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Effect of Vehicle Speed on Injury of Child Passenger in Frontal Crashes

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Abstract

Speed is major cause of death to vehicle occupants especially children. Studying effect of speed on child injury severity is crucial to establishing safety regulations. This work investigates the effect of vehicle speed on the severity of injury sustained by three-year-old (3YO) children. Restrained 3YO child dummy Finite Element (FE) model was used to conduct crash simulation at impact speed of 40km/h, 46 km/h and 48 km/h in Ford Taurus FE model using LS DYNA code. Vehicle deceleration was found to increase with increase in speed. Head Injury Criteria (HIC36), HIC15, chest acceleration (CA), chest severity index (CSI), chest deflection (CD) and neck moment (NM) were evaluated and compared with National Highway Traffic Safety Administration (NHTSA) threshold. It was found that the injury parameters sustained by 3YO child increased with increase in speed. HIC36 was found to be above threshold for 48km/h and 46km/h. Speed of 40 km/h had all the injury values below the threshold. Chest deflection was lower than the threshold for all the three speeds. Chest acceleration and neck moment were also presented and their values also increase with speed, though, NHTSA doesn't capture their threshold. The study disseminates information on the effect of speeding on child injuries in frontal crashes for road safety agents and vehicle designers and users. Limiting vehicle speed is therefore crucial to child occupant protection.

Keyword: chest acceleration, crash dummy, head injury criteria, vehicle speed

INTRODUCTION

Speed is the major factor responsible for severity of injuries in vehicle accidents. It causes death to adult and child car occupant. Vision zero or sustainable safety in Europe is aimed at minimizing death or serious injuries as results of accident from road users (Jurewicz et al. 2016). This vision can be achieved by reducing kinetic energy of the moving vehicle or avoiding impact. Kinetic energy can only be reduced by limiting speed, since mass of vehicle can't be reduced by public. In developing countries over speeding is considered as major cause of accident and the injury sustained especially to child occupants is fatal.

Vehicle moving at high speed is moving with high kinetic energy which on impact will be conserved by deformation of vehicle body structure and part of it will be transmitted to vehicle occupant. Child Restraint System (CRS) is used to hold child in position to reduce the

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effect of decelerations. High deceleration transmitted to child occupant on impact lead to injuries especially to head, neck and chest. Studies on child occupant is focused on restrained system design (Jermakian & Edwards, 2017; Jiang, 2022; Wu et al. 2023) with little attention to effect of speed on the injury outcomes.

Effect of speed on injury severity of adults has been reported in literature (Rafukka et al. 2018) while it has not been well studied for 3YO child. Children differ from adult in biomechanical response on impact. However, few researches investigated the effect of injury of children in frontal crashes due to lack of reliable physical data for validation (Elmarakbi et al. 2013). FE simulation using available crash dummy FE model could be a good method to study child response during impact. The aim of this work is to investigate the effect of impact speed on child occupant injuries for the purpose of revealing the negative impact of over speeding to child passenger.

METHODOLOGY

FE modelling and simulation

Hybrid III 6 year old Finite Element Model Version: LST0.104.BETA, available on LSTC website, which is currently the latest child model, was used in this study. It was developed by LSTC in cooperation with National Crash Analysis Centre (NCAC) and made available to LS-DYNA users. The model was validated based on the certification tests contained in the Code of Federal Regulations, Title 49, Part 572, Sub-part N. It contains 199,102 nodes, 127,154 solid elements, 45,032 shell elements and 142 beam elements (LSTC, 2013). LS-DYNA specific "History" beam elements and nodes are positioned in some specific locations of the body in order to provide value of response required for the extraction of occupant injury criteria. The dummy was scaled to 3YO child anthropometric data using morphing technique in LS Dyna. Scaled child dummy was positioned on rear seat of the vehicle using LS PrePost dummy positioning tool and the constant downward gravity was applied in z-direction as shown in Figure1. AUTOMATIC_SURFACE_TO_SURFACE definition with static and dynamic friction coefficient of 0.3 and segment based soft contact option with a scale factor of 0.1 was defined between the dummy and car seat.

Ford Taurus vehicle FE model publicly available for research purposes in NCAC website (NCAC, 2015) was used in the crash simulation. Taurus model front-end structures were meshed with fine mesh because it is used for frontal impact assessment. The rear portion was meshed with coarse elements so as to reduce computation time without affecting the simulation results quality. Most parts of the vehicle were modelled mainly using shell elements of quadrilateral and triangular sections and with piecewise linear plasticity material model. The parts were joined using rigid body and spot-weld constraints. Figure 1 shows the 3YO child dummy in the car FE model in frontal impact simulation.

Figure 1 Restrained three year old child FE model in vehicle FE model for frontal crash test

Simulation setup

A frontal impact test was a conducted with 3YO dummy in the rear vehicle seat. Impact speed of 48 km/h was chosen based on Federal Motor Vehicle Safety Standards (FMVSS) 208. Simulation was carried out for 140ms time duration and total simulation time was 10 hrs. The control options are set according to 6YO HIII dummy manual. The time step scaling factor was reduced from default of 0.9 to 0.7 in *CONTROL_TIME_STEP card. Injury parameters were evaluated for 40 km/h, 46 km/h and 48 km/h speeds from the dummy FE model and compared with NHTSA thresholds.

Injury parameters

Injury in the head can cause brain concussion or affect some sensory organs (Ji, 2015). HIC is the main criteria used in assessing the head injury risk on impact. It is the standardized maximum integral of head acceleration measured at the centre of gravity within a specified time windows. It is calculated based on the equation (Bois et al. 2004; Henn, 1998):

$$\boldsymbol{HIC} = \left[\frac{\boldsymbol{1}}{\boldsymbol{t_2 - t_1}}\int_{t_1}^{t_2} \boldsymbol{a_{result.}} \cdot \boldsymbol{dt}\right]^{\boldsymbol{2.5}} \cdot (\boldsymbol{t_2} - \boldsymbol{t_1}) \quad (1)$$

Where t_1 and t_2 are the initial and final times of intervals within which HIC reaches a maximum value (Liu et al., 2016). Acceleration is measured in unit of acceleration of gravity (g) and time in seconds.

The resultant acceleration of the dummy model is measured by accelerometer located at the head centre of gravity which provides the components of acceleration in $x, y, and\ z$ directions and the resultant acceleration is evaluated as:

$$a_{result.} = \sqrt{\left(a_x^2 + a_y^2 + a_z^2\right)} \quad (2)$$

The maximum time interval can be limited to 36ms or 15ms which yields HIC_{36} and HIC_{15} respectively.

Chest severity index gives the degree of chest injuries. It is determined same way as HIC, only that the accelerometer used to measure chest resultant acceleration is located in the dummy spine. This parameter though can be determined using finite element software such as LS-DYNA, it is not being considered in current certification standards.

The neck moment about occipital condoyle in y-direction, M_{yc} is given by (LSTC, 2013):

$$M_{yc} = M_y - (D \cdot F_x) \quad (3)$$

Where, M_y= Neck moment in y-direction; tendency of head and neck to bend towards chest (flexion) or towards back (extension).

D = Distance between the load cell axis and the condyle axis

F_x = Neck force in x-direction

Chest deflection was measured by potentiometer located in the dummy thorax. It was calculated by subtracting y-rotation of node no. 51433298 from y-rotation of node 51433301 (both filtered at 60 Hz), and then multiplied by distance between potentiometer head and base which is 93.23 mm.

RESULTS AND DISCUSSIONS

Deceleration transmitted to the occupant on impact is directly related to the injury out comes. Higher decelerations results in high injuries. It is seen in Figure 2 that 48km/h impact speed results to -43g peak vehicle decelerations and this indicates high injury values with HIC15 and CA for 48km/h and 46km/h impact speed, exceeding the NHTSA standard values as shown in Table 1.

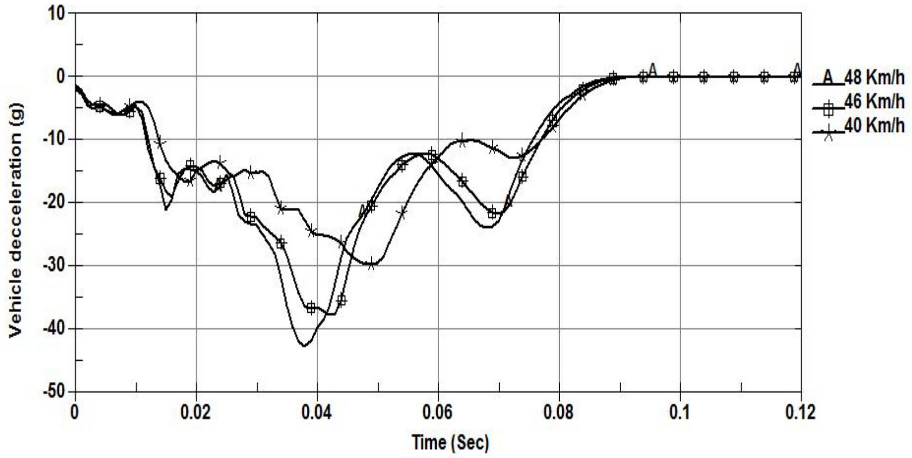

Figure 2 Vehicle deceleration for different impact speeds

HIC36, HIC15 and CSI plots are shown in Figures 3, 4 and 5. The values were also presented in Table 1 for comparison. CSI and NM though their values found to increase with speed increase, they were not compared with thresholds because they are not currently available in NHTSA standards. CD and NM time histories are shown in Figures 6 and 7. The trend of the curves were similar but 48 km/h speed yield a CD and NM peak values of 15.89mm and -12.69 Nm which was higher than that obtained for 46km/h and 40 km/h. Chest deflection was far below the threshold and this is attributable to dummy model stiff thorax characteristics. The biofidelity of the dummy in this respect needs to be verified and improved.

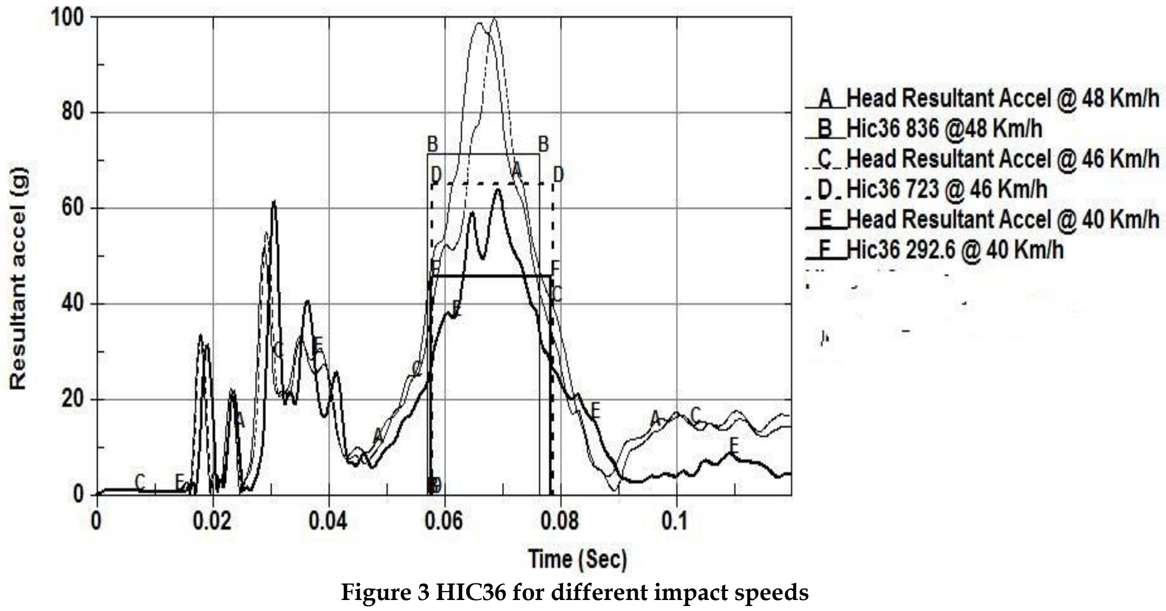

Figure 3 HIC36 for different impact speeds

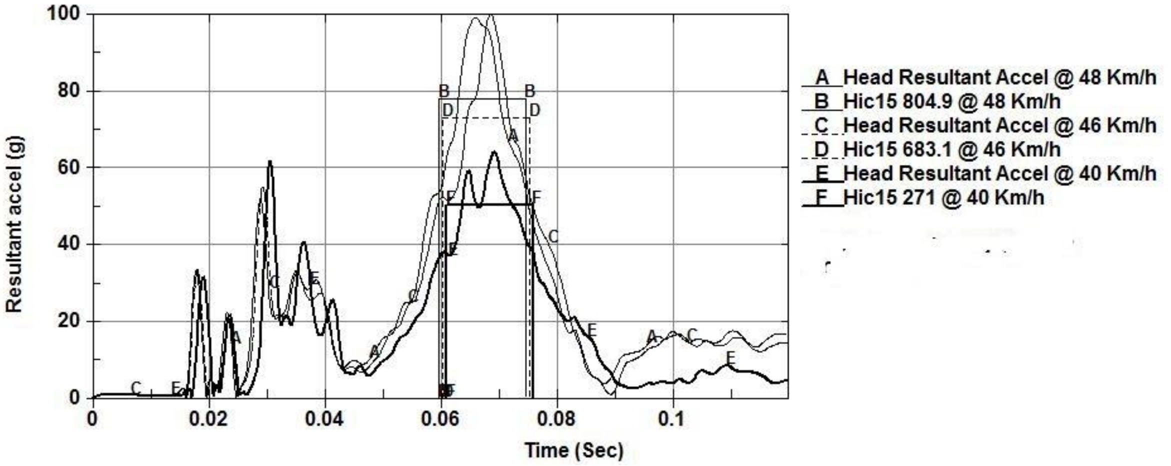

Figure 4 HIC15 for different impact speeds

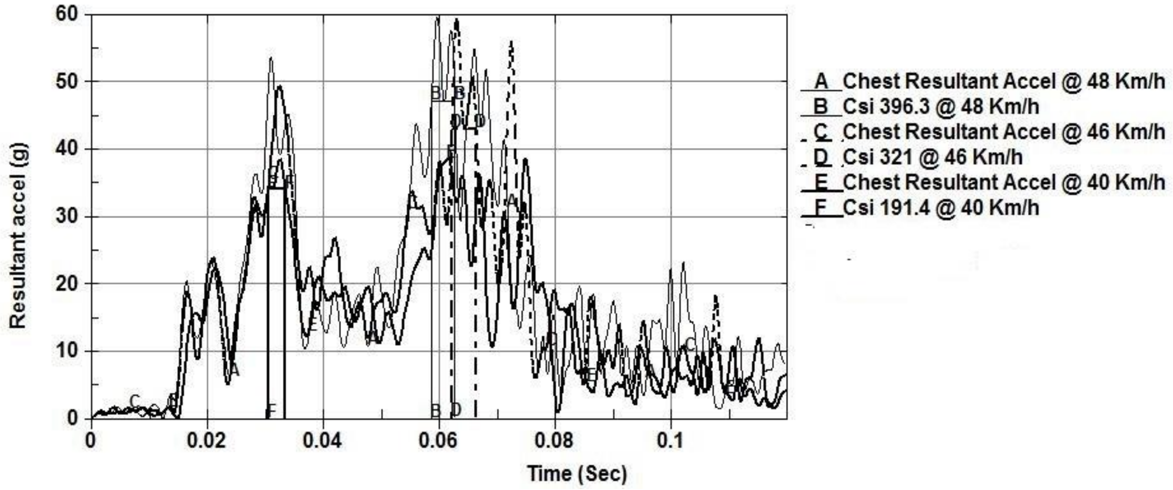

Figure 5 CSI for different impact speeds

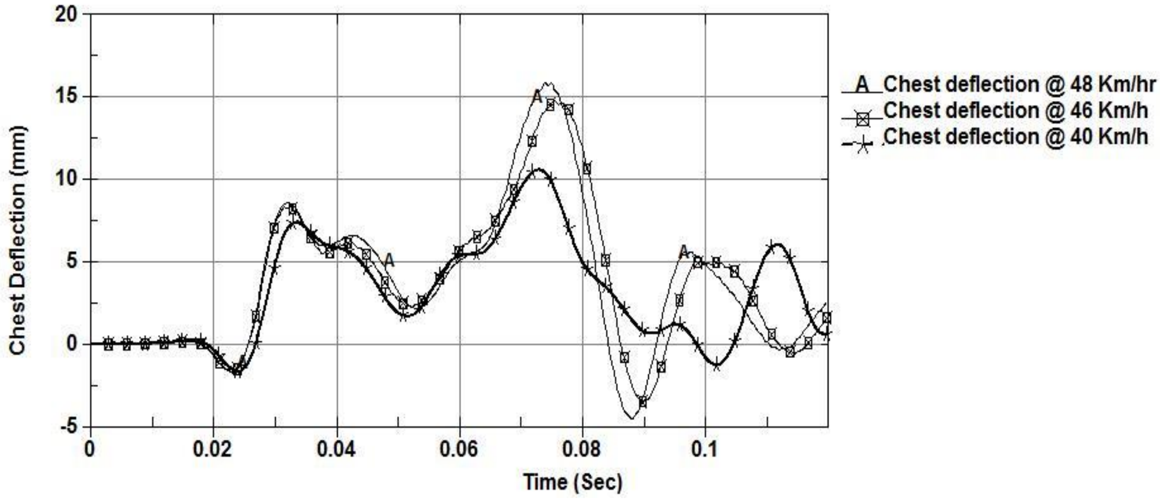

Figure 6 Chest deflection for different impact speeds

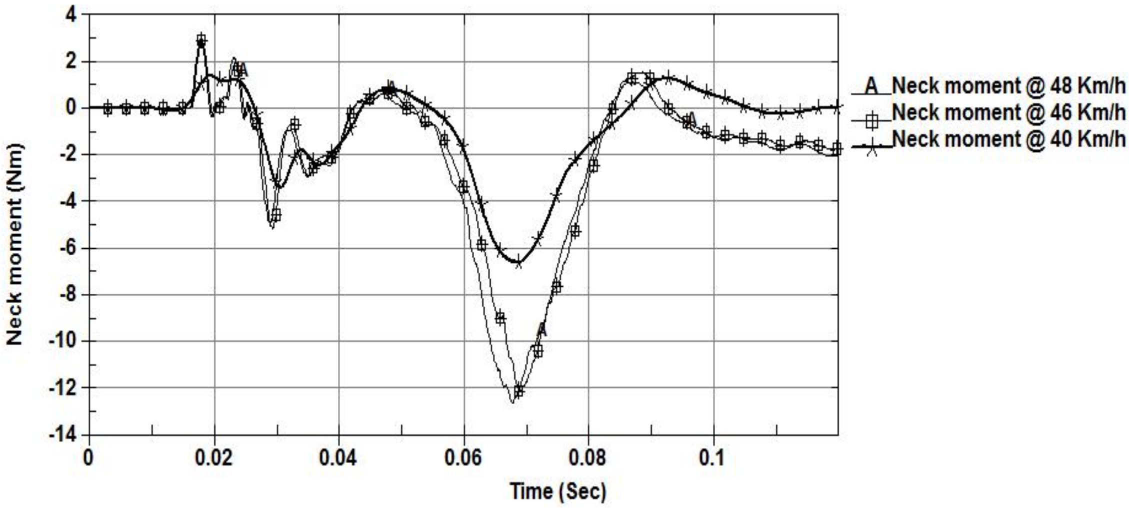

Figure 7 Neck moment for different impact speeds

HIC36 values were below NHTSA threshold for the three-impact speeds showing that the children are safe at this pulse for head injury of HIC36 level. NHTSA threshold for child injury were obtained by scaling adult data. Knowledge of children injury thresholds is still limited due to paucity of test data as children cannot volunteer as test subject and the unavailability of cadaver data (Fraser et al. 2019). Impact speed of 40 km/h was found good for 3YO child as all the injury parameters were within the limit tolerated for 3YO as shown in Table 1.

Table 1 Comparison of injury values for different speeds and with NHTSA recommended values.

Injury parameter	48 Km/h	46 Km/h	40 Km/h	NHTSA FTSS, 2008: Wu et al. 2023)
HIC 36	836.9	723	292.6	1000
HIC15	804.9	683.1	271	570
CSI	396.3	321	191.4	-
CA (g)	77.6	71.6	38.3	55
CD (mm)	15.89	14.8	10.6	34
NM (Nm)	-12.6	-12.2	-6.6	-

Above NHTSA Limit

CONCLUSION

This work presents the effect of vehicle speed on injury of 3YO child in frontal crash test. The speed was found to affect all injury parameters and is more pronounced for HIC15 and chest acceleration with their values far above the threshold for 48km/h and 46 km/h impact speeds. Injury severity increases with increase in speed. Chest deflection was lower than standard because of the dummy characteristics. The study provides injury severity in quantitative manner for the speeds investigated. 40 km/h low speed impact can save a 3YO child. Road users should therefore be mindful of speed on the roads as it has great effect on child occupant just like adults. Government agencies should enforce speed limits to the vehicle users and enforce CRS usage.

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