Pedestrian Safety

Session delivered by:

Dr. Vinod K. Banthia

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• Session Objectives
  – At the end of this session the delegate would have understood the
    • Need and concern for pedestrian safety and
    • Types of injuries to the pedestrians
    • Developments in simulation of pedestrian collisions
    • Structural design aspects for pedestrian safety
Session Topics

1. Pedestrian injuries and statistics
2. Pedestrian model development methodology
3. Developments in pedestrian collision testing
4. Design considerations for various parts of the structure for pedestrian safety
Automobiles/Accidents/Safety

The First Accident: Cugnot’s steam tractor hits a low wall in the grounds of the Paris arsenal (1977)

First documented fatalities: Mary Ward, Parsontown, Ireland (August 31, 1869)
   Henry Bliss, New York City, NY (September 13, 1899)

First occupant fatality: First motor-car accident resulting in the death of the driver Grove Hill, Harrow-on-the-Hill, London (February 25, 1899)

The First Act: The Locomotives and Highway Act was the first piece of British motoring legislation. This was also known as the Red Flag Act of 1865. The act required three persons in attendance one to steer, one to stoke and one to walk 60 yards ahead with a red flag to warn the oncoming traffic.

20 million and counting
Need for Study of Pedestrian Safety

Start? As soon as the speed differential was created (early 1900)

Attempts: • Rules and Regulations
• Infrastructure
• Driver
• Pedestrian

Occupant Safety: • Seat Belts
• Airbags
• Structure
• Interior
• Fire hazards
• ...............

Pedestrian Safety: ?

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Traffic fatalities – Some Statistics

Pedestrian fatalities (1979 - 1999)

Promising trend BUT Total is still very high

Concern
Serious injury to children
Resulting long term effect
In terms of human resources and economy

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Traffic fatalities – Some Statistics

Developed countries
Low % of pedestrians
Yet % of pedestrian deaths ~ 15-20%

Japan (~25%)
UK (~29%)
(misleading as total # of fatalities are low)
1.7/100000 population
Traffic fatalities – Some Statistics

1 in 50 deaths caused by traffic accident
Yearly toll approximately 1.2 million

#2 killer in 5-29 yr age group
3\textsuperscript{rd} largest health problem by 2020

US: 5000 fatalities 70000 injuries
Europe: 8000 fatalities 30000 injuries
India: \textasciitilde100000 fatalities (\textasciitilde270/day)

\textasciitilde40\% involve pedestrians
(\textasciitilde80\% in Mumbai, \textasciitilde55\% in Delhi)

Socio-economic cost: Rs. 55000 crores (\textasciitilde3\% of GDP)
Traffic fatalities – Some Statistics

Children and Elderly are more vulnerable

Pedestrian protection solutions must cater to all the age groups

Age   Gender

Types of injuries?

Body response?

Human body kinematics and human body injury indices (simulation and testing)

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Pedestrian Safety – Research Approach

- Society

- Vehicle Design/Tech.

- Statistics for continuous improvement
Pedestrian Injury Statistics

<table>
<thead>
<tr>
<th>Injuries</th>
<th>Fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>71.1%</td>
<td>15.0%</td>
</tr>
<tr>
<td>7.3%</td>
<td>1.1%</td>
</tr>
<tr>
<td>17.0%</td>
<td>1.1%</td>
</tr>
<tr>
<td>2.3%</td>
<td>4.1%</td>
</tr>
</tbody>
</table>

~15.7%

~15.6%

~6.9%

~13.3%

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Nature of Vehicle-Pedestrian Collision

Cause of automotive accidents

Speed or Speed differential?

* 

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Nature of Vehicle-Pedestrian Collision
Validation & Application of a
Finite Element
Pedestrian Humanoid
Model for Use in Pedestrian Accident Simulation

Mark Howard, Alan Thomas, Werner Koch
Ford Forschungszentrum, Aachen GmbH

James Watson, Roger Hardy
Cranfield Impact Center Ltd.
Humanoid Model -- Formulation

- Head: rigid skull with deformable skin
- Neck: 7 rigid vertebrae each with 6 d.o.f for flexibility
- Thorax, abdomen & Pelvis: flexible formulation under construction
- Upper & lower legs: deformable solids & flexible beams for bones
- Knee joints: 6 d.o.f

(simulating soft tissues, femur and tibia)
(Joints to model fracture)

Humanoid Model (~ 7000 elements) in LS-DYNA3D for Pedestrian Accident simulation

Features and mechanisms for improved model biofidelity and injury prediction
Humanoid Model -- Formulation

Basis: 50\textsuperscript{th} percentile humanoid model

↓

Scaling Program

↓

Children (3-15)
Adult (males/females)

Customization possible (leg lengths, torso widths etc.)
Humanoid Model -- Formulation

Validation using cadaver tests

<table>
<thead>
<tr>
<th>Test</th>
<th>Velocity (km/h)</th>
<th>Car Shape</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Mass (kg)</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>25</td>
<td>C1</td>
<td>54</td>
<td>m</td>
<td>75</td>
<td>1.80</td>
</tr>
<tr>
<td>T9</td>
<td>39</td>
<td>C2</td>
<td>68</td>
<td>m</td>
<td>88</td>
<td>1.75</td>
</tr>
</tbody>
</table>

2 speeds

2 vehicle shapes

Model:
- Bumper
- Bonnet
- Windshield

Springs to model vehicle stiffness

Rigid connections to vehicle cg
Humanoid Model -- Formulation

Leg strike
Lower leg: High BM and deformation
Load transfer to Knee joint
Knee joint: Rotation (fore/aft axis)
Knee joint: Tension/Compression
Wrap around as legs lift
Head strike over the hood/windsvreen

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Tibia strike
Tibia: Severe bend (breaks)
Knee joint: Severe Rotation (Ligament)
Head strike the windshield

Head trajectory (X), hit point (√)
Differences: Dummy and Cadaver
Humanoid Model -- Formulation

Head velocity relative to the moving vehicle
Good match of trend and impact velocity
**Accident Simulation Model**

50% pedestrian dummy

Different vehicle model formulation

Simple vehicle model

Y0: Center

Y500: Offset

Effect of deceleration

Effect of brake dive

Non-linear vehicle model

Rear end structure: Coarse model from frontal crash model

Vehicle structure/Components: Ford Standard

Ped accident specific components: Validated using tests
# Accident Simulation Model

## General comparison of contact timing ranges

<table>
<thead>
<tr>
<th>Contact time (ms) to</th>
<th>Full leg</th>
<th>Pelvis/abdomen</th>
<th>Head</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>10 to 135</td>
<td>69 to 209</td>
<td>185 to 210</td>
</tr>
<tr>
<td>Detailed</td>
<td>10 to 50</td>
<td>150 to 200</td>
<td>250 to 350</td>
</tr>
<tr>
<td>Simple</td>
<td>10 to 105</td>
<td>40 to 200+</td>
<td>126 to 132</td>
</tr>
<tr>
<td>Detailed</td>
<td>10 to 50</td>
<td>100 to 150</td>
<td>150 to 200</td>
</tr>
</tbody>
</table>

Simplified model less able to absorb energy and hence more bounce
Accident Simulation Model

National Transportation Biomechanics Research Center (NTBRC) of the NHTSA Research and Development Office


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Accident Simulation Model

175 mm  
75 kg

First of its kind (pedestrian dummy) developed in 1998

Used in the development of HR-V and Odyssey

In 2001 Civic, 75 mm gap was provided between the hood and the engine
Accident Simulation Model

MADYMO

Birmingham Automotive Safety Centre (BASC): Pedestrian Research

For MADYMO (more accurate parameterisation)

PAM-CRASH *


Design for Pedestrian in Impact

Bumper
Front end profile
Pedestrian physique

Absorption of impact energy without undue deformation or acceleration

Absorption of impact energy with controlled deceleration

Front end profile
Pedestrian physique
Hood design
W/s X-mbr
Design for Pedestrian in Impact

"...solutions to the problem of achieving better pedestrian safety are often readily available, low cost and could be applied over a higher proportion of the car surface" [1]

Proactive approach

"It appears that cars will need to undergo profound changes in design to meet the required standard“ [2]

Existing design approach

Design for Pedestrian in Impact

Front Bumper:

Deeper profile/Secondary support bar below bumper/Bumper height
  Reduced pitching of leg form and bending of knee joint
Localised compliance and efficient energy absorption
  Reduced forces on the leg form

Headlamps:

Material (plastic vs glass)
Mounting location (below upper leg crush zone, back)
Mounting compliance (contradicting requirements)

Bonnet Leading edge:

Reduced stiffness at the front end
  (moving the latch and stiffeners to side and back)
Increase crush depth
  (contradicting requirements)
Design for Pedestrian in Impact

Bonnet and Fender tops:

- Increase in low stiffness region
  - Fewer hard seams (generally at the edges)
  - Alternative design and material
    (is opening the bonnet necessary?)
    (can bonnet be a structural member?)

- Increase under bonnet clearance (75 mm)

- Placing softer components on the top

- Bonnet that wraps around the sides

- Bonnet with modified inner structure

http://www.thecobraferrariwars.com/1543389.html
Systems for avoiding/softening collision with Pedestrian

- Over the hood air bag – 54”x22” deployed in 50-75 ms
  requires pre-impact sensor

- Base of the windshield air bag – two air bags deployed in 100 ms
  sensing initial impact with the pedestrian
  A-pillar to A-pillar
  Low enough not to block driver’s view

- Daytime running lights – Headlights whenever the car is running
  Increased visibility (resulted in 9% reduction)

- Laser Radar – For detecting pedestrians unto 50 yds in front
  Driver warning (visual and aural)
  Apply brakes in case of imminent collision

- Pop-up bonnet – Increases clearance between hood hard components underneath
  triggered by the initial impact (styling remains intact)

- Night vision technology – Infrared system identifies a pedestrians and warns
  triggered by the initial impact
Systems for avoiding/softening collision with Pedestrian

- 3 radar system – Triangulation to pinpoint the object
  Infrared system to distinguish between human and inanimate

- Brake assist technology – More efficient braking (assisting system)
Trends in Bumper Design


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Trends in Bumper Design

Leg to Bumper

Upper Leg to Hood Edge

Head to Hood Top

Directive 2003/105/EC
Knee bending < 21°
Knee shear < 6 mm
Tibia acceleration < 200 g

Directive 2003/105/EC
(Monitor Only)

Directive 2003/105/EC
HPC < 1000 (2/3 of area)
HPC < 2000 (1/3 of area)

EuroNCAP
Knee bending < 15°
Knee shear < 6 mm
Tibia acceleration < 150 g

EuroNCAP
Total load < 5 kN
Bending moment < 300 Nm

EuroNCAP
HPC < 1000


Trends in Bumper Design

1. Cushion the impact and provide support to limbs to limit bending of the knee
2. Active systems triggered by the impact

Cushion the Impact:

Main purpose of the bumper system – for vehicle impact

For pedestrian impact, impact energy density is much lower (~50%)

Performance criteria (e.g. allowable peak load) is different

Bumper system for pedestrian safety sacrifice vehicle damageability and increase depth of the bumper system

• Foam energy absorbers: Improve efficiency of existing foam absorbers with minimal increase in the vehicle length
• Design of contacting shape (use some energy for rotation)
• Use of multiple density foams
• Use of fluid filled foam
• Provide more space for foam (depression in the beam)
• Coring of foam (removing material on the backside of the foam)
Trends in Bumper Design

- Molded plastic energy absorbers: Molded plastic structure to absorb energy
  - ‘Egg-crate’ shapes
  - Structure with variable stiffness (changing thickness)
  - Open shells with no foam (for pedestrians only)

- Air filled energy absorbers: Constant or variable stiffness for different impacts
- Flexible or Plastic beam: Changing the structural member of the bumper
- Deploying bumper: Push out system when impact is predicted (vehicle length is not increased)
- Crush cans: Attached to the bumper beam – provide lower peak load
- Add-ons: Separate deformable structure added outside of the vehicle
- Foam encapsulated metal: Balance the two materials to achieve the goal
- Steel energy absorber: Use steel springs (with or independent of foam)
Trends in Bumper Design

Support: Distribute the load to minimise bending moment on the knee

Constrained by
Ground clearance requirement
Vehicle damageability requirement

- Fixed lower stiffeners: Additional stationary component below the bumper preventing intrusion of lower leg form (metal beam, plastic tray, engine under tray etc.)

- Deploying lower stiffeners: Deployed based on object detection or speed

- Mechanical Linkages: Deployed by pressure on the bumper through linkage

- Deploying Upper Structure: Structure to prevent upper leg form movement

- Broad Face Bumpers: Tall bumpers for additional support
How not to design/modify the front end


Sequence from the Video "The Physics of Car Crashes" by the Roads and Traffic Authority of NSW.

• European Experimental Vehicles Committee (EEVC) (in 1980s)
  European NCAP, EU

  Regulations in place for new vehicles to pass crash testing designed to mitigate head and leg injuries to the pedestrians involved in a collision

  Regulations to be made stricter starting 2010.

In the US, fewer pedestrian fatalities and increased cost have slowed the progress
Resources:

   DOE study of the pedestrian impact events and prediction of the post impact kinematics

   DOE study of the pedestrian impact events and prediction of the post impact kinematics

3. J.Hoffmann, A.Kretzschmar and Dr. M.V.Blundell, “Investigation into the use of Adaptable car Structures concepts for pedestrian impact protection”
   Resettable Active-reversible bumper and bonnet (spring, electromechanical drive, hydraulic/pneumatic drive), Sensor (Δv, m, δ)

   Bumper design alternatives for protection through cushioning
Summary

• Need for consideration of pedestrian safety has been highlighted
• Mechanics of pedestrian collision and resulting injuries have been described
• Developments in the area of simulation for pedestrian collision have been discussed
• Design concepts being developed for pedestrian safety have been discussed