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Testing for Occupant Rollover Protection

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ABSTRACT

Past rollover condition testing reported by the author utilized experimental seat belts, a rigid seat and a sitting pelvis Hybrid III mannequin or volunteer to observe dynamic vertical excursion. Other testing in a rollover condition utilized a rigid mannequin molded from a Hybrid III, sitting in a production vehicle restraint system. Application of rigid device in the test allows for simplification of the problem under study, yet limitations in the interpretation of the results. A third test program was conducted combining the rigid device of prior testing into one test, thereby allowing further scientific inference as to the affect of the seat belt restraint system in rollover conditions. Results show that an important factor in the extent of occupant vertical excursion is the kinematics and compliance of the occupant. Seat belts, in particular for this study, the lap belt, play a significant role in conjunction with other components of the motor vehicle in limiting the extent of occupant displacement in rollover conditions.

INTRODUCTION

Proper use of seat belt restraint systems has been shown to be one component of a rollover protection system that favorably affects occupant response during rollover. This conclusion is shown retrospectively through numerous in-depth and statistical analyses of motor vehicle crashes [1,2,3,4]. An understanding of seat belt restraint system effects upon occupant response is further substantiated through simulation and experimentation. In belted dummy dynamic dolly rollover tests and inverted vehicle drop tests conducted by Bahling, et al., safety belts were noted to prevent both ejection and projected impacts with the vehicle interior, yet did not result in reduced head and neck loads for dummies in the area of ground contacts [5]. While a historical understanding of seat belt restraint systems in rollover crashes has emphasized their effectiveness in ejection prevention, more recent research demonstrates their potential in reducing occupant displacement and flail inside the vehicle.

Prior research identified effective slack as a seat belt system characteristic [6]. Effective slack quantifies characteristics of the seat belt and seat system, which manifest in the dynamic conditions of crashes. For rollover conditions the manifestation of effective slack is the observation of occupant whole body vertical displacement due to combined seat system and seat belt system characteristics. A second test project measured effective slack as a conceptual equivalent to a length of seat belt webbing [7]. The second test project identified seat and seat belt system design characteristics affecting effective slack. The identified attributes included, among many factors, seat position, seat compliance, seat belt spool out and/or pretension, seat belt routing and fit, seat belt webbing stiffness, seat belt anchorage geometry and other anchorage compliance.

RIDGID SEAT TEST

Previous tests involving the rigid seat were conducted in both a static and dynamic mode utilizing human volunteers and a sitting pelvis 95th percentile Hybrid III mannequin [6]. All volunteers and the mannequin were

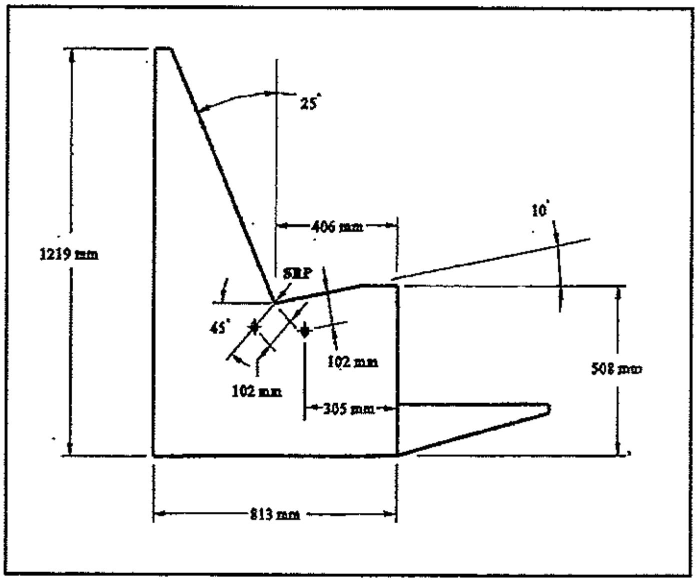

Figure 1, Seat Configuration

were each tested statically. The Hybrid III underwent a minus five Gz acceleration after a .914 m (3 ft) free fall producing impact velocities of approximately 4.25 m/s (9.5 mph). Each volunteer and surrogate was restrained by lap belts of varying configuration. A schematic drawing of the seat and lap belt mounting positions is shown in figure 1. The seat was 508mm (20in.) wide and lap belt anchorage's were 559mm (22in.) apart.

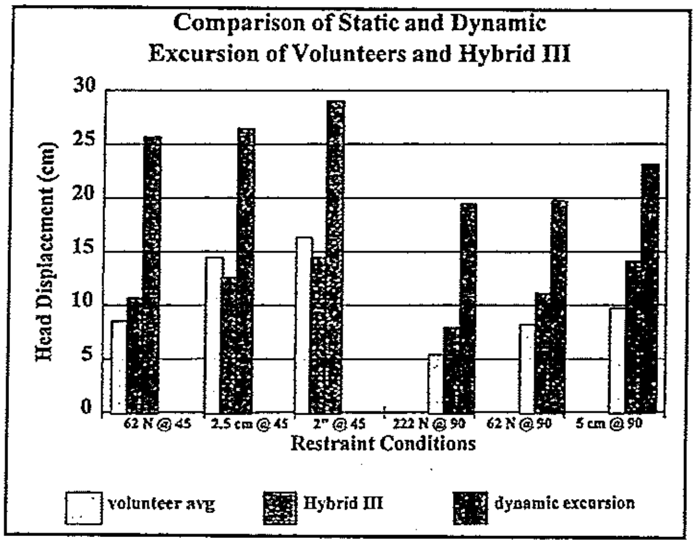

Figure 2, Displacement Comparisons

Static measurements were recorded on an available population of seven human volunteers. Dimensions of individuals from this population varied with minimum and maximum values measuring: stature - 170 cm to 188 cm; mass - 61kg to 104 kg; seated height - 76.0 cm to 94.6 cm; and age - 29 yr. to 45 yr. It was thought the measurements from the population of volunteers would provide some basis for comparing the static and dynamic response of the 95th percentile Hybrid III mannequin for the various seat belt configurations in a minus (-) Gz acceleration environment.

SUMMARY OF PEAK DYNAMIC RESPONSE

Test No.	Nominal Belt Angle (deg)	Belt Tension /Slack (N) or (mm)	Peak Resultant Neck Load (N)	Peak Belt Load Load (N)	Peak Z Displacement (cm)
B	45	62N	867	8553	25.29
C	45	222N	890	9677	22.51
D	45	25mm	850	8497	26.44
E	45	50mm	841	8408	29.05
F	90	222N	721	5754	19.45
G	90	62N	716	5687	19.77
H	90	444N	672	5498	15.60
I	90	50mm	738	5947	23.13

Table 1, Summary of Peak Dynamic Response

Average static head displacement of the volunteer, static head displacement of the Hybrid III and maximum head displacement due to dynamic test of the Hybrid III were compared in figure 2. A summary of the peak dynamic response of the Hybrid III was shown in Table 1.

The purpose of the test program utilizing the rigid seat was to provide some objective quantification of the effects of different restraint system variables. The relationship of the variations in lap belt slack to the effective slack that any production vehicle may exhibit was undefined. It was clear from the test results that reducing effective slack by reducing the length of webbing in the seat belt system and providing more efficient anchorage location made substantial reduction in displacements.

RIDGID MANNIQUIN TEST

In later testing, utilizing a rigid test mannequin two different motor vehicles with different seat and seat belt systems were measured for effective slack [7]. While there were numerous differences between the two vehicles and their respective occupant protection systems, they were similar in that both contained bench seats with continuous loop three-point lap/shoulder belts. Effective slack in vehicle 1 with the seat in the aft position resulted in mannequin displacements: X – 1.52 cm (0.60 in), Y – 2.54 cm (1.00 in), Z – 8.64 cm (3.40 in). Displacements associated with vehicle 2 with the seat in the aft position were reported: X – 1.02 cm (0.40 in), Y – 3.81 cm (1.50 in), Z – 11.94 cm (4.70 in).

For vehicle 1, the additional measurements to determine a conceptual equivalent webbing length associated with effective slack was measured. For the tested vehicle the conceptual equivalent seat belt webbing associated with effective slack to produce zero net vertical displacement of the test mannequin under the test condition is 20.6 cm (8.1 inches) and 24.4 cm (9.6 inches) for the seat in the full rearward and full forward positions respectively.

In the process of developing the test protocol, it was noted that characteristics of the vehicle seats had important effects on mannequin displacement. Compliance of the seat cushion played a roll in the attainment of zero net mannequin vertical displacement. A compliant seat allowed the dummy to compress downward in the cushion when webbing is removed from the seat belt system.

Significant aspects of effective slack were characteristics of the seat belt system. Webbing spool out from the retractor was significantly greater for vehicle number 2. This spool out is associated with considerably more webbing length in the seat belt system. Seat belt anchorage position and routing geometry also played a significant role in the mannequin displacement. The phenomena may also be noted in measured differences of effective slack for the forward and rearward seat position shown for vehicle 1. It should be obvious that removing webbing from the seat belt system, effectively pretensioning the seat belt webbing, also favorably reduced displacement of the test mannequin.

The prototype mannequin, by virtue of its weight, rigidity and smooth surface presented an idealized representation of the human occupant. The effect of the idealized characteristics of the mannequin provided the opportunity to consider the seat and seat belt characteristics in isolation. The low weight of the mannequin inadequately compressed the seat cushion in baseline measurements and certainly has an affect on the determination of zero net vertical displacement of the mannequin in measuring effective slack. Effective slack was described as a conceptual equivalency of a length of seat belt webbing removed from the seat belt system which results in zero net vertical displacement of the mannequin under the test condition.

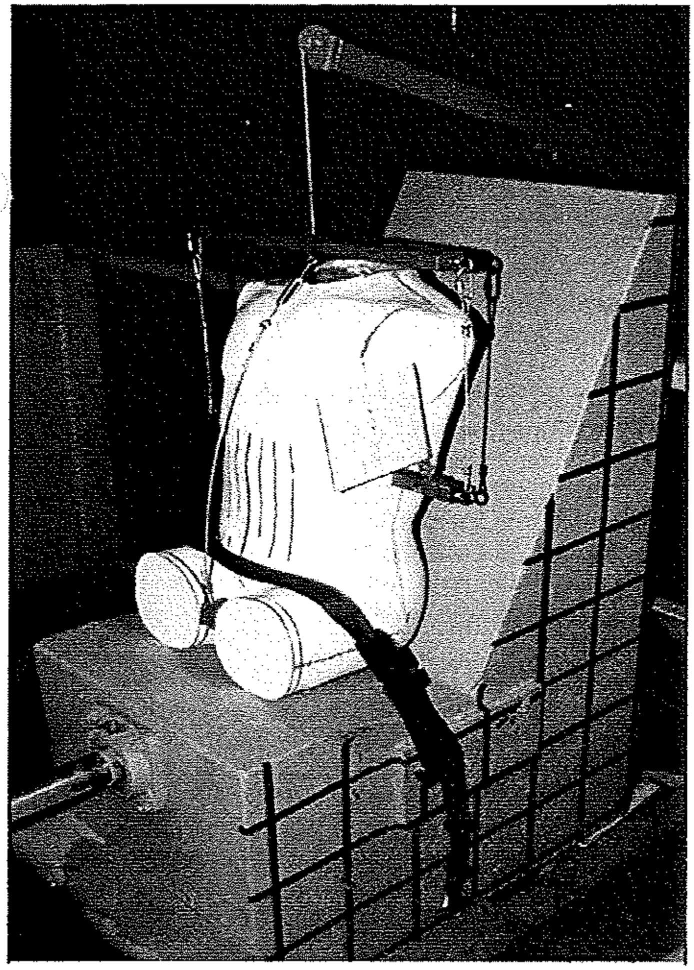

Figure 3, Test Configuration

RESEARCH QUESTION

Prior testing had shown results utilizing, in one instance, a rigid seat, and in a second instance, a rigid mannequin. Both test programs had examined the motor vehicle seat belt system and its role in the kinematics response of occupants during roll over collisions. The question as to what could be learned when the rigid test devices were applied together in a single test program was addressed by the simple test herein described.

METHOD

Similar to the method described in testing utilizing the rigid mannequin [7], the mannequin and lifting device were positioned over the rigid seat test apparatus. The seat is positioned such to provide maximum access. Test configuration is shown in figure 3. The seat geometry is shown in figure 1. Lifting of the mannequin was chosen over inversion in the seat due to the lightweight of the mannequin, 16 kg (35 lb.) Initial positioning of the mannequin resulted in a slightly unnatural position. The pretest mannequin position is

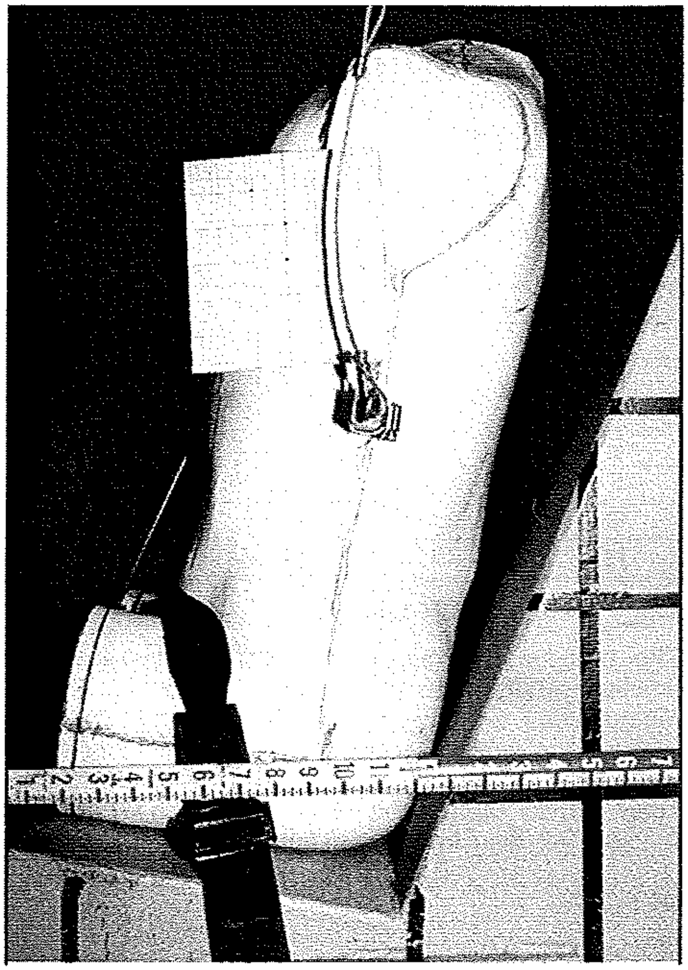

Figure 4, Mannequin Initial Position

shown in figure 4 and was chosen because of the ability to easily reproducing the initial condition. Testing proceeded as described in the rigid mannequin test program [7].

Because of the rigid mannequins lightweight initial positioning of the mannequin is substantially dependent upon its rigid geometry. The shape of the rigid mannequin and the rigid seat dictated initial position of the rigid mannequin. A compliant structure would have accommodated a more natural initial position. In the final analysis a repeatable initial condition was chosen over the more natural seat position. Figure 4 shows the pitched slightly forward position of the mannequin with the nominal 90-degree seat belt relative to the seat.

Seat belt configurations analogous to those in the rigid seat test were utilized. These configurations assumed a natural seat belt position with sufficient belt tension to remove all extra webbing from the restraint system. Applying 62 N (14 lb.) of force to the adjustment strap produced the nominal tension in the belt. The test configurations are listed in table 2. The column in table 2 labeled "removed" refers to the amount of webbing removed from the baseline system when adjustment strap tension was applied. Negative removed webbing refers to the addition of webbing to the seat belt system. Since in the original testing webbing tension was employed by applying force to the adjustment strap, that method was duplicated.

Test no.	Nominal Belt Angle (deg)	Adjustment Tension (N)	Removed (cm)
A	45	62.16	0.00
B	45	444.00	1.27
C	45	62.16	-2.54
D	45	62.16	-5.08
E	45	62.16	0.00
F	90	62.16	0.00
G	90	62.16	-5.08
H	90	444.00	0.79

Table 2, Test Conditions

The procedure of applying tension to the seat belt adjustment strap was problematic. While a consistent methodology produced consistent seat belt webbing tension, the tension in the belt webbing is significantly lower than the tension force applied to the adjustment strap. Do not confuse the seat belt webbing tension with the seat belt adjustment strap tension.

RESULTS

Corrected average vertical displacements are shown for each test configuration in table 3. In general three tests were conducted for each seat belt configuration. For the nominal 45-degree seat belt angle configuration interference between the lower back of the mannequin and the seat back played a role in limiting the vertical movement of the mannequin. This interference accounts for the reduced vertical displacement associated with test performed in this configuration. In nominal 90-degree seat belt test the mannequin would pitch forward to a greater extent than the nominal 45-degree configuration. This pitching movement was corrected, but is attributed to the short leg of the mannequin and the lift point of the test apparatus.

Test no.	Test Result Vertical Displacement (cm)	Rigid Seat 95th Hybrid III Vertical Displacement (cm)
A	4.81	11.00
B	2.67	n/a
C	7.23	14.75
D	8.93	16.10
E	5.05	11.00
F	4.78	11.50
G	11.07	14.00
H	1.50	n/a

Table 3, Test Results and Comparison

For both seat belt nominal angle configurations increase webbing in the system allowed increased mannequin displacement. Considering the interference and rigid device the lower displacement of the nominal 45-degree configuration, compared to nominal 90 degrees, is understandable. A linear relationship between seat belt webbing length and vertical mannequin displacement appears to exist for the conditions tested. Test produced repeatable results and results consistent with intuitive expectations.

When comparing the nominal 45-degree response to the nominal 90-degree response the beneficial effect of belt angle can be observed at the higher adjustment force condition. In the higher tension condition the mannequin is held closer to the rigid cushion and is less affected by the interference between the seat back. At the nominal 90-degree seat belt configurations the interference between the mannequin and the seat back did not occur.

Since the lifting force applied to the mannequin in the recent test program is similar to the force due to the hanging mass of a 95th percentile Hybrid III dummy, comparison of static test results is of interest. The Hybrid III dummy, while relatively rigid compared to human motor vehicle occupants, is substantially more compliant than the rigid test mannequin. Head displacements of the 95th percentile Hybrid III in rigid seat test were significantly greater under the same restraint conditions when compared to the rigid mannequin. A comparison between results of these tests is shown in table 3. The column labeled "Rigic Seat 95th Hybrid III Vertical Displacement" shows the reported results of prior testing.

CONCLUSION

While difference in the mode of force application to the seat belt system were different, the substantial differences in displacement point to the importance effect of the human condition when considering the flail of motor vehicle occupants in rollover conditions. The human condition affects flail in rollover conditions due to several factor. These factors include kinematic movement of body segments, and viscoelastic compliance, compression and stretch, of body tissues. Flail of body segments in rollover conditions includes movement of the head, upper torso and extremities. To date test mannequins whether rigid or Hybrid III lack sufficient biofidelity to replicate expected human response in rollover conditions. These deficiencies do not negate the potential contribution that these important test tools may have in the development of rollover occupant protection systems. Reductions in rollover injury are an obvious benefit with improved seat belt systems for rollover conditions.

Test data demonstrates the opportunity for occupant contact and interference between modern passenger car interiors - roofs and door structures. Of course occupant contact with the interior is not what causes injury. Occupants contact the vehicle interior all the time. Contact occurs in collisions and during every day use. For injuries inside the vehicle simple contact or interference inadequately describes potential rollover injury mechanism. Injury in rollover crashes is caused by a more complex series of conditions related to the deformation and velocity of the occupant and the deformation and velocity of intruding vehicle components. The means to reduce and possibly negate occupant conditions related to many interiors caused rollover injuries through the use of improved seat and seat belt technology has been demonstrated. Efforts are now necessary to reduce the contribution to rollover injuries of other vehicle components.

While seat belts have proven to make substantial difference in rates of whole body ejection during rollover, partial ejections remain a primary important injury mode with modern seat belt systems. Apparent shortcomings of seat belts systems in rollover conditions due not negate the obvious substantial reductions in occupant flail and displacement that could be realized. In addition to improved seat belts systems, occupant ejection and partial ejection should be addressed by other motor vehicle design intervention. Passive mechanisms are available which further limit or preclude the opportunity for any ejection mode. Deployable side structures and retentive window glazing will reduce and possibly eliminate the opportunity for ejection and partial ejection from a motor vehicle in any collision mode.

The engineering of motor vehicle safety is not a process with a foreseeable end. Indeed, the "problem" has not been solved. No point in history, standard, or design improvement has constituted an acceptable answer to mitigating unintentional injury or death associated with the motor vehicles. The process of engineering often conceives incremental improvement, built upon existing platforms of technology.

Technological breakthroughs occur often outside the confines of existing paradigms. This point can be illustrated in the history of rollover protection. Roof crush has been described as a cause of certain rollover injuries, likewise occupant flail has been described as the cause off the same injuries. Exhaustive studies, statistical and experimental, have been conducted evaluating the effects of a single rollover safety design intervention. The studies through retrospective analysis or substantial reliance on existing vehicles features incorporate the rollover protection deficiencies incorporated in the vehicle fleet. For example tests may be conducted comparing the response of restrained occupants in vehicles with standard and rigid roof. If the seat belts in the vehicles are unmodified the allowable occupant flail may be so great such to mask some benefit of a rigid roof. In fact, in many existing motor vehicles for certain injuries, the single factor of roof crush and occupant flail is so significant that drawing scientific conclusions about a single possible safety interventions is questionable.

The answer to the "problem" requires formulation of a rollover protection system. In the context of such a rollover protection system, seat belts will have to further restrict occupant movement, roofs will have to be stronger and the problem of partial ejection must be addressed.

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