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
"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 heavy vehicles.

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

Constrained to the cross members

Applied load
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

Setup
3 parameters

Finish

Verification
1 design

Domain reduction (SRSM)

Termination criteria
15 iterations

Optimization
1 objective
1 constraint

Sampling Thickness
2 vars, 10 d-opt designs

LS-DYNA

Crash-Stage
3 pars, 2 resos

Build Metamodels
2 quadratic surfaces

Global Sensitivities
10000 points
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

Slanted Back 2x2 tube (thickness variable tback)

Slanted Front 1.5x1.5 tube (thickness variable tsfront)

Gusset (thickness variable tfront)

Rail (fixed thickness)
Tubular Aluminum Brace

Back 2x2 tube (tback = 4.2 mm)
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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