SEAT PAN LOADING DIFFERENCES USING A NEW TEST APPARATUS

John J. DeRosia
Frank A. Pintar
Dale E. Halloway
Mark A. Meyer
Narayan Yoganandan
Medical College of Wisconsin
and VA Medical Center
Milwaukee, WI
USA
Paper Number 13-0102

ABSTRACT

Despite decreases in mortality and overall injury in the last 15 years, in that same time lower thoracic and upper lumbar spine fractures have not decreased, and there is growing evidence that these fractures are actually increasing in frontal impact collisions. Due to the usual upward inclination of passenger seats and structural features added to optimize frontal impact performance, there is a question as to how much the construction of the seat pan might contribute to the incidence of thoraco-lumbar fractures. A seat testing apparatus was designed and evaluated to determine the static stiffness of any vehicle seat when it was loaded in a forward direction. The device used an appropriately pre-weighted seat form to load the vehicle seat and moved the seat form forward relative to the seat cushion. As the seat loading device interacted with the seat, horizontal and vertical forces were generated by the increasing load due to the inclination of the seat and the under cushion structure. While paired same model seats exhibited similar loading patterns and values, there was a variable response from different model seats. Of the five different models tested, maximum vertical loadings varied from 1082 N to 5655 N. After disassembly, structural differences were found between the tested seat models that could account for the difference in seat reaction loads. The device proved that the differences in stiffness between seat models could be evaluated in a non-destructive and timely manner.

BACKGROUND

Research and mitigation strategies regarding injury due to frontal impacts has concentrated on protecting the head, neck and thorax of front seat occupants (Mertz, Irwin et al. 2003). The development of airbags and three point seatbelts has been instrumental in reducing mortality and injury severity in collisions. Mortality rates while wearing only a seatbelt were reduced by 51% compared with users utilizing no restraint devices. The mortality rate of those utilizing an airbag only, without belts, had a 32% reduction, but the rate for those users protected by both airbag and seatbelt had a 67% drop (Cummins, Koval et al. 2011). Injury severity scores showed a similar pattern. However, while the use of both seatbelts and airbags has decreased the probability of sustaining many injuries, the occurrence of spine fractures in front seat occupants has not decreased between 1994 and 2002 (Wang, Pintar et al. 2009).

Although thoracolumbar injuries due to axial compression have been known to occur due to frontal impacts, the mechanism of injury to the spinal column is somewhat elusive (Begeman, King et al. 1973). Begeman used a series of sled tests of lap and shoulder belted cadavers placed on a welded steel chair with a load cell under the seat to monitor axial forces from the spine. In a series of frontal braking tests of up to 15g, they found that the vertebral column suffered wedging or compression fractures at L1, T9, or T7. The authors felt that the fractures were the result of the straightening of the spine curvature during a frontal impact.

Huelke et al. found that, vertebral fractures can occur to lap-shoulder belted front car occupants in frontal crashes, and that thoracolumbar fractures can happen during low speed crashes without the occupant's head striking the interior of the car. They hypothesized that the fractures were due to the submarining of the occupant's pelvis under the lap belt with a pre-flexed lumbar spine (Huelke, Mackay et al. 1995). In a study involving 37 patients with thoracolumbar fractures, Ball found that of those wearing three point restraints, 80% sustained burst fractures while 28.6% of patients wearing lap belts alone had burst fractures (Ball, Vacarro et al. 2000). They stated that the thoracic spine would straighten “suddenly and forcefully” as the torso was restrained by the shoulder belt. Bilston used NASS data to identify AIS2+ spinal injuries among restrained vehicle passengers. The study identified risk factors for thoracolumbar fractures such as higher severity crashes, crashes into fixed objects, and crashes in the presence of intrusion (Bilston, Clarke et al. 2010).

Pintar et al. studied NASS data and performed an in-depth study of the US-DOT NHTSA Crash Injury Research and Engineering Network (CIREN) database to identify crashes that involved the potential for seat pan and lap belt interaction with the pelvis. (Pintar, Yoganandan et al. 2012) They identified 73 cases from the CIREN database that met the criteria: frontal direction; fractured spine at T10 or below; fracture due to compressive loads (burst, overall compression, or wedge-type with more anterior than posterior involvement); no rollover greater than two quarter turns; row one occupants only. Exclusion factors included occupants who had a history of previous thoracic and/or lumbar surgery and occupants who were in sub-optimal posture at impact. They found that 73% of the Delta-V’s occurred at 56 km/h or less and that the location of the crash was approximately half on-road and half off. The vehicles were predominantly (75%) late-model between 2000 to 2010 model years. They noted some interesting relationships between the location of the fracture and type of object struck: five of the ten occupants with T10 or T11 fractures struck a heavy truck, eight of the ten that struck a fixed hard object had L1 fractures, and 17 of the 30 tree/pole impacts suffered fractures at L2 or below. Given the detailed crash descriptions in the CIREN results, it was possible to identify many direct planar frontal impacts with no obvious upward component. As pointed out by Pintar et al. this implies that the seating components of the car are implicated in producing significant upward compressive loads on the distal spine. The structure of the modern automobile seat, in particular the seat pan and forward frame components such as thigh-bars, should be examined for interaction with the lumbar region of restrained occupants. To investigate the potential for seat pan involvement in generating vertical spine loads, a seat testing apparatus to determine static stiffness for vehicle seats was designed and evaluated.

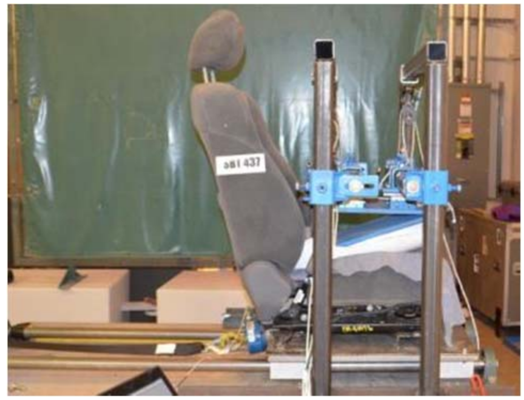
Photo 1. Seat mounted in test fixture. Test platform angle is adjustable relative to seat form. Seat was pulled rearward during test.

APPARATUS

The static seat testing (SST) device was intended to test the resistance of vehicle seats to forward motion of an occupant during a forward, planar collision. The test apparatus was constrained to remain in a horizontal plane while the seat was pulled out from beneath. The device incorporated a cart fastened to linear bearings riding on two parallel, large diameter (38.1 mm) round rods enabling free forward and back motion (Photo 1). The vehicle seat to be tested was bolted to the cart with the seat tracks parallel to the cart’s plane of travel. A seat form of fiberglass composite was fabricated that matched the contours of a standard H-Point machine. The shaped form was rigidly mounted to a base plate. The plate was hinged to a second plate along its front edge to vary the angle of the device relative to the seat being tested while keeping four 3-axis load cells mounted above the upper plate horizontal (Photo 2). Two lateral beams were mounted to the upper surface of the front and rear pairs of load cells. The beams extended to a solid fixed frame rigidly mounted around the movable seat and cart. The vertical position of the two beams could be varied, then fixed in position. The cart with vehicle seat was pulled rearward using a manual winch through a single axis load cell. The total weight of the movable portion of the SST was, at 134 pounds (60.8 kg), equal to the sitting weight (total weight less the feet, lower legs and one half of the upper leg) of a Hybrid 3 dummy. The signals from all load cells were collected and recorded by a TDAS PRO (Diversified Technical Services, Seal Beach, CA, USA) data acquisition system. As the test was quasi static, the sample rate was

1000 samples per second with a duration of 60 seconds.

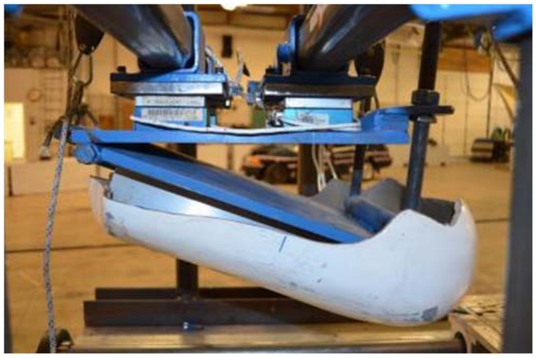

***Photo 2*. Fiberglas seat form mounted to instrumented platform.**

METHODS

In this preliminary series of tests eight seats were tested. All seats were bucket seats with fabric covers. Six of the seats were previously used and two were from recently crash tested vehicles. The six used seats were from three different car models with two seats from each model. The vehicle model year of the six used seats ranged from 2006 through 2012. The two new seats were made available from NCAP tested vehicles. Each of the those seats were from the passenger side of 2012 model year vehicles that had been used for a side impact test to the opposite side and a side airbag occupant out-of-position test using SID-2s 5th percentile female dummies. Those seats had not been subjected to either the loading of frontal tests or the wear and tear of used seats. The seats represented five different models, each model with different seat frame designs, seat suspensions, and foam thicknesses.

Before testing, the seats were fixed to a plate with the seat track level, and seat centerline centered on the plate. If the seat pan angle was adjustable, it was set per FMVSS 208 guidelines. For consistency between pairs of seats, if only one seat of a pair was adjustable, it was adjusted to match the seat angle of the unadjustable seat. For each test setup, the seat form and load cell assembly were placed in the vehicle seat over a fabric sheet similar to the dummy setting procedure outlines in the FMVSS 208. The seat was brought forward into contact with the rear of the seat form. Additional weights were placed on top of the assembly to bring the total weight resting on the seat to 930 N. The portion of the device representing the ischial tuberosities location of a human occupant was allowed to rest into the rear of the seat cushion while the front of the device was stabilized in a fixed position to maintain an upward angle of the seat bottom of approximately 20 degrees with a level reference plane for the load cells. The outboard ends of the lateral beams on the pairs of load cells were then tightened into position while monitoring a real time output from the load cells to avoid introducing any significant preload into the system during the tightening. The seat was pulled slowly rearward using a manual winch, pausing every 50 mm of travel. The process was repeated until the seat was pulled free of the seat-form loading assembly. Care was taken to avoid maintaining the loading of the seat cushion for longer than 15 minutes, and the seat cushion was allowed to rest unloaded for a minimum of 30 minutes between repeat tests. Each seat was tested at least twice to assess repeatability. Results of the repeated tests of each seat were compared by summing the vertical loads recorded by the four load cells. The mean difference between peak seat pan loading between repeated tests was 5.2% (SD 4.9%).

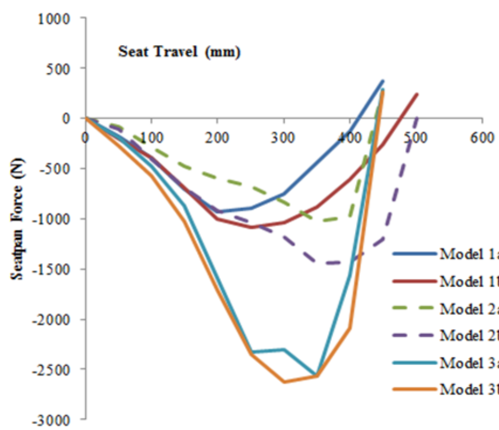

***Figure 1.* Comparison of tests of three model seats.**

The loading responses between the paired seats were compared. For each seat, the mean of the maximum seat pan loading of the repeated tests was compared to the similar values calculated for the other seat of the pair. For Model 1 and Model 2 the differences between the two seats were 9.0% and 2.5% respectively, while the same comparison for the Model 3 seats was 32%. Combined, the mean difference was 14.6% (SD 12.8%). An explanation for the larger difference in peak loading within pairs of seats was found by examining the tested seats. Two seats of the third pair, although they were externally similar, had considerably different foam cushions (Figure 1). The age and condition of the seat foam seemed to be a factor in the stiffness of the tested seats.

RESULTS

Each of the seat models displayed different stiffness behaviors with respect to the position of the loading device (Figure 2). The Model 1 and 2 seats exhibited linear stiffening to approximately 250 mm of seat travel. While seat Model 1 gradually decreased in stiffness, seat Model 2 did not reach peak stiffness until approximately 400 mm of travel. Both models unloaded smoothly after reaching the peak. The Model 3 seat was considerably stiffer than the first two (Table 1). It also exhibited a smooth unloading phase after its peak at 300 mm. The Model 4 seat paralleled the behavior of Models 1 and 2 until 200 mm, after which the stiffness rapidly rose to a peak higher than the three previous seats at 350 mm, then began to unload smoothly. The Model 5 seat showed a considerably different behavior. For the first 100 mm, Model 5 was initially only marginally stiffer than other seats, but the stiffness increased at a higher rate and reached a considerably higher peak at 350 mm. It remained stiff for 50 mm before dropping off suddenly.

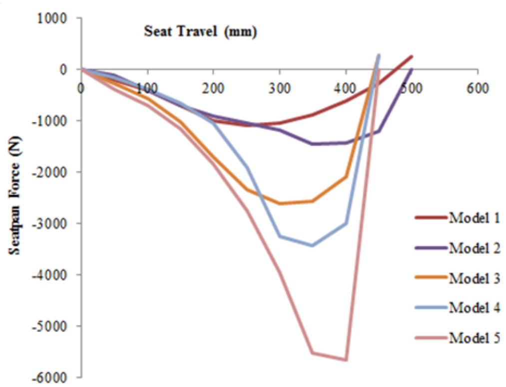

Figure 2. **Comparison of five different model seats.**

The horizontal force (X axis) required to move the seat pan out from under the test device was proportional to the seat pan force at approximately half of the Z axis load.

SEAT CONSTRUCTION

The construction of the Model 1 through 4 seats was generally similar but with important differences in detail. The seats utilized stamped sheet metal side frames fastened to movable tracks that allowed fore and aft adjustment of the seat in the vehicle.

Table 1. Matrix of test results.

Seat	Max Seat-pan Load [N]	Max Horizontal Pull [N]	X/Z
Model 1	-1081.8	-580.2	54%
Model 2	-1442.0	-809.0	56%
Model 3	-2621.3	-1429.3	54%
Model 4	-3437.9	-1696.0	49%
Model 5	-5655.2	-2698.4	47%

The two sides were fastened together with a tubular member across the back and a front structure consisting of another tube and/or other structure. A wire upholstery spring suspension was used to suspend the rear of the seat by clipping onto the rear tubular cross-member. At the front of all the seats a stamped sheet metal cover fastened over the front cross-member and springs (Photo 3).

Photo 3. **Cross-section of typical car seat construction. Under fabric upholstery and cushion is sheet metal cover on front of seat (to right) and a portion wire spring suspension is shown. Two side pieces are connected by a round tube in the rear and a second tube toward the front under the front cover.**

A foam rubber cushion then covered the metal portion of the seat, and fabric upholstery encased the foam cushions. Due to the spring suspension in the rearward portion of the cushion, the seats were more yielding under the buttocks of the vehicle occupant. During testing, as the testing device moved toward the front of the seat, the device compressed the foam cushion of the seat to the point that the structure of the seat under the cushion played a role in its relative stiffness.

The higher stiffness seats were constructed with more and heavier bracing between the side rail framework in the forward third of the seats. For instance, while Model 1 utilized a thin (0.67 mm thick) stamped steel forward cover and a 25 mm diameter tubular cross-tube beneath the cover, the cover was fastened to the side structures by four relatively small mechanical fasteners. Conversely, Model 3 was constructed with a thicker (1.0 mm) front upper metal cover over the top front corner of the seat frame that was welded to the side frames

***Photo 4*. Model 1 structure. Sheet metal front cover over front frame tube wire seat suspension springs wrapped around rear tube.**

Rather than the single steel tube connecting the two sides under the front cover sheet metal, Model 3 seat also had a considerably more rigid stamped sheet metal member fastened between the two sides. It used a closed section welded sheet metal beam of thicker (1.4 mm) construction connecting the two sides beneath the upper cover. Model 3 was more than twice as stiff as the Model 1 shown in Photo 3.

In addition to the normal seat components, Seats 4 and 5 also were equipped with seat cushion airbags. Neither seat bolster bag was deployed before or during the testing. While the Model 4 used a wire spring suspension system Model 5 used a considerably different approach (Photo 5).

***Photo 5*. Model 5 seat. Sheet metal sides incorporating three cross-tubes.**

The side members of the seat were larger and taller than the other seats. Front and rear cross-tubes connected the two sides. In addition, a tubular frame rose from the floor level, up the front of the seat side frames, bent forward to extend the front of the seat, then laterally to form a rigid frame around the front of the seat. Rather than springs, a sheet metal pan spanned from the front tubular structure, rearward over the front tube, down to form a depression for the seat, then back to the rear tube (Photo 6). The pan was not attached to the sides but was welded to all three tubes. The airbag lay on top of the pan, under the cushion.

***Photo 6*. Airbag folded forward to show seat pan.**

DISCUSSION

Three factors were identified as being involved in the disparate stiffness of the seat models tested. The original angle of the seat cushion affected the measured stiffness of the seats. An increased angle of seat cushion brought the interaction of the test device with the under structure of the seat earlier and to a greater extent. Model 1, the least stiff seat, had a total seat cushion angle of six degrees, while Model 3 seat was 8.3 degrees and Model 5, the stiffest seat, was 10.9 degrees. Structurally, the stiffness of the front structure of the seat contributed to the overall stiffness as the load was moved forward. For the seats with a stiffer front structure, stiffness increased as the seat form encountered the hard structures. The condition of the foam also influenced the tested stiffness although it was less of a factor than the seat geometry and structure.

In the small sample of seats tested, the unique design of Model 5 stood out. The unyielding seat pan was initially stiffer than the other seats and increased in stiffness in a nonlinear fashion until it reached a peak stiffness, 61% higher than the next most stiff. The front tubular structure was more forward and higher relative to the other seats. The effect of this structure was that it formed a rigid barrier at the front structure of the seat. An example of this effect was the abrupt fall off of force once the test device cleared the front structure. The resistance of the seat pan to forward motion of the occupant's pelvis may be significantly altered with under-seat airbag deployment by tightening the occupant against the lap belt, preventing appreciable forward interaction between the pelvis and hard structures of the seat pan.

There were limitations to conducting only static testing of the seats. As mentioned above, there is no opportunity to judge the effect of the under-seat airbags and how they would affect forward motion of the lower body. The small number of seats available to be tested is a drawback that will hopefully be addressed in the near future. Finally, it cannot be assumed at this point that a given seat that was evaluated with a higher stiffness will be more prone to inducing thoracolumbar spinal fractures. The dynamic nature of a crash and the interaction of the human pelvis with the seat pan have not been considered in this study.

CONCLUSIONS

As the rate of thoracolumbar spine fractures is increasing in more modern designs of automobiles, the contribution of seating systems to the problem should be addressed. A test device was developed and evaluated to determine the relative stiffness of automobile seats.

The device was able to measure differences in the vertical load resistance of an occupant surrogate between designs of modern seats. The device should be useful in determining which seating systems are more likely to cause high axial loading into the spine of an occupant. The next phase of the study will evaluate the most and least stiff seats subjected to more dynamic tests to verify the potential for spinal injury.

ACKNOWLEDGMENTS

This research was supported in part by US DOT NHTSA CIREN research funds DTNH22-10-H-00292 and by the Department of Veterans Affairs Medical Research. The views expressed are those of the authors and do not represent those of the funding agency. We gratefully acknowledge the work of Joe Frank and Chuck Bokath in the construction of the apparatus.

REFERENCES

Ball, S., A. Vacarro, et al. (2000). "Injuries to the T-L spine associated w restraint use.pdf>." Journal of Spinal Disorders **13**(4): 297-304.

Begeman, P., A. King, et al. (1973). "Spinal Loads Resulting from -Gx Acceleration." Stapp Car Crash J.: 343-360.

Bilston, L. E., E. C. Clarke, et al. (2010). "Spinal injury in car crashes: crash factors and the effects of occupant age." Injury Prevention **17**(4): 228-232.

Cummins, J., K. Koval, et al. (2011). "Do seat belts and air bags reduce mortality and injury severity after car accidents?" Am J Orthop (Belle Mead NJ). **40**(3): E26-29.

Huelke, D., G. Mackay, et al. (1995). "Vertebral column injuries and lap-shoulder belts." J Trauma. **38**(4): 547-556.

Mertz, H., A. Irwin, et al. (2003). "Biomechanical and scaling bases for frontal and side impact injury assessment reference values." Stapp Car Crash J. **47**: 155-188.

Pintar, F., N. Yoganandan, et al. (2012). "Thoracolumbar spine fractures in frontal impact crashes." Ann Adv Automot Med. **56**: 277-283.

Wang, M. C., F. Pintar, et al. (2009). "The continued burden of spine fractures after motor vehicle crashes." Journal of Neurosurgery: Spine **10**(2): 86-92.