Surface Behavior of Metal Plates Subjected to Projectile Impact

Cole Fowler
CE 511-01/ ENGR 699-21
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Objectives

- Analyze steel plate behavior under impact loading
- Calculate stiffness coefficient of plate structure
- Determine speed needed for penetration
- Compare calculated and experimental data
Experimental Set-up

Side View

Top View

Annie

Structure

Camera
Properties

- **Projectile**
  - Mass = 0.318 lbs
  - Density = 0.027 lbs/in$^3$
  - Diameter = 2.83 in
  - $V_o = 641.44$ in/s
  - Acc = 42130 in/s$^2$
  - Distance = 5.848 in

- **Plate**
  - Mass = 2.67 lbs
  - Density = 0.131 lbs/in$^3$
  - Thickness = 0.103 in
  - $\text{Disp}_{\text{max}} = 0.271$ in
  - $E = 29,000,000$ psi
  - $I = 0.0000911$ in$^4$
Free Body Diagram

\[ m \ddot{x}'' = kx \]

SDOF—Neglect Damping

\[ F \rightarrow M \]

\[ k \]
## Data Output

### Export of Displayed Graph Data

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B: Time</th>
<th>Column C: 1D - Line 1 - Target 1 - X</th>
<th>Column D: 1D - Line 2 - Target 1 - X</th>
<th>Column E: 2D - Feature 1 () - X</th>
<th>Column F: 2D - Feature 1 () - Y</th>
<th>Column G: 2D - Feature 1 () - Distance</th>
<th>Column H: 2D - Feature 1 () - Speed</th>
<th>Column I: 2D - Feature 1 () - X Velocity</th>
<th>Column J: 2D - Feature 1 () - Y Velocity</th>
<th>Column K: 2D - Feature 1 () - Acceleration</th>
<th>Column L: 2D - Feature 1 () - X Acceleration</th>
<th>Column M: 2D - Feature 1 () - Y Acceleration</th>
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<td>frame number</td>
<td>in Red Line</td>
<td>in Green Line</td>
<td>in Ball</td>
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<td>less accuracy than displacement</td>
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Calculations

- **Equivalent Spring Constant**
  
  ![](Clamped-Clamped beam)
  
  \[ k_{eq} = \frac{192EI}{L^3} \]
  
  \[ = \frac{(192)(29,000,000 \text{ psi})(0.0000911 \text{ in}^4)}{(15.25 \text{ in})^3} = 143 \frac{\text{lb}}{\text{in}} \]

- **Impact Force**
  
  - Relative to max deflection of plate:
    \[ F = k_{eq} q_{max} = \left(143 \frac{\text{lb}}{\text{in}}\right)(0.271 \text{ in}) = 38.8 \text{ lbm} \]
  
  - Relative to mass and acceleration of projectile:
    \[ F = m_{ball} a_{ball} = (0.318 \text{ lbs}) \left(42130 \ \frac{\text{in}}{s^2}\right) = 13397.34 \ \frac{\text{lb-in}}{s^2} \left[\frac{1}{g}\right] = 34.7 \text{ lbm} \]
Calculations

- Penetration Velocity—Naval Ordinance and Gunnery

\[ \log v = 3.00945 + 0.75 \log d + 0.701 \log x - 0.5 \log w \]

\[ = 3.00945 + 0.75 \log(2.83) + 0.701 \log(0.103) - 0.5 \log(0.318) \]

\[ = 2.9 \]

\[ v = 10^{2.9} \]

\[ v = 794 \frac{ft}{s} = 541 \text{ mph} \]

\[ v = \text{penetration velocity} \]
\[ d = \text{diameter of projectile} \]
\[ x = \text{penetration in inches} \]
\[ w = \text{weight of projectile} \]
541 mph ~ Mach 0.70

- 70% speed of sound (768 mph)
- Commercial jets travel Mach 0.80
- Military Jets can travel Mach 2-6
- Most bullets travel Mach 2-3
- Average MLB pitcher throws 90 mph
  - Aroldis Chapman 105.1 mph in 2010
  - He would have to throw it 5.15 times harder to penetrate the steel plate
Simulation Set-up

\[ V = 16.29 \text{ m/s} = 36.4 \text{ mph} \]

No Penetration
Results

Displacement from AutoDyn -- 0.320 in

Calculated Displacement -- 0.240 in

Video Captured Displacement -- 0.270 in

Percent Error

33.3%

12.5%
Penetration Simulation

Compression Contour at Max Deflection

V = 541 mph

No Penetration

Velocity Graph
Max Vel: 242 m/s = 541 mph

Integral of Velocity Graph
Max Defl: 85mm = 3.35”
Sources of Error

- **AutoDyn**
  - No built in material for ball and plate
    - No strength model
    - Chose similar material
  - Impact in x-direction only
  - Assumed rigid support structure

- **Video Capture**
  - Camera angle
  - Difficult to pinpoint element boundaries
  - Projectile movement in x and y directions

- **Hand Calculation**
  - Assumed rigid support structure
  - Assumed E value from similar materials
Thank You