INVESTIGATIONS INTO THE EFFICACY OF THREE-POINT SEAT-BELTS IN OBLIQUE IMPACT EXPERIMENTS

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The present oblique impact investigations rely on earlier research aimed at determining the optimum positions for the anchorage points of seat-belts and the effectiveness of seat-belt elements in head-on collisions.

The first phase of the head-on collision experiments showed the influence of the positions of the seat-belt anchorage points, the seat position, the firmness of the seat and the slack of the belt on the effectiveness of seat-belts. It was then possible to indicate optimum conditions for head-on collisions for vehicles with conventional belt systems. In the second phase of the investigations, possible improvements to belt systems were examined with a view to constant belt geometry, shorter response time and more efficient energy absorption.

Although manifold investigations were performed on seat-belts in head-on and side collisions, this is not true in the case of oblique impacts, where only a few experimental investigations have been performed.

Investigations into oblique impacts using older designs of seatbelts have shown that there is a major risk to the neck area. Further experience with oblique impact experiments is available from investigations into "test crashes" of cars. Certain European vehicle manufacturers require the $+30^{\circ}$ collision as a supplement to or substitute for the head-on collision. In a +30[°] collision the average decelerations of the passenger compartment are significantly reduced in comparison to the headon collision, and the deceleration curve is triangular rather than trapezoid as in the case of a head-on collison.

Accident statistics indicate that a high percentage of accidents involves oblique impact. This provided the stimulus to investigate the extent to which the conditions that were found to be optimum for head-on collsions in which seat-belts of the current type are used are also optimum in oblique impacts, or if amendments have to be made.

In the following an oblique impact is taken to be a 30° collision, where the angle of impact can be either $+30^{\circ}$ or -30° . This angle alone accounts for about 20 percent of all accidents.

On the basis of the previous studies the following questions arise:

- How great is the protective effect of the three-point seat-belt under the conditions found to be optimal for head-on collisions?
- How and under which circumstances can passengers sitting next to each other endanger each other?
- Are the optimum belt conditions for oblique impacts different from those for head-on collision?
- How can the effectiveness of the seat-belt be improved even in oblique impact situations be means of additional elements?

Finding answers to these questions was the subject of the study described here.

Experimental Set-up and Performance

As in the previous studies, the impact experiments were performed on the catapult unit of Battelle-Institut e.V., each experiment being repeated three times.

The catapult unit (shown schematically in Fig. 1) consists of a sled mounted on rails, an acceleration device and a deceleration device.



Fig. 1: Block diagram of the measuring and evaluation unit for impact experiments

The aquisition and processing of the measured data is effected largely in accordance with the instrumentation specifications given in SAE J 211a. The stress values (decelerations, forces) and experimental control values (impact speed and deceleration) were measured. The data were recorded using an uv plotter and on magnetic tape. The experimental equipment mounted onto the sled (Fig. 2) consists of a body shell of a medium-sized car with seat and dummy, belt anchorage points and additional elements. The energy to accelerate the sled to the experimental speed is generated or stored by stretching three elastic ropes using a winch and is freed by (pneumatically) releasing the sled from the winch. The impact speed is determined by the stretching length. The impact deceleration is produced by deformation of flat steel. The front of the experimental sled is provided with a spike which causes permanent deformation of the flat steel which is inserted into a frame. Flat steel 120 mm x 12 mm with a sled deceleration as shown in Fig. 3 was selected;this corresponds to the average of the vehicle decelerations evaluated.



Fig. 2: Experimental set-up of the catapult unit

Rotation of the vehicle about the vertical axis, which is possible in oblique or side impacts, is suppressed in this experimental set-up.



Fig. 3: Sled decelerations (family of curves) in comparison to a defined tolerance zone at 50 km/h (dotted)

The dummy used was a 50 percentile male, Sirra Hybrid II/572 (height 175 cm, weight 75 kg), in the front passenger seat position. The dummy was dressed and positioned largely in accordance with specification V/49 CFR 572.

A "ramp seat" with firm seat upholstery was used; this had been found to be most suitable. The seat-belt used was of the same type as that used in the head-on collision experiments, a threepoint belt with a rapid automatic-locking retractor.

Delineation of the Series of Experiments I, II and III

The conditions in the various series of experiments were determined by the objective; these conditions are shown in Tabel 1 Table 1: Experimental conditions in the series of experiments I, II and III

Series of experi- ments	Angle of impact -30 ⁰ +30 ⁰		Approx. impact speed km/h 35 50		Belt anchorage positions	Additional elements
I	x x	x x	x x	x x	normal belt an- chorage for front passenger seat	none
II	x x	x x	x x	x x	mirror-inverted belt anchorage for front pas- senger seat, point A lowered by 10 cm	none
IIIA	x	x		x x	normal belt an- corage for front passenger seat, point A lowered by 10 cm	shoulder support on door, shoulder sup- port inside, pelvis support inside
IIIB	x	x		x x		shoulder support on door, shoulder sup- port inside, pelvis support inside, pre- load device

The belt anchorage positions found to be best for the head-on collisions were retained for the oblique impact experiments of series I. These positions were modified for the oblique impact experiments in series II in such a way that no significant disadvantages for head-on collisions result. In series III additional elements were used with a combination of the anchorage positions of series I and II: in IIIA shoulder supports were provided on the seat and on the door, and pelvis support mounted on the side toward the centre of the car were used; in III B a pre-load device was used in addition, which affected the point A. In the experiments the angle of impact $(-30^{\circ}, +30^{\circ})$ and the impact speed (approx. 35, 50 km/h) were varied; series III was performed only at 50 km/h.

Series I under the Conditions Found to be Optimal for Head-on Collisions

In the experiments with angles of impact of -30° , it was observed that the upper part of the body slips through the shoulder straß in the initial forward motion phase (about 30 ms after impact). The pelvis shifts to the edge of the seat cushion causing it to deform notably.

After about 80 ms the head hits the steering wheel and the dashboard (main thrust lateral). At about 35 km/h the impact is bearable, at about 50 km/h it is critical to unbearable. The strong head impact observable at about 50 km/h is due to a particularly large shift of the body as a result of it slipping out of the shoulder strap. A further result of this shift is that the final position of the dummy is outside of the seat.

In the experiments with impact angles of +30[°] the strong slipping out of the shoulder straß and the large forward shift of the pelvis are not observed since as the dummy shifts forward it is "dragged" along the door. After 50 ms the shoulder is already leaning against the lower part of the frame of the side window; it then slides along the fram while the head rotates in a forward direction, finally hitting the front part of the frame. The dummy then returns to its original position.

In spite of this "controlled forward shift", which is also noticeable in the form of an increased chest deceleration, i.e. the motion of the upper part of the body is braked by the door, stresses on the head are observable which correspond to those resulting from impact angles of -30° , in other words they are bearable at about 35 km/h and critical to unbearable at about 50 km/h. These

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high horizontal and vertical stresses on the head result from the hard structures at the impact points (lower frame of side window, compared with steering wheel and upper dashboard in the case of -30° impacts).

Series II Under Conditions Modified for Oblique Impacts

In series II the belt anchorage points were located in mirrorreversed positions in comparison to series I, and the position of the ancorage point "A" was lowered. As a result, in the experiments with impact angles of -30° to forward shift of the dummy was reduced to such an extent that the dummy was not observed to hit the dashboard or steering wheel either at ca. 35 km/h or at ca. 50 km/h.

However, the forward motion of the dummy and the position of the anchorage point A mean that the shoulder strap slips to the neck region, representing a high risk of injury. The associated decelerations of the head are non-critical at ca 35 km/h, but not at ca. 50 km/h. At the higher speed, due to the retaining forces operating directly on the head region, a high, more prolonged deceleration of the head is observed, which leads to an unacceptably high HIC value.

The shifting of the dummy out of the seat is not so strong as in the corresponding experiments of series I, but here, too, the rebounding head does not hit the head-rest.

At impact angles of +30[°] the mirror-reversed belt arrangement prevents the dummy slipping out of the belt since the shoulder strap restrains the left part of the body and the fact that the right shoulder leans against the door produces a "parallel guide" in the restraint system. The maximum forward displacement of the head is significantly reduced, i.e. by ca. 10 cm, in comparison to normal belt anchorage and is thus non-critical; the rebound of the dummy is also without adverse motions. However, in this case, too, risk of injury as a result of the belt cutting into the neck can not be excluded.

Series III with Additional Elements

Series III was subdivided into series IIIA and IIIB to permit various combinations of additional elements to be examined. In order to compensate the resulting increased expense of the experiments, this series was performed only at an impact speed of 50 km/h.

In series IIIA the seat and the door adjacent to it were provided with shoulder and pelvis supports to improve the forward displacement kinematics. At an angle of impact of -30° the shoulder support prevent the upper part of the body slipping out of the belt at the beginning of the forward motion; instead the body slides along the shoulder support retaining the belt as required. Similarly the pelvis is guided along the pelvis support without leaving the seat.

Toward the end of the forward displacement the shoulder passes beyond the region of the shoulder support, but does not touch the steering wheel. Since the forward displacement of the head is reduced by 10 cm in comparison to the experiments without shoulder supports, the head does not hit the dashboard either. The stresses on all parts of the body are non-critical.

Due to the shoulder support the body does not return to a sitting position after the forward displacement phase, but remains resting against the shoulder support in the forward displacement position.

At impact angles of $+30^{\circ}$ it is not the support mounted on the seat that affect the forward displacement, but the supporting padding fitted at shoulder height to the door. This prevents the body slipping over the shoulder strap since the shoulder and thus the upper

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part of the body are restrained by the belt and the supporting padding.

Compared to the experiments without shoulder supports, the forward displacement of the head is reduced by ca. 5 cm, which means that there is no major head impact. The stresses are non-critical. Rebound is without any unfavourable motion features and leads to a return to the normal sitting position.

In series IIIB a pre-load device operating on the anchorage point A was used in addition to the elements used in series IIIA. At impact angles of -30° the forward displacement of the head is reduced by a further 10 cm by the pre-load device. There is no significant change in the forward displacement kinematics and the stresses in comparison with series IIIA.

At impact angles of $+30^{\circ}$ the forward displacement is reduced by as much as 15 to 20 cm. The pre-load device did not significantly affect the forward displacement kinematics of the stress level in this case either.

Conclusions

The investigations into the effectiveness of three-point seat-belts showed that with the usual belt system and the usual anchorage positions the risk of injury in oblique impacts is sometimes higher than in the case of head-on collisions.

Supplementing the restraint systems with additional elements such as shoulder and pelvis supports and a pre-load device results in a significant improvement in the effectiveness of the seat belt in oblique impacts without compromising the protective effect for head-on collisions. It can therefore be concluded that the introduction of the preload device, which is also highly effective in head-on collisions, should be promoted (particularly in view of the limited space available in smaller vehicles) and that design improvements should be recommended that guarantee the effectiveness of the seat/belt combination for oblique impacts as well as head-on collisions.

It was not observed that the front passengers might endanger each other at impact angles of \pm 30[°]. Nevertheless it is recommended that corresponding investigations be performed for the angles 60 and 90[°] since "interaction risks" for the passengers must then be expected.

It also recognisable at this stage that the conflict of objectives in the design of both the seat-belt and the passenger compartment will become much more acute when impact angles of $\pm 60^{\circ}$ are also taken into account.

The problem of interaction is so pressing that research into $\pm 90^{\circ}$ impacts should be started as soon as possible although the available dummies are not ideal for simulating side impacts and although reliable statements on the stresses on the passengers will therefore not yet be possible.

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