A Study of Occupant Responses in Side Impact Collision
(측면충돌시 승객의 거동에 대한 연구)

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ABSTRACT

With the recent issuance of a dynamic side impact test regulation in the Federal Motor Vehicle Safety Standard in the United States of America, many aspects of occupant protection in side impact crashes have been under investigation. Many investigations of real world accidents, crash test results and simulation studies have established that in side impact crashes of passenger cars, thoracic and pelvic injuries of occupant are, large part, caused by occupants' impact against the interior side of the vehicle, primarily the door.

This paper is concerned with the development of a lumped mass computer model, which simulates the interaction of a struck car door and an adjacent seated occupant in side impact, based CTP code which has been successfully used in vehicle and occupant simulation. New model developments include elimination of influence of vehicle side structure stiffness in the occupant injury responses. The model was used to investigated the effect of various door padding characteristics on occupant responses to improve vehicle safety performance. The evaluation of different crush properties of door padding have also focused to understand of behavior of impacted occupant. Results from simulations, The effects of both material coefficients C_f and p were illustrated in terms of occupant injury criteria TTI and pelvis.

INTRODUCTION

Currently, one of the major challenges for automotive engineers is to provide additional protection to motor vehicle involved in side impact collisions. In 1990, NHTSA finally imposed regulations, an acceleration based injury criteria, directed at reducing occupant thorax and pelvis injuries in side impacts in an amendment to the Federal Motor Vehicle Safety Standard (FMVSS) No. 214.

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Data collected by the National Accident Sampling System (NASS) of the United States provide a basis for ascertaining the extent of injuries to automobile occupants in side impacts. Considering only ploice-reported accidents, NASS reported that of the 4,067,000 occupants of passenger cars and light trucks in these accidents, 1,186,000 or 29 % were in collisions involving side impact. 28,000 of these occupants sustained serious (AIS $\geq$ 3) injuries. The Fatal Accident Reporting System (FARS) of NHTSA provides another injury estimation source of the relative significance of side impact. In 1989, among the all passenger cars involved in fatal accidents, 47 % of fatality was due to side impact accidents. Furthermore, the percentage of fatality in side impacts is likely to increase now that air bag restraint systems are being widely adopted to occupants in frontal impacts.

During the past decades, a considerable amount of research [1-3] is being conducted into this side impact problem by governments and motor vehicle manufacturers on a world-wide basis. It was found that the increase of side structure stiffness and additive padding on the door would reduce the thoracic injury severity. Unlike to frontal impact, in general, the dynamic effects of the vehicle side structure was not considered in their simulation model [4,5]. However, more recent experimental works [6,7] show that the occupant injuries and the characteristics of deformation shapes in the both vehicle side structures and doors are highly dependent on the closing impact speeds. Especially, some materials, the energy absorbing capability of padding is strongly dependent on the crush rate. It is well known factor that adequate door padding would be significantly improved occupant injury protections in side impact. However, in 1991 Lau of GM [8] showed that the increasing padding thickness will be caused chest deflection problems due to a longer duration occupant contact times and higher impact speed. But, practically, the additive of door padding can not be exceeded maximum 75 mm in the small passenger car, the effects of higher door impact speed can be ignored.

In this study, a lumped mass computer model is developed and used to simulate the interaction of a struck car door and an adjacent seated occupant in side impact. In the simulation, influence of vehicle side structure stiffness was eliminated in the occupant injury responses. In particular, the evaluation of different crush properties of door padding also focused to understand behavior of impacted occupant.

SIDE IMPACT MODEL

The simulation studies described in this paper are based on test conditions, test devices, and test procedures described in the final rule FMVSS No. 214 announced by NHTSA. However, for the simplicity, the model simulates an unrestrained frontal seated occupant by interacting with intruded door only whereas the final rule called that the target vehicle impacted by moving deformable barrier and all occupants were belted. Figures 1 through 2 illustrate the test configuration of FMVSS 214 using a 3000 lb aluminium honeycomb barrier in the crabbed mode simulating a car-to-car collision where the striking vehicle is moving at 30 mph and the struck vehicle at 15 mph, perpendicular to each other.

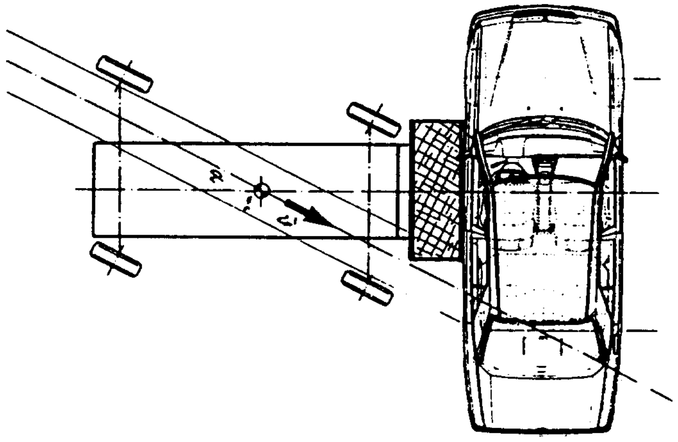

Fig. 1 Side impact test configuration by FMVSS 214

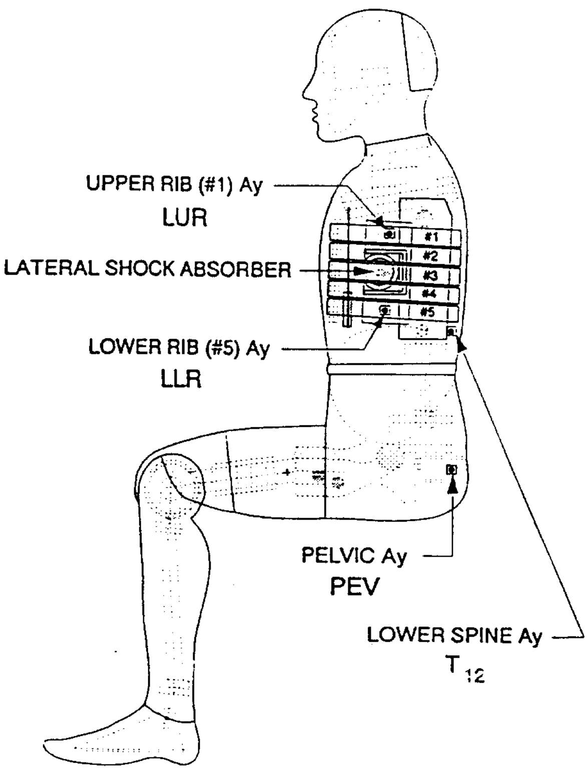

Fig. 2 SID injury measurement locations

The NHTSA SID (Side Impact Dummy) response behavior was modeled in the same manner as the one dimensional model, CTP developed by CCMC [9] where three masses and eight non-linear energy absorbers characterize the main body elements of the dummy participating in the crash as shown in Figure 2. Two of the masses represent the thorax, one representing an equivalent mass of the ribs about the longitudinal axis which comes in contact with the impacted vehicle door upper inner surface. The other representing the equivalent mass of spine. These two masses are interconnected in parallel by a non-linear energy absorbing spring, a viscous damper and a linear spring-damper arranged between their centers of gravity. The pelvis mass is connected to the spine mass, through a simple energy absorbing shear element system. In a standard side impact testing configuration, generally, a head has not been experienced any significant injury, therefore, the head mass is neglects. The effective mass and force versus deflection traces for all the masses and energy absorbing elements in this dummy model are from [9], which provided by the experimental studies.

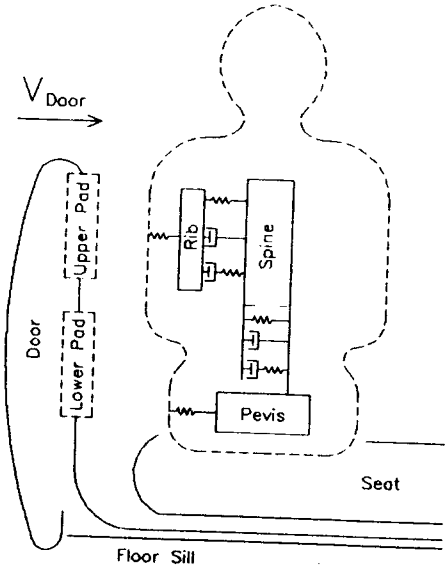

Fig. 3 Mathematical simulation model

In modeling a padded door , two strips of padding were used, one attached to the lower-inner door panel and the other to the upper-inner door surface allowing contacts with the pelvis and rib regions respectively. Trella et al [10] modeled these strips of padding as one dimensional, non-linear energy absorbers and masses. However, in the simulation, the responses of the masses which representing padding would be severely oscillated and not accurately predicted, the occupant responses. The reason would be that placing the relatively small masses in the between door and occupant. In this study, it was modeled as massless non-linear energy absorbing springs and established as an equivalent spring which combined with padding spring and door-inner panel spring by linear connections.

Force-deflection characteristics of energy absorbing padding can be obtained by either dynamic impactor or quasi-static crusher testing. A general expression relating the force of impact to padding deformation at each instant time was used to described the dynamic force versus deflection responses of padding strips. In this model, the characteristics of number of different padding materials suitable for application in car manufacture have been analytically represented by the function [10]:

$$F_d = C_f \; [\; S \,/\, (\, S_{max} - S \,)\,]^p \qquad \text{Eq. (1)}$$

where F_d = the dynamic force (N)
C_f = a dynamic force coefficient (N)
S = the padding deflection (mm)
S_{max} = the padding thickness (mm)
p = a deformation shape factor $0 \le p \le 1.0$

Results from the author's previous study for padding materials [11], some of paddings responses were very similar to the behaviors of Eq. 1 except in the initial deformation stages (up to 20 % deformation of total thickness). Since the modeling studies of a SID impacted at speeds narrow ranging from 8 meter/second to 11 meter/second by door, strain rate was not included in this expression.

PARAMETRIC RESULTS FROM SIMULATIONS

In general, it is true that increasing the padding thickness can improve the occupant injuries. Especially when the padding thicknesses are over the 75 mm thick, the occupant protections can be significantly enhanced in side impact. Unfortunately, for the domestic motor vehicle manufacturers which mainly produced compact or sub-compact small passenger cars, enhancement of the occupant protections by simply increased padding thickness are not feasible due to the very limited vehicle space. In the simulation, only practically adaptable padding thickness, 50 mm was considered.

As shown in Figure 4, the force-deflection curves for door upper and lower inner-door panels used in the simulation were results from a CC-CTP (Computer

Controlled Composite Test Procedure for side impact evaluation) testing for a typical sub-compact European passenger car [11]. Figure 5 shows a force -deflection characteristics at C_f = 7000.0 N with various deformation shape factors obtained optimization for Thorax Trauma Index (TTI), conjunction with baseline door inner panel data as shown in Figure 4. TTI can be calculated by averaging the maximum peak values of rib and spine acceleration in gravity (g's).

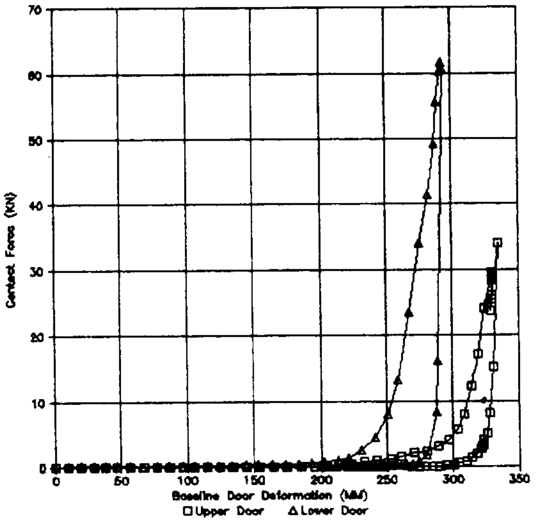

Fig. 4 A typical door F-D curve

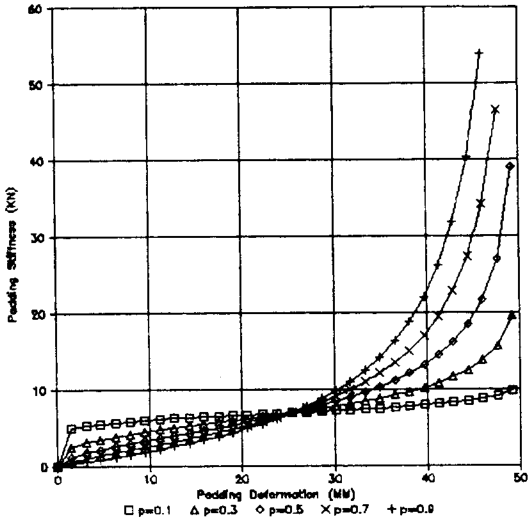

Fig. 5 Padding F-D curve with C_f = 7000 N

Without an additive padding in the inner-door panel, when an occupant experienced directly impacted to the door by 9 meter/sec initial speed, TTI was 100G and pelvis injury was 137.5 G. Based on this results, the simulations were performed to determine an optimal dynamic force C_f with deformation shape factors p=0.1 and p=0.9 in extreme cases. Figure 6 and 7 show the occupant responses in terms of injury criteria TTI and pelvis G's values at p=0.1 and p=0.9 respectively. The effects of both material coefficients C_f and p on TTI and pelvis were clearly noticed. As shown in Figures 8 and 9, padding materials characterized by shape factors p lying between 0.0 and 0.3 were most effective in reducing TTI with higher dynamic force coefficients. However, for the optimal pelvis injury, relatively higher p values (0.5 - 0.9) are more beneficial. It was determined that at the optimal padding conditions, C_f = 7000 N and p=0.1, the TTI was effectively reduced by approximately 46 % with TTI = 54.0 G. Pelvis injury was reduced about 18 %. In the

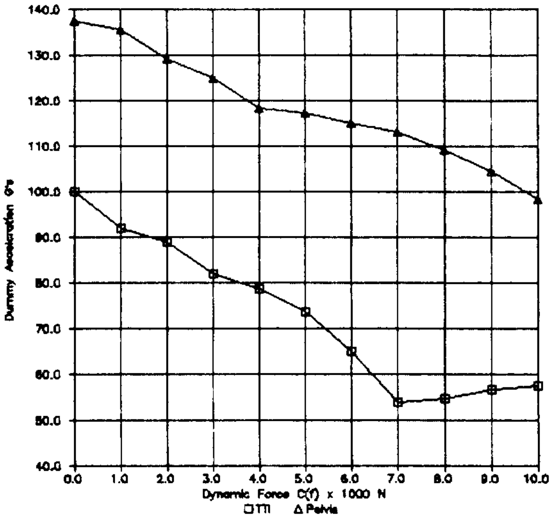

Fig. 6 Effects of C_f on TTI and pelvis with p=0.1

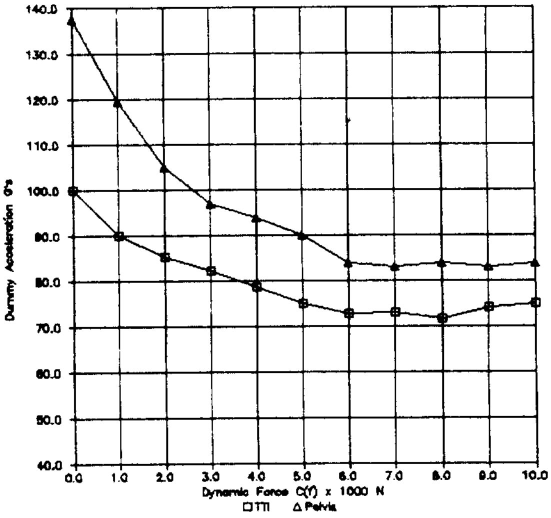

Fig. 7 Effects of C_f on TTI and pelvis with p=0.9

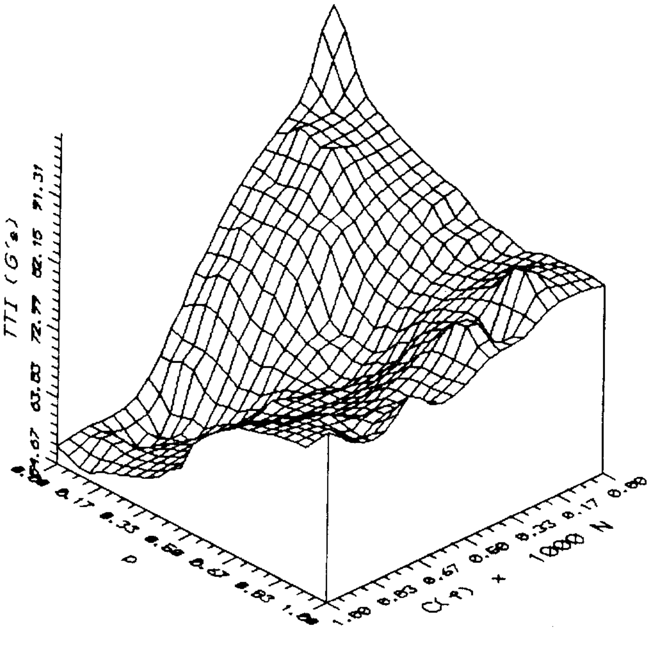

Fig. 8 3-D view of TTI function of C_f & p

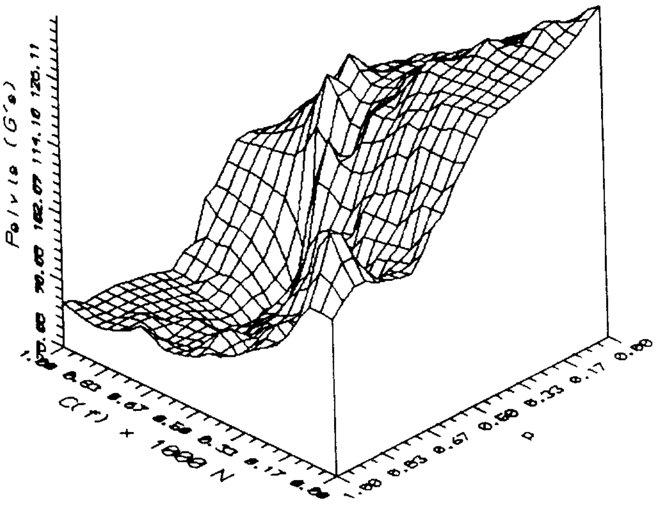

Fig. 9 3-D view of pelvis function of C_f & p baseline simulation (unpadded door), the rib and pelvis of occupant reached maximum force level at 22 KN and 42 KN respectively. The reasons are that first, the mass of pelvis was heavier than that of rib. Secondly, on the occupant seating position and barrier shape, the pelvis was contact with door earlier with higher impact speed. For the optimal pelvis protection, relatively higher dynamic forces C_f are expected to compensate the impact energy.

Figure 10 shows that influences of initial impact speed of door by means of occupant injuries. As shown in figure, the both TTI and pelvis injuries were strongly influenced by the intruding door speed. It was noticed that 22 % increase of impact speed resulted 50 % higher injuries in both TTI and pelvis. In general, initial contacts are occurred between 15 mili-seconds and 30 mili-seconds in most of side impact events. Reduction of intruding door speed could be effectively established by vehicle side structure modification. A stiffer vehicle side structure, particularly in the initial stage of impact can be disputed the energy and eventually slowed down the door speed.

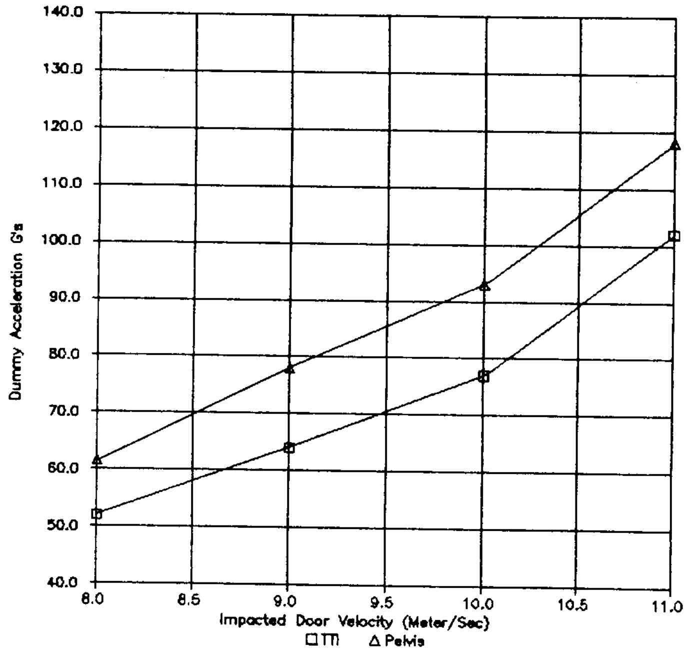

Fig. 10 Influence of door speed in injuires

SUMMARY AND CONCLUSIONS

In this study, the effectiveness of door padding characteristics to minimize potentials for occupant thoracic and pelvic injuries was investigated. Through a number of simulation using a developed mathematical nonlinear lumped mass model concludes that

1) Occupant responses were strongly dependent on the two padding material coefficients C_f and p

2) The deformation shape characterized by p's in the range of 0,1 to 0.3 were found to be most effective in reducing TTI, while p in the range of 0.5 to 0.9 were more effective in pelvis.

3) Without any side structure modification, TTI and pelvis injuries could be improved up to 50 % by the optimized paddings.

4) TTI and pelvis linearly varied on the speed of the collision.

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