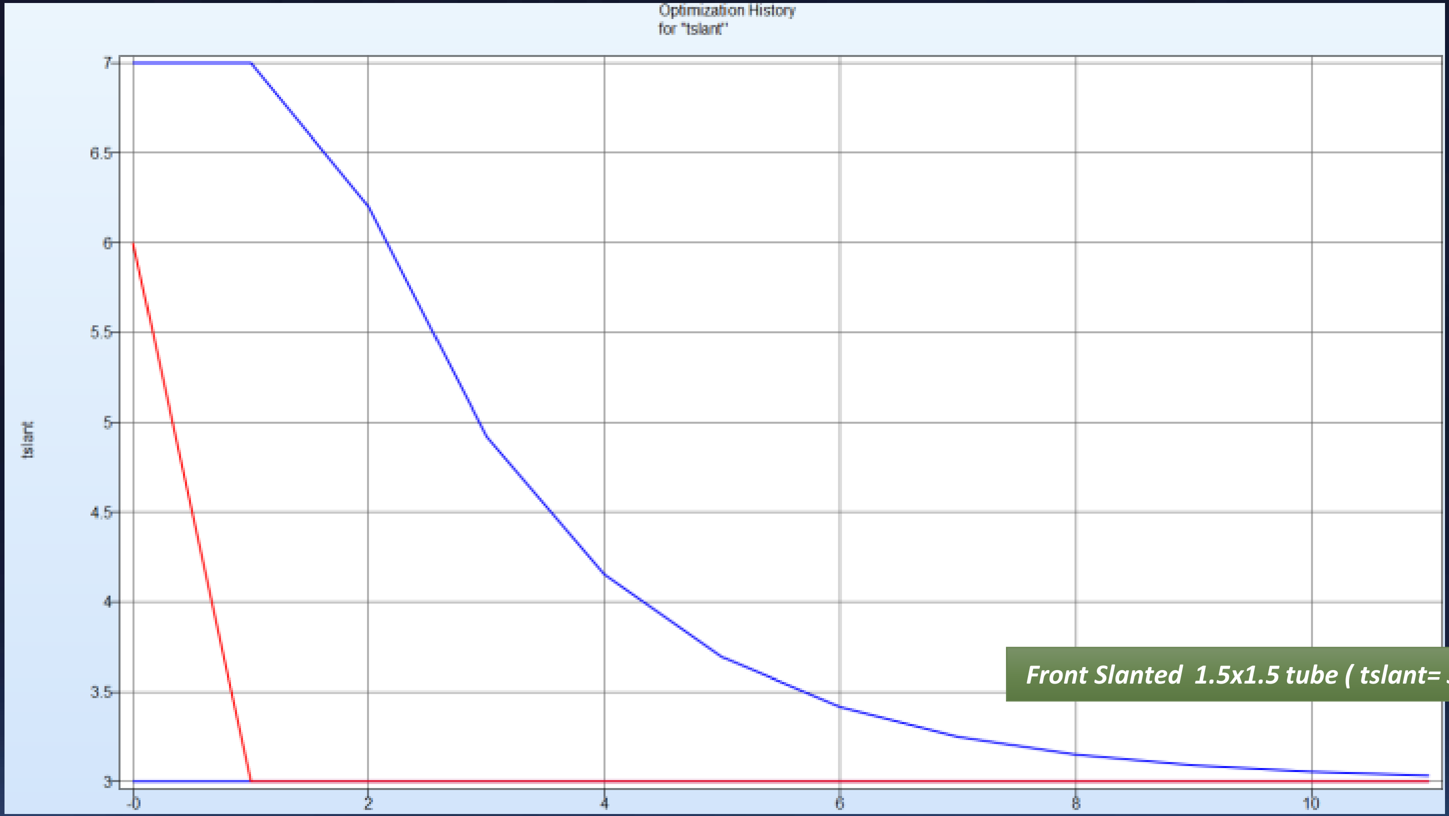
Tubular Aluminum Brace



Tubular Aluminum Brace

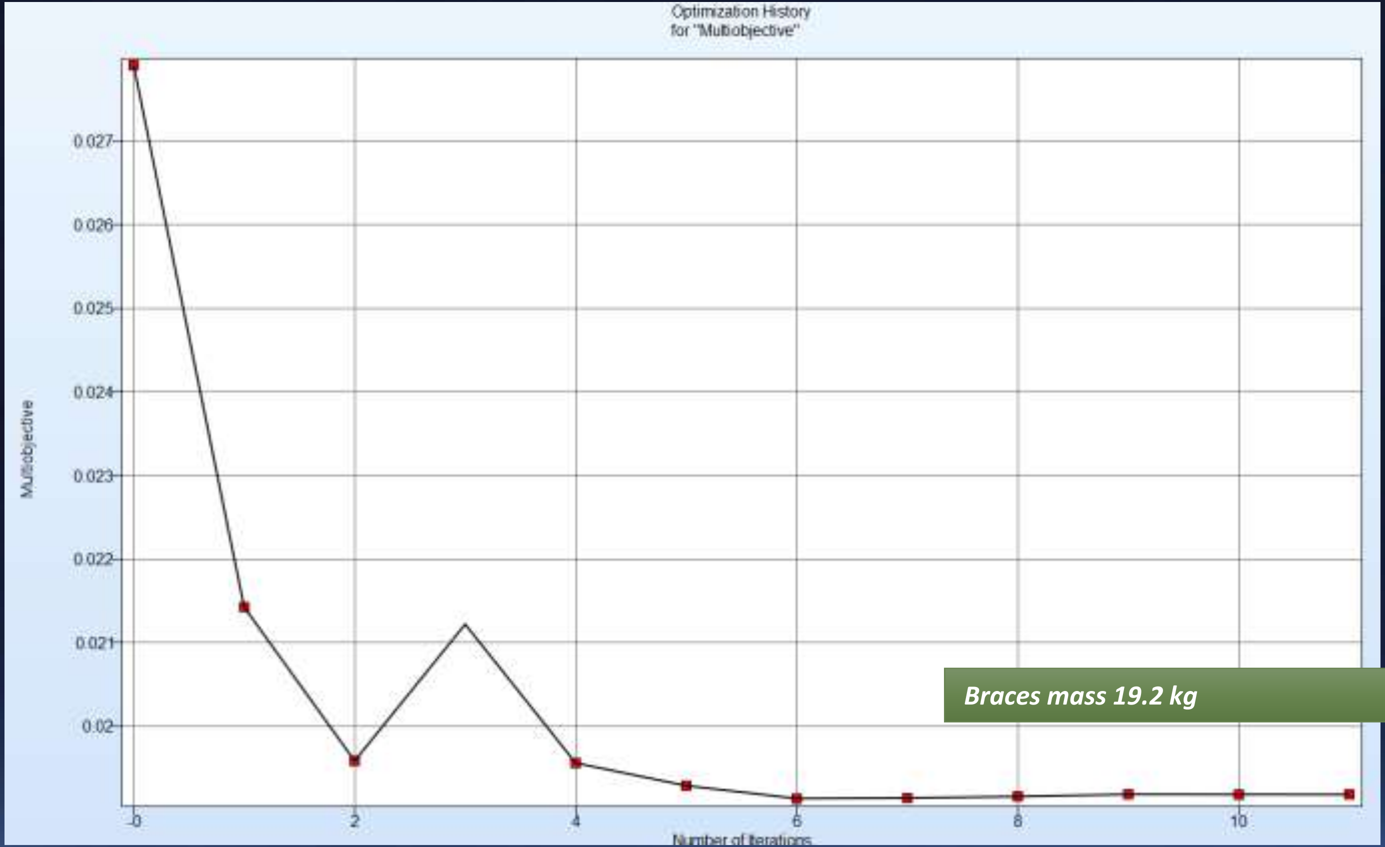


Tubular Aluminum Brace



Front Slanted 1.5x1.5 tube (tslant= 3.0 mm)

Tubular Aluminum Brace

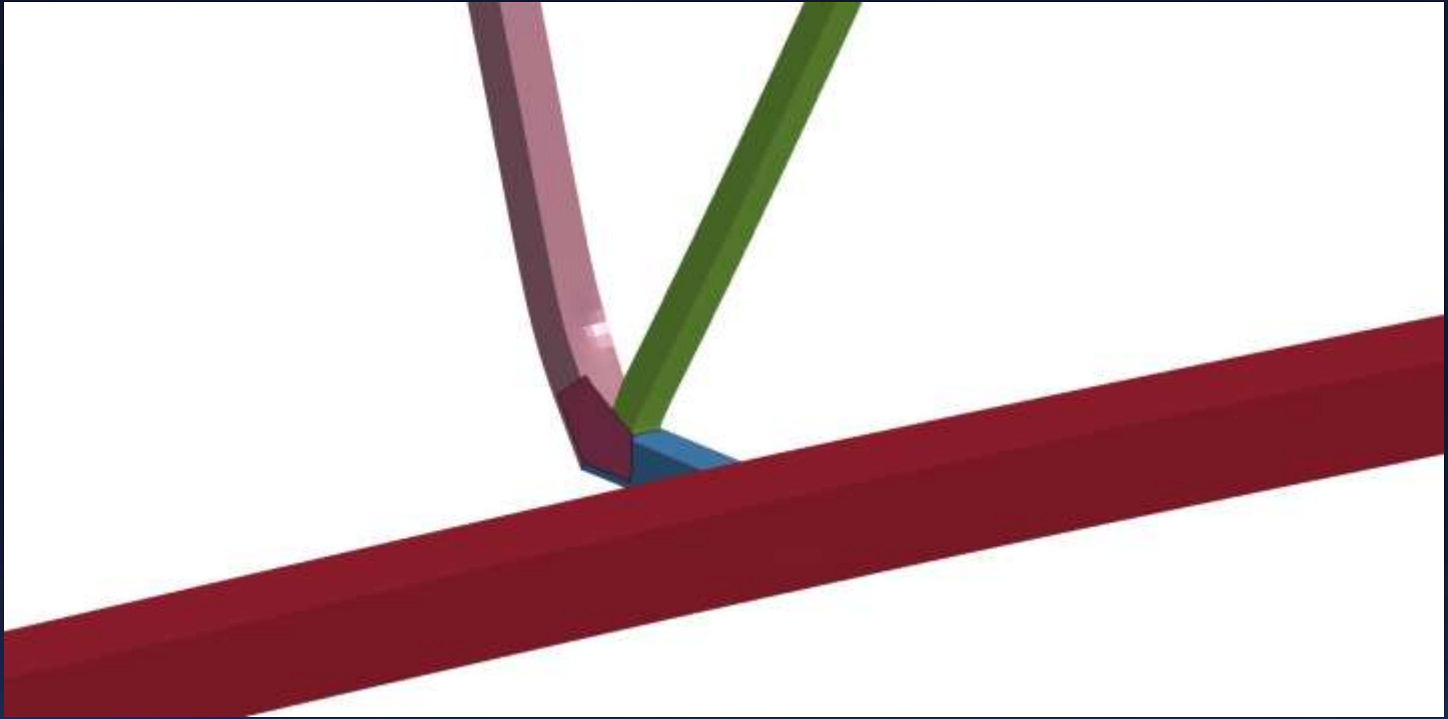


Braces mass 19.2 kg

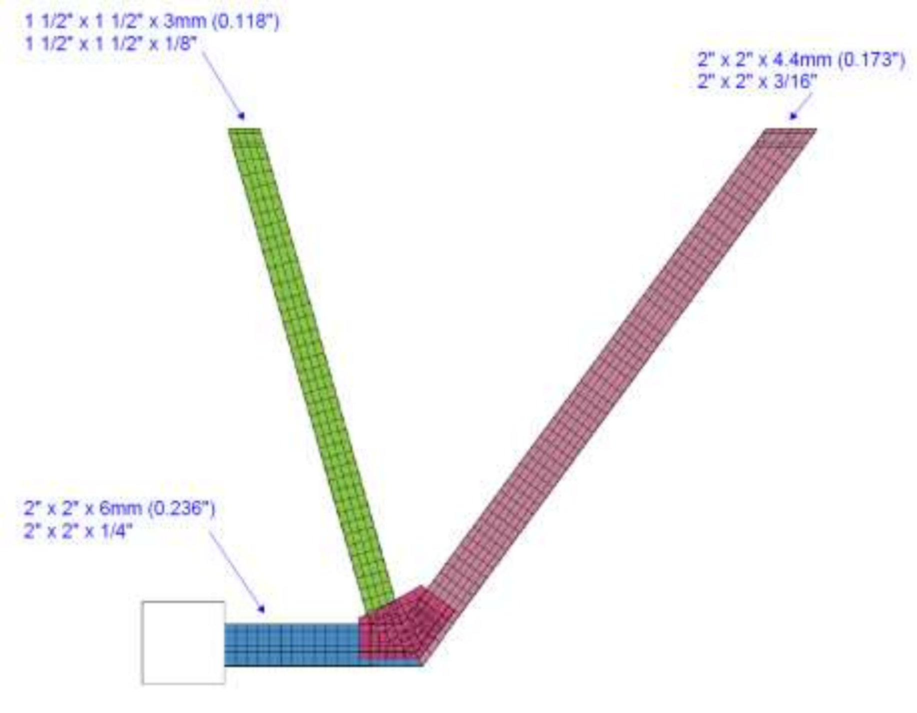
Tubular Aluminum Brace

- Braces mass = 19.2 kg
- Aluminum tubular rail (6”x6”x3/16”) = 46.7 kg
- SUPD mass/side (braces + rail) = 19.2 kg + 46.7 kg = 65.9 kg (146 lb.)

Tubular Aluminum Brace



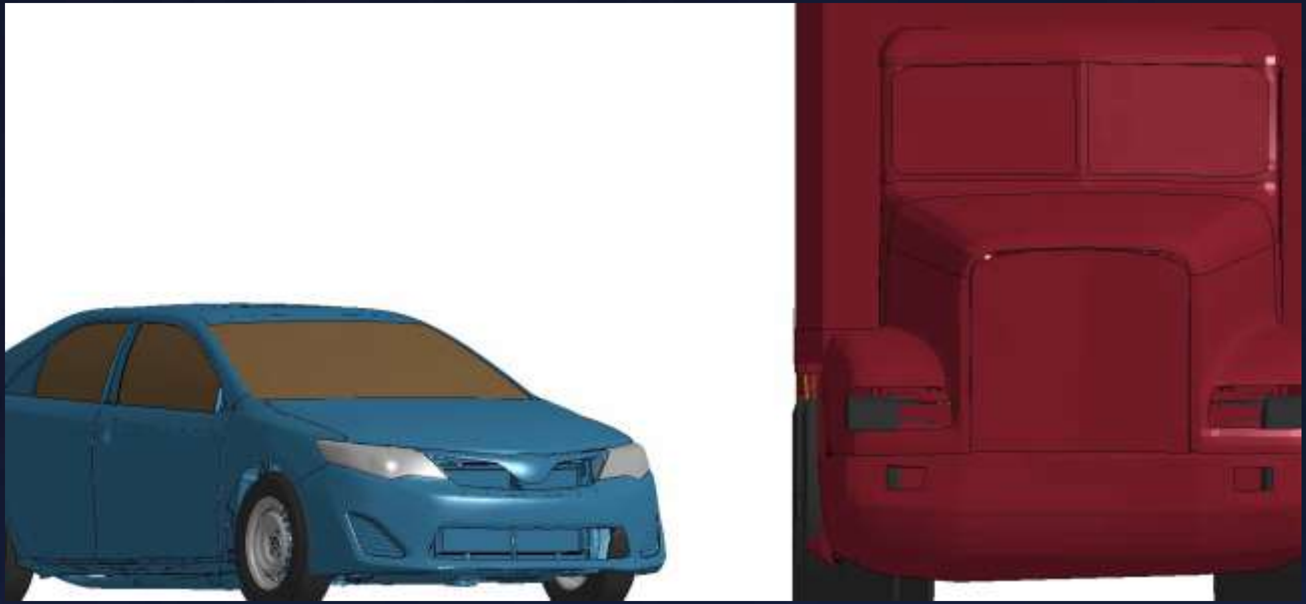
Aluminum Brace Optimum Design



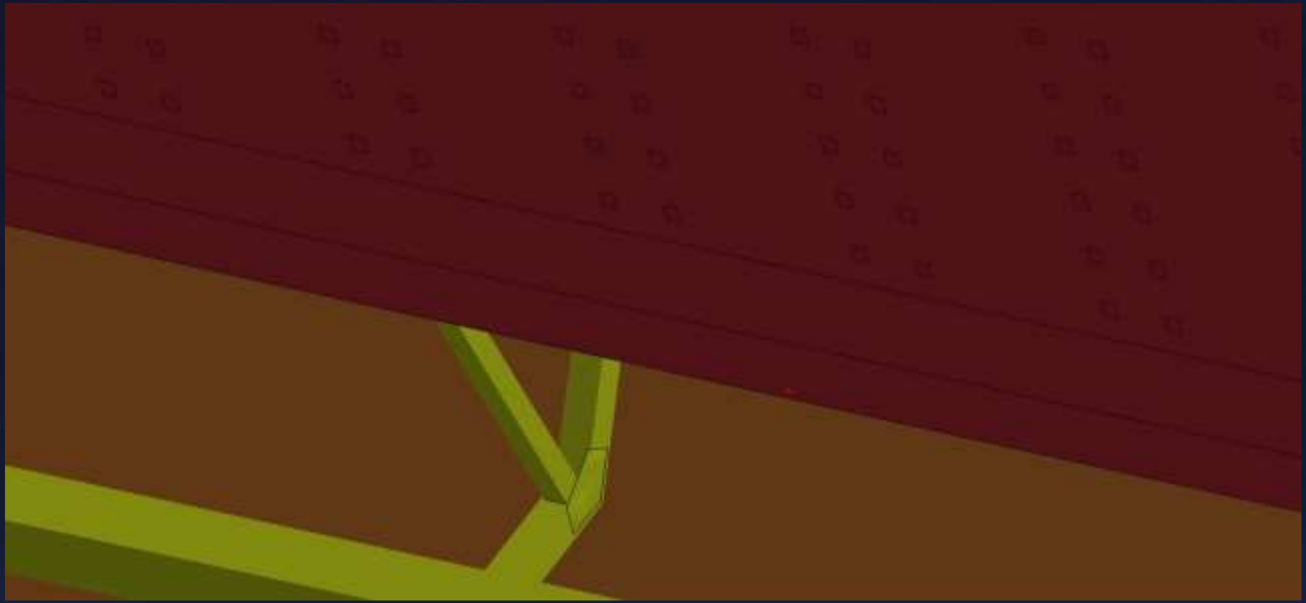
Aluminum, 30 degrees – 50 mph

- Material: Aluminum
- Rail Cross-section: 4x4
- Impact speed: 50 mph
- Impact angle: 30 degrees
- Number of Braces: 5
- Impact 3 ft. upstream of SUPD mid-span
- No contact with pillar
- Total two side SUPD: 251 lb.

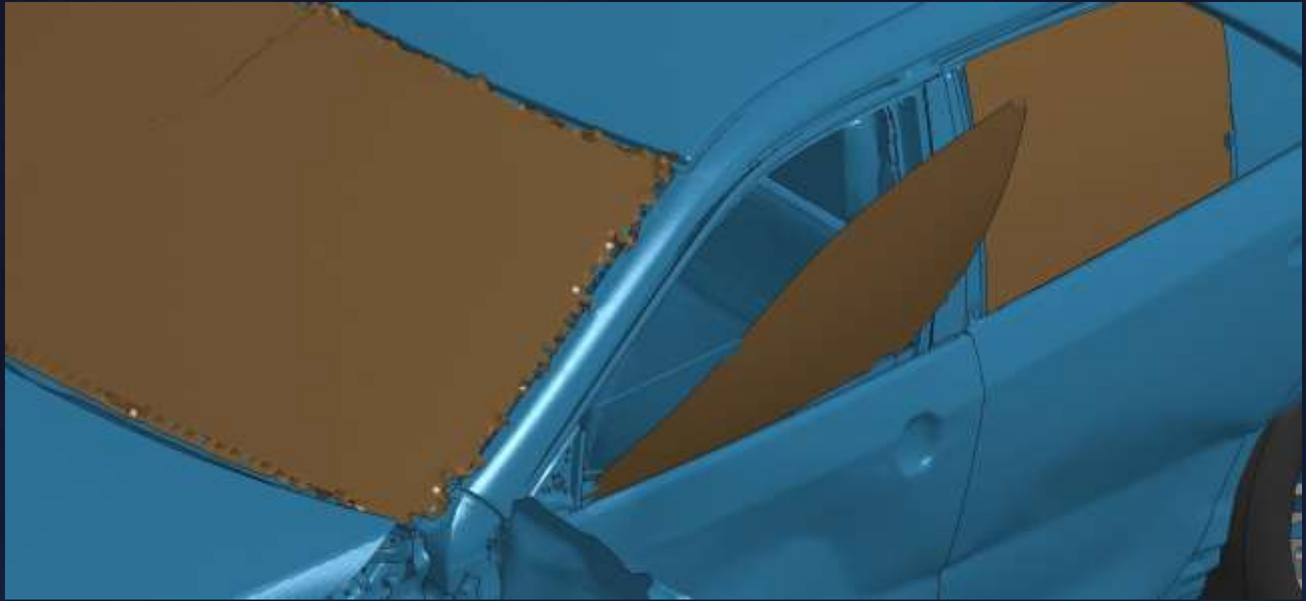
Verification, 30 degrees – 50 mph



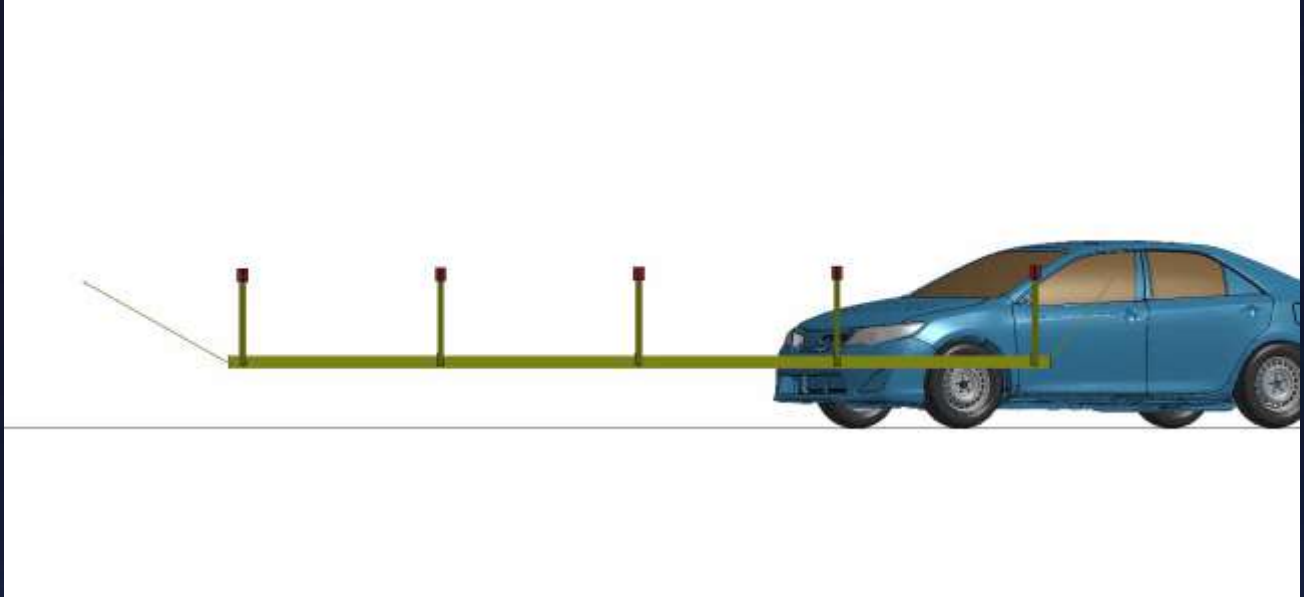
Verification, 30 degrees – 50 mph



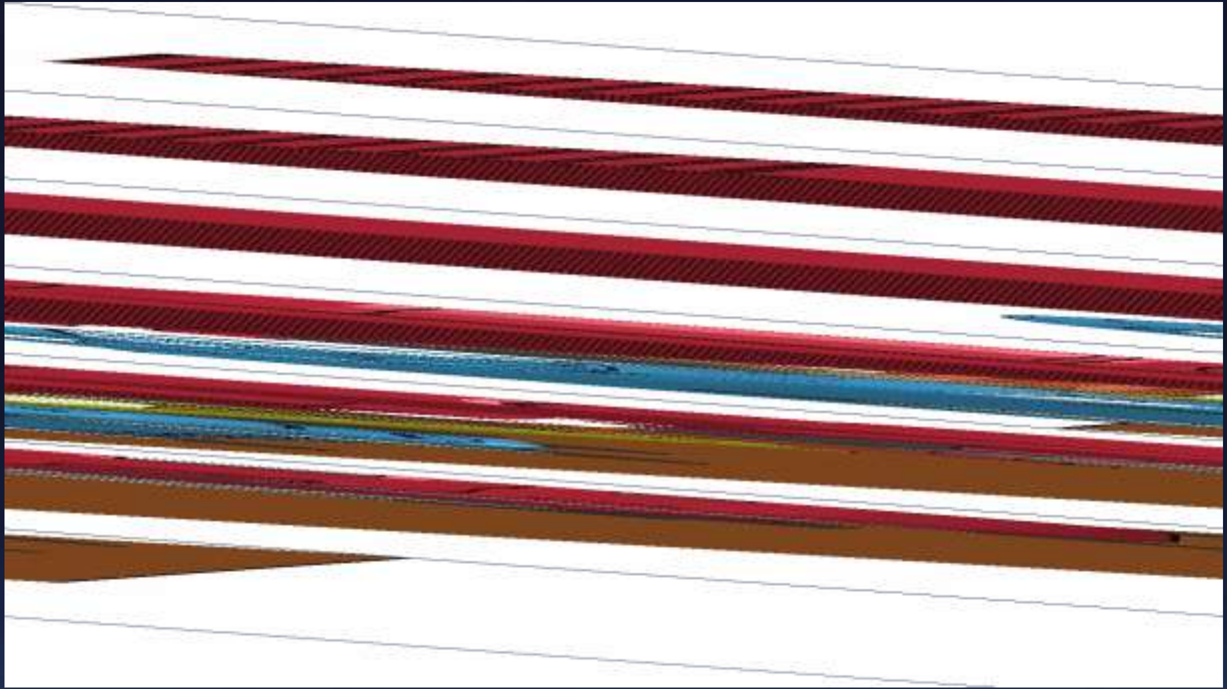
Verification, 30 degrees – 50 mph



Verification, 30 degrees – 50 mph



Verification, 30 degrees – 50 mph



Summary and Conclusion

- A Side Underride Protective Device (SUPD) was developed using nonlinear finite elements and optimization techniques.
- Topology and meta-modeling based optimizations techniques were used to minimize the weight of an under-ride guard for a van trailer
- A regression based meta-model was constructed in the optimization process.
- Both polynomials based and RBF based meta-models were considered.
- Verification analyses were conducted with LS-DYNA using detailed models of both a tractor van-trailer and Toyota Camry.

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