Truck Occupant Protection Considerations in Heavy Vehicle Crashes

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A Fatal Crash
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Fundamental Question

• What force levels should safety critical attachments on heavy trucks be designed to withstand?
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• What force levels occur in real-world truck crashes?
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- What force levels occur in real-world truck crashes?
Australian Context

- Longer trucks with higher Gross Combination Weights. B-doubles, B-triples, Roadtrains, ...
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• Stiffer trucks with front- and rear-underrun barriers.
Australian Context

- Longer trucks with higher Gross Combination Weights. B-doubles, B-triples, Roadtrains, ...
- Stiffer trucks with front- and rear-underrun barriers.
- It has been assumed until now that the mechanical design of the truck is not a hazard to the truck occupant.
Attachments of Interest

• Suspension seat installations.
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- Cab to Chassis attachment.
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• Mechanical couplings

ADR 62 / ECE Reg 55 have no proof-strength test. A fatigue test is required at the 60% force level of the assigned D-Value.
Attachments of Interest

- Load restraints
Load Restraint
Collision Dynamics

• Elastic Collisions.
Collision Dynamics

- Elastic Collisions.
- Plastic Collisions.
Collision Dynamics

- Elastic Collisions.
- Plastic Collisions.
- Real-World Collisions.
Collision Dynamics

(a) Beforehand

(b) Engagement

(c) After - elastic collision. No energy absorption

(d) After - Plastic collision - Vehicles move together

(e) After - Separated vehicles
Collision Dynamics

Crush Length (CL) = a + b
Collision Dynamics

• Conservation of Momentum applies if braking and dragging forces are negligibly small.
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- For an elastic collision there is no energy absorption.
Collision Dynamics

• Conservation of Momentum applies if braking and dragging forces are negligibly small.
• For an elastic collision there is no energy absorption.
• For a plastic collision ...
Plastic Collision Forces

\[ V_{2f} = V_{2i} \cdot \frac{M_2}{(M_1 + M_2)} = \varepsilon_{p2} KE_{initial} \]

\[ \varepsilon = 1 - \frac{KE_{final}}{KE_{initial}} \]

\[ \varepsilon_{p2} = \frac{M_2}{(M_1 + M_2)} \quad \varepsilon_{p1} = \frac{M_1}{(M_1 + M_2)} \]

\[ F_{av} = \varepsilon_{p1} KE_0 / CL \]
Collision forces for two 64.5t B-Doubles

Impact Forces v Speed
with Crush Length as parameter

Impact Force kN

Impact Speed km/h

Front
Coupling 1
CL=0.25m

Front
Coupling 1
CL=0.5m

Front
Coupling 1
CL=0.75m

Front
Coupling 1
CL=1.0m

Front
Coupling 1
CL=1.5m

D-Value
3 (D-Value)
King Pin strength (pushing)
Collision deceleration for two 64.5t B-Doubles

Deceleration vs Speed for Five Crush Lengths

Impact Speed (km/h)

Deceleration (-g)

0 2 4 6 8 10 12 14

0.25m
0.5m
0.75m
1.0m
1.5m
Linear Spring Model

Vehicle 2 initial speed $V_{2i}$

Vehicle 1 initial speed 0

Linear spring model

Uncompressed length $X_0$

Compressed Length $X$

Force = $F$

$F = k(X_0 - X)$
Linear Spring Model

Speed

$V_{2i}$

$V_1$

$V_2$

Plastic collision

Final Vehicle 2 speed - Elastic

Final speed $V_1$ and $V_2$ – Plastic

$V_{2f} = \varepsilon_{p2} \cdot V_{2i}$

Final Vehicle 1 speed - Elastic

$t_{elastic} = 2 \cdot t_{plastic}$

$t_{plastic} = \frac{\pi}{2} \cdot \sqrt{M_1 M_2 / k (M_1 + M_2)}$
Linear Spring Model

Collision energy

Plastic collision

\[ \varepsilon_{p1}E_0 = \frac{1}{2} M_2 M_1 V_{2i}^2 / (M_1 + M_2) \]

Elastic

Time t

\[ t_{\text{plastic}} = \frac{\pi}{2} \sqrt{\frac{M_1 M_2}{k(M_1 + M_2)}} \]
Linear Spring Model

\[ V_2(t) = \varepsilon_{p2} V_{2i} + V_{22} \varepsilon_{p1} \sqrt{1 - \varepsilon / \varepsilon_{p1}} \]

\[ V_{1f} = \varepsilon_{p2} V_{2i} /+ V_{22} \varepsilon_{p2} \sqrt{1 - \varepsilon / \varepsilon_{p1}} \]

- Speed
- Force

\[ F_{av} = \varepsilon_{p1} E_0 / CL \]
Force Dispersion
Real-World Behaviour

- Buckling behaviour
- Yielding and bending behaviour
- Returned Energy
- Effective linear spring characteristic

Forces vs. Interaction distance

- Absorbed Energy = $\varepsilon_{p1}E_u$
Review

• Truck crash forces will increase with truck weight and stiffness. The relevant index is:

$$\sqrt{k \cdot M_2 \cdot M_1 / (M_1 + M_2)}$$
Review

• Truck crash forces will increase with truck weight and stiffness. The relevant index is:

\[ \sqrt{\frac{k \cdot M_2 \cdot M_1}{M_1 + M_2}} \]

• Every real-world collision has a ‘plastic’ moment.
Review

- The average crash force up to the ‘plastic moment’ can be easily calculated.
Review

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• The average force under-estimates the peak force.
Review

• The average crash force up to the ‘plastic moment’ can be easy calculated.
• The average force underestimates the peak force.
• Forces are absorbed and dispersed along the truck chassis. This reduces the peak forces.
Review

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• The average force underestimates the peak force.
• Forces are absorbed and dispersed along the truck chassis. This reduces the peak forces.
• For crashes between heavy and stiff trucks, the decelerations may > 10g level.
Recommendations

- A design deceleration reference level should be established so that designers have a guide to necessary strength.
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• A design deceleration reference level should be established so that designers have a guide to necessary strength.

• The strength requirements in the mechanical coupling rules ADR 62 and ECE Regulation 55 should be reviewed.
Finally

Thank you for listening