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Department of Injury Prevention

**PASSENGER CAR CRASH WORTHINESS IN
MOOSE-CAR COLLISIONS**

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Passenger Car Crash Worthiness in Moose-Car Collisions

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Abstract

This paper describes the development and verification of a moose-dummy for testing the crash worthiness of cars in moose-car accidents.

The dummy is based on and verified against the results of a staged collision in which a passenger car impacts a moose cadaver. The cadaver test is also described in the report.

Moose-car accidents contribute to about 2 percent of the death casualties in the Nordic road traffic and the type is even more represented among slighter injuries. Since several attempts to reduce the frequency of moose-car accidents have proved to have minor effect improvements of the crash worthiness of passenger cars in this kind of impact might be desirable.

Introduction

The Scandinavian moose, sometimes also called elk, is a huge member of the deer family. A newborn moose weighs about 10 kg and a full grown male might, in rare cases, weigh up to 1000 kg but with an average of between 300 and 400 kg.

In other words this wild animal is almost as heavy as a horse and of similar size but has longer and slimmer legs. This means that when an ordinary passenger car impacts a moose, only a negligible part of the animal's mass will be struck by the strong, frontal part of the car. Most of the animal's mass instead will be impacted by the windshield and roof construction. Car-moose collisions occur in the country side, on roads with speed limits in the range of 70-110 km/h. Requirements on unobstructed field of view and modern styling trends have made many cars inadequate to withstand such an impact.

The animals are well hidden in the vegetation and do often enter the road very swiftly and without warning. Cautiousness and driving experience thus offer poor protection against this type of accident. Passenger car-moose collisions contribute to about 2% of the death casualties in the Nordic road traffic [1], [2].

Different attempts to prevent the accidents have been undertaken. The most important are:

- * Trees and bushes along the road sides of the major roads have been cut down to give clear sight a few meters on each side of the road.
- * Road signs have been put up in order to warn the drivers at places where the animals are known to cross frequently.
- * Wildlife fences have been mounted along such parts of the major roads where moose most frequently cross.

The first two methods seem to have slight effect. The third method has proved to be efficient, but is rather expensive. The animals change habits and find new places to cross the roads.

It has become obvious that improvement of the crash worthiness of passenger cars in this type of accident would be a better way to decrease the numbers of killed and injured road users. This has been observed by the Swedish authorities and in 1982 a working group was established with the official research institutions and the car manufacturers.

A moose-dummy was assembled and crashtests were conducted [3]. Although obtaining valuable data from these tests the group decided in 1985 that an improved moose-dummy was needed for the future work.

This paper describes the development of the latter dummy.

Materials and Methods

This project can be divided into two sections:

- 1) Staged collision with a passenger car impacting a moose cadaver in order to get insight into the mechanisms of moose-car collisions.
- 2) Design of a moose-dummy and validation by a staged collision similar to 1) with the cadaver replaced by the dummy.

General test conditions

The tests were made with an equivalent test set up. The mid plane of the car coincided with the center of mass of the moose-cadaver/dummy (fig. 1).

The speed of the test cars were 79 and 76 km/h respectively. Each collision was high speed filmed from both sides of the vehicle and from above.

Test cars

The cars were instrumented with accelerometers (Endevco 2262) and force sensors (Load-indicator, AB20).

The accelerometers were placed on the roof at the b-pillars and on the floor at the side mem-

bers. The roof-rails were sawn up just behind the b-pillars and force sensors were installed. The cars were equipped with high speed film cameras. The two vehicles had cameras mounted on top of the boot, covering the wind screen area from behind. In the cadaver test two floor mounted cameras covered the windscreen and frontal half of the roof construction from below. In the dummy test the deformation of the roof structure and the penetration of the dummy into the passengers compartment was covered by one floor mounted camera which covered four specially designed gauge rods. Three rods were made of PVC-pipe and were fixed to the upper wind shield frame, one in the middle and the other two in line with the front seat occupants positions. All three rods pointing straight backwards along the inside of the roof. The fourth rod was made of a thin aluminum pipe and was designed to measure the penetration of the dummy through the wind shield opening. It was mounted horizontally in a rig which allowed the rod to glide with friction. It was placed in the mid plane of the car inside the passengers compartment at a height corresponding to the middle of the wind screen opening. At the frontal end of the rod was fixed an aluminum plate 150 X 200 mm. The frontal end had its initial position 300 mm behind the upper wind screen frame.

The vehicles were equipped with an automatic braking system which was pneumatically powered and electro-mechanically triggered. The device was connected to the original hydraulic braking system of the car.

Moose cadaver

The moose cadaver was of a four year old male, weighing 260 kg. The center of mass of the moose body was at the 7:th rib, 1.35 m above the ground. The cadaver hung in four steel wires that were cut off, with specially designed cutting devices (Norabel AB), at first contact between the car and the moose. The cutting device was made up by a small housing through which the wire was passing. Inside the housing, a wedge, driven by explosive agent, cut the wire when an electrical detonator was triggered. The trig-to-cut time did not exceed 2 ms.

Moose-dummy

The design and construction of the moose dummy was based mainly on the experiences from the cadaver test. In that test the moose-body responded roughly like a water filled sack, that is no evident rigidity due to e.g. the skeletal structure could be observed, to the impact.

The dummy thus mainly consisted of water. The water was divided into impermeable compartments, twenty high pressure hoses (Heliflex,11299) with an inner perimeter of 320 mm and an outer of 340 mm. The hoses were filled with water to 5.7 dm³/m which gave a cross sectional area corresponding to a rhomboid with diagonals with the ratio 2/1.

The hoses were tightened at the ends by welding and all air inside was removed. To avoid ripple inside the hoses they also contained five interlayers of a polypropylene fiber mat (ENG-TEX AB, Y065) (fig. 3). The mat consisted of two sheetings separated by thin, transverse, synthetic fibers which gave a high flow resistance.

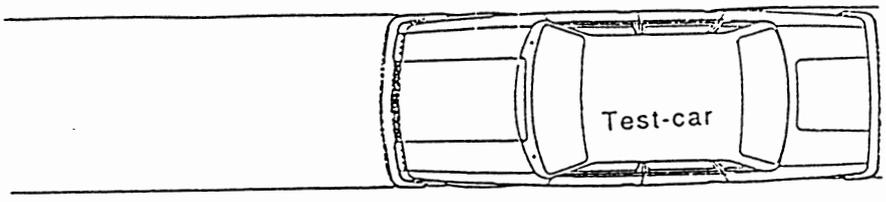
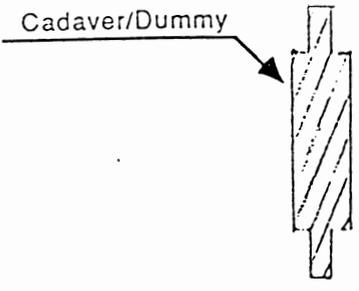


Figure 1: Test configuration.

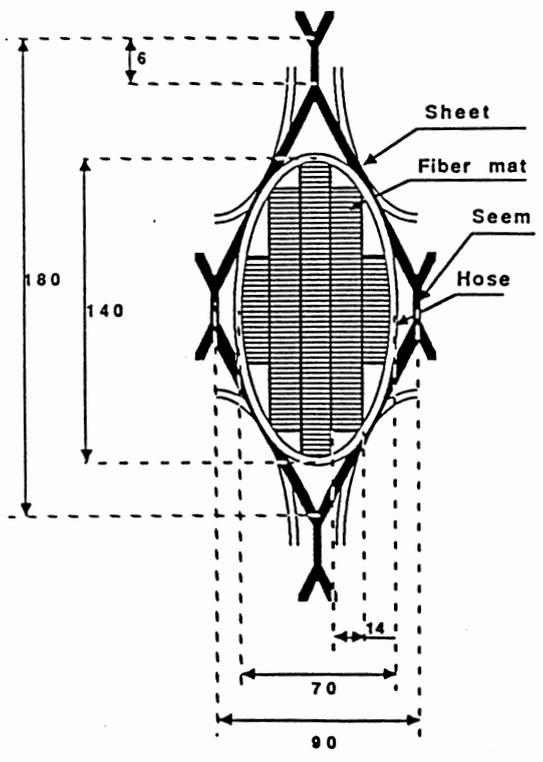
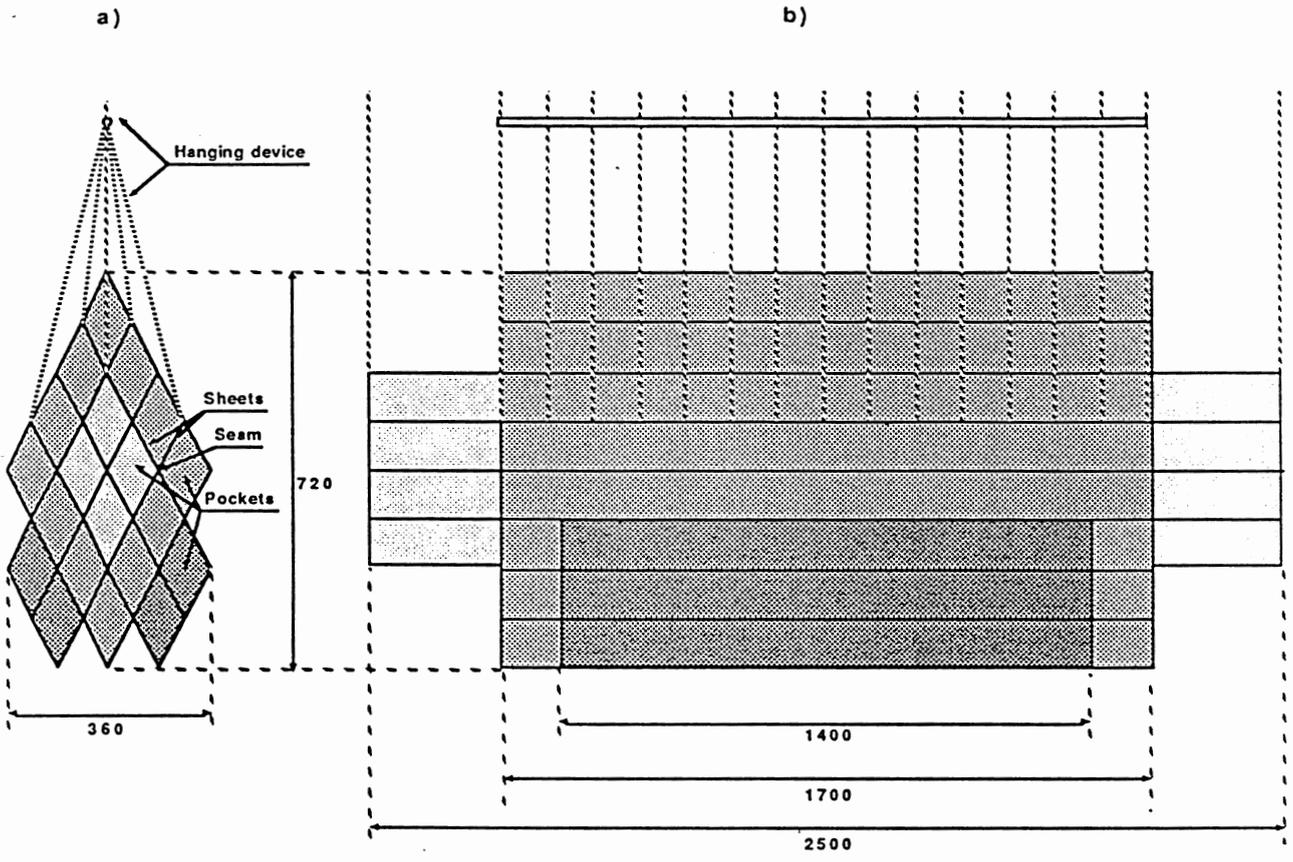


Figure 2 (above): a) Cross-section and b) sideview of the moose-dummy. Lengths in (mm).

Figure 3 (left): Cross-section of one of the pockets with a hose in the dummy matrix. Lengths in (mm)

The hoses were mounted together in a material matrix. The matrix consisted of a number of sheets of a knitted fabric (ENG-TEX AB, Y155) sewn together with a 6 mm wide flat-lock seam (fig. 2). The cross section of the dummy thus got a rhomboidal pattern. Each rhomboid "pocket" had a perimeter of 390 mm. Each hose was covered with a polyethene film to allow easy glide inside its pocket, which is essential in a bending motion of the dummy.

Results

Cadaver test

With this test setup the forelegs were hit by the car front, while the hind legs were passed. When the front hit the forelegs the hooves bent up under the bumper thus fixing the legs at this position during the first 50 ms after first contact. This forced the moose body downwards, towards the bonnet. Observations from the high speed films indicated that not much of the cadaver's mass was rotated in this initial sequence even though the superficial parts, the skin in particular, were considerably twisted (fig. 4).

At approximately 80 ms after first contact the pelvis was hit by the right frontal part of the roof. This occurred at a speed of 76 km/h and induced a force peak of about 20 kN in the right force sensor and caused an acceleration peak of about 30 g at the b-pillar (figs. 5 and 6).

The force then rapidly decreased at the right side and slowly increased at the left side. The force pulse on the left side was lower but with a longer duration. The maximum value was about 14 kN (fig. 7). The impact had a duration of about 80 ms during which the car velocity dropped from 78.9 to 65.9 km/h, in complete accordance with the law of impulse. The pulses in the floor accelerometers never exceeded 10 g and had an average value of about 4 g (fig. 8).

The moose body proved to be very deformable and flexible. It bent around the a-pillars and the windscreen frame and penetrated deep into the compartment. Maximum penetration occurred after 150 ms, at which time the moose body was as far inside as a few cm:s in front of the b-pillars (fig. 6).

The windscreen dropped into the car at an early stage, thereby shielding the two floor mounted cameras. Thus the penetration could only be observed from one side view and the boot mounted camera.

The residual deformations of the car roof was up to 18 cm in the x-direction and 13 cm in the negative z-direction (fig. 9).

Dummy test

The dummy showed great similarities with the cadaver in the interaction with the roof construction. The penetration into the passenger's compartment was about as deep as in the

cadaver test. The acceleration and force pulses also showed good correlation (figs. 7 and 8).

The impact speed was 76 km/h, corresponding to the windshield impact at the previous test. The residual deformations of the car roof was up to 40 cm in the x-direction and 18 cm in the negative z-direction (Figure 9).

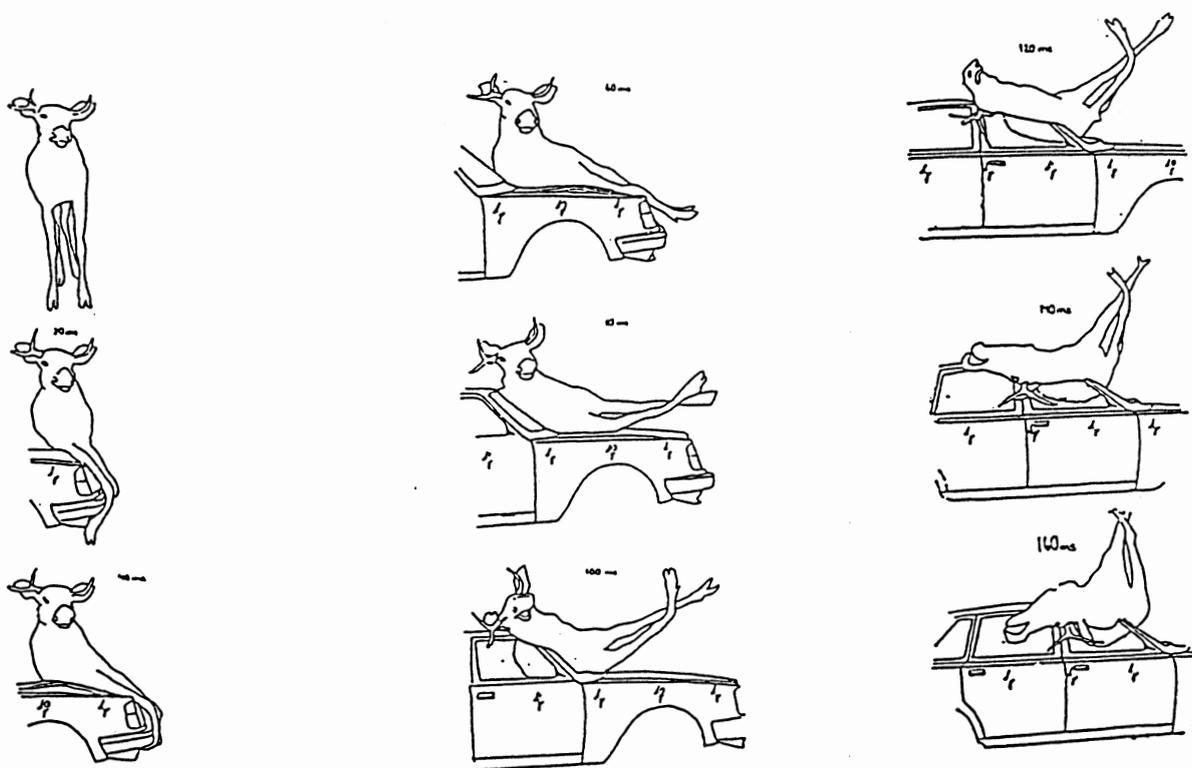


Figure 4: Drawings from the high-speed film of the cadaver-test showing the intrusion of the moose-body into the passengers' compartment. The first picture show first contact between the moose and the car, then each picture is drawn with a time interspace of 20 ms.

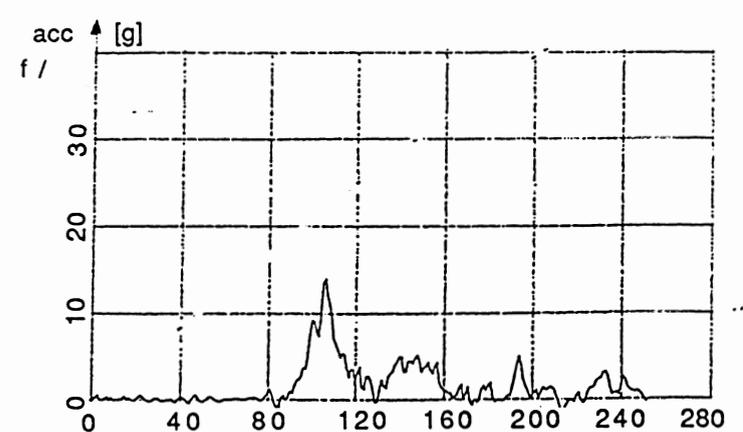
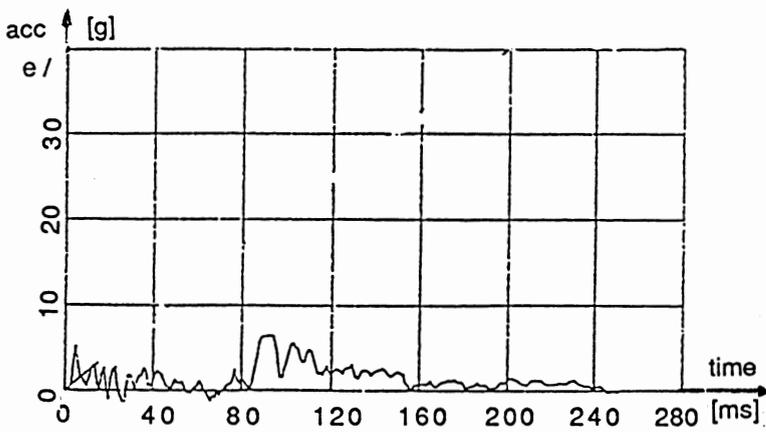
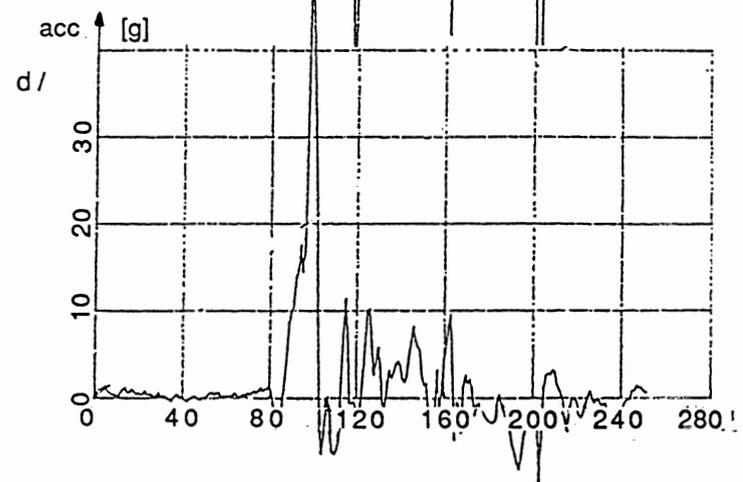
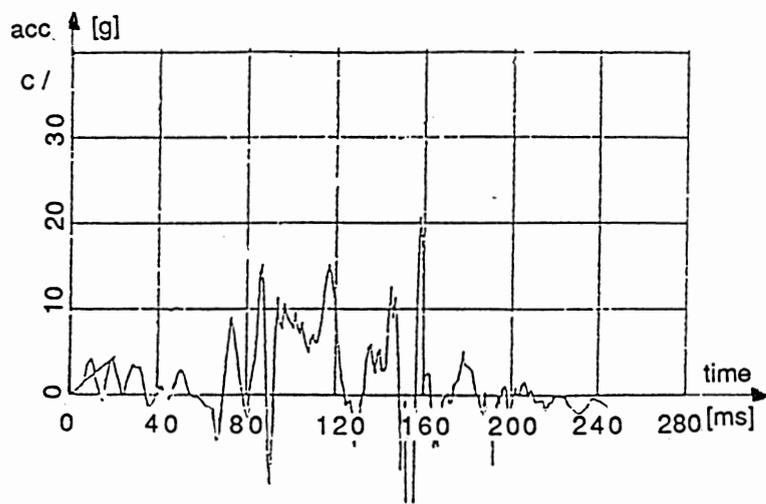
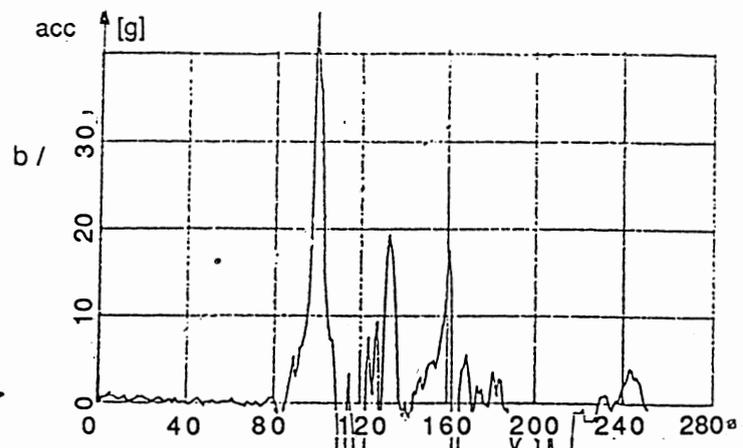
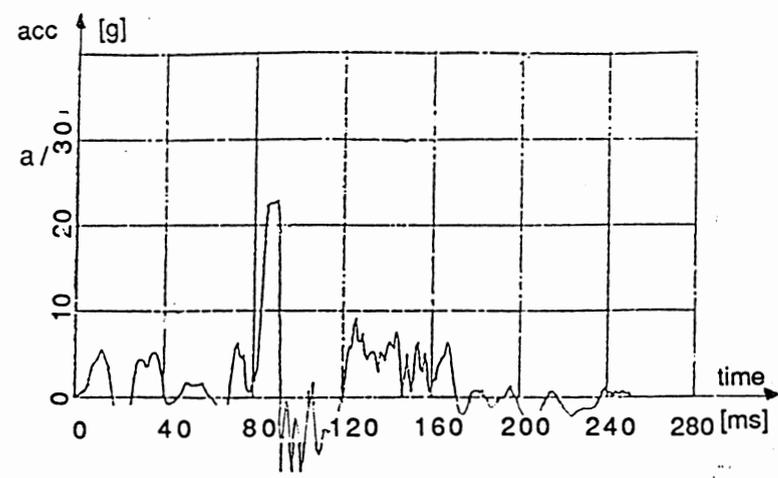


Figure 5, a-f: Accelerometer signals from the cadaver (to the left) and the dummy test. a/right b-pillar, cadaver test. b/right b-pillar, dummy test. c/left b-pillar, cadaver test. d/left b-pillar, dummy test. e/floor, cadaver test. f/floor, dummy test.

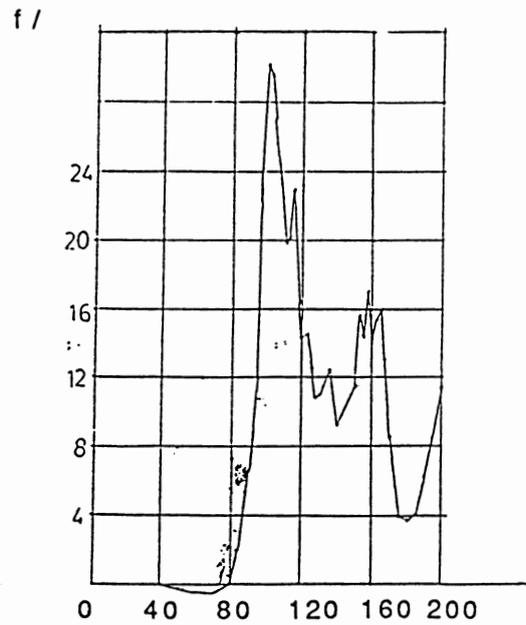
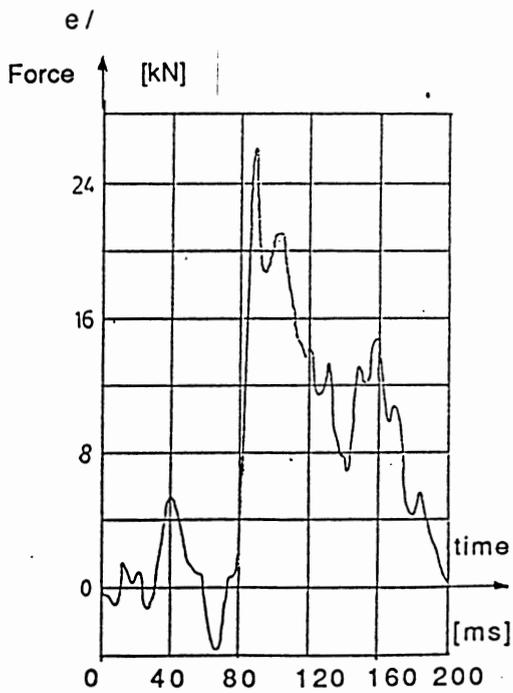
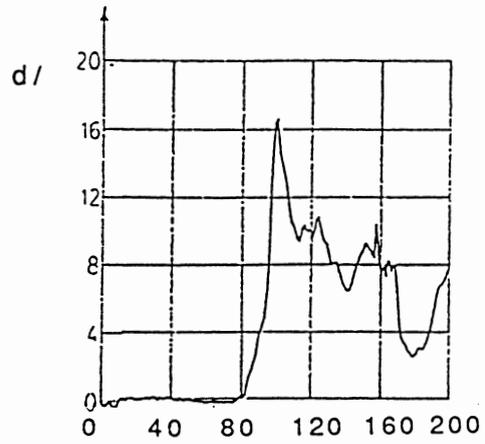
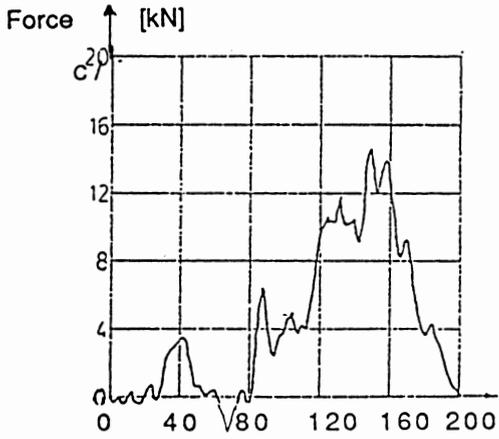
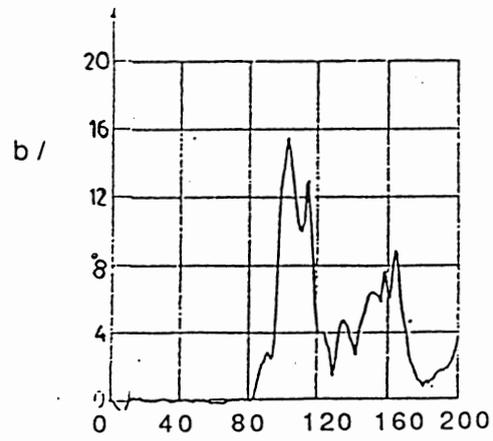
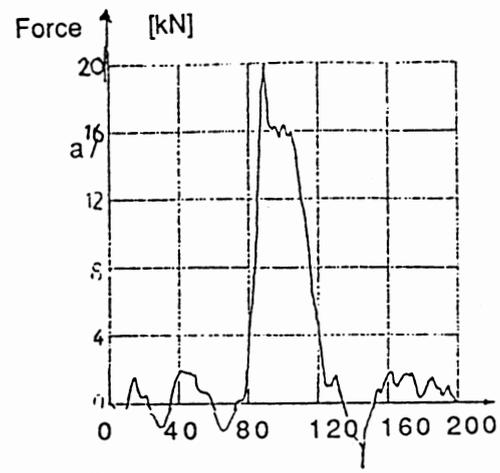


Figure 6, a-f: Force-sensor signals from the cadaver (to the left) and the dummy test. a/right b-pillar, cadaver test. b/right b-pillar, dummy test. c/left b-pillar, cadaver test. d/left b-pillar, dummy test. e/sum, cadaver test, f/sum, dummy test.

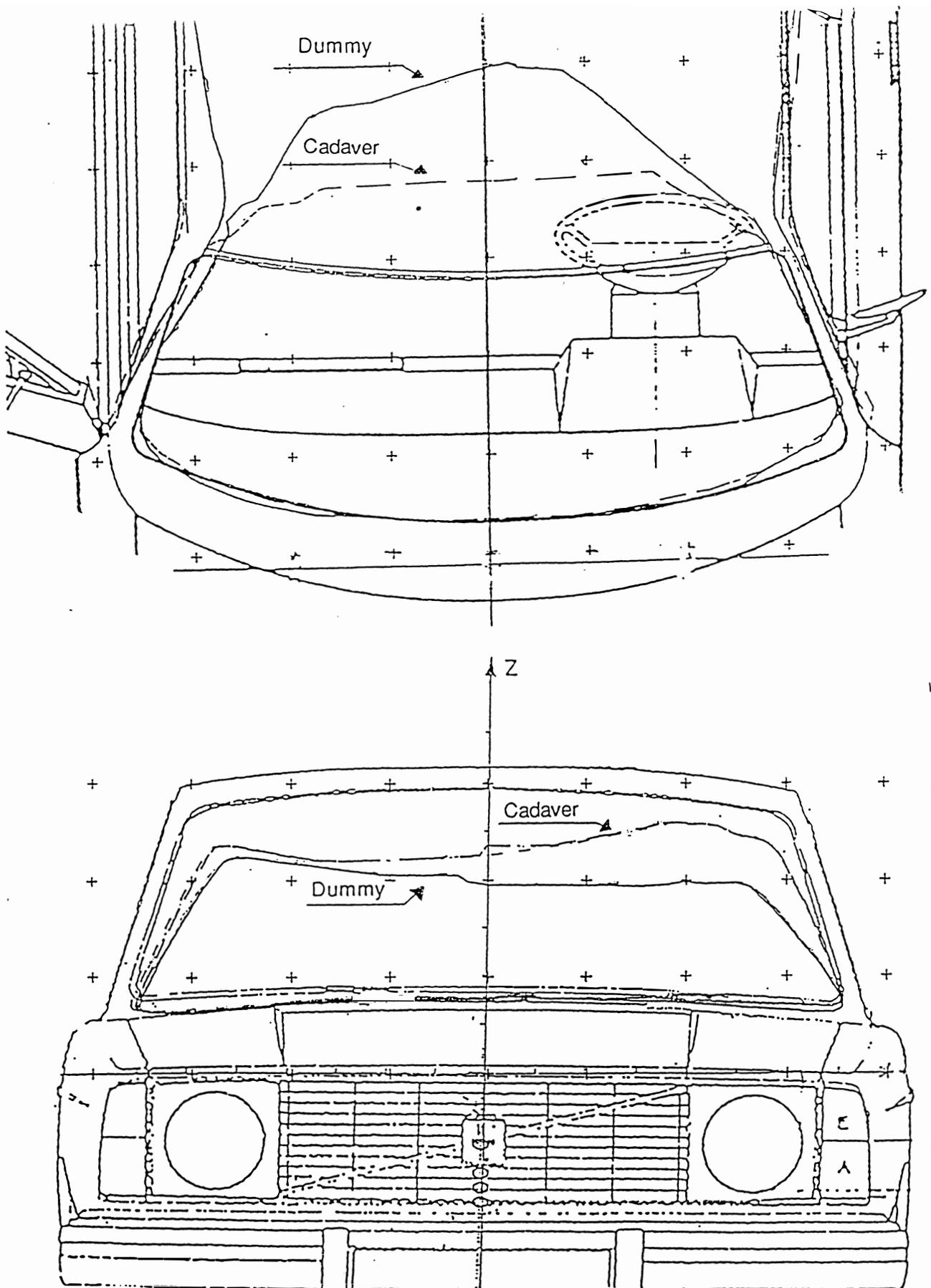


Figure 7: Residual deformations of the car in a horizontal (over) and frontal (below) plane.

Discussion

Cadaver test

Statistics show that moose in the first months of their second year of life are in majority amongst the animals involved in car-moose accidents. In this age they usually have a body mass in the range of 180-280 kg. We therefore decided to use a cadaver in this weight range. The cadaver used was a starved four year old male weighing 260 kg. A normal weight for this animal would have been about 350 kg.

The cadaver was dissected immediately after the test. The strength of the rib bones was then tested and found considerably higher than of ribs of a one year old animal. The evidently flexible and ductile behaviour of the body, shown in the high speed films, indicated that the moose body was loading the roof construction with a pressure that was rather evenly distributed over the contact surfaces. The final deformations of the car gave the same indications. It was believed that the skeleton plays a minor role in this kind of impact.

The center of mass of the cadaver used in this test is about 100 mm higher than what is typical for a one year old animal. It was however concluded that the cadaver was an acceptable model for a one year old moose.

Due to rotation of the moose, the spine "rested" against the upper windscreen frame during the crash. It is difficult to tell whether the spine in another configuration would behave as a load carrying structure or not, which would give implications to the dummy development.

The speed of impact was chosen in the range of 70-110 km/h since this is the interval where the injurious accidents appear. 80 km/h was considered a reasonably tough speed which was expected to give moderate deformations and thereby to enable meaningful force measurements. Accidental data show that impacts where the center of mass of the animal coincides with the mid plane of the car are the most serious [2]. That is why this configuration was chosen in the two tests.

The Volvo 244 was chosen as test car since it was the most common car in the Scandinavian countries at that time. A large reference material was available in Volvo Car Corporation's accidental data, with a great number of well documented moose-car collisions.

In the Volvo accident files the severity is noted by the the Vehicle Deformation Index (VDI)-scale (SAE J 224 B, Collision Deformation Classification).

The car in the cadaver test got a VDI of 60, which places the crash among the severe in the most frequent group (VDI 55-60) in Volvo's accidental data for this kind of impact. This accords quite well to previous discussions. The most severe accidents with moose have a VDI in the region 75-80. Accidents with VDI>80 are very rare. Volvo experts found the deformations very characteristic for this type of accident [1].

The moose was equipped with three pairs of accelerometers (Kyowa AS200A). That is three devices on the hit side and three at the reciprocal spots on the other side. The accelerometers were meant to give baseline data for estimating the compression of the moose body. However the rotation of the outer parts of the moose took the sensors out of direction at an early stage why the available information is of minor relevance.

Dummy development

The cadaver test indicated that the moose could be described mainly as a water-filled sack in this kind of impact. Thus, a strong, soft and none-elastic container with a viscous content of a density close to 1000 kg/m^3 was expected to be an appropriate dummy solution. Roughly, the container should have the shape of a moose body.

As mentioned the crash-configuration with the center of gravity of the moose hitting the car's mid plane is considered the worst one. The moose itself is rather asymmetric in all dimensions around its center of gravity, but to increase repeatability and to simplify moose-dummy construction the dummy was made symmetric around its transversal plane through the centre of gravity.

In all dimensions the mass distribution was arranged to simulate the configuration of the cadaver (from centre of gravity to head end in the asymmetric case) in the critical part of the collision, 80-160 ms after first contact when the head and the hind legs are moving at the sides of the car in a horizontal plane .

To accomplish this we used hoses of different lengths (fig. 3).

The hoses were only filled to half their maximum volume in order not to hinder the bending. Since the sheets in the material matrix are made of a knitted fabric and thus are tensile, the matrix must have a pre-tension in the vertical direction. Pre-tension decreases the deformation of the matrix when the dummy is hung up. The cross sectional area of each pocket in the matrix will increase and the length of the matrix decrease due to gravity when the dummy is hung up. Each pocket was given a perimeter of 320 mm in the empty unloaded matrix and had a perimeter of 390 mm when the dummy had been put together and hung up. The length of each pocket in the empty matrix must be 150% of the hose length in order to get the same length as the hose when the dummy is hung up.

Dummy test

This test showed good agreement with the cadaver test. Both the signals from the accelerometers and the deformation of the car showed such good agreement that we considered the dummy to be a valuable and inexpensive test tool for this kind of impact. The dummy test was a more severe impact to the car due to the fact that the mass of the dummy was equal to the mass of the cadaver with forelegs. The mass of the forelegs of the cadaver was accelerated by the car front before the body impacted the windscreen area and did not contribute to the wind-

screen impact but did reduce the car speed prior to windscreen impact. The speed at windscreen impact was set 3 km/h lower in the dummy test, to give the same impact speed at the windscreen area in both tests. The mass to be accelerated by the windscreen-roof construction was however still higher in the dummy case. In this respect the 260 kg-dummy was reciprocal to a 310 kg-moose. The contact with the forelegs in the cadaver test pulled the cadaver slightly downwards. Thus the lower edge of the windscreen frame and the top of the dashboard took a greater part of the impact energy in the cadaver test. This also adds to the fact that the dummy impact was more severe to the roof construction.

The car in the dummy test got a VDI of 75, which places it among the moderate in the most severe group.

Acceleration measurements were left out in the dummy test since the design of the dummy did not allow the same method for mounting the accelerometers and since no reference information from the cadaver test was available.

General considerations

The injury-inducing mechanisms in moose-car impacts can be divided into two major groups. 1) Direct contact between passenger's head and moose body. Prior to this study the generally accepted theory was that contact occurred between the head and the upper windscreen frame due to the fact that the frame is pushed backwards during the crash. This study however shows that the moose body is much deeper inside the compartment than the frame through all the critical part of the crash. The occupants head will thus hit the moose body rather than the car structure. A deeper analysis of Volvo's accidental data tends to confirm this conclusion. The medical reports on head injured passengers in all cases show diffuse, blunt trauma.

The deformed windscreen frame is however a great risk factor in the so called secondary impacts. That is when the car after impacting the moose collides with something else, e.g. a tree or another car. Secondary impact occurs in approximately 20 % of the moose-car accidents.

Volvo's accidental data also showed that the use of seat belt significantly decreases the risk for severe injuries in this kind of impact. All accidents in all Volvo models where injuries were reported over a period of five years were studied. We found 396 injured passengers, all from the front seat. Of these, 372 had used their seat belt. In this group we found one killed (AIS 6) and two critically injured (AIS 5). In the left 24 cases where the seat belt was not used or the usage was hard to determine, four fatally and two critically injured were found.

Even with restrictions and reservations to this brief study it is likely that significant differences will remain.

2) Glass pieces from the windscreen give face and arms injuries [1], [2]. This is a very common injury mechanism in moose-car collisions but the injuries are in general moderate. Severe cases can occur e.g. when glass lacerates the eyes, but these are very rare.

Reduction of the amount of glass pieces emerging from the windscreen would reduce the number of injuries of this kind.

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References

1. Lind, Bo (1981) "Viltolyckor, sammanställning av olycksmaterial", Report from Volvo Car Corporation, Göteborg.
2. Thorson, Jan (ed.) (1985) "Moose Collisions and Injuries to Car Occupants", Report from Departments of Environmental Medicine, Surgery and Forensic Medicine, University of Umeå and Occupational Health and Safety for State Employees, Umeå.
3. Turbell, Thomas (1984) "Simulerade älgkollisioner, en metodstudie", VTI-meddelande nr 402, Swedish Road and Traffic Research Institute, Linköping.