Introduction

Sprains to the neck and back occur in more than half of all casualty producing accidents. Associated insurance injury claims are estimated at over $100M (Cdn.) for the province of British Columbia, Canada annually. A recent provincial publication indicates that whiplash reports in B.C. increased approximately 30% from 1986 to 1987 (1).* The report also noted that damage to these cars was typically less than damage occurring in other casualty producing accidents.

Abstract

Many low speed, rear impact accidents produce occupant neck injuries which have become a concern to the insurance industry and the medical profession. The authors, with the cooperation of the Insurance Corporation of British Columbia (ICBC), conducted approximately 30 low speed pendulum tests to measure the elastic and plastic properties of selected vehicles in rear end collisions. Displacement/time traces were generated from high speed video recordings of selected points on the vehicle and an anthropometric dummy occupant. The authors noted that a high impact speed was required to produce perceptible damage to the test vehicle. This speed caused violent movement to the test dummy neck. Discussion of these results with insurers indicates there is a conflict between bumper stiffness (required for the Canadian 8 km/h bumper standard) desired by the material damage section of the insurance industry, and the need for vehicle compliance for occupant protection. Investigation into the vehicle's elastic and plastic properties will also aid in the design of Civil Engineering roadside structures and provide a better understanding of injury causation at low impact speeds.

Low Speed Rear Impacts and the Elastic Properties of Automobiles

D.P. Romilly, R.W. Thomson, F.P.D. Navin, M.J. Macnabb
Department of Mechanical Engineering
Department of Civil Engineering, University of British Columbia

A litigious syndrome does not appear to be the sole reason for the increasing numbers of injury claims. Whiplash or neck hyper-extension is, in many cases, symptomatic and subjective in its diagnosis as existing evaluation techniques are unable to identify soft tissue injuries (2,3). Assuming that genuine injuries are reported for accidents where vehicles show little or no damage, the authors have initiated an investigation into the dynamic response of the vehicle and its occupant to low speed impacts.

The mechanics of a high speed collision are relatively well documented. The vehicle structure deforms, converting the system's kinetic energy into sound, thermal and strain energies. The rate of deformation is a result of the vehicle's stiffness characteristics while the amount of recoverable deformation is a function of its elastic properties. At high impact speeds, very little elastic recovery occurs and the vehicle generally behaves as a plastic body. At low impact speeds, however, plastic behaviour may be absent allowing most of the total impact energy to be recovered in elastic rebound. For the occupant, the best ride down profile occurs when the vehicle behaves as a plastic body with large deformations to reduce the overall acceleration. This creates a major dilemma for the manufacturer, occupant and insurer. Each would like the vehicle to provide the maximum protection for the occupant with the minimum material damage to the vehicle during a collision. As the vehicle becomes stiffer, the vehicle damage costs are reduced as less permanent deformation takes place. However, the occupant experiences a more violent ride down which increases the potential for injury. This implies that vehicles which do not sustain permanent damage in low speed impacts produce correspondingly higher dynamic loadings on their occupants than those which deform plastically under the same or possibly more severe impact conditions. It is this premise which is under investigation in this research project.

Much of the existing literature has addressed vehicle and occupant dynamics in the moderate to high speed range (greater than 50 km/h). This is due to many countries setting

*Numbers in parentheses designate references at end of paper.
vehicle performance standards based on occupant survival of 50 km/h barrier impacts. However, it should be noted that the majority of accidents occur below this speed. Injury costs from these low speed accidents are not insignificant, especially in neck injuries from rear impacts.

Based on the experience derived from the development of an earlier low speed crash barrier (4), the researchers initiated a project to study both vehicle and occupant response using a more accurately controlled, and repeatable, low speed impact facility. A pendulum style impactor was developed permitting preselected impact conditions in a controlled test environment. This allowed a systematic study to determine the vehicle and occupant responses as functions of the impact parameters (i.e. mass, velocity, impact energy, impact geometry, etc.).

This paper presents the first phase of work completed with the new impact facility. Impact tests were conducted to investigate the dynamic response of a vehicle and driver to known rear-end impacts. The results of these tests are presented and discussed with respect to quantifying the relative motion between the vehicle and occupant for low impact speeds and the crash performance of the vehicle.

Low Speed Impact Test Facility

Impact pendulum design

In order to provide controlled impacts in the low speed range, the pendulum style impact facility shown in figure 1 was designed and constructed. The facility is capable of impact speeds up to 20 km/h with a swung mass selectively variable from 300 to 2000 kg. It has been designed to be recognized as a valid information source based on the Canadian Motor Vehicle Safety Standards (CMVSS 215) (5) and the Society of Automotive Engineers (SAE J980a) (6) guidelines. The pendulum impactor faces prescribed in these guidelines were modified to provide a surface profile more representative of a vehicle front end. This facility is located at the ICBC Research and Training Center in Burnaby, B.C. and is portable, having a relatively quickly assembly/disassembly time. Manual set-up and operation were used to maintain simplicity which is reflected by the low material cost of $1300 Cdn. and the relatively short construction time of six man-weeks.

Instrumentation

The occupant, vehicle, and pendulum motions were recorded using a Kodak Ekta-Pro 1000 high speed video system with a maximum sampling rate of 1000 full frames/second. Video images of the occupant and vehicle (benchmarked with targets as in figure 2) were recorded throughout the test and post-processed to yield displacement histories for subsequent analysis and modelling. This proved to be a simple, flexible, data acquisition system which also provided qualitative information beyond the recording capabilities of a sensor based system.

The pendulum velocity was measured by a speed trap consisting of three equidistant mechanical switches mounted such that the last switch was tripped by the pendulum just prior to impact.

Test vehicles and crash dummy

The vehicles tested in this project were two and four-door Volkswagen Rabbit hatchbacks. These models were chosen because they are representative of compact cars currently on the road and have been extensively tested by UBC in previous research studies (7). All of the test vehicles were insurance “write-offs” supplied through ICBC. Each vehicle was free of damage in the rear portion and free rolling. This ensured that the test vehicles were representative of functional cars. Due to accessibility, a Hybrid II anthropometric dummy was used to represent the occupant and was made available to us courtesy of the Transport Canada Test Centre in Blainville, PQ. A comparison, provided by Foster et al (8) of the Hybrid II neck performance, relative to the criteria put forth by Mertz and Patrick (9) is shown in figure 3. The results suggest the Hybrid II has limited use in whiplash testing because of an overly stiff neck arrangement. With this performance noted, it was expected that the dummy would yield conservative head-neck deflections. Interpreta-
tions of the results is based on the relative neck response to different test conditions and avoids direct inference of possible human injury. Although this may be unsatisfactory, it is necessary due to the lack of available human neck response data.

Testing procedures

Prior to each test the vehicle mass was determined and matched by the pendulum. Test vehicle specifications (model, year, seatback type, occupant safety system, etc.) and information relating to any pre-existing damage was logged. The car was positioned in line with the pendulum, the parking brake engaged and the transmission placed in gear. The crash dummy was then positioned in the seat and the distance between the mounted targets (as in figure 2) were recorded. Triggering of the camera preceded the release of the pendulum by 2.5 seconds to provide the necessary lead time for initializing the recording process.

After each test, a general vehicle inspection was performed by the researchers and the Material Damage staff at ICBC to locate any damage resulting from the impact. The dummy was also examined for final position, signs of interior contact, etc.

Impact Test Results

For the Volkswagen Rabbit, limited damage to the vehicle was found for speeds under 15 km/h. Only a 5 mm movement of the bumper isolator mounting bolt within its adjustment slot was detected. Above 15 km/h, crush was found to begin developing in the rear fenders and trunk area floor panels. For impact velocities below this threshold, only cosmetic damage to the bumper itself was found. A slight curvature initially present in the bumper was removed as a result of the impacts, however, the amount of energy absorbed during this process was minimal compared to the total elastic energy. Some fluid leakage from the bumper isolators also occurred, but did not have any significant effect on the isolator performance during subsequent higher speed impacts. The full stroke length of the isolators appeared consistent at 5 cm. The 15 km/h damage threshold also supports the value presented in (8) where interpolation from barrier crush values indicated a damage threshold of 13.7 km/h. Figure 4 shows the impact pendulum, bumper and rear fender displacements versus time for a 14 km/h impact. The envelope between the bumper and vehicle (rear axle) displacements is representative of the energy absorbed by the bumper system.

To utilize the vehicles in the most effective manner, six were impacted three times each, at increasing speeds from 8 to 20 km/h (it should be noted that the first two lower speed impacts did not produce any detectable residual deformation). Two additional vehicles were tested to study the effect of variation in occupant posture (head inclination angle) and the presence of a head restraint system on occupant response at impact speeds of 8 km/h.

All of the tests which employed head restraints had the restraint adjusted to the lowest position. This reflected trends reported by States et al (10) and MacKay (11) where adjustable head restraints were found to be in the lowest position in 70-90% of the vehicles surveyed.

Kinematic Data Analysis

To obtain the required kinematic information, the video images were digitized to give displacement information for both the occupant and the vehicle. Benchmark points were digitized frame by frame, producing displacement versus time curves which were corrected for projection distortion and depth effects. Data smoothing was performed by obtaining a least squares fit to the data. The software provided time rate of change values of the displacement data which was used to generate velocity and acceleration curves.

Whiplash or hyper-extension is generally related to the rearward deflection of the head relative to the body. Figure 5 shows the relative displacement and acceleration of the head’s center of gravity, relative to the shoulder. The results shown were produced by a 9.2 km/h impact. As indicated, the maximum horizontal deflection and accelerations occur at approximately 120 ms. The rotational deflections of the head, figure 6, also reach maximum values at this time. The positive rotation and velocity in this diagram signify the
extension movement (head rotating rearwards). It is also evident from these figures that the head continues to move rearward while the shoulders rebound off the seat and move forward (shown at 108 ms on figures 5 and 6). This differential motion between the head and shoulders will result in increased neck loading especially as the inertial forces developed by the head grow larger at higher collision speeds. The presence of whiplash in cars with head restraints was recognized by States (10) where differential rebounds, from the seatback and head restraint, may produce increased rearward deflections of the head, relative to the shoulder. The shoulder was found to rebound before the head in all the tests analyzed in this study. To further investigate this effect, the acceleration and displacements (relative to the car) for the shoulder and head are plotted in figure 7 for cases with and without head restraint. These plots are the results of 8 km/h pendulum impacts. Figure 7 provides a seatback "stiffness" performance indicator. The curves already show that the shoulder moves through a smaller range of motion than the head. States' suggestion for a tuned seating system stiffness may require a similar "stiffness" approach to properly match the seatback and head restraint response.

Figure 5. Relative motion of head to shoulder for a 9.2 km/h impact.

Figure 6. Rotational motion of the head (pitch).

From figure 7, one can see that the shoulders exhibit smaller deflections with higher accelerations in the presence of a head restraint than without a head restraint.

Figure 7. Effect of head restraint on occupant displacement and acceleration.

For the head, higher accelerations are encountered after rebound than before headrest contact (for the same displacement) because of the spring effect of the restraint. The converse is true without the headrest because there is no reloading of the neck from the seat structure. These trends also appear in the angular motion plots of the head depicted in figure 8 for the same tests. A higher peak angular velocity is experienced with smaller rearward rotations of the head with the use of a headrest (0.62 rad) compared with lower peak angular velocity and larger rearward rotations without the use of a headrest (0.7 rad). This resulted in an increase in positive differential acceleration of the head of approximately 25% with the introduction of an improperly adjusted head restraint. This suggests that injury severity may be a function of both displacement and dynamic loading.

Figure 8. Effect of head restraint on angular motion of the head.

Figure 9 shows a set of vehicle and occupant response curves for an 18.4 km/h impact with a normally positioned dummy. The influence of initial posture can be observed from figure 10. This test was conducted with a 20° forward leaning head position at an 8.1 km/h impact speed. The initial rearward velocity of the head (ear) in the 18.4 km/h impact is less than that found at half the collision speed, with the occupant head forward. This is because the head has less time to rotate rearward before contacting the head restraint and indicates that small changes in head position can
markedly effect head velocities encountered during an impact. Figure 11 shows the relative displacement between the head and the shoulder for these two tests. The displacements are of the same magnitude, indicating that a forward leaning occupant could increase their chance of injury to levels found at much higher impact speeds. As noted on the diagrams, again the shoulder rebounds to a forward velocity relative to the car before the head. The corresponding occupant head deflections at 9.2 km/h (figure 5) show a normally placed dummy moves less than the inclined occupant shown in figure 11, even though the latter experienced a slightly lower impact speed. All the impacts recorded suggest that the elastic effects of the seat allow the vehicle to almost reach its maximum forward speed as the occupant's head reaches its maximum rearward speed. This increases the rearward displacements encountered which increases the propensity for a whiplash injury. Decreasing the rearward deflection of the head would reduce this velocity disparity and the attending neck loadings. It is felt that a human neck would allow a much greater relative displacement between the head and shoulders than shown with the Hybrid II. However, it is also felt that the same trends can be expected in a human subject for the same conditions albeit at different magnitudes.

The elastic behaviour of the seat is a critical factor as evidenced by the magnitude in which it catapults (in the order of 150% of the original impact velocity) the occupant forward after reaching a maximum rearward deflection. Reducing this forward acceleration would both lower the seat loading on the neck structure and reduce the likelihood of interior impacts. One method to control the seatback influence on the occupant would be to use the seat to absorb energy in some non-recoverable manner; through frictional or damping dissipators. Alternatively, a rigid seat and headrest coupled with a non-rebounding surface may be a means to limit the relative head-shoulder motion by forcing the head and shoulders to move as a unit. Deployable head restraints were researched by Melvin et al (12) and were found to be promising, but no additional work in this area has been found in the literature.

Noting the vehicle velocity curves (figures 9 and 10), there is a difference between the vehicle velocity attained and the original impact velocity. This reduction is 38% at the higher speed where structural crush takes place and 22% at the lower speed where a greater portion of the energy is elastic and is translated to the occupant compartment. At lower speeds, losses through the sliding wheels and compliance of the bumper and suspension systems become increasingly important as dissipation mechanisms during impact.

Visually noted from the video recording was the ramping displacement of the occupant up the seat back, even at the lower (8 km/h) speeds. Also detected from the video was the slack which developed between the seatbelt and the dummy's chest at the higher impact speeds. This identifies the inability of the retractor to spool up the free play of the seat belt. The use of a faster seatbelt retractor to control shoulder rebound is another possible solution for reducing the whiplash injury potential. Should the belt spool in and lock in the rearmost position as the occupant moved back, the differential velocity between head and shoulder would be reduced.

**Conclusions of Preliminary Testing Phase**

A brief description of the low speed, rear impact test program at UBC has been presented. The developed
pendulum impact facility performed reliably, providing controlled and repeatable impacts throughout the initial testing phase of this project. The video recording system employed in these tests provided useful information for understanding the collision kinematics of both the vehicle and occupant. Of interest to researchers is the lack of, or minimal, structural damage resulting from impact speeds below 15 km/h, and the increase of personal injury claims associated with these impacts. The absence of structural damage indicates that the bumper isolator system and retardation forces at the tire/ground interface are the predominant mechanisms of energy absorption by the vehicle during impact.

It was observed that the resulting deflection of the seatback with subsequent rebound, tends to pitch the occupant forward during impact with the shoulder displacement leading the head. This relative head to shoulder motion is the likely source of whiplash injury. The spring rate effects for the seat back and the head restraint have been presented in a quantifiable form in figure 7. Since the stiffer neck of the Hybrid II is more resistant to the loadings experienced in this testing, the limited neck rotations recorded with the Hybrid II suggest that higher rotations can be expected by humans in similar loading situations and that an increased potential for neck injury will occur.

The effect of an improperly positioned head restraint and initial occupant posture was shown to affect the maximum deflections of the head. The occupant experienced lower accelerations with increased deflections when the headrest is not present. The head also experienced larger deflections relative to the shoulder when the occupant’s initial position was moved farther from the seat. This latter effect was seen to produce effects comparable to responses at twice the impact speeds with a normally seated occupant.

The present compliance standards in Canada for head restraint employ a “best case” scenario. The tests are conducted for a 95 percentile male with a fully upright adjusted head restraint (CMVSS 202). As mentioned before, the majority of drivers do not properly adjust the head rests. The presence of ramping in the 50 percentile occupant used in this research suggests that a large portion of the population will not receive all the protection that is provided to them. The standards set by the government are met by the manufacturer, but unfortunately the occupant is not responding by using the existing head restraints properly.

Future work includes more full scale vehicle impact testing planned for the summer of 1989. During these tests the vehicles will be instrumented (accelerometers and strain gauges) to provide accelerations and frame deformations (unavailable from video recording) needed to fully develop and quantify elastic body stiffness. Of specific interest is an attempt to reduce occupant compartment loading through an improved energy absorbing bumper system.

References

Aknowledgements

This project would not have been possible without assistance from the following organizations:

National Science and Engineering Research Council;

Transport Canada, Road Safety Directorate (Chris Wilson, Director General);
ICBC Material Damage Division (John Gane, Manager);
UBC Accident Research Team (F.P.D. Navin and G.R. Brown, Coordinators)

Effect of Internal Fittings on Injury Value of Unrestrained Occupant

Written Only Paper

Koichi Oho, Isao Sugamori and Kazuhisa Yamasaki

Abstract

An overall improvement in the crash characteristics of vehicle body, occupant restraint devices (seat belt and air bag etc.) and energy absorption characteristics of the secondary impact objects (steering and instrument panels etc.) is essential for minimizing injuries to occupants when a vehicle gets involved in an accident. It is needless to say that striking proper balance among these is the main crux in designing. For this, it is necessary to analyze the behavior of occupants at the time of accident and the state of injuries they sustain so that the contribution of each factor to the injuries can be pinpointed.

This paper discusses the investigations carried out by the authors on the effects of crash characteristics of the vehicle body, position of the windshield glass and instrument panel and the rigidity of instrument panel and cross beam etc. on the injury values of the dummy, after analyzing the behavior of unrestrained dummy in the passenger seat during frontal collision at 30 MPH and 15 MPH by carrying out simulation with MVMA-2D program and by sled test.

This study enabled the authors to gain some significant information on the effects of internal fittings on the injury values of the dummy. Sled test carried out with vehicle modified on the basis of these data confirmed the validity of the findings.

Method of Investigation

Simulation calculation model

The program MVMA-2D developed at Michigan University for analyzing the behavior of occupant was used in calculation. As shown in figure 1, a two dimensional model with 9 concentrated masses and 10 links was used for the dummy. Elliptical bodies were provided to each link to represent the body outline and to produce contact reaction force.

Sled test

The behavior of unrestrained dummy was studied by 30 MPH (48 km/h) and 15 MPH (24 km/h) sled tests. Figure 2 shows the vehicle acceleration curves of the sled tests. A Hybrid III type dummy was used. The sitting posture of the dummy was decided on the basis of the method specified in FMVSS 208. The seat position was set almost at the center. As the secondary impact objects like the instrument panel etc., get pushed towards the rear due to backward movement of the engine and the dashboard during barrier test, these were fixed after making proper allowance for the amount of displacement toward rear.

Figure 1. Calculation model.

Figure 2. Acceleration curves for sled test.

Behavior of Unrestrained Occupant and Verification of Accuracy of Calculation Model

Simulation model was prepared after studying the behavior of unrestrained occupant by sled test. For verifying the accuracy of calculation model, it is necessary to investigate the degree of accuracy by which the behavior of the dummy and the acceleration curves for each section of the dummy determined in the calculation model correlate.