THE DEVELOPMENT OF COACH SEATS AS A RESTRAINT SYSTEM

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ABSTRACT

In Western Germany about 14 % of passenger transport on the roads is accounted for by buses. In comparison to the accident statistics of all road vehicles, buses and coaches rate as vehicles with the most upgraded internal safety. Nevertheless the statistics also testify that the elderly and children figure significantly as the victims of bus accidents. It is because of their special vulnerability, that further efforts for the development of the internal safety of buses and coaches are required and seem to be possible.

INTRODUCTION

Head-on collisions are the most frequent type of bus collision with a total percentage of about 50-60 %. In more than half of all accidents with buses, the opponent is a passenger car, which generally suffers worse damage and higher passenger loads / 1 /. For the bus passengers, seated at a height of about 1.2 m above the traffic plane, there is only a low risk of being injured in such an impact. But whenever severe bus accidents with fatalities occur, there are always repeated public demands for safety belts in buses, too / 2 /. Quite apart from the constructional problems linked with the installation of three-point safety belts in buses, it is questionable, whether they would even be accepted by the passengers. Therefore the subject of comprehensive studies has been how to improve the restraining effect of the seat system in order to add to the passenger's safety / 3, 4 /.

TESTING METHOD

In a simulated head-on bus collision we conducted a number of sled tests on the TÜV Rheinland crash test facility. A floor element of a certain type of bus which was reconstructed on the original scale was securely mounted on the sled vehicle. Two or even three double seat benches were positioned on it one behind the other at a determined longitudinal distance. They were anchored to the floor element according to the manufacturer's instructions. Our interest was centred on the seat in front while the rear "slave seat" was occupied by 50 percentile anthropometric male test dummies or child dummies, 6 years old.

At a speed of 24 km/h the complete test rack was frontally impacted with a 5 respectively 10 g deceleration by means of a special deceleration device, figure 1. The dummy loads were measured by 3-dimensional accelerometers positioned in the centre of the head, in the chest and in the pelvis, and by two dynamometers in the femurs. On the backrest of the seat in front we measured the dynamic and static deformation and the displacement caused by the body impact from behind. Furthermore the impact was filmed with high-speed cameras for evaluating the kinematic behaviour of the dummies.

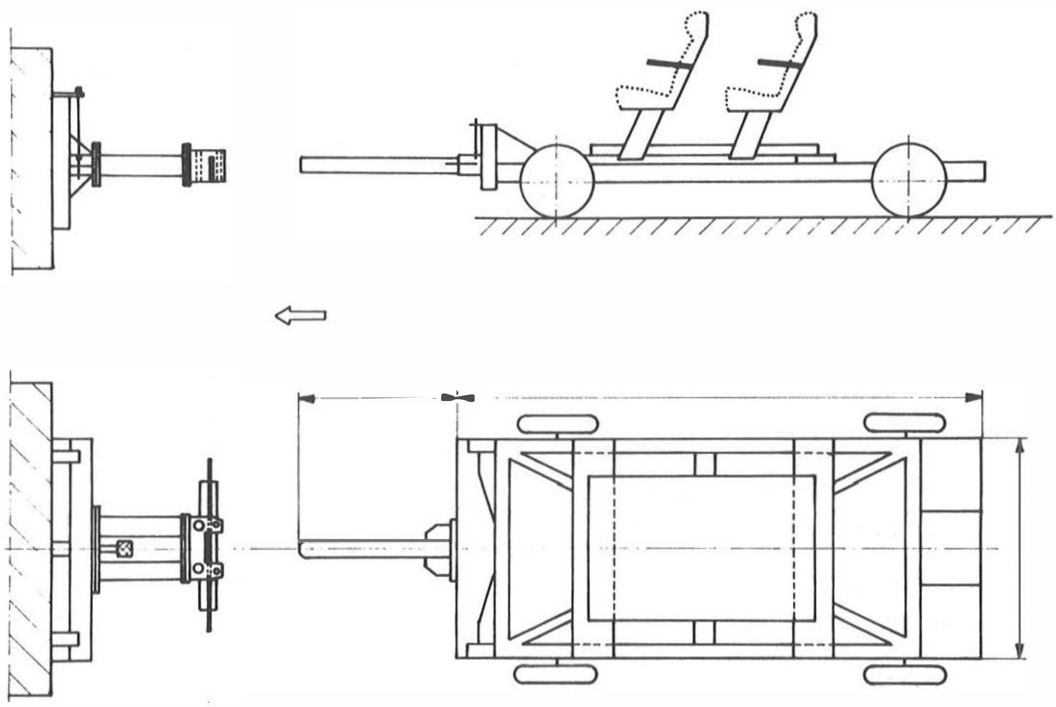

Figure 1: Sled test vehicle with two bus seat rows mounted on a floor element, schematically.

RESULTS

LONGITUDINAL DISTANCE BETWEEN SEAT ROWS

German-manufactured coaches have mostly seat rows with variable longitudinal distance. The mounting frame of the seats is anchored to two longitudinally-directed rails along the inner side wall and the aisle edge by clamping elements. In the first stage, studies were carried out to determine how the distance between the seat rows could influence the movement and the strain of the passenger colliding with the reverse side of the backrest in front. In principal, corresponding to the slack of a

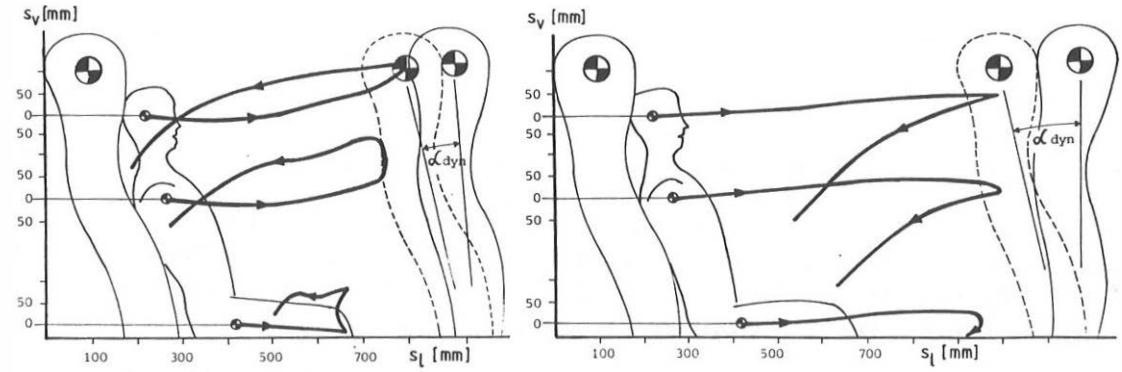

Figure 2: Trajectories of child dummy movements at 700 mm seat row distance (left) and at 900 mm at a 5 g deceleration each.

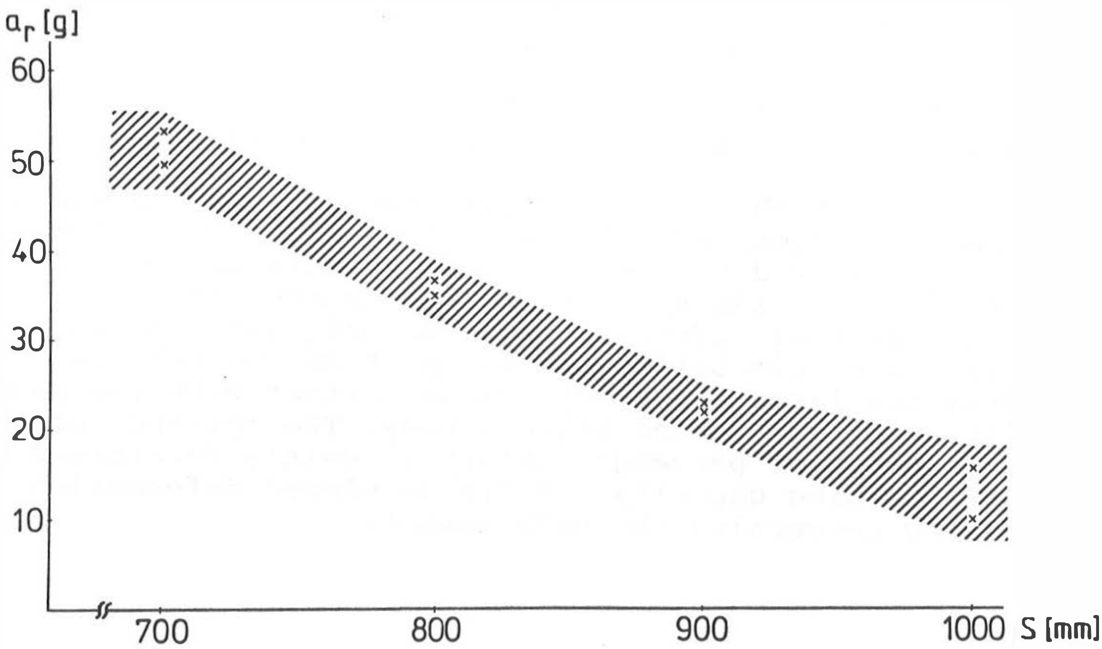

Figure 3: Resulting head deceleration of child dummy as a function of the seat row distance at a 5 g deceleration.

restraint system, the row distance was varied in stages of 100 mm within the range of 700-1000 mm. In 18 sled tests with adult and child dummies the deceleration pulse was settled at 5 g for a time duration of 90 ms.

In particular the head loads of the child dummy as well as its head trajectories reveal that the injury risk steadily decreases with increasing distance to the next seat in front, figures 2, 3.

The corresponding values for the adult dummy show a minimum strain at a row distance of 800 mm and begin to increase again at greater distances, figures 4, 5. It was not until the movement of the dummy and the impacted backrest was analyzed that the significantly higher loads at narrow and wide seat row distances could be interpreted correctly.

The primary knee impact of the dummy initiates vibration of the non-occupied backrest in front. At the same time, the femoral impact causes the dummy to bend at the trunk. The severity of the head impact is determined by the counter-movements of the dummy's head and the upper edge of the backrest. At the lower and higher seat row distances the dummy's head hits the oscillating backrest almost in the direction of its plane. In this constellation the rigidity of the structure produces high head loads. However, at the medium seat row distance the head meets the upper edge of the backrest, whereby the head movement is angled tendencially more from behind. Thus the significantly lower head loads can be explained by the energy- absorbing capacity, which is higher when the backrest is bent than when it is loaded in its plane direction.

The evaluation of these tests shows that, at the present state of development, passenger protection of both children and adults can be realized best with a seat row distance of 800-850 mm. The intended incorporation of the passenger seat as a component of internal safety exceeds the original function of seats by far. The suitability of this part of the vehicle results from its large shape, its close contact with the passenger and its anchorage to the vehicle body. The aptitude of the seat as an element of passenger safety is mainly determined by its energy-absorbing capacity and its developed deformation characteristic concerning the body impact.

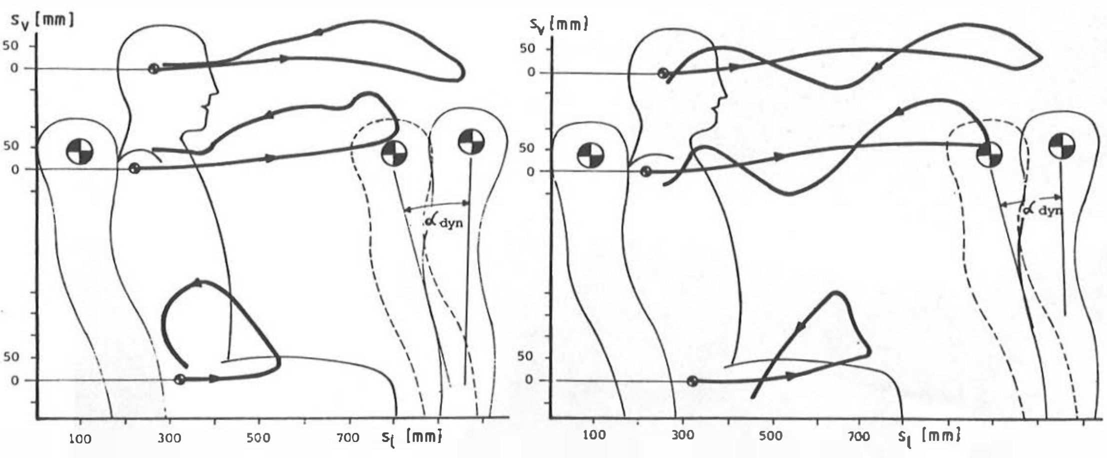

Figure 4: Trajectories of adult dummy movements at 700 mm seat row distance (left) and at 900 mm at a 5 g deceleration.

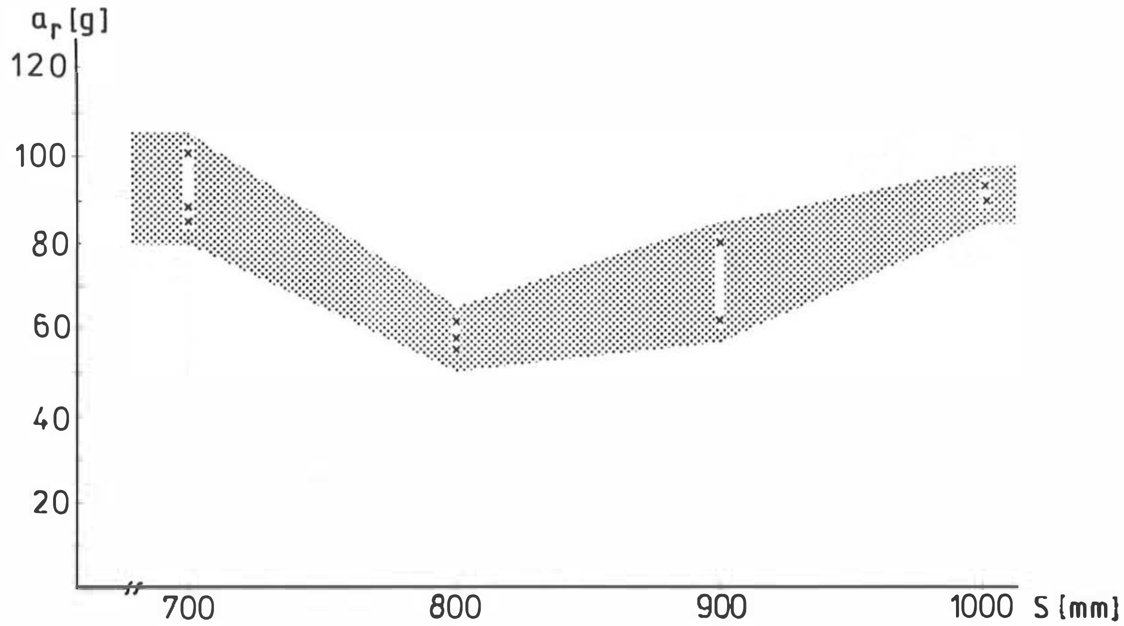

Figure 5: Resulting head deceleration of adult dummy as a function of the seat row distance at a 5 g deceleration.

Figure 6: Failure of the wall-sided anchorage elements after a 10 g deceleration test.

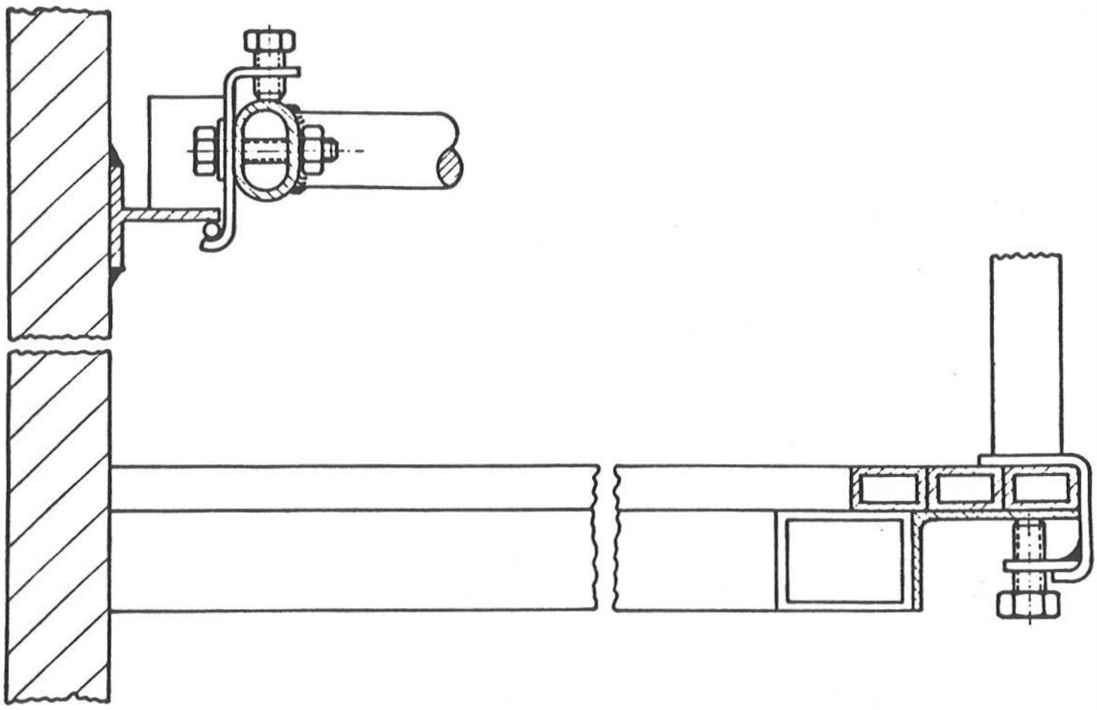

Figure 7: Seat anchorage element at the side wall (left) and the aisle side, schematically.

DEFORMABILITY OF SEATS AND DUMMY LOADS

In a further series of crash tests with bus and coach seats we kept the optimized seat row distance constant when simulating a 10 g deceleration of a frontal impact. First it must be stated that the original anchorage of the seat to the vehicle body did not withstand the impact and broke loose, figure 6.

In the case of longitudinally-adjustable seat rows in coaches the anchorage elements, such as clips or clamps with pressure screws, work on a frictional resistance basis, figure 7. In a simulated 10 g deceleration they cannot withstand the combined forces of the seat mass and the passenger impacting from the rear. The failure of the anchorage elements under the simulated accident strains is either due to their design or due to the presence of previous damages which we discovered even in new vehicles, figure 8.

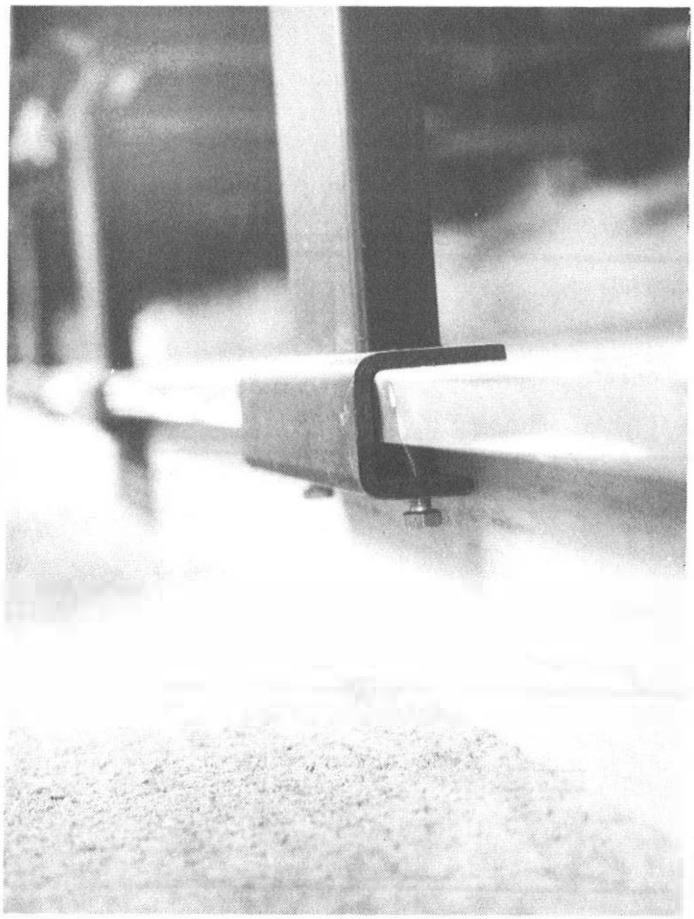

Figure 8: Previously deformed pressure screws of seat anchorage clamps in a new vehicle.

The serial break-off of seat rows was also detected in real-life coach accidents. In one case a double decker vehicle

overturned on a motorway and came to a standstill without any longitudinal collision. Alone the efforts made by the victims of this accident to escape from the bus caused about 30 % of all seats to break off their anchorages and effectively block the way to the exits. In principal the serial failure of seat anchorages hinders rescue work and decreases the efficiency of emergency help after a bus accident.

As can be seen from a comparison of figures 9 and 10, the breaking loose of seats in the crash test considerably reduces the strain of the individual impacting dummy. However, if several rows of seats breake loose, additional strain and compression arise for the other passengers sitting ahead.

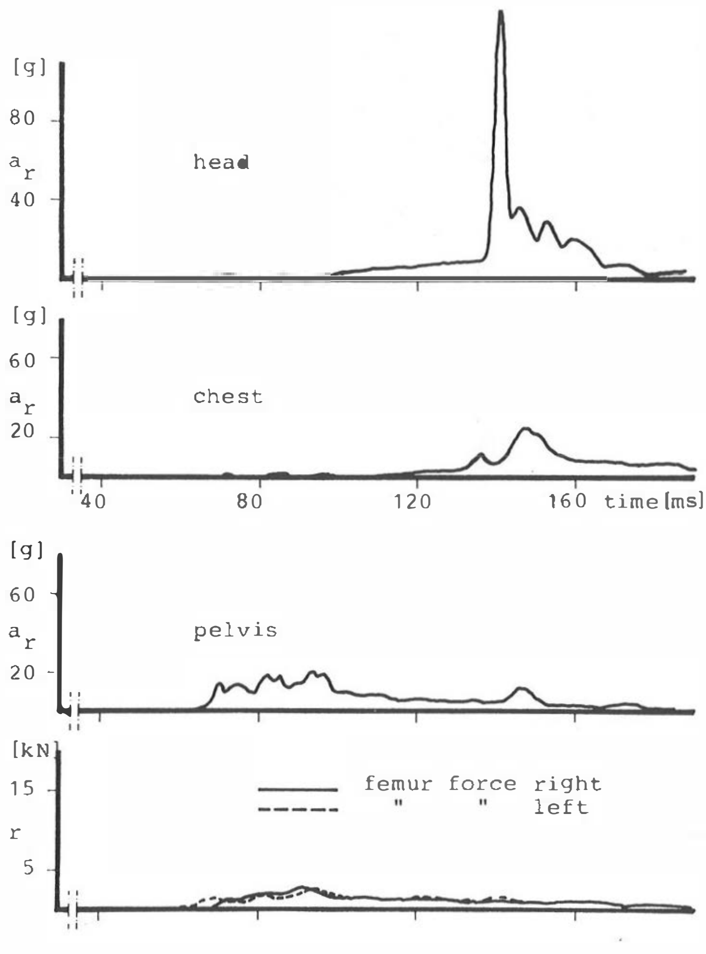

Figure 9: Diagrams of adult dummy loads at non-displaced seat position in a simulated 10 g deceleration impact.

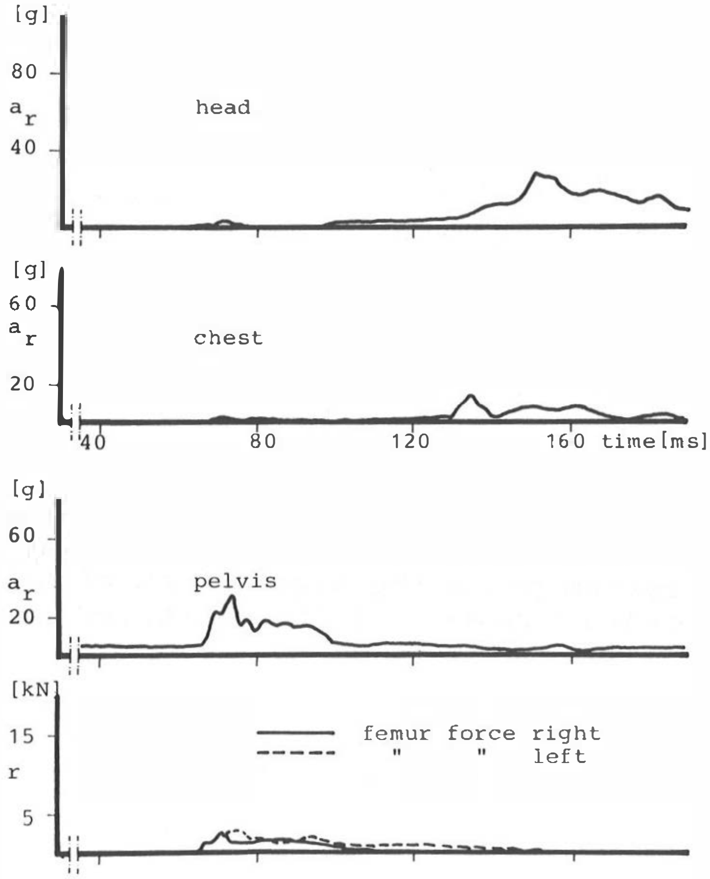

Figure 10: Diagrams of adult dummy loads at partially loosened anchorage and one-sided displacement of 500 mm in a simulated 10 g deceleration impact.

Before a more thorough examination of the anchorage strength was carried out, the test seats were additionally reinforced and secured against slipping forward by other constructional elements.

The impact strain measured on the dummy for the chest, the pelvis and the femur forces were uncritical and far below the biomechanical thresholds. However, the head strain level reached peak values of up to 150 g, figure 10. Even the resulting head loads at the 3 millisecond exposure time reached values of up to 65 $\pm$ 12 g. The unfavourable strain mechanics of the head, as described above, can be related to the induced testing deceleration by an amplification factor of about 6.5. For the other strain values this factor only amounts to about 2.5.

The deformation behaviour of the loaded backrests was measured for dynamic and permanent angle changes caused by the dummy impact from behind. Measurements were taken on the left and right-hand sides of the upper edge of the backrest.

The dynamic deformation of the backrest amounts to up to 34 ± 2° while the permanent angle change of the backrest reaches a mean value of 15 ± 2°. Thus the deceleration path at the upper edge of the backrest is between 140 and 185 mm over which the movement energy of the dummy's upper thorax is transformed into the deformation energy of the seatback framework. Structural deformation of that was only recorded at the adjustment device and at the knee impact area, but not at the upper backrest frame or at its upper edge.

In the sense of an effective passenger retention, the breaking loose of the seat anchorage as described above represents unacceptable malfunctioning of this safety component. However, the relatively low dummy loads in the test with partial failure of the anchorage system prove the high potential of reducible strains if the forward movement of the passenger can be increased within defined limits of space.

Test No.	Peak Values of Dummy Loads						Peak Values of Backrest Deformation	
	Head		Chest	Pelvis	Femur Force			
	a_r (g)	HIC (-)	a_r (g)	a_r (g)	F_l (kN)	F_r (kN)	α_{dyn} (°)	α_{stat} (°)
K1*	117	196	23	28	3,3	3,1	*	12
K2	154	342	21	49	3,8	3,6	31	13
K3	107	206	24	23	2,6	2,6	37	16
K4**	29	59	15	32	2,9	2,6	**	0
K5	139	224	26	21	2,5	2,6	33	15
K6	96	214	34	20	3,3	2,6	35	18
K16***	112	-	12	26	2,5	3,3	36	17
	125	-	15	31	3,2	3,2	34	16

Figure 11: Table of evaluated dummy loads and backrest deformations in simulated 10 g deceleration impacts.
*failure, **displaced seat, ***two dummies

With respect to the future development of seats as an advanced element of a restraint system, the results measured indicate that the actual deformability and energy-absorbing capacity of seat backrests is too low. The head impact towards the upper edge of the backrest does not cause any permanent deformation there, but it produces high head loads. By means of a defined, but limited increase in the bending deformation characteristic of the backrest, the kinematics of the head can be favourably influenced and the total strain on the dummy can be reduced.

Based on the measurement results of tests with partially failing seat anchorages a reduction of about 20 %-30 % of the resulting head load can be estimated for advanced injury-preventing seat systems.

As basic values for necessary and adequate backrest deformation in such a standardized impact by a 50 percentile anthropometric test dummy, it is suggested that the permanent backrest angle change should reach at least 20° but should not exceed 30° as compared to teh designed upright backrest angle. In addition the upper edge of the backrests should either have a defined energy-absorbing capacity according to EEC 74/60 respectively ECE-Regulation 25, or they should be designed with a minimum height of 635 mm above the seat reference point, similar to the specified dimensions of aircraft type seats. After all high seat backrests can possibly contribute towards maintaining the individual survival space when a vehicle has overturned in an accident.

CONCLUSIONS

By this investigation it could be demonstrated that the original function of bus seats can be developed as a restraint system for injury prevention in bus accidents. An advanced seat system can provide a minimum of injury risk by its energy-absorbing characteristic and by maintaining the survival room for the individual occupant.

But there are still problems in the accident related rigidity of the seat anchorage and in a defined energy-absorbing capacity of the seatback in front. By means of improved seat systems the high standard of verified internal safety of buses can still be developed with special respect to the vulnerability of elderly people and children who are more dependent on buses than others.

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