Occupant Injury Criteria for Roadside Safety Design

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Abstract

The design criteria for structures or 'hardware' installed on the sides of roadways requires suitable vehicle, occupant, and structural behaviour. The response of the roadside hardware and vehicle are measured or directly observed during proof-of-compliance crash tests. However, the occupant safety is currently inferred from the recorded vehicle dynamics and assessed using a simplified,
lumped mass model of the occupant. Thresholds for these predicted occupant kinematics determine the suitability of the roadside equipment. The present risk assessment procedure is compared to a multi-body mathematical representation of the occupant motion for similar crash conditions. The purpose of the study is to identify the effectiveness and potential shortcomings of the current approach.

Introduction

Design of roadside environments, essentially all terrain outside the paved road lanes, is a complex challenge for the highway design engineer. Aesthetics, cost, construction/maintenance demands and safety are traded off in order to build the road. Because of this complex process and limited resources, the design engineer cannot have expertise in all areas and relies on design guidelines or 'warrants' to assist in the process. These warrants are often conservative generalisations to simplify the design process. The past success of road and vehicle safety strategies cannot be duplicated without scrutinising the individual design elements to achieve an optimal design. The occupant safety requirements are one such component that can be further examined to determine if more information could provide a more cost-effective solution.

Current Standards

The area of roadside structures has been actively researched since the 1960's, but detailed biomechanical research in this area has been limited. This deficiency has not been an oversight by researchers, but the imposing requirements to study complex dynamic and structural behaviour during a myriad of impact conditions. Thus, the focus has been weighted towards the structural performance of a roadside device, as this is the end product of the research. Therefore, resources to study detailed biomechanics have been limited.

The EU (CEN 1317) and US (NCHRP 350) standards for roadside hardware prescribe three evaluation criteria: Structural Adequacy, Vehicle Trajectory, and Occupant Safety. The first two criteria can be directly monitored or observed during a crash test. However, the occupant risk is inferred from vehicle dynamics recorded during the test. The basis of this occupant risk assessment is the flail space model.

Flail Space Model

The basis for an occupant safety evaluation using the flail space model is the planar motion of the vehicle during a collision. The vehicle accelerations in X and Y (Figure 1) are used to predict the occupant trajectory relative to the vehicle. The occupant is represented by an unrestrained lumped mass and is allowed to move within the interior surfaces shown in Figure 1. The model has also been expanded to include yaw motions of the vehicle, but the basic assumptions for either model are described below.

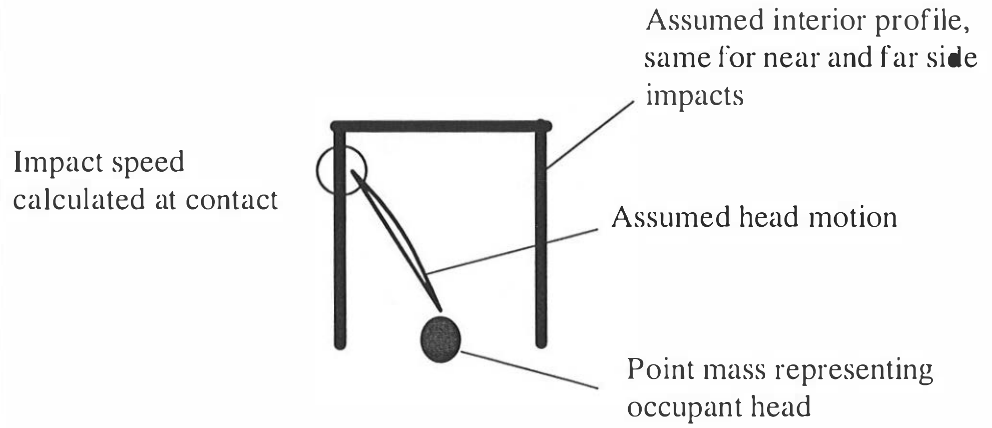

Figure 1: Flail Space Model

The flail space evaluation procedure is based on two quantities. First, the occupant impact speed is calculated when they first contact an interior surface. The calculated impact speed is compared to thresholds developed from biomechanic measurements during frontal impact test. This threshold is considered to produce a severe or fatal injury for most people.

The second parameter measured in the flail space model is the ride-down acceleration. This is the vehicle acceleration resultant recorded after the time of contact (described above) determined for the passenger. This acceleration is averaged over a 10 ms window to smooth out structural vibrations that may be recorded during the test. Again, a threshold for serious or fatal injury is used to establish acceptable behaviour of a roadside structure.

Limitations of this procedure are a result of the simplified model employed to represent the occupant. The use of one mass for the occupant precludes the ability to include restraint (seatbelt - inflatable restraints) or injury mechanism predictors like the Head Injury Criteria (HIC) already used in safety regulations. Although the conservative approach ensures good occupant protection, more information could be derived - and then exploited - from modern techniques developed subsequent to formulation of the flail space model.

Multi-body Occupant Model

The investigation of occupant dynamics during a collision has become more accessible through the use of computer models. The multi-body representation of ATD's is possible using different commercial codes. These codes are increasing their fidelity through the use of biomechanic test information and improved model descriptions. One of the assumptions leading to the development of the flail space model was the absence of a reliable 'oblique' impact dummy. Although this dummy still does not exist, it does not seem reasonable to reduce the occupant kinematics to the trivial case.

The use of a computer model for occupant simulation offers several attractive features. The vehicle description can be as specific or generic as possible, allowing a range of vehicles to be investigated. The occupant size can be altered to represent different occupant statures. Finally, and most important, it can provide a repeatable simulation of the occupant motion from a designated original position. This last feature is difficult to achieve with a dummy seated in a moving vehicle.

A vehicle interior has been represented within the commercial code 'MADYMO'. This model uses a 50 percentile Hybrid III dummy to represent the driver. Accelerations and vehicle motion recorded from crash tests are the model input. From the model output, estimates of the occupant risk during a collision are interpreted. The occupant motion can be observed and potential injuries from contact with the interior surfaces investigated. In addition, the influence of different restraint systems on the occupant motion can be observed.

Results

Simulations conducted with the multi-body occupant model have been carried out to simulate a roadside barrier impact. This oblique collision involves small longitudinal and moderate lateral accelerations. There is little direct loading of the occupant compartment, which results in little or no intrusion. Data from a crash test conducted on a W-beam guardrail (107 km/h, 20 degrees impact angle) was used as input to the simulation. Table 1 below provides the crash test results (flail space model) as well as dynamic simulation output.

The multi-body model provides a much-improved qualitative and quantitative assessment of the collision event. Occupant contacts within the passenger compartment (arm to steering wheel, shoulder to door, etc.) can be observed to occur before the head actually contacts an interior surface. These interactions will affect subsequent head loading of particular importance, the effect of restraints can be observed on the occupant motion. By containing the occupant within their seating position, the seatbelt reduces the occupants contact with interior objects (Table 1). The model also allows driver (far side) and passenger (near side) loading to be examined for the same test results.

Table 1: Head Contact Assessments Results

Parameter	Result		Limit
	Near Side	Far Side	
Time of Flight, FSM			(none)
Time of Flight, MBS (unbelted occupant)	138 ms	235 ms	
Time of Flight, MBS (belted occupant)	163 ms	*No head contact*	
Theoretical Head Impact (THIV) FSM	26.7 km/h	*Same as near side value*	33 km/h
Theoretical Head Impact (THIV) MBS, (unbelted occupant)	15.1 km/h	12.2	20 g
Theoretical Head Impact (THIV) MBS, (belted occupant)	0.4 km/h	*No head contact*	20 g
Post Impact Head Deceleration (FSM)	8.2 g	*Same as near side value*	20 g
HIC (unbelted occupant) (MBS only)	1080	>>1000	1000
HIC (belted occupant) (MBS only)	98	13	1000

* Suggested values from current safety standards

FSM – Flail Space Model Prediction, MBS – Multi-body Simulation - Prediction

The current model remains an approximation of the occupant dynamics. Contact stiffnesses for all possible occupant-vehicle loading events are unknown. Suitable injury thresholds for contact speeds, HIC, TTI, etc, remain a continuing field of investigation. However, by incrementally improving kinematics models of these dynamic events, we can identify the critical areas for subsequent research and exploit improved vehicle safety equipment.