DYNAMIC LOADS EXERTED ON LEGS OF SEATED PASSENGERS DURING FRONTAL COLLISION OF A BUS WITH AN OBSTACLE

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Abstract

The dynamic loads exerted on legs of seated bus passengers during a frontal traffic collision were studied. Passengers are being displaced as a result of a bus collision with an obstacle and the nature of such displacement depends on the design of seats and personal protections applied (2- or 3-point safety belt or no belt). The study describes the dynamic loading of thighs as a function of time and the relationship between the operation of personal protections and leg injuries. Most injuries result from hitting components of seats faced by passengers.

The results were recorded using sensors placed in the dummies' thighs and filmed with a Photosonics camera. The video was used for studying the kinematics of the dummies' legs of the dummy secured with a 3-point belt, secured with a 2-point belt and unsecured, including possible combination of extreme forces with a specific type of leg displacement. Knee movement trajectories and consequences of dummy hips rotation on the bus seat were also presented. Problem of rotation of the hips of the dummy secured with a 3-point belt has also direct influence onto the dynamic loads affecting legs.

The research demonstrates the existing design of 3-point safety belts is unsuitable for protection of seated passengers and the clearances between seat rows are insufficient. The need for applying new energy-absorbing materials or modification of seat design is obvious.

Keywords: *transport, road transport, security on buses, buses, road safety*

1. Introduction

The continuing development of automotive industry and growth of traffic flow call intensification of research into means of improving road user safety. This applies to both bus designs and seated passenger protections, including in particular those responsible for safety in the event of a collision. Frontal collisions with other vehicles or objects are the most frequent incidents. The body of a seated passenger is projected forward by large forces of inertia and usually hits components of seats faced by the passenger. A research of the consequences of such impacts was initiated in [2] and is subject to further elaboration in the present paper.

This paper aims to demonstrate the relationship between the operation of personal protections provided for various designs of seats and leg injuries. The analysis of kinematics of the lower part of the dummy provided in this paper, based on experimental research, led to describing the mechanism of extreme loading of passenger legs during traffic collision.

2. Preparations to measurements

The measurements of dynamic loads exerted on seated passenger legs were performed by the Automotive Industry Institute at a dedicated impact-test station. A section of a bus floor was attached to the testing sledge and two pairs of seats were fixed to the floor section (Fig. 1).

Fig. 1. Two sets of double seats

The clearing between the two sets was standard: 750 mm (Fig. 2). Two Hybrid dummies (50th percentile male dummies weighing 77 kg each) were seated in the second row. See Fig. 3 for the design and location of the force sensor in hips for each dummy.

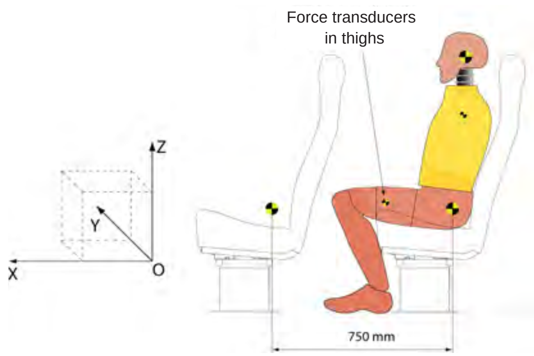

Fig. 2. Sensor positions in the Hybrid dummy and the frame of reference for the transducer axes in the initial (static) state

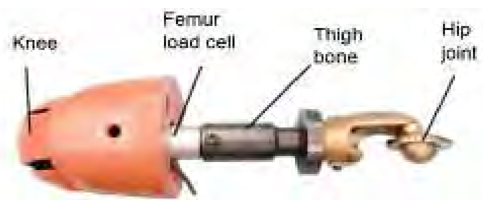

Fig. 3. Force transducer in the dummy's femur

The results of measurements were recorded using the DTS system (Fig. 4) conforming to PN-ISO 6487 (*Road vehicles. Measurement techniques in impact tests. Instrumentation*.).

The progress of impact testing depends on obtaining the unique effect of delayed sledge with bus section braking. The effect reflects the impact properties of the front part of the bus [1]. It is particularly important for repeatability of the experiment for different seat types. Our experiment reproduced the impact test described in UNECE Regulation #80 [1]. The regulation defines requirements for the strength of the bus seats and their anchorages.

During the test, the measuring sledge with the two pairs of seats and two dummies on the rear seats are exposed to precisely programmed deceleration produced by the station's brake. In effect, each impact test reproduces the same delay and inertia forces exerted on the dummies.

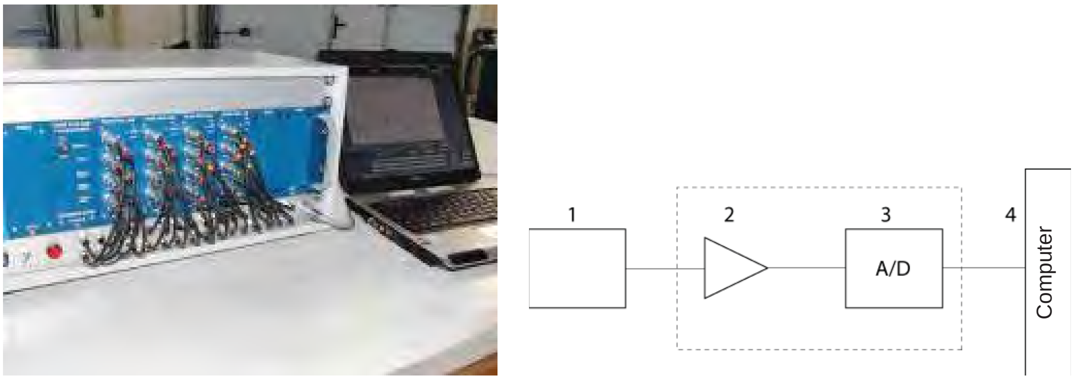

Fig. 4. TDAS DTS ProLab digital recorder and measuring system diagram: 1 – Force and acceleration transducers, 2 – power supply, measuring amplifier, 3 – Analog/digital converter, 4 – PC with TDAS Control registration software

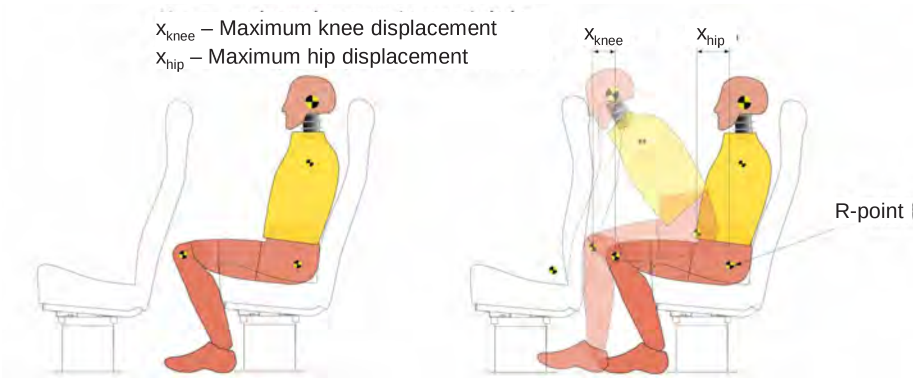

Fig. 5. Dummies ready for the test and knee and hip displacement measures

3. Results and analysis

3.1. Leg displacement

During impact tests deceleration affecting trunks of the dummies and forces exerted on thighs were registered. The results were recorded using sensors placed in the dummies' thighs and filmed with a Photosonics camera. The video was used for studying the kinematics of the dummies' legs, including possible combination of extreme forces with a specific type of leg displacement. The leg displacement was reproduced based on the video, frame by frame [2]. The displacement toward the Ox and Oz axes of the marker placed on each dummy's knee was marked at 10 ms intervals. The time window was set for readouts to 100 ms, which was sufficient for obtaining the maximum leg displacement. See Fig. 6 for the trajectories of the leg (knee) markers for dummies:

- Secured with a 3-point belt,
- Secured with a 2-point belt,
- Not secured with a belt.

The results apply to seats inclined at an angle of 10° (Fig. 7).

Figures 8-10 show the following dummy leg displacement phases in the test. The drawings can be referred to one of the body positions shown on the photograph. Such juxtaposition of displacements of the dummy secured with a 3-point belt (Fig. 8), secured with a 2-point belt (Fig. 9) and unsecured (Fig. 10) is also worth referring to the knee movement trajectory (Fig. 6). The slanted thick line in Fig. 6 represents the back of the seat facing the dummies. The fact that the knee trajectory crosses this line means that the backrest of the seat was distorted or broken by the impact of the dummy's legs. The point in time when the knee touches the backrest is the start of abrupt build up of the forces shown in Fig. 11, 13 and 14.

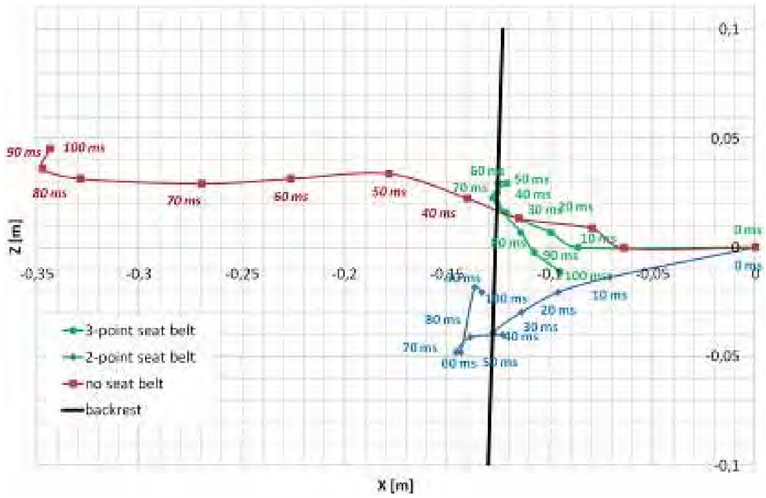

Fig. 6. Knee movement (displacement) trajectories during an impact at 30 km/h; seat angle 10°

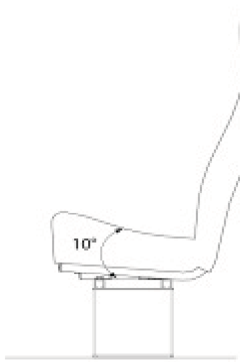

Fig. 7. Seat inclination angle

Fig. 8. Dummy secured with a 3-point belt, seat angle 10°

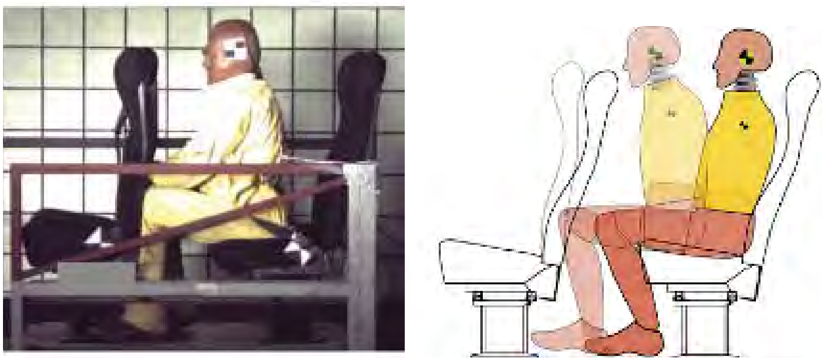

Fig. 9. Dummy secured with a 2-point belt, seat angle 10°

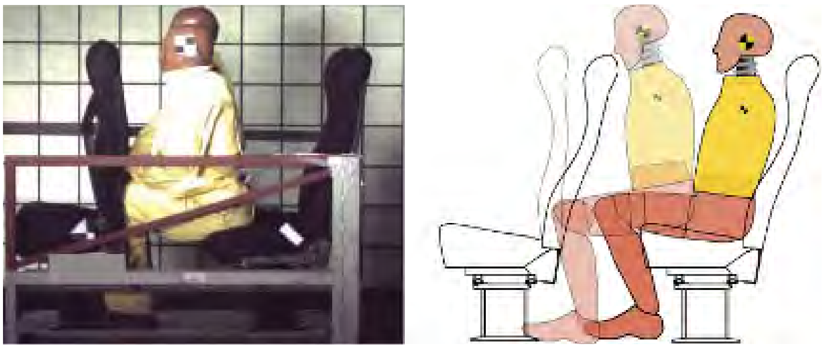

Fig. 10. Dummy not secured, seat angle 10°

3.2. Forces affecting the left and right thighs

The results of measurements of dynamic loads exerted on the dummies' thighs in the same sequence as used in section 3.1 were described below. This is the sequence that should demonstrate obvious benefits of using 3-point belts, the design generally recognized for its good performance.

Typically, an evaluation of performance of protective devices uses standard measures, including specifically HIC (Head Injury Criterion), TTI (Thoracic Trauma Index) and FFC (Femur Force Criterion). The latter can provide a basis for analyzing the results. However, we should also address the possibility of unusual twisting of the dummy's torso caused by relatively low flexibility and small inclination angle of the seat (Fig. 7). These two properties are markedly different than in the back seats of passenger vehicles. The rotation of the dummy's hip and lower part of the trunk results in large differences in forces measured for the left and right leg. This hip rotation is possible because the hip section of the dummy can rotate against the trunk. The division line and rotation plane are positioned between the parts of the dummy painted in different colours (see Fig. 8-10).

The difference between forces recorded for the left and right thighs, shown in Fig. 11, is caused by the dummy's position against the belt and the front seat during the impact. In this case, the left leg (knee) hits the back of the front seat stronger than the right one. The cause of the difference is the dummy's hips rotation resulting from asymmetric operation of the seat belt and inertia forces acting on the hip section of the dummy's trunk. It is the seat belt that is responsible for this effect [3, 4]. In the initial impact phase, when the dummy is thrust forward by forces of inertia, the chest and shoulder and hip sections of the 3-point belt hold the trunk (see the center section of Fig. 12). Then, forces of inertia acting on the upper part of the dummy (torso and head representing the bulk of the weight of this part of the body) load the chest and shoulder section of the belt much stronger but asymmetrically against inertia forces. The result is the stretching of the lower, hip section of the belt through the buckle on one side of the belt. Accordingly, the lower part of the dummy's trunk (hips) is rotated by forces of inertia in the direction opposite to the direction of rotation of the upper part (chest). Obviously, even a small hip rotation produces a strong difference in knee thrust against the base of the front seat (Fig. 12).

Figure 13 presents forces in dummy's thighs recorded for a 2-point belt. This figure shows the mode values of thighs loads that are evenly distributed to both legs, thus the legs dynamic load is even as there is no hip rotation.

Figure 14 presents impact test results for an unsecured dummy. The forces acting on the thighs are markedly larger than it is shown in the two previous figures, with dummies secured with 3- and 2-point belts. Note that during the analyzed impact tests the legs are the first to hit the back of the front seat, and only then follow the head and the trunk. The consequences of such impact are visible on the spot the knees contact the back seat (Fig. 14). The impact at a speed as low as 30 km/h is so strong that the dummy's knees break the plastic components of the backrest, damage the steel frame, or even break the whole structure of the backrest. Accordingly, the following important factors affect injuries to the legs of bus passengers: seat attachment fittings, seat design, seat frame

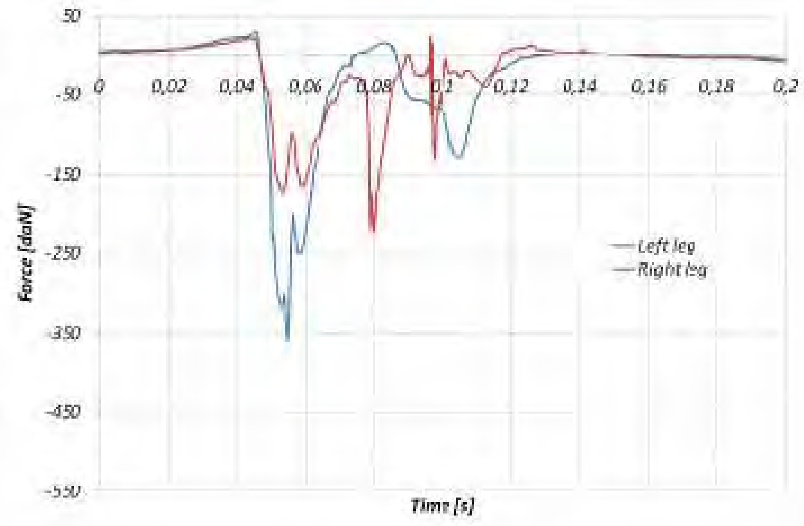

Fig. 11. Force exerted on thighs of the dummy secured with a 3-point belt, seat angle 10°

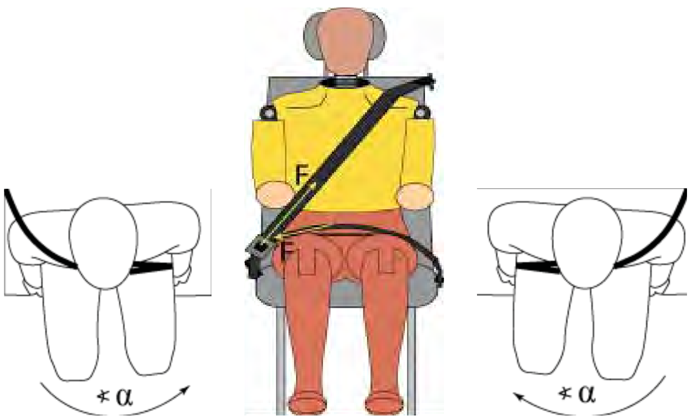

Fig. 12. Lower torso (hips) rotation depending on belt orientation and seat position

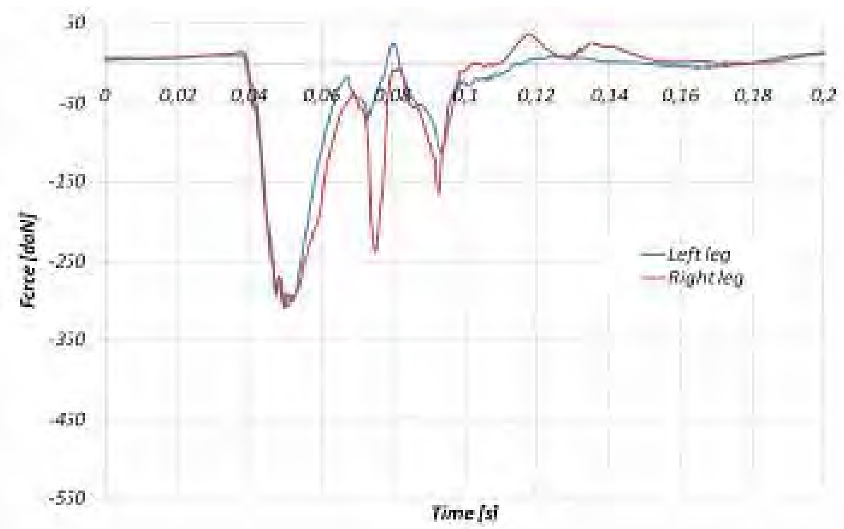

Fig. 13. Force acting on the thighs of a dummy secured with a 2-point belt, seat angle 10°

reinforcements, and the positions of such reinforcements. The structure of the seat at the point of dummy's knees impact has to be strong for functional reasons. However, such bracings can cause injuries in case of a frontal collision. This means such seat components should be energy-absorbing [5].

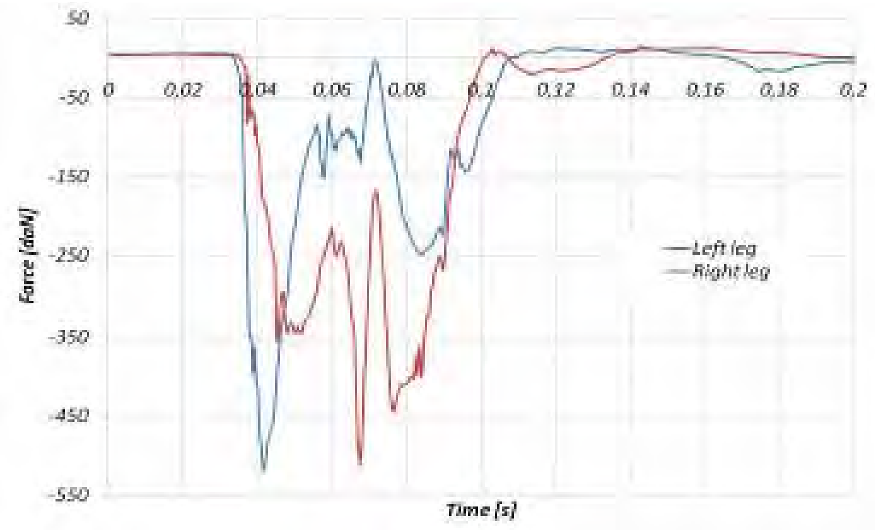

Fig. 14. Force acting on the thighs of an unsecured dummy, seat angle 10°

Fig. 15. Visible damage to the backrest caused by the Hybrid dummy's knees impact

4. Conclusion

The problem of rotation of the hips of the dummy secured with a 3-point belt, illustrated by the damage to the bus seat, calls for continued research, which is particularly important for speeds above 30 km/h. The figures provided in Tab 1 provide an indication of significance of the issue. The differences between forces acting on the left and right legs depend on the angle of inclination of the seat, among other factors.

Tab. 1. Differences between forces acting on the left and ri ght thighs for various seat i nclination angles (at 30 km/h impact speed)

#	Seat inclination angle [°]	Left thigh force [daN]	Right thigh force [daN]	Difference [daN]
1.	10	358	223	135
2.	13	270	194	76

Further investigations into the factors critical for the dynamic loads affecting legs are being scheduled, particularly for speeds above 30 km/h, particularly for speeds above 30 km/h. At 30 km/h the Femur Performance Criterion (FPC), i.e., the requirement for reducing axial force acting on thigh bones to 10 kN, and the Femur Force Criterion (FFC) are met [7]. However, our tests have demonstrated that the present design of 3-point safety belts is unsuitable for protection of bus seated passengers and the clearances between seat rows are insufficient. The need for promoting new, energy-absorbing, materials or changing seat designs is obvious.

References

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