Abstract. In car/truck collisions, the size, weight, and stiffness mismatch results in much larger structural deformation of the car compare to the truck. This is further aggravated when the passenger vehicle trends beneath the rear or side of the taller truck. Truck under-ride increases the probability of death or serious injury for smaller vehicle occupants due to intrusion of parts of both small car and the truck into the smaller car passenger compartment. A computational technique is utilized in this study to quantify the influence of a side guard attached to a large truck in reducing the intrusion to the car and thus reducing the injury sustained by the occupants of a car in side impact scenarios. A parametric study is utilized to identify the critical guard height resulting in optimum cabin deceleration and compartment intrusion of the small car.

1. Introduction and Background

When a large truck or trailer makes a lane change, an adjacent car may not be readily perceived by the truck driver, and the car can be trapped in the long open side of the trailer. [1]. In the US, under-ride guards are required only for the rears of large trucks, although the review of fatal truck-car crashes databases indicates that fatal under-ride crashes involving the sides of large trucks are almost as common as fatal rear under-ride crashes [2].

The prevention of passenger compartment intrusion (PCI) is clearly the primary purpose of having an under-ride guard. However, the acceleration transmitted to the driver of the small car due to impact of lower side guard of the truck with the car’s main frame, is also important.

2. Methodology, Results and Discussion

The validated finite element models of a small- and a mid-size car are used as passenger cars, impacting a rigid side guard of a large truck. To show the effect of installation of the side guard, a rigid guard structure is attached to the truck side/rear at different ground heights.

According to insurance institute for highway safety (IIHS), the PCI is measured at different parts which are crucial in determination of the injury to the occupants [3]. A weighted normalized passenger compartment intrusion \( NPCI_w \) is defined in this study as:

\[
NPCI_w = \alpha \frac{\delta_{sx}}{\delta_{sx0}} + \beta \frac{\delta_{sz}}{\delta_{sz0}} + \eta \frac{\delta_{ax}}{\delta_{ax0}} + \gamma \frac{\delta_{ix}}{\delta_{ix0}} + \lambda \frac{\delta_{fx}}{\delta_{fx0}}
\]  (1)

where the \( \alpha, \beta, \eta, \gamma, \) and \( \lambda \) are the weight factors of each parameter affecting the \( NPCI \). In Eqn. (1) \( \delta_{sx} \) and \( \delta_{sx0} \) are the steering wheel backward and upward displacements respectively, \( \delta_{sz} \) is the closing distance between A- and B-pillars, and \( \delta_{ax} \) and \( \delta_{ix} \) are the instrument panel and the footwell backward displacement respectively. The denominator values are defined as reference values of each parameter according to IIHS and European Economic Community, EEC [3, 4]. Considering the same level of importance for all parameters, Eqn. (1) could then be written as:

\[
NPCI = 0.2 \left( \frac{\delta_{sx}}{\delta_{sx0}} + \frac{\delta_{sz}}{\delta_{sz0}} + \frac{\delta_{ax}}{\delta_{ax0}} + \frac{\delta_{ix}}{\delta_{ix0}} + \frac{\delta_{fx}}{\delta_{fx0}} \right)
\]  (2)

The acceleration level sustained by the driver can be shown as proportional to the total acceleration applied to the vehicle center of gravity for the same scenario, as:

\[
A_p = k A_{VCG}
\]  (3)

where the \( A_p \) and \( A_{VCG} \) are the magnitudes of passenger transmitted acceleration and vehicle center of gravity acceleration respectively. For consistency in all impact scenarios, the frontal impact of the small car with rigid-wall at the speed of 30 mph is defined as a reference test according to the EEC for the steering wheel protection in frontal crash. By dividing the \( A_p \) to the acceleration of the same point at the reference test, the normalized acceleration of car occupant can be obtained as:

\[
NA_p = \frac{A_{VCG}}{A_{VCG0}}
\]  (4)

The injury potential of the driver of the under-riding car also depends on both the \( NPCI \) and the acceleration applied to the driver:

\[
IP_r = \mu NPCI + \rho NA_p
\]  (5)

in which \( \mu \) and \( \rho \) are the weight factors for each parameter and \( IP_r \) is the relative injury potential. Considering the same weight factor for all parameters, the injury potential can be re-written as:
To validate the guard impact scenario, the simulation of a mid-size car impacting with a rigid guard is validated against the NHTSA Ford-Taurus under-ride test. It illustrates a fairly acceptable agreement in gross pattern and peak values.

Two different impact configurations, the 90 degrees impact and the 45 degrees impact, are conducted in this study. Fig. 1 depicts the after-impact configurations of the small car impacting at 90 degrees impact angle the truck with and without side guard at 50 mph. Figs. 2 and 3 show the NPCI and IP for the low and high-speed impacts of the car at different impact angles for all side guard heights.

The impact angle between the under-riding vehicle and the truck affects the pattern of the damage and the way the impact energy is dissipated. If the angle of impact is relatively small, the vehicle will be in contact with the trailer over a larger distance and slide along the side of the trailer. This will expose the under-riding vehicle to a greater opportunity to contact the underbelly structures. Also a significant amount of energy may be dissipated as the vehicle moves and slides along the side guard.

The transmitted acceleration of the small car center of gravity depends on the directional stiffness of the impact and the mass of both small car and trailer as well. However, the sliding of the small car along the truck side guard slightly attenuates this acceleration. Increasing the guard height from the ground, the acceleration applied to the small car mitigates due to less probability of the impact of the rigid guard with under-riding car’s stiff components such as sub-frame and suspension components. As the size of the impacting car increases, the transmitted acceleration increases and the level of PCI decreases quite fast. As a result, the relative occupant injury potential decreases although non-linearly.

For the 90-degree impact of the small car with no guard or large guard height truck, the impact of the car parts with the various parts of the truck at the same time and at the different locations results in the low acceleration and PCI in the car. However the under-riding of the small car can take place. This might lead to a disastrous situation for the case for which the truck has a relative longitudinal impact velocity. Hence, these cases are not desired in the design of the truck and trailer side guard. This is shown in graphs by the fading red color starting at the side guard height of 30 in.

For low-velocity impacts, the impact of the truck rigid guard occurs with the outer body parts and due to less impact energy, the deformation of the outer body will absorb all the impact energy. This will avoid the impact of the relatively rigid chassis, suspension, or engine components of the under-riding car with the rigid guard.

3. Conclusion

It was observed that the size of the impacting car poses a significant effect on the passenger compartment intrusion as well as injury potential to the occupants. The smaller the size of the impacting car is, the lower the height of the side guard is required to keep the impact in the safe region. For a small car, addition of the side guard reduces the probability of severe injury of occupants by about 250% compared to no guard configuration. Further it prevents the under-riding probability of the car which increases the injury potential catastrophically. As long as the maneuverability of the large truck is in the desirable range, any design between the heights of 20 to 23 in seems to have the lowest injury potential to the small car occupants.

References


Fig. 1: The small car/truck impact with and without side guard at impact speed of 50 mph and 90 deg. impact angle

a) 90 degree, 50 mph impact, 22 in (560mm) guard height

NPCI=1.2

NA₃=1.4

IP=1.24

b) 90 degree, 50 mph impact, no side guard

NPCI=1.3

NA₃=1.5

IP=1.36

Fig. 2: Small-size car NPCI for low and high-speed impacts

Fig. 3: Small car occupant injury potential