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ABSTRACT

Effective slack associated with seat belt systems for rollover protection is studied for the purpose of improving or anticipating improvements to a motor vehicle rollover protection system. A test method and test devices were constructed to study and develop objective understandings of the effects of motor vehicle seat and seat belt characteristics on effective slack. The test devices and test method were proved in two separate motor vehicles with differing seat belt systems. Results demonstrated that effective slack as a conceptual equivalent to a seat belt webbing length could be repeatable and objectively determined for the systems tested. Determining a seat belt system's effective slack is useful for the purpose of comparing experimental restraints and experimental restraint testing to motor vehicle restraint design and performance.

INTRODUCTION

Proper use of seat belt restraint systems has been shown to be one component of a rollover protection system which favorably affects occupant response during rollover. This conclusion is shown retrospectively through numerous in-depth and statistical analyses of motor vehicle crashes. Huelke, et al., in 1977 compared injuries to restrained contained and unrestrained contained occupants of rollover involved motor vehicles and found that the benefits of seat belts were significant, with fewer AIS 3-5 injuries and fatalities to all body regions except head[1]. Huelke also estimated a 91 percent reduction in rollover fatalities due to restraint use, primarily by preventing ejection [2]. Evans, using FARS data, showed that lap/shoulder belts are 82 percent effective in fatality reduction in rollovers, with 64 percent due to ejection prevention[3]. Most recently Moffatt and Padmanaban analyzed NASS data and concluded seat belt usage significantly reduces the likelihood of severe injuries in rollovers primarily by preventing ejection. In addition they concluded that non-ejected belted occupants had fewer severe injuries than non-ejected unbelted occupants[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 by Arndt and Associates, Ltd. reported, for a rollover condition, the relative effects of a lap belt restraint on occupant displacement under various geometric and webbing adjustment (tensions/slack) conditions[6]. The prior work by Arndt identified effective slack as a seat belt system characteristic. 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. Effective slack may be expressed as a conceptual equivalent to a length of seat belt webbing. Seat and seat belt system design characteristics include, 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. This work quantifies seat belt effective slack in rollover protection systems.

PROBLEM AND HYPOTHESIS

Proper use of seat belts has been shown to favorably affect the probability of injury during rollover crashes, yet high rates of serious and greater injury occur even for seat belted occupants. Commonplace illustrations show the interference between a seat belted occupant head and vehicle roof interior during simple inverted vehicle demonstration. Testing and other analyses have demonstrated significant potential for seat and seat belts systems of varying configuration to effect occupant displacement and flail inside the vehicle during rollover crashes. In general, characteristics of a seat belt system which may effect its improvement potential are not objectively documented and not completely understood. More specifically, seat and seat belt system characteristics associated with effective slack lack objective definition. Understanding effective slack as it relates to seat and seat belt systems may address, in conjunction with other components of the rollover protection system, injury mechanisms far beyond whole body ejection, among others, partial ejection, occupant interior contacts, and occupant interior interference.

TEST DEVICE

Test devices were designed and built for the purpose of measuring dynamic slack. These devices consisted of a lightweight, rigid, smooth-surfaced occupant mannequin, a lifting device and various instruments used during testing. Documented procedures and checklists were designed to assure test consistency and test repeatability.

The rigid occupant mannequin was a fiberglass reproduction of a sitting pelvis Hybrid III dummy. The legs and head and neck of the mannequin were not included to ensure sufficient clearance relative to the steering wheel and roof . Arms were not included, however, a partial shoulder was included for the purpose of assuring a proper shoulder belt routing. The angle of the mannequin torso was set at 97 degrees relative to the upper legs. The surface of the mannequin was a smooth gel coat finish to ensure ease in movement of the seat belt webbing over the mannequin in the process of testing. No changes in mannequin contours were made to enhance seat belt routing over the rigid pelvis and legs. Figure 1 illustrates the mannequin in a test vehicle.

The lifting device was attached to the mannequin to enable a vertical force application and minimize pitching due to seat and seat belt imparted couple. In addition, the lift device was designed to maximize the space for upward displacement consistent with the intent of testing restraint systems *in situ*. The Lifting device was supported by castors and a movable boom enabled

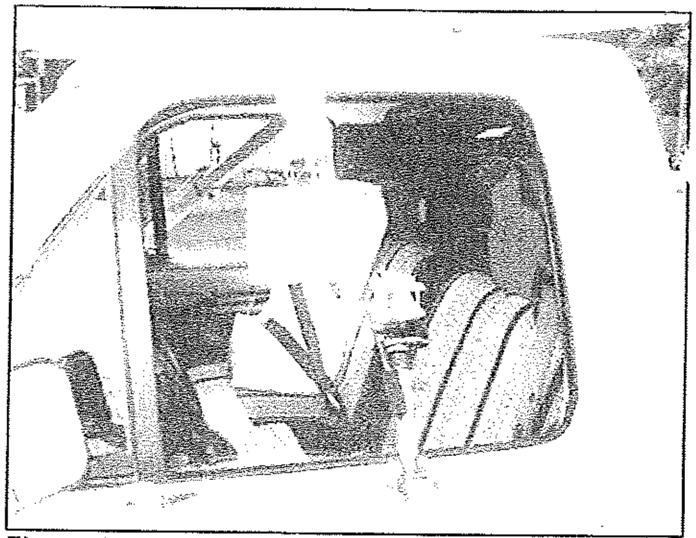

Figure 1. Mannequin in vehicle

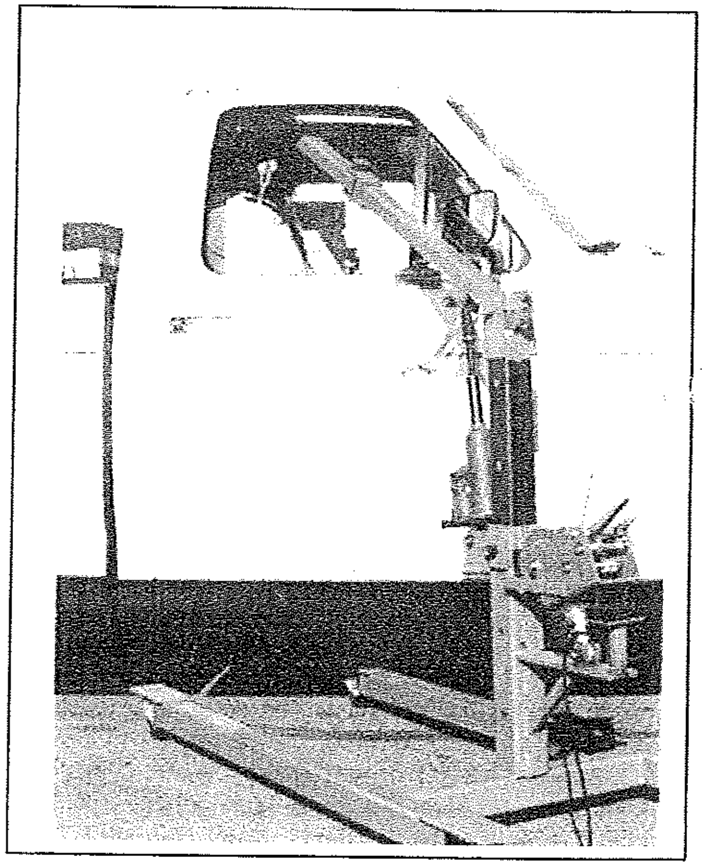

Figure 2. Lifting device in use.

adjustment. Figure 2 illustrates the lifting device as utilized during testing.

Calibrated instruments used in conjunction with the test devices included a load cell which measured the vertical force application and two seat belt load cells. One seat belt load cell was mounted on the outboard lap belt webbing, and the other load cell is mounted on the shoulder belt between the D-ring and mannequin shoulder. Two lasers directed at a reference grid attached to the mannequin were used to determine the three-dimensional displacement of the mannequin due to vertical lifting forces.

PROCEDURE

A generalized procedure required, first, the description of various seat belt restraint system characteristics. For baseline testing, documenting the displacement associated with effective slack, the mannequin was placed in the center of the vehicle seating position. Generally the seat adjustment was documented. The seat back angle was adjusted, if possible, to the full forward position and/or otherwise documented. The seat belt restraint system was placed around the mannequin properly routed and latched. Care was taken to place the seat belt webbing in the most efficient routing (least webbing off the retractor reel). Seat belt routing was consistent with the system mounting, fit and routing characteristics while assuring that no extra webbing was present in the system. Force associated with the retractor reel provided webbing tension for the baseline test. Measurements documenting the mannequin and seat belt system initial orientation and condition were respectively recorded.

Prior to the application of vertical force the seat belt retractor lock and/or webbing lock were activated. In the case of seat belt retractors, the locking bar was assured to have fully engaged the locking teeth of the retractor reel thereby negating the need to consider any phenomena of skipping or other delay in retractor reel lockup. Locking the retractor as stated allowed inclusion in the effective slack measurement webbing spool out from the retractor reel.

Following the initial setup and documentation of the test, the mannequin was vertically lifted with a 890 N (200 lb.) force. Since the intention of testing for effective slack is to find the maximum displacement possible under the baseline test configuration during the process of lifting, the mannequin was adjusted to encourage the seat belt system to find the most efficient routing and mannequin position. In most cases, the mannequin moved rearward due to the lap belt angle. Relatively minute rolling or pitching of the mannequin was observed. Repositioning of the lifting device was performed as necessary to ensure a vertical force application.

MEASUREMENTS

Once the mannequin was lifted, the changes in three dimensional displacement, pitch and roll angle were measured. Effective seat belt slack associated with a seat and seat belt system was determined by incrementally removing webbing from the baseline seat belt configuration described above. Removing webbing from the system effectively applied pretension to the seat belt. The initial position for each of these "pretension" conditions of the seat belt webbing required adjusting the mannequin to assure efficient webbing position for consistent, repeatable measurements. For each increment of webbing removed from the seat belt system, a lifting procedure was conducted.

The procedure of incrementally removing seat belt webbing was repeated until the condition of mannequin zero net vertical displacement was converged. Zero net vertical displacement of the mannequin is a condition which occurs when enough seat belt webbing has been removed that when lifted the mannequin displaces to a vertical height equivalent to its baseline initial position. At the mannequin's zero net vertical displacement condition, a seat belt webbing equivalent length was determined, which, as defined previously, can be called effective slack.

RESULTS

Tests were conducted on two different motor vehicles with differing seat and seat belt systems. While there are 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. Table 1 lists some characteristics of the vehicle and vehicle systems which were utilized. In addition, the numerous experimental lap belt configurations tested in a previous program were measured to determine mannequin

	System Webbing Length	Lower Webbing Length to Mannequin Center	Webbing Length from D-ring to Mannequin Center	Lap Belt Angle	Shoulder Belt Angle
Vehicle 1					
Fwd Position	238.76 cm / 94 in	88.27 cm / 34.75 in	48.26 cm / 19.00 in	37.7 deg.	6.4 deg.
Aft Position	238.76 cm / 94 in	82.23 cm / 32.38 in	43.82 cm / 17.25 in	22.5 deg.	15.6 deg.
Vehicle 2					
Fwd Position	307.34 cm / 121 in	72.23 cm / 28.44 in	56.83 cm / 22.38 in	49.5 deg.	2.3 deg.
Aft Position	307.34 cm / 121 in	68.10 cm / 26.81 in	46.83 cm / 18.44 in	50.3 deg.	5.0 deg.

Table 1. Characteristic of vehicle and vehicle systems.

Vehicle No. 1			
Seat Position	X	Y	Z
Aft	1.52 cm / 0.60 in	2.54 cm / 1.00 in	8.636 cm / 3.40 in
Fwd	-4.83 cm / -1.89 in	1.91 cm / .750 in	8.763 cm / 3.50 in
Vehicle No. 2			
Seat Position	X	Y	Z
Aft	1.02 cm / 0.40 in	3.81 cm / 1.50 in	11.94 cm / 4.70 in
Fwd	1.02 cm / 0.40 in	2.54 cm / 1.00 in	11.00 cm / 4.33 in

Table 2. Displacements due to effective slack.

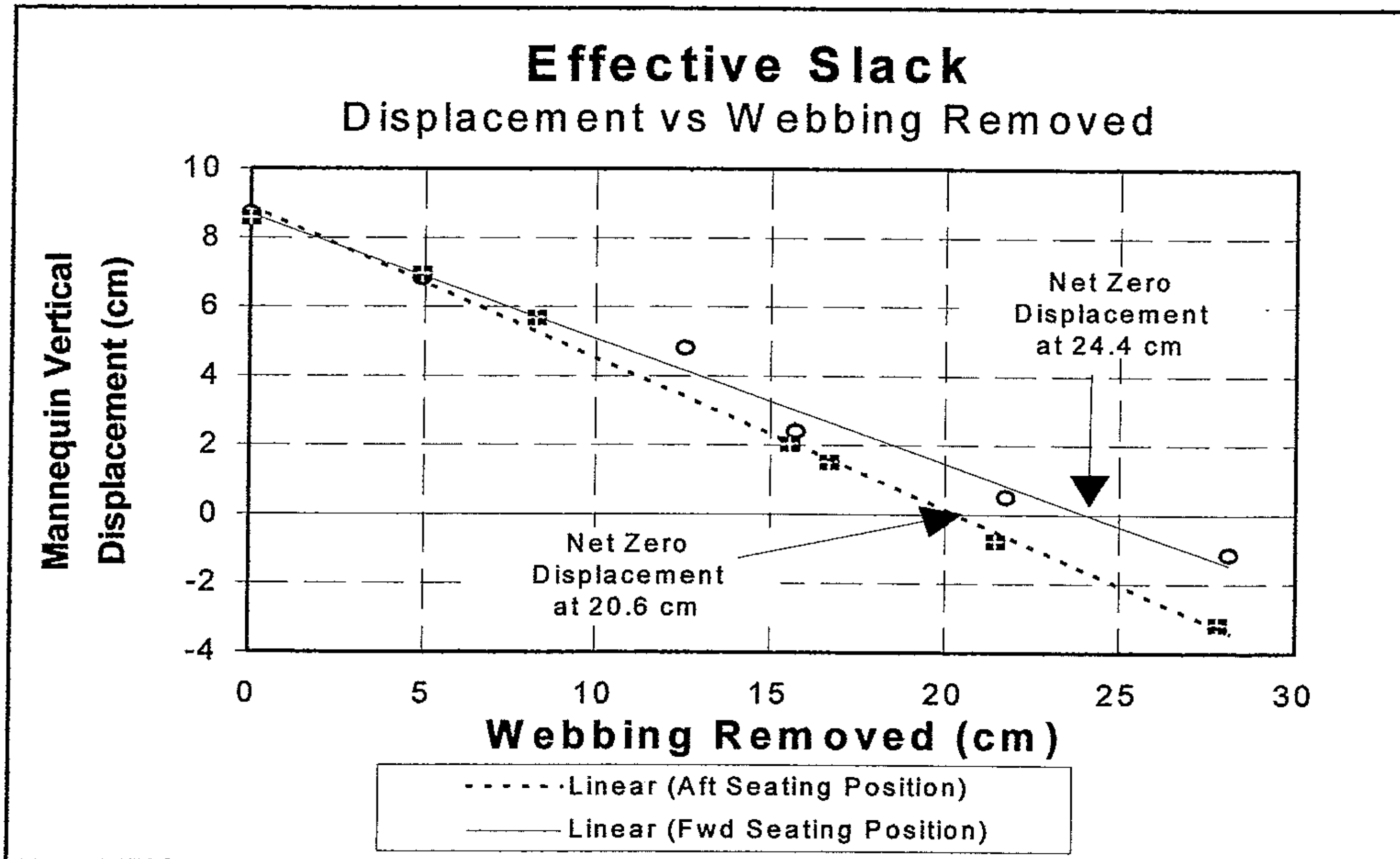

Figure 3. Determining effective slack.

displacement[6]. Results showing mannequin displacement associated with effective slack for vehicle tests are shown in table 2.

For vehicle 1, the additional measurements to determine a conceptual equivalent webbing length associated with effective slack was measured. Results of this procedure for the seat in the full forward and full rearward positions are shown in figure 3. A curve is drawn through the various data points to determine the amount of seat belt webbing which must be removed from the system to produce zero net vertical displacement of the mannequin under the test condition. 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.

DISCUSSION

At the onset, it is acknowledged that the test device and test method are in a developmental stage. In the process of developing the test protocol, it was noted that characteristics of the vehicle seats had important effects on mannequin displacement. The mannequin in general had a tendency to pitch forward during lifting due to the couple caused by interaction of the mannequin with the seat back and seat belt and the test device lifting force. The mannequin contacted the seat back with its lower buttocks area as it was forced rearward due to seat belt geometry. In addition, the 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.

The most significant aspect of effective slack was the characteristic 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. This phenomena was most clearly noted in measurement of the experimental lap belt configurations. The phenomena may also be noted in difference for the forward and rearward seat position as shown in table 3 and further demonstrated for vehicle number 1 in figure 3. 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 presents 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. It was noted during preliminary measurements with the mannequin that, because it is missing a complete shoulder and upper arm, some limitations exist if the shoulder belt slips off the mannequin shoulder. In addition, if measurements are to be taken to study the possible occurrence of an occupant slipping out of a shoulder belt restraint during a rollover event, the absence of the upper arm may effect mannequin displacement.

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. The light weight of the mannequin does not defeat its efficacy as a tool when comparing various systems, nor does it invalidate the concept of effective slack as described previously. One must, however, consider mannequin weight as it relates to seat cushion deflection when evaluating effective slack of systems *in situ*. Seat cushions with low stiffness or large possible deflections will perform differently than stiff, nondeflecting cushions with respect to mannequin displacement and effective slack. It may be possible to produce a negative net vertical displacement of the mannequin under the test conditions with realistic, available, and/or attainable vehicle characteristics and technology. Negative net vertical displacement might be called reverse effective slack.

Effective slack has been 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. Attaining a condition of zero net displacement for the population of seat and seat belt systems, in general, may not be possible. There are many factors which may effect obtaining zero net displacement. Some of these factors have been discussed above and are related to the seat, seat belt system and the mannequin.

Zero net displacement in the determination of effective slack may be attainable in some vehicles, but only under conditions of unrealistic belt tension and or lengthy webbing removal. For instance, where a condition of zero net displacement may be unattainable or unrealistic other measures of effective slack may be considered. Alternative measures may include the determination of mannequin displacement for a fixed webbing length removed from the seat belt system. A second alternative may be the measurement of the mannequin displacement and/or webbing removed from the system associated with a target belt tension.

SUMMARY

The work presented demonstrates a prototype device and method for investigating the effects and the magnitude of effective slack in rollover conditions. Both seat belt system characteristics and seat system characteristics play a leading role in the manifestations of effective slack. Reducing, or better, eliminating or reversing seat belt effective slack produces the opportunity to minimize the motor vehicle occupant pelvic displacement relative to other vehicle interior structures including the roof. Reducing other occupant body segment displacement during rollover events is related to reduced pelvic displacement.

Additional development is necessary to produce a generalized method for obtaining characteristics for the population of systems used today. Additional development may include an enhanced mannequin which includes a complete shoulder, upper arm and characteristics which sufficiently contextualize seat cushion displacement. Additional work which places the device in a larger population of vehicles developing alternative criteria to the zero net displacement would be of interest. Finally, a refinement on the present understanding of motor vehicle occupant displacement, flail and injury in rollover crashes should be undertaken. The prototype test device is a tool for measuring a rollover protection system characteristic.

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