

OCCUPANT AND VEHICLE RESPONSE FOR OFFSET POLE CRASH SCENARIOS

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ABSTRACT

Vehicle impacts with fixed roadside structures, such as poles, constitute a significant portion of road fatalities in North America. The purpose of this study was to evaluate occupant response in pole crash scenarios for varying offsets, and to compare the current occupant-based metrics with vehicle-based metrics. A Hybrid III ATD was integrated with a mid-size sedan equipped with seatbelts and an airbag. Impacts with deformable or energy absorbing and rigid poles were investigated. The predicted response was higher for the rigid pole, and varied significantly with offset from the vehicle centreline. The deformable pole resulted in lower levels of predicted injury compared to the rigid pole for the impact scenarios investigated in this study.

INTRODUCTION

Vehicle impact with fixed roadside structures can result in significant occupant injury. In 2009, the Fatality Analysis Reporting System reported 1759 fatalities resulting from crashes involving poles (National Highway Traffic Safety Administration FARS, 2011). Recent work has demonstrated that offset impacts (offset from the vehicle centreline) may result in different vehicle and occupant kinematics compared to central impacts for deformable and rigid poles (Lockhart et al., 2012). The goal of this study was to apply previously developed coupled vehicle, occupant, restraint and pole structure models to investigate occupant kinematics and the potential for head and chest injury in offset crash scenarios. This study is an extension of research performed by Lockhart et al. (2012).

METHODS

A detailed human surrogate model (Hybrid III v7.1.6 50th percentile male, Humanetics Innovative Solutions Inc.) was integrated with a seat model and restraint system into a mid-sized sedan (2001 Ford Taurus, NCAC) and validated using NHTSA frontal

crash tests. The energy absorbing pole and rigid pole models were developed, validated against a physical pendulum test, and coupled with the vehicle-occupant model (Lockhart et al., 2012). The impact location was varied left (driver side) and right (passenger side) from the vehicle centreline. The current North American Test standard (Ross et al., 2007) uses different test levels (weight and initial velocity of the vehicle) depending on the application of the roadside structure. The range of test vehicle weights is 700, 820 or 2000 kg with an initial velocity of 30, 50, 70 or 100 kph. In this study we investigated a mid-sized sedan (1635 kg) at impact velocities of 50 and 70 kph. Occupant response was investigated by calculating the potential for head injury (HIC_{15}) and thorax injury (chest compression).

Rigid pole model

The rigid pole (Figure 1) was modeled as a column of hexagonal cross-section with a major diameter of 330mm (Ontario Provincial Standard Specification, 2010), attached rigidly to the ground. Steel material properties were used for contact purposes only and the pole did not deform during the impact. The model consisted of 25,200 shell elements.

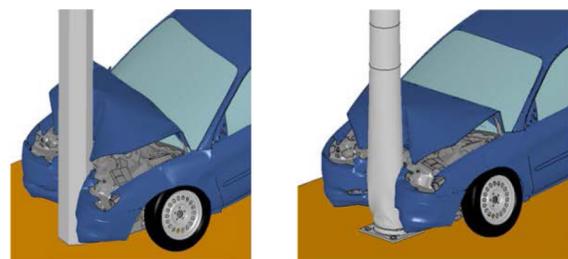


Figure 1. Rigid [Left] and deformable [Right] pole impact.

Energy absorbing pole model

The energy absorbing pole was modeled as a 12.34m high tapered column with 7 sections, and fixed to the

ground (rigid) with a 12.7mm thick base plate and four deformable bolts (Figure 1). The nominal diameter was 329mm in the impact zone and the mesh comprised 215,344 solid elements and 33,280 shell elements, 10x10mm in size in the impacted area. An incremental plasticity material model with isotropic hardening was implemented using tensile material properties from an actual pole. The material model was rate independent following the model validation given by Lockhart et al. (2012).

Vehicle, restraint system and occupant models

The vehicle model used for this study was a 2001 Ford Taurus mid-sized sedan (1,057,113 elements), developed by NCAC (Opiela, 2008) and validated under frontal impact conditions. The model was enhanced to include a seat and restraint system and was validated using available NHTSA frontal impact crash data (Lockhart et al., 2012).

The 50th percentile Hybrid III ATD was positioned in the seat during a separate simulation, prior to the crash simulation, to achieve an equilibrium position with the ATD. The seat foam was pre-compressed and integrated with the standard seat frame. The ATD was then coupled with a restraint system including a single stage airbag, seatbelt with a pre-tensioner (60mm in 7.5 ms) and a 6 kN force limiter. Two-dimensional shell elements were used for the seatbelt sections in contact with the ATD and 1-D elements were used for the parts of the belt that were outside the contact zone. The belt was fit to the occupant using a pre-processor fitting option (LS-PrePost, LSTC, Livermore, CA).

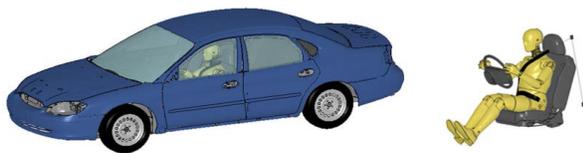


Figure 2. ATD seated in the car and coupled with the restraints.

Impact at the vehicle centreline (0mm offset, Figure 3) was the reference case, and the pole location was varied symmetrically on both sides of the centerline. The 570mm offset corresponded to the vehicle axial crush structure being centred on the pole.

Offsets outboard of the crush structures were also considered; however, this scenario requires further investigation and model development to verify the interaction with the vehicle tire, wheel and suspension during the impact. Therefore, the injury

assessment for these offsets is not included in this paper. All the offset simulations were performed for both deformable and rigid pole and relevant results are presented.

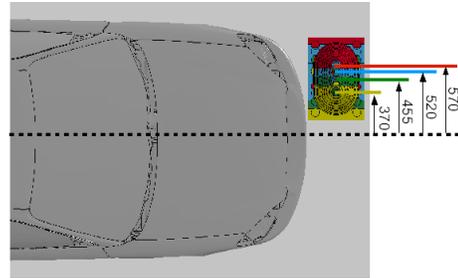


Figure 3. Offset locations from the vehicle centreline (top view, driver side shown for clarity).

Injury criteria

The injury criteria considered were HIC₁₅ and chest compression, calculated according to the Canadian Motor Vehicle Safety Standard (CMVSS) 208 Protection Criteria for Frontal Impact Tests. Future studies will consider the knee-thigh-hip (KTH) injury criteria to assess lower extremity response.

Head injury risk was evaluated using the HIC₁₅ criterion calculated based on the resultant head CG acceleration over a 15ms duration. The threshold values determined by US and Canadian federal regulations are given in Table 1. The threshold value of 700 corresponds to 31% probability of a skull fracture for a 50th percentile male (Schmitt, 2010).

Chest injury risk was evaluated based on chest compression measured as the maximum deflection between the spine and the sternum of the ATD. A CC value equal to 50mm (Transport Canada threshold) corresponds to a 50% probability of the serious (AIS 3+) chest injury.

Table 1.
Occupant-based criteria for the 50th percentile male

Federal code	Head injury criterion	Chest injury criterion
FMVSS 208	HIC ₁₅ <700	CC<63mm
CMVSS 208	HIC ₁₅ <700	CC<50mm

Vehicle based metrics

A vehicle-based metric, recommended by the National Cooperative Highway Research Program (NCHRP) 350 report, was used in this study. The Occupant Ride Down Acceleration (RA) is determined from the vehicle kinematics and has a maximum value of 20.49 G with a preferred limit of 15 G. This value is determined from the centre of gravity of the vehicle, where acceleration data was filtered with a 10ms moving average in accordance with the NCHRP 350 report. Another vehicle-based metric, Occupant Impact Velocity or OIV, was not investigated in this study since previous work has shown that this metric produces very different results and trends compared to the occupant-based metrics.

RESULTS

The occupant injury metrics are presented for both rigid and deformable poles at different offsets for the 50 kph impact speed (Figures 4 and 5). The negative offset values correspond to the passenger side, and positive offset values correspond to the driver side.

HIC₁₅ values did not exceed the threshold of 700 for the 50 kph impacts. For the deformable pole, the highest HIC value was predicted for a 370 mm offset from the vehicle centreline on the driver side. The rigid pole impacts result in higher values of HIC and the maximum value for the driver occurred for impacts on the passenger side of the vehicle, at 370mm offset. The difference in HIC₁₅ value for the centerline impact was significant between the rigid and deformable poles (373 versus 78).

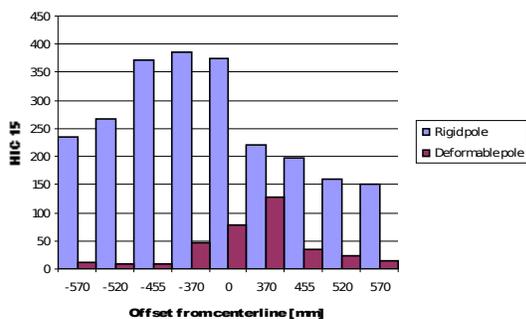


Figure 4. Head Injury Criterion values at different offsets for both pole types at 50kph impacts.

The chest compression values for the deformable pole were symmetric about the vehicle centreline, while the values were higher for the passenger side offsets in the rigid pole impacts (Figure 5).

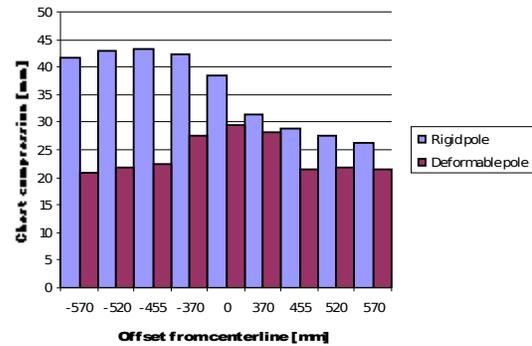


Figure 5. Chest compression values at different offsets for both pole types at 50kph impacts.

DISCUSSION

The occupant and vehicle injury metrics were normalized using the threshold values (Table 1) for comparison purposes.

For the deformable pole, the predicted occupant response depended on the offset location. The maximum HIC₁₅ value was predicted for the 370mm driver side offset while the chest compression values were highest for the vehicle centreline, from 370mm passenger to the 370mm driver offset (Figure 6). In all cases, the injury criteria values decreased when the pole was aligned with the vehicle crush structure.

The vehicle based injury metric (Ride Down Acceleration or RA, Figure 6) was normalized using the threshold value of 20.49 G and compared to the occupant based metrics trends (Figure 6). The RA values over-predicted injury, compared to the occupant based metrics and would be very conservative if the preferred limits were considered. The highest RA values were measured for the vehicle centreline and decreased when the offset moved towards the crush structures on either side.

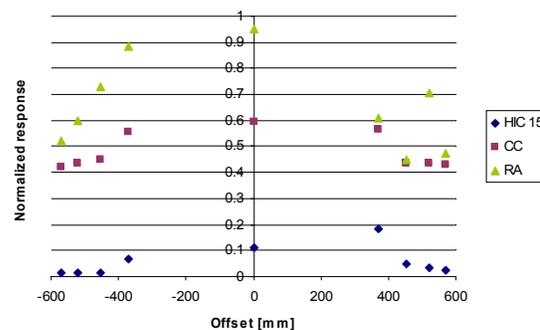


Figure 6. Normalized occupant and vehicle metrics – deformable pole at 50kph.

For 70 kph impacts (Figure 7), similar trends were noted; however both HIC₁₅ and chest compression values were lower since the pole sheared off at the base with a reduced effect on the vehicle kinematics.

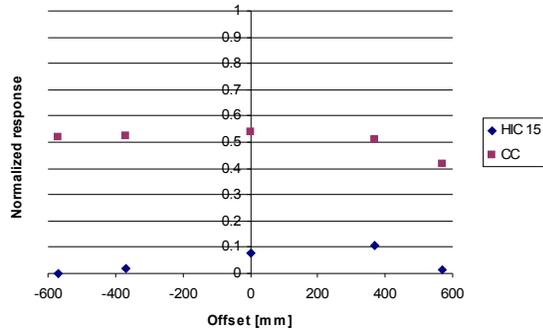


Figure 7. Normalized occupant metrics – deformable pole at 70kph.

For the rigid pole impacts at 50 kph, the passenger side offsets resulted in higher predicted injury risk (Figure 9) compared to the deformable pole. The maximum value of chest compression was predicted when the impact location was aligned with the vehicle crush structure on the passenger side and the maximum value for the HIC₁₅ was predicted for the 370mm offset on the passenger side. Both criteria predicted decreased injury risk when the impact moved towards the vehicle crush structure on the driver side where the responses were a minimum.

The increase in response for passenger-side impacts was related to the occupant kinematics and interaction with the seatbelt (Figure 8).



Figure 8: Comparison of the occupant kinematics for the 520mm passenger [Left] and 520mm driver side [Right] rigid pole offset impact at the final stage of the simulation (160ms). Front view.

For driver side offsets, the shoulder belt slid upwards towards the neck and led to a decrease in the chest compression value. For passenger side offsets, rotation of the vehicle caused higher belt loads on the occupant leading to higher chest compression and

increased head acceleration values, particularly in the lateral direction, resulting in higher predicted HIC₁₅ values. The 70 kph rigid pole simulations terminated early due to the aggressive nature of the impact; however, the data available for the limited simulation time suggests that the occupant and vehicle-based injury metrics would be exceeded in all cases.

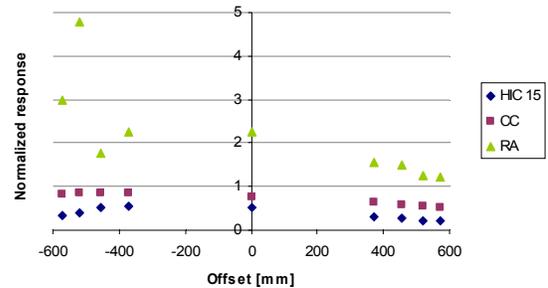


Figure 9. Normalized occupant and vehicle metrics – rigid pole at 50kph.

The RA trend (Figure 9) was in reasonable agreement with the trends for HIC₁₅ and CC. The highest values were measured for the passenger side offsets and decreased when the impact moved towards the crush structure on the driver side.

CONCLUSIONS

The predicted response and injury risk for frontal pole impacts was found to depend on the impact location relative to the vehicle centreline. In general, impacts that were directly aligned with a vehicle crush structure resulted in the lowest predicted response for HIC₁₅ and chest compression. Trends with offset distance were consistent between 50 and 70 kph impacts for the deformable pole, with the maximum response occurring for impacts located between the vehicle crush structures. The maximum response for the rigid pole impacts was predicted for offsets on the passenger side of the vehicle, attributed to vehicle rotation and occupant interaction with the shoulder belt. The vehicle-based metric, Ride Down Acceleration, over-predicted injury for both the rigid and deformable pole. The deformable pole resulted in lower levels of predicted injury compared to the rigid pole for the impact scenarios investigated in this study.

LIMITATIONS OF THE STUDY

A standard seating position was considered in this study. Future studies should also consider the effect of occupant position on predicted response. The

simulations were run for 200ms, which covers initial contact between the pole and the vehicle as well as between the ATD and vehicle interior; however, secondary impacts between the ATD and vehicle interior or between the vehicle and surrounding structures were not considered. A standard mid-sized sedan was used for this study which represents only part of the car fleet in terms of the mass and geometry. The maximum impact speed was limited by the available validation data for the numerical models.

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