# Load Carrying Structures

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## Start of crashworthiness research

# Vehicle Crashworthiness Videos

# Crashworthiness Goals

- The body structures include progressive crush zones to absorb part of the crash kinetic energy.
- Vehicles maintain integrity of the passenger compartment and simultaneously control the crash deceleration pulse.
- Accident reconstruction and analysis of vehicle crashes provide information regarding the safety performance.
- Currently, vehicle crashworthiness is evaluated in four distinct modes: frontal, side, rear and rollover crashes.

# Basic Principles of Designing for Crash Energy Management

Stiff cage Structural Concept

- Objective is to design a stiff passenger compartment structure
- Structure should have a peak load capacity to support the energy absorbing members in front of it, without exhibiting excessive deformation (intrusion)

# Basic Principles of Designing for Crash Energy Management

Controlled Progressive Crush or Deformation With Limited Intrusion

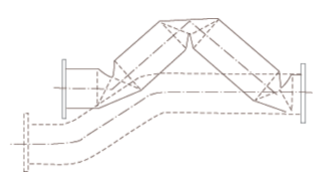
- Rear, roof, and side impact energy-absorbing structures deform upon direct impact in a mixed axial and bending mode
- Bending dominant role – low energy content
- In designs where light weight is desirable, axial mode will be a more appropriate candidate for energy absorption

# Controlled Progressive Crush or Deformation With Limited Intrusion (contd)

- Primary crush zone - relatively uniform, progressive structural collapse
  - Main energy absorbing structure- fore section of the power train compartment
- Secondary crush zone -structural interface between the energy absorbing and occupant compartment structures
  - Avoid excessive load concentrations
- Design strategy
  - soft front zone- to reduce the vehicle's aggressivity in pedestrian-to-vehicle and vehicle-to-vehicle collisions
  - Two stiffer zones - primary and secondary.
  - Primary – main EA structure in the fore section
  - Secondary – structural interface between absorber and compartment
    - Extends to the dash panel and toe board areas

# Axial / Bending Mode

- Axial
  - Most Effective
  - Difficult to achieve
- Bending
  - Local hinges are formed
  - Structures designed for axial mode can also fail in this mode



# Mahmud and Paluszny

- Local buckling at critical loads
- Leads to collapse and subsequent folding
- For low t/b ratios
  - Large irregular folds
  - Crumpling
  - Global Buckling or
  - Bending type instability

Folding pattern of thin-walled box with very small thickness/width ratio



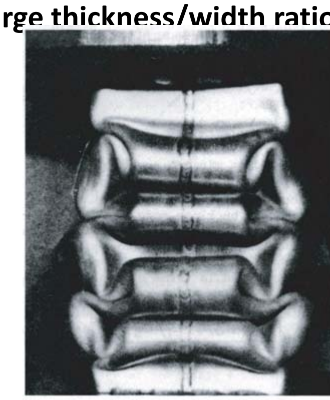
# Experimental Results

- For high t/b ratios
  - Buckling loads more than material strength
  - Stable even with geomtrical / loading imperfections
  - Limit for compactness

$$(t/b)^* < 0.48[\sigma_y(1-\upsilon^2)/E]^{0.5}$$

  - Similar formulations for rectangular sections

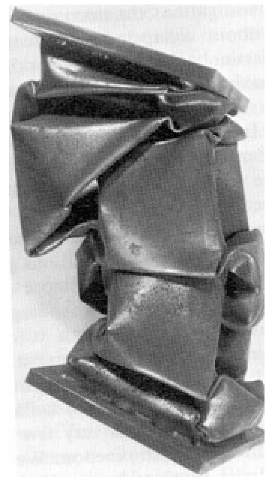
**Folding pattern of thin-walled box with large thickness/width ratios**



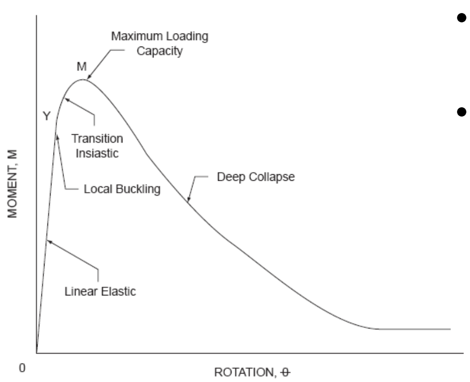
Figures from Priya Prasad , 2005

# Bending modes

- Local buckling initiates a plastic hinge
  - When compressive stress reaches a critical value
- Further increase of load causes more hinges
- Overall collapse mechanism is controlled by hinge locations



# Moment-rotation characteristics of thin-walled beam




- Very little energy absorbed in that initial deformation
- Most of the collision energy is converted into the plastic deformation energy of the hinge, which corresponds to the area under the tail segment of the M-θ curve

Figures from Priya Prasad , 2005

## So, .....

- Structure sections have to be chosen with appropriate t/b ratios and sections to get the crushing behavior needed
- Structural imperfections introduced to initiate plastic hinges
- Local buckling can also be estimated based on FE or other analytical techniques
  - Experimental / empirical relations are commonly used
- Keep peak loads under limits so that occupant cabin remains intact

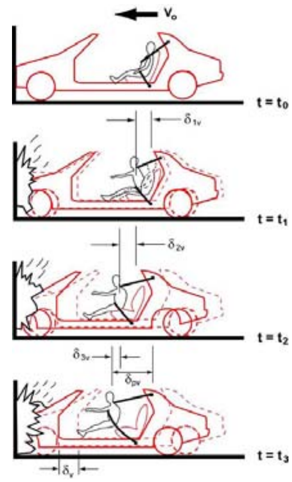
## Surviving high speed crashes

- Essential to use the frontend crush and available distance between the occupant and the interior.
- Accomplished when a restraint is used.
- The air bag, energy absorbing steering column and safety belts are all restraint systems that slow the occupant shortly after the vehicle starts to decelerate.
- Part of the distance is lost in a harness by slack and belt stretch.
- The distance between the driver and the steering wheel is lost in the case of the energy-absorbing column restraint, and
- the distance of the front-end crush and occupant space traversed during the sensing and deployment time for the air bag are lost.
- However, the remaining useful distance does increase the survival velocity appreciably.

# Compatibility Between Restraint System and Vehicle Front Structure

- Vehicle front needs to be designed for compatible crush characteristics with restraints.
- $\delta_1$ – dummy moves at const speed
- $\delta_2$ – increasing deceleration
- $\delta_3$ – constant deceleration
- $\delta_v + \delta_{p/v} > \delta_p$

  $\delta_{p/v}$ is the occupant displacement with respect to the compartment

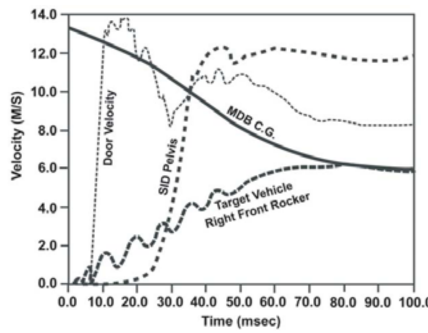


**Idealized model**

# Side impact Crash Tests

# Side Impact Analysis

- Velocity profiles obtained by the numerical integration of accelerometer data taken from the following locations:
  - Center of gravity (CG) of the moving deformable barrier (MDB)
  - Non-impacted left-hand rocker of the target vehicle
  - Door inner panel at the armrest
  - Side Impact Dummy (SID) pelvis

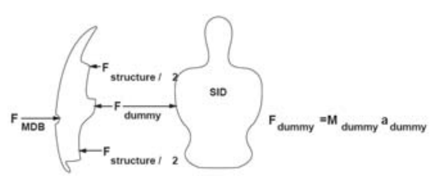


**Typical velocity profile in side impact**

Figure from Priya prasad, 2005

# Side Impact -FBD

- The forces acting on the door are:
  - $F_{MDB}$ is the punch-through force of the MDB acting on the door
  - $F_{structure}$ is the body side structural resistance of the target vehicle that resists door intrusion.
    - structural resistance is provided by door support frame.
    - Force is the integral of the door support frame reaction pressures acting on the door peripheral areas and is shown as one-half of its concentrated load in two parts
  - $F_{dummy}$ is the door-to-dummy interaction force, also is the reaction force acting on the dummy

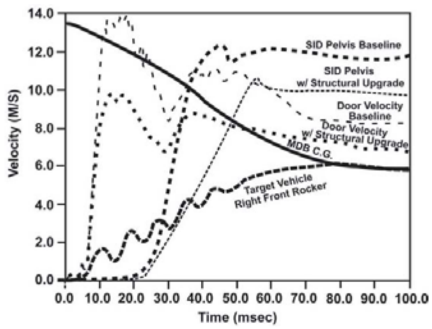


**Door and SID "free-body" diagrams**

Figure from Priya prasad, 2005

# Structural Upgrading

- The crash event between the MDB and the target vehicle is shortened.
- MDB slows at a faster rate while the struck vehicle rigid body motion speeds up at a higher rate.
- The door intrusion and intrusion velocity are reduced.
- The dummy pelvis, hit by a slower intruding door, is subjected to a milder acceleration as evident by the slope the dummy pelvis velocity curve.
- The structural upgrade weight penalty to achieve this effect is enormous.
- The weight penalty is estimated at more than 18 kg (40 lbs) for a 2-door compact vehicle.
- TRL has shown that certain structural upgrading of the vehicle body side structure could lead to an undesirable intrusion profile of B-pillar/door by tilting inboard at the “waistline” and concentrating the impact load on the occupant in the thorax region.
- A more desirable crush pattern for the B-pillar/door is to remain upright during side impact for a more evenly distributed impact loading on the occupant.

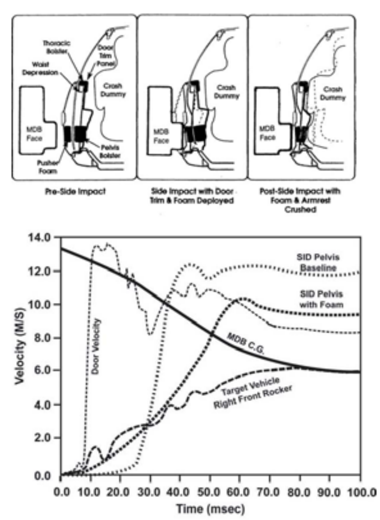



**Effects of a hypothetical structural upgrade**

Figure from Priya prasad, 2005

# Deployable Door trim

- The crush duration between the MDB and the target vehicle will remain unchanged from the baseline
- Door velocity profile will remain unchanged
- Deploying load-limiting foam cushion contacts the dummy pelvis early in the crash event and accelerates it away from the intruding door sooner than that of the baseline
- Consequently, the dummy pelvis will experience a milder acceleration as evident from the slope of its velocity history
- Strategy is to use a deploying door trim with the load-limiting foam cushion behind it to quickly push the stationary SID away from the intruding door steel at a controlled rate.



THANKS