Impact Testing and Modeling of DP600 Front Rails

Tau Tyan
Ford Motor Company
Contribution

Automotive Center
US Steel
• Guofei Chen
• Ming Chen
• Ming Shi

NAE Truck Safety
Ford Motor Company
• Meagan Gonzalez
• Karthik Chitoor
• Heung-Soo Kim
• Yijung Chen
• Miinshiou Huang
• Matt Maltarich
• Timothy Bailey
• Dennis Heinanen
Outline

• Introduction – Generic Cross-section
• DP600 Multicorner Columns in Axial Crush
• DP600 Multicorner Columns in Side Bending
• DP600 12 Corner Columns in Full Vehicle Frontal Impact Application
• Conclusions
Introduction

• SUV/Truck Frame
  • CAE Modeling
  • DP600

• Weight Optimization
  • Geometry
  • Material
  • Thickness
  • Cross-section
Generic Cross-section Comparison

Square  Hexagonal  Octagonal  Circular  Adv Multi Cell
Dynamic Crush Mode Comparison

Square

Hexagonal

Circular

Octagonal

Adv Multi Cell
Mean Crushing Force Comparison

Legend:
- Square
- Hexagonal
- Octagonal
- Circular
- Adv Multi cell

Mean Crushing Force (kN)

Crushing Distance (mm)
Outline

• Introduction – Generic Cross-section
• **DP600 Multicorner Columns in Axial Crush**
• DP600 Multicorner Columns in Side Bending
• DP600 12 Corner Columns in Full Vehicle Application
• Conclusions
DP600 (a) Hexagonal and (b) Octagonal rails of thickness 1.5mm.

All dimensions are measured between outside surfaces

DP600-Material curves - plastic portion

Mechanical properties of DP600

<table>
<thead>
<tr>
<th>t(mm)</th>
<th>YS(MPa)</th>
<th>TS(MPa)</th>
<th>n</th>
<th>E(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>392</td>
<td>696</td>
<td>0.868</td>
<td>13.6</td>
</tr>
</tbody>
</table>

Strain rate data for DP600.
Axial Crush Test Setup

<table>
<thead>
<tr>
<th>Speed</th>
<th>Machine</th>
<th>Attached mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 in/min</td>
<td>Tinius Olsen</td>
<td>N/A</td>
</tr>
<tr>
<td>15 mph</td>
<td>VIA Sled</td>
<td>2999 lbs</td>
</tr>
<tr>
<td>30 mph</td>
<td>VIA Sled</td>
<td>548 lbs</td>
</tr>
</tbody>
</table>

Quasi-static test setup

Dynamic test setup
CAE Methodology

The following effects are included in the model:

- Dimensions and thickness were measured from actual parts (sample size = 3)
- Material properties were taken from coupon tests and input using Radioss type 36 material law
- Forming and welding effects are considered in the model
- Strain rate effect is also included in the model with tabulated material law
CAE & Test Comparison

- Hexagonal Quasi-static Axial Crush
CAE & Test Comparison

- Octagonal Quasi-static Axial Crush
CAE & Test Comparison

- Hexagonal 15mph Axial Crush
CAE & Test Comparison

- Octagonal 15mph Axial Crush
CAE & Test Comparison

- Hexagonal 30mph Axial Crush
CAE & Test Comparison

- Octagonal 30mph Axial Crush
# Sensitivity Study of Axial Crush Parameters

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>15mph Effect on peak force</th>
<th>15mph Effect on crush distance</th>
<th>30mph Effect on peak force</th>
<th>30mph Effect on crush distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Element formulation</td>
<td>Belytschko-Tsay element</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>QEPH element</td>
<td>decrease</td>
<td>increase</td>
<td>decrease</td>
<td>increase</td>
</tr>
<tr>
<td></td>
<td>QPPS element</td>
<td>increase</td>
<td>decrease</td>
<td>increase</td>
<td>decrease</td>
</tr>
<tr>
<td>2 Friction coefficient</td>
<td>0.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>increase</td>
</tr>
<tr>
<td>3 Mesh size</td>
<td>5.0mm</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2.5mm</td>
<td>none</td>
<td>increase</td>
<td>increase</td>
<td>decrease</td>
</tr>
<tr>
<td>4 Strain rate</td>
<td>Strain rate properties</td>
<td>decrease</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>No strain rate properties</td>
<td>-</td>
<td>increase</td>
<td>decrease</td>
<td>increase</td>
</tr>
<tr>
<td>5 Corner/weld properties</td>
<td>Corner + weld properties</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Weld properties only</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>increase</td>
</tr>
<tr>
<td></td>
<td>Forming properties only</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>increase</td>
</tr>
<tr>
<td></td>
<td>No forming/weld properties</td>
<td>none</td>
<td>none</td>
<td>increase</td>
<td>increase</td>
</tr>
<tr>
<td>6 Gage</td>
<td>1.5mm</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1.65mm</td>
<td>increase</td>
<td>decrease</td>
<td>increase</td>
<td>decrease</td>
</tr>
<tr>
<td></td>
<td>1.35mm</td>
<td>decrease</td>
<td>increase</td>
<td>decrease</td>
<td>increase</td>
</tr>
<tr>
<td>7 Initial velocity</td>
<td>15mph</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>14mph</td>
<td>none</td>
<td>decrease</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>16mph</td>
<td>none</td>
<td>increase</td>
<td>none</td>
<td>increase</td>
</tr>
<tr>
<td>8 Shape change</td>
<td>nominal</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>oblong</td>
<td>none</td>
<td>none</td>
<td>decrease</td>
<td>increase</td>
</tr>
<tr>
<td>9 Tilt angle</td>
<td>0 degrees</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.1 degrees</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>decrease</td>
</tr>
<tr>
<td></td>
<td>0.2 degrees</td>
<td>none</td>
<td>increase</td>
<td>none</td>
<td>decrease</td>
</tr>
</tbody>
</table>
Outline

• Introduction – Generic Cross-section
• DP600 Multicorner Columns in Axial Crush
• **DP600 Multicorner Columns in Side Bending**
• DP600 12 Corner Columns in Full Vehicle Frontal Impact Application
• Conclusions
Lateral Bending Test Setup

<table>
<thead>
<tr>
<th>Crush Type</th>
<th>Machine</th>
<th>Speed</th>
<th>Attached Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quasistatic</td>
<td>Tinius Olsen</td>
<td>1 in/ min</td>
<td>N/A</td>
</tr>
<tr>
<td>Dynamic</td>
<td>Bendix</td>
<td>30 mph</td>
<td>77 lbs</td>
</tr>
</tbody>
</table>

Hexagonal and Octagonal quasi-static and dynamic bending test fixture
CAE and Test Crush Mode Comparison

Hexagonal & Octagonal 30mph lateral bending
CAE and Test Comparison

Hexagonal and Octagonal quasistatic bending

Hexagonal and Octagonal 30mph lateral bending
Energy Comparison

Hexagonal and Octagonal quasistatic bending

Hexagonal and Octagonal dynamic bending
## Sensitivity Study of Axial Crush Parameters

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Effect on Peak Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element Formulation</td>
<td>Belytschko-Tsay Element</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>QEPH Element</td>
<td>Increase</td>
</tr>
<tr>
<td></td>
<td>QPPS Element</td>
<td>Increase</td>
</tr>
<tr>
<td>Friction Coefficient</td>
<td>0.3</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>-</td>
</tr>
<tr>
<td>Mesh Size</td>
<td>5.0 mm</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2.5 mm</td>
<td>Increase</td>
</tr>
<tr>
<td>Strain Rate</td>
<td>Strain Rate Properties</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>No Strain Rate Properties</td>
<td>Decrease</td>
</tr>
<tr>
<td>Forming / Weld Properties</td>
<td>Forming + Weld Properties</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>No Weld Properties</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>No Forming Properties</td>
<td>Decrease</td>
</tr>
<tr>
<td></td>
<td>No forming / Weld Properties</td>
<td>Decrease</td>
</tr>
<tr>
<td>Gage</td>
<td>1.5 mm</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1.65 mm</td>
<td>Increase</td>
</tr>
<tr>
<td></td>
<td>1.35 mm</td>
<td>Decrease</td>
</tr>
<tr>
<td>Initial Velocity</td>
<td>30 mph</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>29 mph</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>31 mph</td>
<td>None</td>
</tr>
</tbody>
</table>
Outline

• Introduction – Generic Cross-section
• DP600 Multicorner Columns in Axial Crush
• DP600 Multicorner Columns in Side Bending
• DP600 12 Corner Columns in Full Vehicle Frontal Impact Application
• Conclusions
Tapered Cross-sections
Tapered Cross-sections with Convolutions
Sensitivity Analyses (Tapered Cross-sections with Convolutions - C1)

DOE Setup
Material - DP600
Gage=3.3 ~ 2.1 mm

Best-Fit
C1 –DP600–2.3mm
Weight x2 = 18.87 lb
Saving = 8.25 lb
(30.42%)
Sensitivity Analyses (Tapered Cross-sections with Convolutions- C2)

DOE Setup
Material – P415 AP1
Gage=3.3 ~ 2.1 mm

Best-Fit
C2 – AP1_mat–2.3mm
Weight x2 = 18.21 lb
Saving = 8.91 lb (32.86%)
# Component Performance Comparison

<table>
<thead>
<tr>
<th>Front Rail Design</th>
<th>Tapered Cross Section Without Convolution</th>
<th>Tapered Cross Section With Convolution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C0</td>
<td>C1</td>
</tr>
<tr>
<td><strong>32Ksi Material</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gage (mm)</td>
<td>3.30</td>
<td>2.70</td>
</tr>
<tr>
<td>Weight (lb)</td>
<td>24.95</td>
<td>20.69</td>
</tr>
<tr>
<td>Saving (lb)</td>
<td>0.00</td>
<td>4.26</td>
</tr>
<tr>
<td>Saving (%)</td>
<td>0.00</td>
<td>17.09</td>
</tr>
<tr>
<td><strong>DP600</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gage (mm)</td>
<td>2.90</td>
<td>2.30</td>
</tr>
<tr>
<td>Weight (lb)</td>
<td>21.91</td>
<td>19.18</td>
</tr>
<tr>
<td>Saving (lb)</td>
<td>3.04</td>
<td>5.77</td>
</tr>
<tr>
<td>Saving (%)</td>
<td>12.18</td>
<td>23.13</td>
</tr>
</tbody>
</table>
Ford

Full Vehicle Crash Application

Baseline

12-Corner
NCAP Performance Comparison

Baseline

12-Corner
NCAP Deformation Comparison

Baseline

12-Corner
NCAP Frame Pulse Comparison
IIHS Offset Performance Comparison

Baseline

12-Corner
IIHS Offset Intrusion Comparison

IIHS 40 MPH 40% OFFSET INTRUSION COMPARISON
Intrusion of Various Locations

- POOR
- MARGINAL
- ACCEPTABLE
- GOOD

Lines represent:
- BASELINE
- 12-Sided Fronthorn

Locations:
- footrest
- lt_toepan
- c_toepan
- rt_toepan
- brkpedal
- left_IP
- right_IP

Intrusion (mm)

Intrusion (in)
Outline

- Introduction – Generic Cross-section
- DP600 Multicorner Columns in Axial Crush
- DP600 Multicorner Columns in Side Bending
- DP600 12 Corner Columns in Full Vehicle Frontal Impact Application

- Conclusions
Conclusions

• Geometry, material properties, forming effect, welding effect, strain rate, and other boundary conditions all contribute to model correlation and prediction.

• The octagon has a small advantage over hexagon with respect to energy absorption in axial crush and lateral bending.

• The 12 corner cross section presents more advantage over the other sections studied.

• The 12 corner cross section saves weight and performs slightly better than the baseline design in front impact crash performances.