

DEVELOPMENT OF HIGH EFFICIENCY LOAD PATH STRUCTURE TO ENHANCE SIDE IMPACT SAFETY PERFORMANCE

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ABSTRACT

In order to protect the occupants effectively in side impact crashes, the main tasks are (a) to minimize the intrusion of the deformed body structure after the impact in order to reduce direct contact force with the occupant and (b) to reduce the relative impact velocity of the intruding structure at the start of contact with the occupant. The existing concepts similar to SIPS (Side Impact Protection) system are basically based on good structural integrity with seat-mounted side air bags and roof-mounted curtain air bags for overall protection of the occupant in side impact crashes. However, for higher level of external input load at an inclined angle from high front-end SUVs acting on the side of an ordinary PV in case of SUV-to-PV side impact crashes, there is a room to have more efficient structural load-path system layout. A new inclined L-shaped High Efficiency Load Path System (HELPS) was developed and incorporated at the back of the existing seat back frame to bypass a part of the incoming load to the central console through the seatback frame. At first, a number of full vehicle FE-simulation studies were carried out to verify the performance in IIHS and SINCAP tests to assure the effectiveness of the concept. Finally, it is tuned to a feasible optimized structure in order to ensure other functional aspects, such as, seating comfort of the front passenger, leg-room of the rear occupants, etc. Its performance was calculated assuming various seating positions of the frontal occupant to examine the robustness of the concept in real world safety. Human Body Model (HBM) simulations were also carried out to compare two systems, one with HELPS and the other without HELPS concept. Similar to the results of the dummy response in IIHS and SINCAP tests, reductions in occupant injury level were observed in HBM simulations.

INTRODUCTION

Side collisions remain a frequent cause of fatal and serious injury. From accident analysis, it is found that 60% of the fatal and serious injuries to front seat occupants in side collisions were to the struck side occupants, and 40% were to the non-struck side occupants [3], [4]. In lateral impact at the intersection of roads, the distance of occupant's chest and the front end of the colliding car is only few hundred millimeters. The advanced safety cage of recent vehicles is designed with careful mix of different steel grades of various strength and thickness to provide carefully controlled lateral deformation of the whole body structure in order to minimize the injuries of the occupant inside the vehicle compartment. The side airbag and roof curtain airbag provide additional protection of the pelvis, abdomen, thorax and head for both the front seat occupants as well as to the rear passengers. Strong rigid steel tubes of Volvo's SIPS concept across the seat frame help to transfer loads to the center console to maintain the seating space after the impact. It is very effective for a lateral input at a lower height when colliding with passenger vehicles. However, in case of collision with SUVs having higher front-end stiffness, it may not be that effective in an inclined lateral input load at a higher height from the ground. It is known that occupants in cars will encounter serious chest injuries when struck by vehicles with high front-end stiffness and high ground clearance such as sport utility vehicles (SUVs), multi-purpose vehicles (MPVs) and 1-box type of vehicles [3],[6],[7]. As these types of vehicles become increasingly more prevalent, consideration should be given to the vehicle structural design in light of the changing and mixed vehicle fleet [2], [5].

BASIC INITIAL DESIGN CONCEPT

The Figure1 shows the basic concept of HELPS. The system consists of four main elements: 1) an outer contact element, 2) an inclined and curved seatback cross-reinforce member 3) an inner contact element and 4) a strong center console. The outer contact element facilitates an early contact of the seat frame to intruding door deformed by the moving barrier or a vehicle at the level of the bumper height. The input load to the seat is then transferred diagonally to the opposite side of the seat through the inclined cross-reinforce member which is located at the back of the seat and connects the two sides of the seat frames to secure a higher level of structural integrity of the whole seat frame (Figure2). It also enables more space between the pelvis of the occupant and the inner door panel for proper deployment of lower chamber of the side air bag to have a better coverage of the whole pelvis as shown in Figure3(a, b).

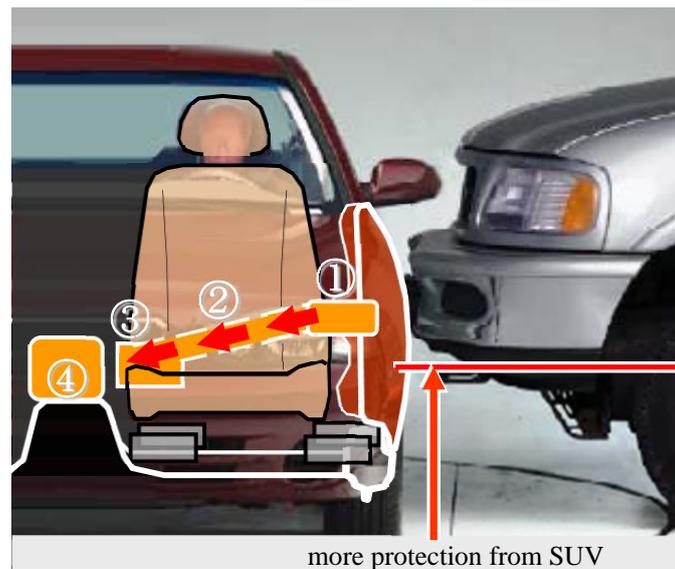


Figure1. Basic concept of High Efficiency Load Path Structure (HELPS).

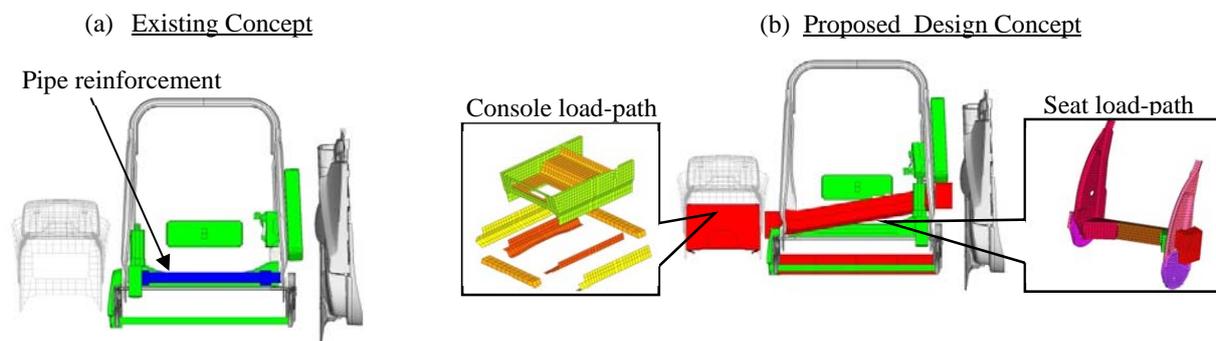


Figure2. FEM model of the initial concept design level. (a) Existing system (b) Proposed design concept.

As shown in Figure2, an initial design concept was made and consequently the safety performance was evaluated with help of a detail FEM model to study the feasibility of the concept in full vehicle side impact crash simulations for IIHS and SINCAP test conditions. With more deployment space for the inflating side airbag, it can absorb more input energy of the incoming deformed door as shown in Figure3. Consequently it becomes easier to decide the crash performance specification of door trims for better energy management. The inner contact element comes in contact with the center console which is properly reinforced to evenly distribute the load to over a large area of the vehicle floor and the propeller shaft tunnel.



(a) without HELPS concept (30msec) (b) with HELPS concept (30msec)

Figure3. Comparison of cross-sectional views of side airbag during deployment phase at abdomen level.

There are other advantages of this concept, such as, better and more flexible design layout of door pockets.

RESULTS OF INITIAL DESIGN CONCEPT

Figure4 shows the comparison of cross sectional views of the deformation patterns with von-misses stress distribution for (a) without-HELPS concept and (b) with-HELPS concept in IIHS side impact test conditions. It is very clear that a large amount of force can be transferred from the body side to the center console through the inclined seat reinforcement structure which absorbs some amount of external input energy. It also constraints the amount of total intrusion of the B-pillar and door with respect to the center line of the vehicle denoted by arrows.



(a) without HELPS concept (b) with HELPS concept

Figure4. Comparison of deformation and stress at B-pillar, door and seat in full vehicle simulations.

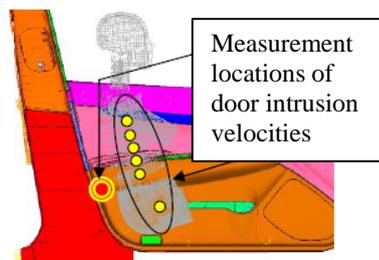


Figure5. Location of evaluation points on interior door trim at different heights of ES2 dummy.

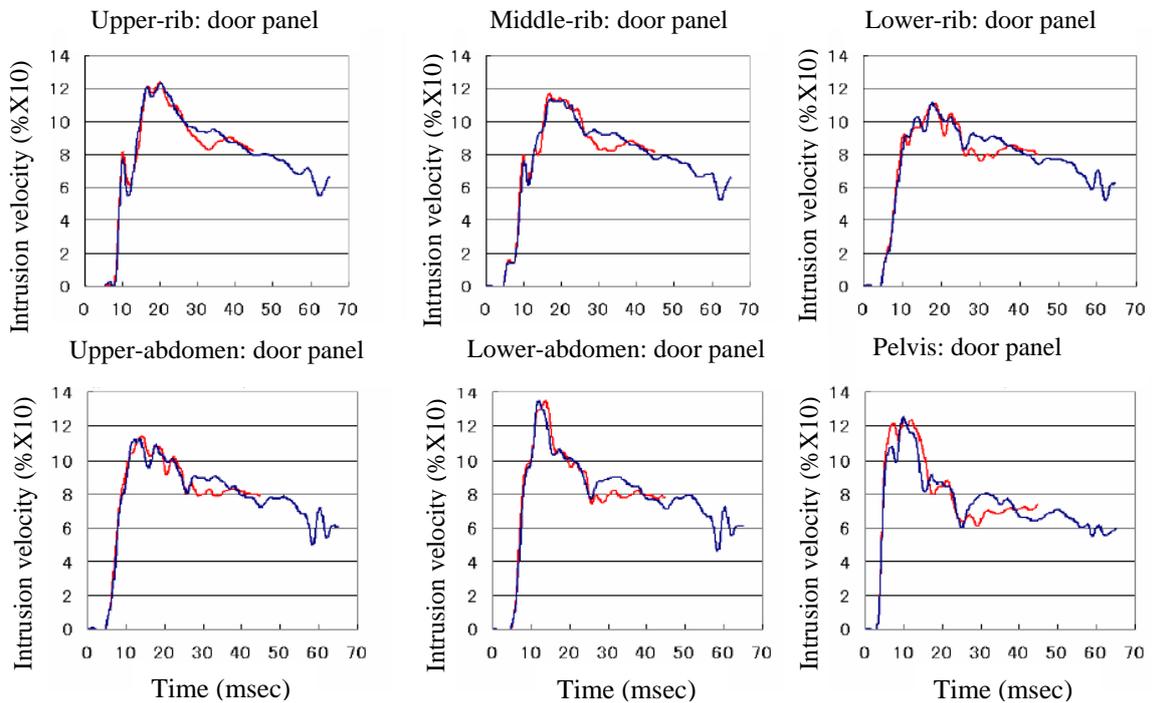
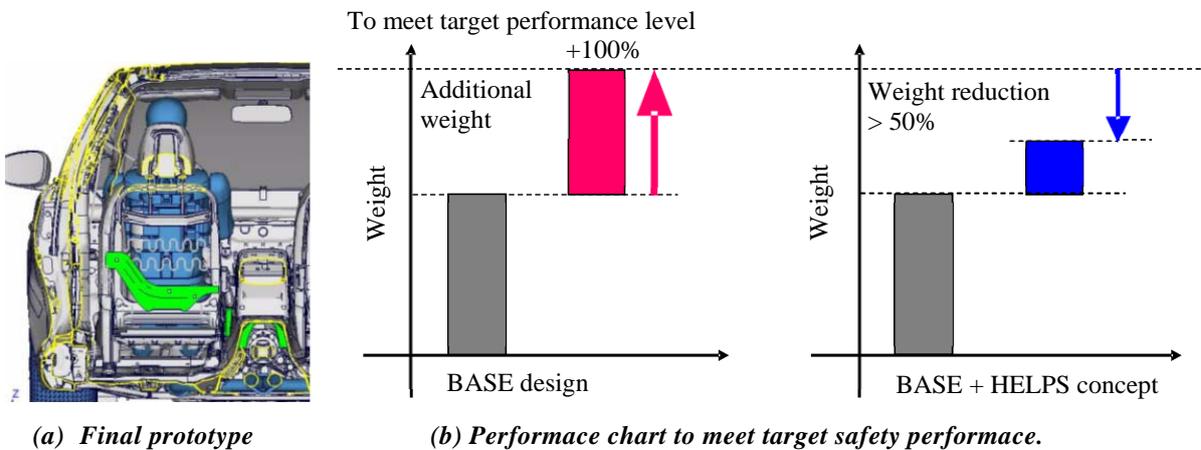


Figure6. Comparison of door intrusion velocities of interior door trim corresponding to different locations of ES2 dummy. (blue line: without HELPS concept and red line: with HELPS concept).

Figure6 shows the comparison of door intrusion velocities corresponding to different locations on the dummy as indicated by yellow circles in Figure5. After 25msec, the intrusion velocities dropped due to the load transfer from the body side to the center console through the inclined reinforcement structure of the seat. It is also effective in reducing the cumulative impact load on the dummy at the later phase of the structural deformation of the B-pillar intruding inside the vehicle compartment. The rib displacement will be reduced by 3 to 4 mm or more depending on the level and position of reinforcement. In this specific CAE result, the effect of outer contact element is omitted. Inclusion of outer contact element will make the starting time of the reduction of intrusion velocity a little earlier than 25msec and it will also change the initial phase of velocity profile before 25msec. Refer to the comparison of intrusion velocity time history plot (base vs final prototype) of a physical test as shown in Figure8.

RESULTS OF FINAL DESIGN CONCEPT



(a) Final prototype

(b) Performance chart to meet target safety performance.

Figure7. Final concept and weight reduction chart to meet required target performance.

Figure7 indicates a considerable amount of reduction in weight due to increased structural integrity of the system in which one will be able to reduce the maximum intrusion and also the intrusion velocity of the surrounding intruding structures at different heights starting from pelvis to chest level of the dummy as illustrated in the intrusion velocity diagram (Figure8) and the deformation pattern diagram (Figure9), respectively.

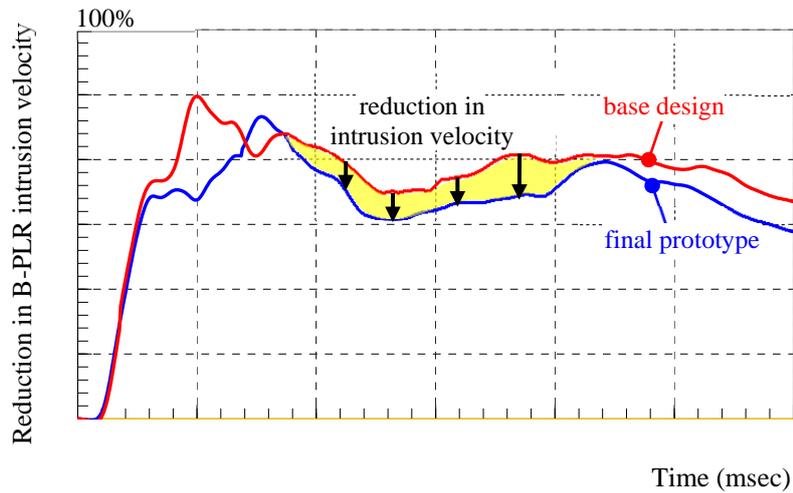


Figure8. Maximum change in intrusion velocity of the surrounding structures around the occupant in physical test (red line: base design without HELPS and blue line: final prototype with HELPS concept).

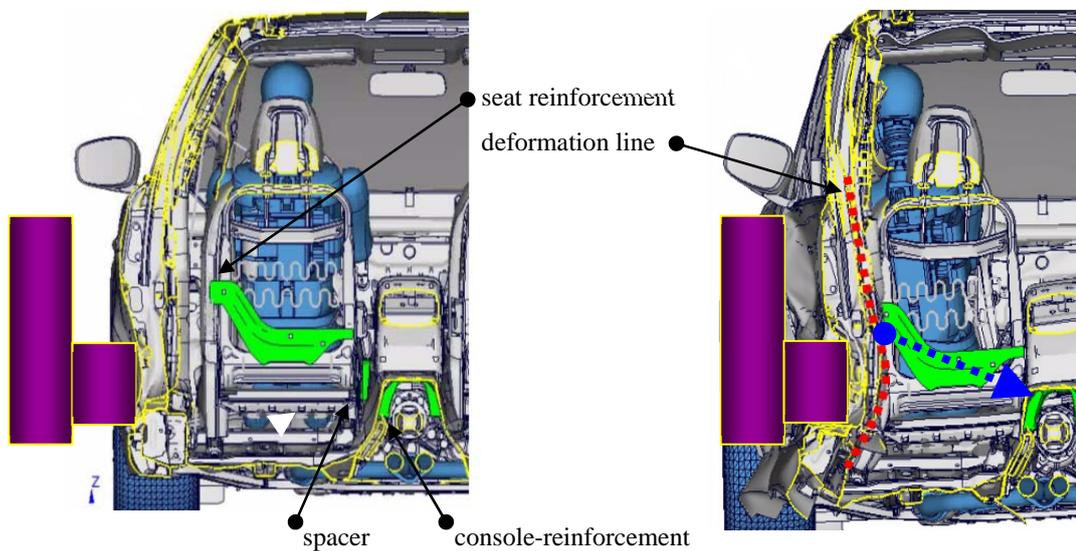


Figure9. Deformation mode of the final prototype

RESULTS OF HBM SIMULATION

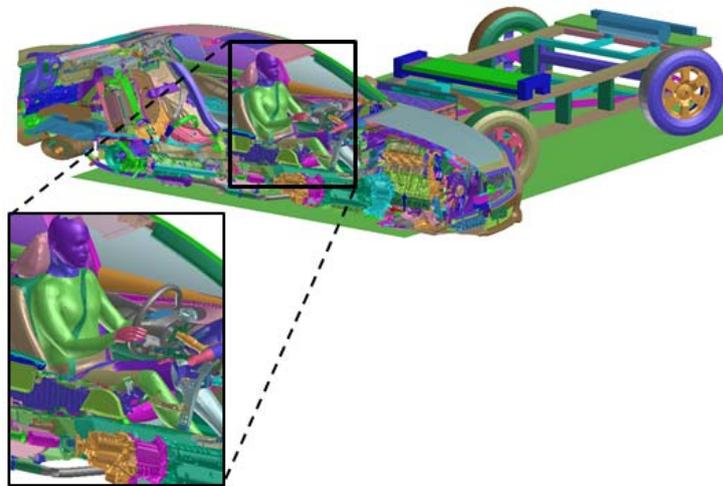


Figure10. Full vehicle FE simulation with HBM.

Figure10 shows a typical FE simulation set-up of a human body model (HBM: GHBM, AM50 model, [8]) in SINCAP condition. By this simulation, a comparative study was carried out (i) with HELPS and (ii) without HELPS concepts to estimate the efficacy of the proposed system in real world. Comparison of (i) and (ii) was carried out on the amount of plastic strain distribution of chest rib and lower leg bones (pelvis and femur regions). The quantity of plastic strained regions across different bones was used as a comparative estimate for studying injury pattern. Bones will sustain plastic strain until a certain limit without failure and beyond certain threshold value of plastic strain, fracture will be initiated. Hence, a threshold of T^* (T^* =one-tenth of GHBM reference value for fracture) was assigned for plastic strain and the total volume of elements crossing the threshold was calculated. By comparing the volumes of threshold elements across different bones, the injury pattern was estimated. The percentages of plastic strain $> T^*$ in chest ribs, pelvis and femur bones are shown in Figure11a,b. Detail of this plastic strain estimation method can be found in reference [1] where a detail description was given in female pedestrian human FE model development and its validation procedure based on PCDS pedestrian accident database combined with detail FE simulations.

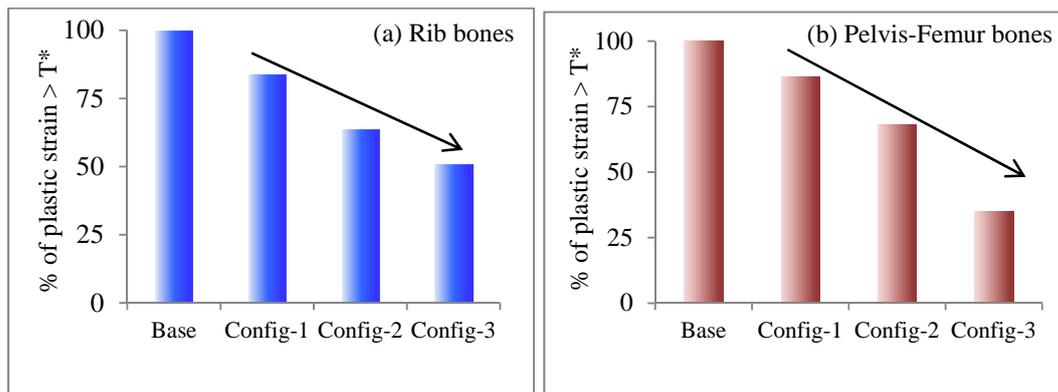


Figure11. Comparison of relative plastic strain in bones for AM50 driver HBM simulation (Base: without HELPS; with HELPS in three different design configurations (i) Config-1: -0.3m.sec, (ii) Config-2: -0.6m/sec and (iii) Config-3: -1.0m/sec average reduction of intrusion velocities)

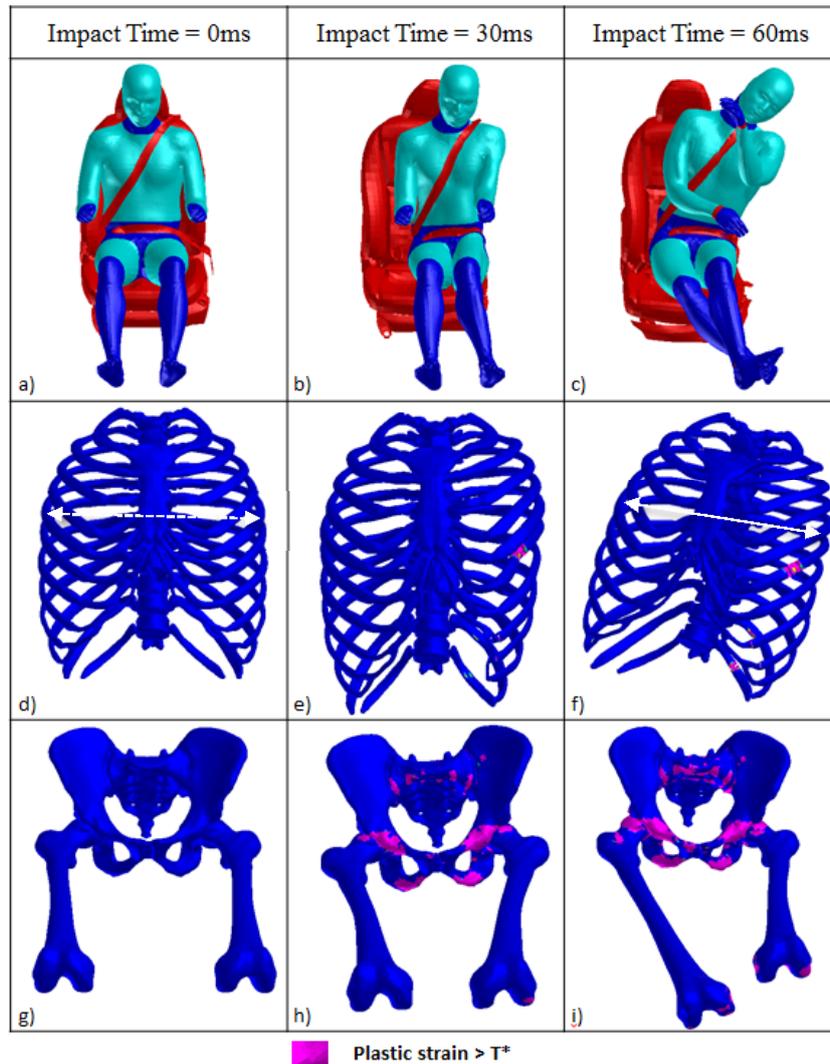


Figure12. Kinematics of AM50 driver occupant (HBM) and plastic strain distribution of bones with a plastic strain threshold T^* ($T^* = 1/10$ th of GHBM reference value for bone fracture criteria)

Figure11 shows the degree of effectiveness of the HELPS system based on the above mentioned plastic strain criterion of the bones with various levels of HELPS reinforcements related to (a) base design without HELPS concept, (b) low level of reinforcement with an average reduction of intrusion velocity of 0.3m/sec and (c) medium level of reinforcement with an average reduction of intrusion velocity of 0.6m/sec and (d) high level of reinforcement with an average reduction of intrusion velocity of 1.0m/sec. The higher is the level of reinforcement, the more is the effectiveness to reduce occupant injury, especially at the abdomen level of the dummy corresponding to the lower most ribs of the thorax of the human model. In case of human, unlike the upper and middle ribs which form a closed ring structure, the last few ribs are open and not connected to the sternum.

Figure12(a,b,c) show the occupant kinematics at 0msec, 30msec and 60msec. The level plastic strain of the chest ribs (Figure12d,e,f) and the lower leg region (pelvis and femur, Figure12g,h,i) are shown in second and third rows, respectively. It is clear that the amount of plastic strain volume of bones in the ribs and the lower leg regions are increasing with the increase of external load and deformation from the start 0msec to the end 60msec.

Figure13 shows the degree of effectiveness of the proposed system in reducing the thorax rib displacements corresponding to various levels of reinforcements of the HELPS concept with respect to the base design in (a)

base design without HELPS concept having no reduction of intrusion velocity, (b) lower level of reinforcement with an average reduction of intrusion velocity of -0.3m/sec, (c) medium level of reinforcement with an average reduction of intrusion velocity of -0.6m/sec and (d) high level of reinforcement with an average reduction of intrusion velocity of -1.0m/sec. It is clear that the amount of rib displacement starts decreasing with the increase of reinforcement level in HELPS concept. The rib displacement at each individual rib is the deformation measured between the outermost points of the left and right side of the corresponding rib. They are indicated by two white lines (i) dotted line (initial state) and (ii) solid line (deformed state) at the 5th rib from top as shown in Figure12d and Figure12f, respectively. Maximum amount of reductions in rib deflections occurred around the ribs 8-12. These three ribs (8, 9, and 10) are located at the similar position and height of the lower chest rib of ES2 dummy. There were also reductions in rib displacements in rib 11 and rib 12 which correspond to the abdomen region of a side impact dummy. Similar trends in injury reduction were also observed in ES2 dummy response of actual vehicle tests.

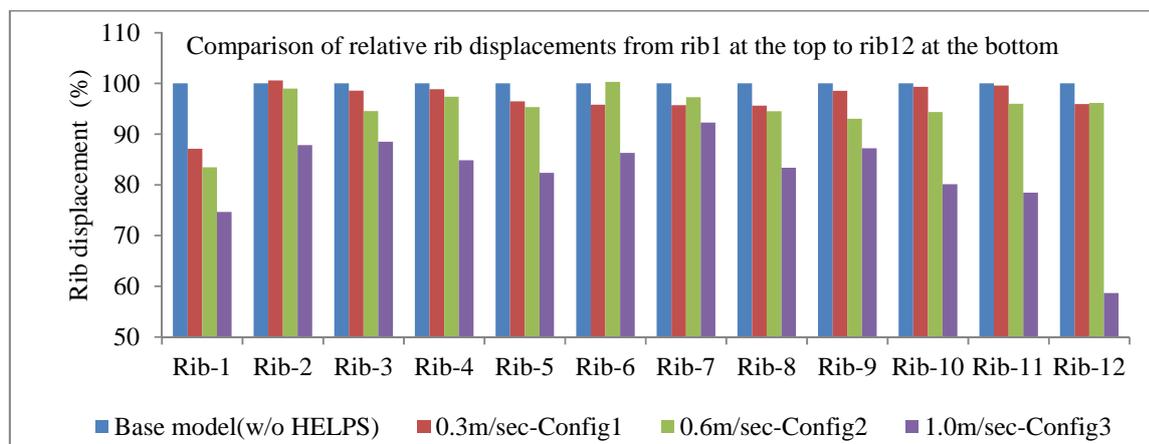


Figure13. Comparison of relative rib displacements for AM50 driver HBM simulation (Base: without HELPS; in three different design configurations Config-1: -0.3m.sec, Config-2: -0.6m/sec and Config-3: -1.0m/sec average reduction of intrusion velocities)

CONCLUSIONS

The following are the main conclusions of this study.

A new concept of side impact occupant protection system is proposed by using the concept of a high efficiency load path system (HELPS) which consists of a combination of reinforced seat, center console and floor-tunnel structure. The system consists of four main elements: 1) an outer contact element, 2) an inclined and curved seatback cross-reinforce member, 3) an inner contact element and 4) a strong center console.

A two-step design development approach was performed to evaluate the feasibility of the present system. The first step is the basic feasibility study phase of the proposed concept to estimate the benefits based on safety performance requirements using extensive CAE simulations. The second step is the final prototype design phase by CAE together with verifications of safety performance in actual crash tests. All the necessary design constraints to meet other functional requirements, such as, seating comfort, minimum leg room space and size of the center console box etc. were also taken into account in determining the final design specifications.

Apart from the verification of the effectiveness of the proposed system using side impact dummy ES2, the human body model (GHBMC, AM50 occupant) was also used to estimate its effectiveness in real world accident. Similar to dummy response, the results of AM50 human model simulation also showed similar trend regarding the level of effectiveness of the system. Even though the numbers of simulation cases performed with HBM were very limited in number and related to certain specific test conditions, one can expect some benefits in real world accidents if HELPS concept is incorporated in conventional design.

The key essence of the present system HELPS is to effectively reduce the average intrusion velocity and the amount of intrusion of the deformed B-pillar, the surrounding door structures etc. to further decrease the level

of front seat occupant injuries in severe side impact crashes. However, the level of effectiveness of this system will vary depending on the size, the category and the type of upper body structure of vehicles under consideration. Hence, to incorporate the proposed HELPS system in the existing vehicle design process, additional merits and demerits should be evaluated and judged carefully in order to get maximum benefits based on total vehicle system performance.

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GLOSSARY

AM50: 50th percentile American male

ES2: Side impact dummy; the next generation of the EuroSID1 dummy

GHBM: Global Human Body Model Consortium

HBM: Human Body Model

HELPS: High Efficiency Load Path System

PCDS: Pedestrian Crash Data Study

SINCAP: Side Impact New Car Assessment Program (US motor vehicle safety standard)

IIHS: Insurance Institute for Highway Safety

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