# QUANTIFICATION OF PROTECTIVE EFFECTS OF SPECIAL SYNTHETIC PROTECTORS IN CLOTHING FOR MOTORCYCLISTS

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## ABSTRACT

Based on a study of 470 injured motorized two-wheel-riders improvements and conceptions of an optimal protection was described. It was found, that a protection against fractures is not given by commonly used leather clothes. The aim of better protection must be by correlation of qualities from shock absorption and power distribution. These two ways of safety-yield is realizable from a compound-system-protector consisted of a hard-shell material with shock absorbing foam inside. The possibilities of the varying protections with and without plate is quantified in this study.

## 1. ACCIDENT SITUATION

Every year, approximately 90.000 users of motorized two-wheelers are injured and 1.400 killed in traffic accidents in the German Federal Republic /1/. 21% of the injured are users of mofas and 8% of mopeds/mokicks, but 71%, however, are motorcyclists. It is significant that 19% of all the injured in traffic accidents are two-wheeler users. Of the officially registered two-wheelers in the German Federal Republic, on average every 13th is involved in an accident. When comparing the annual driving performance for motorcycles of approximately 6.579 km /2/, an accident involving and injured motorcyclist occurs on average every 113.000 km.

How can this be evaluated ?
Is the safety for motorcyclists greater than one may presume ?

Compared with car occupants, motorcyclists face an about ten times higher injury risk, regarded statisticaly, than car occupants, who drive approximately 12.100 km each year /3/. The probability of getting injured in a traffic accident is extremely high for motorcyclists, while two-thirds of the accidents with cars result exclusively in material damage (65,2%). The predominating proportion, i.e. 97,8% of accidents with motorized two-wheelers involves personal damage (fig. 1). This shows that motorcycle riders are far more endangered than car occupants. The danger of getting injured in an accident must be seen in the exposed position connected with a two-wheeled vehicle.

## 2. OBJECTIVE

The high injury risk for two-wheeler users is due to the fact that they are very exposed to external impacts, in absence of the passenger compartment. It is further due to the lack of elastic interceptors for the body in a fall or a deceleration of the two-wheeler. An impact of the driver with objects in his path of movement must inevitably lead to injuries.

A great number of publications concerning the injury situation for this group of traffic participants already exist, but beyond descriptions of injury frequency and injury mechanisms or such like, none of them give any direct recommendations for modifications. Only a few realistic and practicable suggestions can be found in the literature. Our intention to take initial steps to increase passive safety for motorized two-wheeler users derives from todays cognitions about accident research. Extensive accident analyses and first steps for the realization of suggested measures have already been introduced during the IRCOBI Conference 1986 at Zuerich, Switzerland /4/. The great importance of selfprotection for two-wheeler users by the use of crash helmets and protective clothes was emphasized. For the reduction of injury severity, especially of fractures, exclusively protector combis are suitable, as will be demonstrated in this study.

## 3. INVESTIGATIONS AND WORKING METHODS OF REAL ACCIDENT DOCUMENTATION

Protective clothes were designed with in the framework of an innovation research, sponsored by the German county of Lower Saxony, carried out by the Medical University of Hannover, together with the Technical University Berlin and industrial companies of the county. They were developed in accordance with cognitions derived from accident analyses by the Accident Research Unit, and evidently offer protection from fractures. The concept of the protector-clothes was developed in long-standing cooperation between the firm of DIFI* and other firms of the metal and synthetic-processing industry of Lower Saxony.

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The special feature of accident analyses is the detailed documentation of traffic accidents by a research team, at the site of the accident, directly after the accident occurrance /5/. Technicians and medical staff drive to the scene of the accident in special operating vehicles. They immediately proceed with the documentation of skid marks, scratches, vehicle deformations, impact points on persons etc.. With the help of stereo photography, true-to-scale drawings are produced, in order to make an exact reconstruction feasible. Injuries are documented, divided into type, localisation and severity AIS /6/, and together with the technical findings, the accident causes can be evaluted.
470 injured motorized two-wheel-riders could documented in this way.

## 4. NECESSITY OF PROTECTOR-COMBIS

### 4.1 INJURY SITUATION

Injury points for 470 users of two-wheelers can be recognized in fig. 2. Beside the head, with 67% of the injured without helmet protection, the lower extremities are most frequently injured (81,2% of all injured people). One-third of them suffered fractures (fig. 3). Especially frequent due to high impact forces are here (to 21%) third-degree fractures, and also the to 55% occurring complete fracture of the tibia. These injuries of the lower extremities are especially grave, in view of the often very serious after-effects, procured by delayed complications. This is the case with 46% of all leg injuries /7/.

Regions for high injury risks are marked by hatchings in figure 4.

Soft-part injuries are especially frequent for shoulders, lateral lumbar regions of thorax, abdomen and pelvis, the forearms dorsally, inclusive the elbows, wrists and hands. Also involved are the lower extremities (ventrally) inclusive the knee and foot region. These body regions of two-wheeler users therefore urgently require protection by special protectors.

### 4.2 WHAT EFFECT CAN BE DISTRIBUTED TO TODAYS PROTECTIVE CLOTHES ?

An examination of injured traffic participants, with and without protective clothes (fig. 5), show a distinct reduction in open soft-part injuries like abresions, lacerations and contusions for leather-protected body regions, and resulting from this, an increase of closed injuries like contusions. Injuries to the unprotected thoracic regions, caused by the tarmac, were to 10,9% closed and to 14.3% open soft-part injuries. With leather protection, only 4% open and 10,7% closed injuries were established. This obvious protective function of the leather is especially evident for open soft-part injuries, injuries of the thorax, the abdomen, the arms and hands, but also for the foot region, which is protected by boots.

For a body impact with the vehicle of the collision partner, the protective effect of leather clothes is not so distinct in our study population. In our opinion, this is due to the generally high energy conversion by the direct body impact to mainly hard and edgy vehicle parts. A protection against fractures is not given by commonly used leather clothes.

## 4.3 CHARACTERISTICS OF PROTECTORS

There are two different possibilities to reduce the conversion of the produced impact forces, prior to transference to the body. These are:

1. shock absorption

   Energies can be absorbed in the process of material deformation and so the amount of transferred energy be reduced. The so-called shock absorption, i.e. amount of the reduced energy is mainly defined by the quality of the material and the potential deformation volume.

2. energy distribution

   By transformation of a punctate energy into a surface stress, the resulting pressures, i.e. the energy for each areal segment ($kp/cm^2$), are reduced. The resistance theory for instance shows in the load drop of a bending-stressed carrier only a half as big bending moment with surface stress, compared with punctate stress.

By correlation of qualities from shock absorption and power distribution, the following objectives could be achieved:

- reduction of active energy
- reduction of pressure stress
- reduction of bending stress.

In order to combine both characteristics, power distribution as well as shock absorption in one system, a protector with compound-system body was chosen, which consists of an impact-enduring plastic material on the outside, and a shock absorbing one on the inside (fig. 6).

A 3,2 mm cold-proof polypropylen, and for the inside a shock absorber of 9 mm polyurethan foam with a high absorption quality was used for the exterior. For the interior lining, a compound of 3 mm soft polyester fleece was chosen, with a skin-compatible porous lining textile.

## 5. CONCEPT OF A PROTECTOR FOR COMPLETE SAFETY COMBINATION

### 5.1 SHELL CONSTRUCTION

In order to design well-protecting comfortable clothes, which will be also acceptable for motorcyclists, protectors should be built in to leather clothes or be additionally pushed into existing garments. Due to the fact that the body regions which require protection (fig. 7) cover a total area of 3.000 qcm, i.e. approximately 80% of the total surface of the human body, it is most important to ensure a good mobility for the motorcyclist. For this reason, all protectors were manufactured in segment construction (fig. 8). Movable segments connected by thin synthetics (so-called film hinges) permit a movement in one direction only. This is due to the type and construction of the connections. By the load direction toward the body, the mobility of the segments is reduced. The protectors function as a plate.

The example of the shoulder protector illustrates construction and foam shape (fig. 9).

### 5.2 QUANTIFICATION OF PROTECTIVE EFFECT

#### 5.2.1 PROTECTION REGIONS

Protectors were designed for the following regions:

- shoulder
- thorax
- forearm
- thigh
- tibia.

For elbow and knee a protected zone was provided with a bolster of polyurethan foam. Hard-shell protectors could not be used here, as this material would limit the mobility enormously.This is also the case with the lumbar and pelvis region, where the seating position does not permit a limited mobility.

In order to quantify the protective effect of the newly designed 'combi', accident simulations and component tests were carried out. Within the framework of accident simulations with test dummies, the impact points to be covered by protectors and already well known from the accident scene, could be verified.

## 5.2.2 SHOCK ABSORPTION AND FORCE REDUCTION

### 5.2.2.1 INVESTIGATION METHOD OF COMPONENT TESTS

The functional test of the protectors in regard to their safety efficiency was carried out in the framework of component experiments in which the system-construction of the protector-shell and protector padding were tested in impact experiments. The materials for the shock-absorbing layer were chosen and determined by impact experiments out of a number of available substances. The following various materials usable for the shock-absorbing inside layer were at our disposal for the investigation

- Polyurethan-foam (PU)
- Polyvenylchlorid-foam (PVC)
- Polystyrol-foam (PS)
- Polypropylen-fleece (PP)

All the substances were available as 9 mm thick sheet products and were chosen to meet the demand of the best shock-absorbing qualities of each material type. Beyond that, test samples were prepared which consisted of various material types and structures, such as air-cavity structures, known in the packing branch as "air-cavity-foil", or the knee protection parts of common-trade leather clothing as well as the new protector-system plate with foamed on Polyurethan.

The test-samples were put under load by a square test body measuring 800 x 200 mm with rounded off edges (R 1 mm) in a fall-test bench (fig. 9). The test body weighed 5 kg, the fall height measured 128 cm and the speed was 18 km/h. The impact force was measured with a force measurement vessel the force/time-process was surveyed digitally and prepared for the analysis by mathematical integration of the decelaration in a force/speed- and force/distance-process. All the test samples were put under load without and with a covering plate so that the force reduction due to the effect of the plate could be evaluated.

### 5.2.2.2 ANALYSIS RESULTS

A tabular evaluation of the following details is shown in fig. 10:

The maximum force under the test-sample, the time in which a force exceeding 5 KN (i.e. 100 g) was in effect and the efficiency of the shock absorption. This results out of the product of force reduction and distance-exploitation-degree and can be regarded as a valuation of the following demands:

1. Low force maximum in relation to the ideal force level under ideal force transmission behaviour (rectangular characteristic line) of the test-sample (in this case 7 KN)

2. Highest possible exploitation of the material distance used for damping (maximum distance in ideal rectangular characteristic line = material thickness).

Force peaks of 19,3 to 30 KN were derived for the various materials without plate in this load case. The lowest values were derived for Polysterol and Polyvenylchlorid. The maximum force level decreases and the shock absorption increases when the density of the material increases. Although the efficiency of Polyvenylchlorid is only slightly lower than that of Polystyrol. Because of the chained structure of it`s tissue, Polypropylen-fleece without plate rated a relatively high efficiency of $\eta$ = 0,11, but a force peak reduction of only 20% under plate load. The shock absorption is very bad compared to other materials under plate load (efficiency $\eta$ = 0,16); a reason not to use this material for shell-protecter-constructions. Even under plate load, Polystyrol has the best shock absorbing qualities with a high density (58 g/1) and $\eta$ = 0,78 and a force reduction of 67%. Because of it`s good processing possibilities, the necessary elastic quality for wearing comfort an the relatively high damping and force reduction quality, Polyurethan-foam or Polyvenyl-chlorid-foam seem to be most suitable for the proposed protecter compound system. An efficiency of $\eta$ = 0,14 without plate load and of $\eta$ = 0,24 with plate load was achieved with Polyurethan-foam 2. An additional reduction of the maximum force level by 24% can be achieved with the plate draft. The time influence of a force exceeding 5 KN, corresponding to 100 g only amounts to 1,9 ms, where as other materials have the same force level for a longer length of time.

### 5.2.3 COMPARISON OF LEATHER CLOTHING WITH AND WITHOUT SHELL-PROTECTER

To enable an evaluation of the advantages of shell-protecters in comparison to present-day "NORMAL" protective clothing, a few test items out of shop collections were chosen and their force reduction and shock absorption qualities were tested on a fall-test-bench.
The following items were tested:

- leather 1,4 mm + 3 mm lining fleece
- knee part leather 1,2 mm + 10 mm very soft foam
- knee part leather 1,2 mm + 5 mm soft foam
- knee part leather 1,2 mm + 5 mm soft foam and additional KEVLAR padding

- knee part leather 1,4 mm + 10 mm temper foam

Air bolster foils (plastic air-cavity bolsters used in packaging), and the protecter-compound-system made of Polyurethan foam (shown in fig. 6) were tested and compared and the results set against each other in fig. 11. Air-bolster-foils show hardly any possibility of force reduction. The highest force level of over 35 KN and the lowest shock absorption degree of less than $\eta = 0,05$ was established for this material. Compared to this, a normal leather knee protector with a 3 mm lining fleece already causes a slight force reduction. In this case 34,4 KN were measured. Compared to this leather/fleece combination, leather plus 10 mm of very soft foam measured 32 KN, and a knee protector from another manufacturer even 33,8 KN. The usage of KEVLAR did not inprove the damping. The protective clothing of HALVARSSON, which is already abtainable, containing integrated foam protective-zones, shows a distinct gain of safety. The maximum force transmitted to the backing was reduced to 21,8 KN. Although the influence time of greater loads exceeding 100 g amounts to 1,7 ms. The protector-compound-system has the best force reduction and shock absorbing qualities. A force of only 17.1 KN and an efficiency degree of 0,15 were established. This means a force level reduction of 51% compared to normal leather clothing. However the greatest force reduction and efficiency degree was established for the combination of plate and HALVARSSON foam (69% force reduction efficiency degree $\eta = 0,5$). The clear superiority of the plate-compound-system can also be seen in the force/time-process shown in fig. 12a and b in which these materials are compared with normal leather clothing. The insertion of a plate achieves the exploitation of a larger area which lowers the force peaks, thus drawing the force-distance-value closer to the rectangular characteristics value. On the whole only a slight force absorption (shock absorption) can be achieved using this method (efficiency rate), and cannot be improved until a thicker foam layer is added.

## 6. DISCUSSION

Users of two-wheel vehicles must protect themselves against fall and crash injuries !

This demand already defines the claims that must be put on protective clothing.
When the various crash and movement types that happen to motorized two-wheel users in accidents are analysed, a combination of tangential slide-movements with a large amount of friction, causing friction-heat, joined with direct crash situations on areas as well as often edgy objects also causing a high force rate, can be determined. Optimum protection by protective clothing must therefore ensure tear-firmness and heat-stability,

as well as shock-absorption. Where as tear-firmness and heat-stability can already be achieved by leather and other textiles, the reduction of the impact to the body must be achieved. The development of crash helmets and vehicle constructions has shown us that shock-absorption can only be achieved through a defined deformation course, which is hardly present in leather-clothing, when one considers the possible thickness of the material layer. But shock-absorption cannot be derived out of the course, it is also influenced by structure and deformation qualities of the material. The developer of protective clothing must make use of these possibilites. Apart from the possibility of using Polyurethan foam of high damping quality of the largest possible and reasonable thickness, the protector-compound-system described here also uses the plate effect, through which force reduction occurs by means of area dispersion. This effect was confirmed in fall-tests. 31% to 41% of the maximum force was transmitted to the body, compared to leather without plate - a contribution to more safety for the two-wheel user !

An improvement of up to ten times better than normal leather clothing with simple foam safety areas. The tests confirmed the high protective potential of the foam areas developed by HALVARSSON, which achieve a force-level reduction of about 35% without plate, compared to normal protection areas, and as much as 61% with plate. The plate system has further advantages because of the reduced preasure and bend strain caused by the force distribution, as well as the ability to prevent the penetration of pointed and sharp-edged parts. This contribution to the reduction of fracture ans soft-part injuries should not be under estimated. When choosing material for the shock absorbing layer, it should be taken into consideration, that too inactive materials can lose their good shock absorbing qualities after being exposed to a prior load. The HALVARSSON foam for instance produces worser results when measured immediately after a prior load of 5 kg. Apart from the possibility of a second impact, a prior load can already be achieved at the elbow and knee areas simply by wearing the garments.

The study at issue is not supposed to favour a certain market product, but to describe the body parts that have to be protected, apart from that, the efficiency of a plate-compound-system and the possibilies of realization of the increasement of the wearing comfort by special construction of the hard shell. It should not be ignored, that other materials exist, which have better qualities than those mentioned here. The plate-compound-system can still be regarded as a guide to the future development of protective clothing for two-wheel users.

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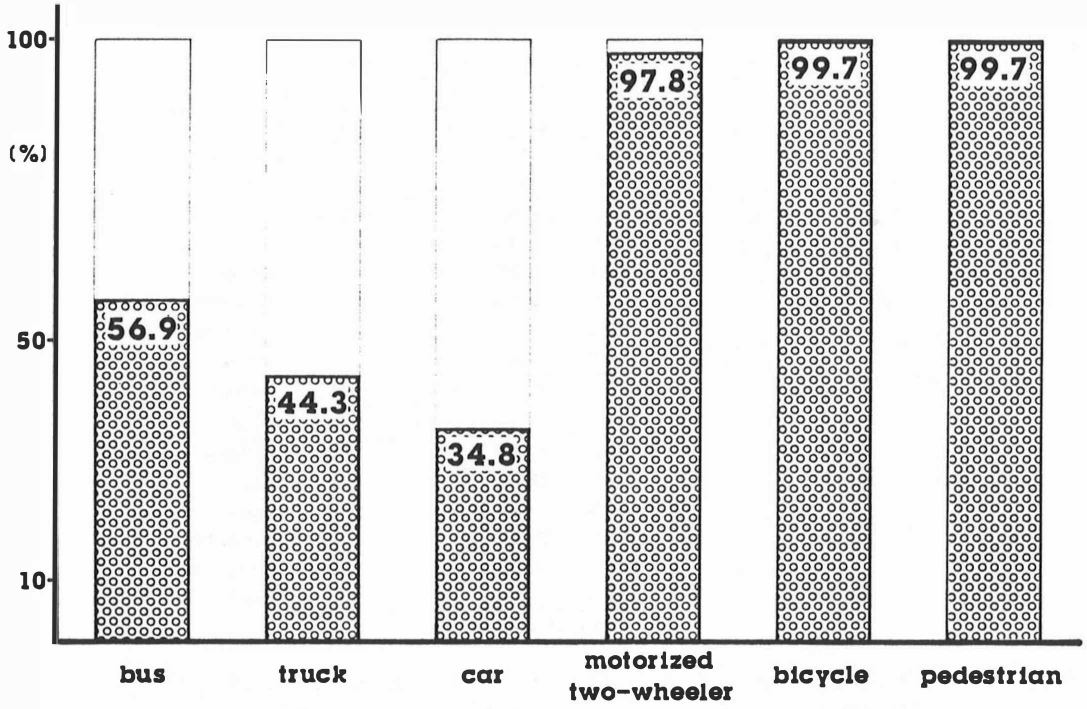



Fig. 1: Proportion of accidents with injured persons in a group of traffic participants (FRG) (source /1/)

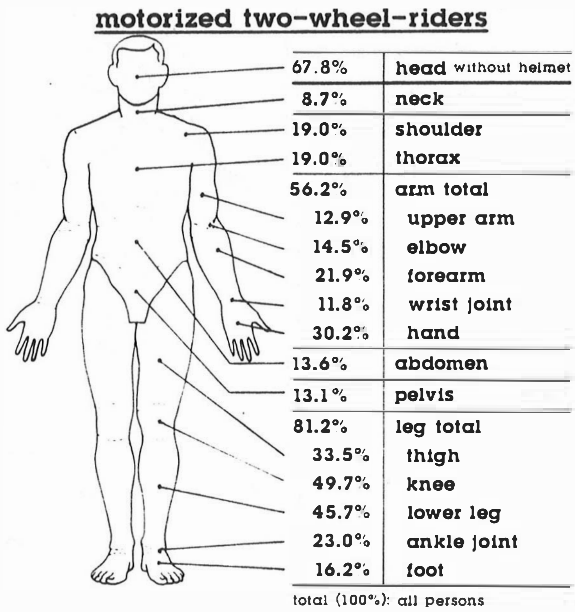
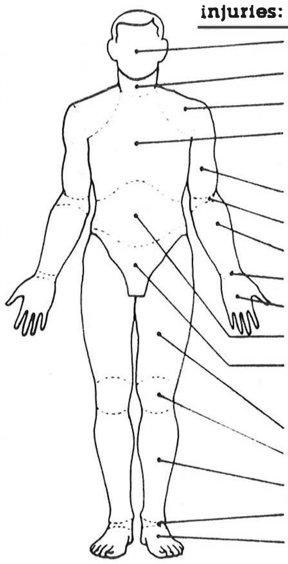



Fig. 2: Frequency of injured body regions of 470 motorized two-wheel-riders (100% all persons)

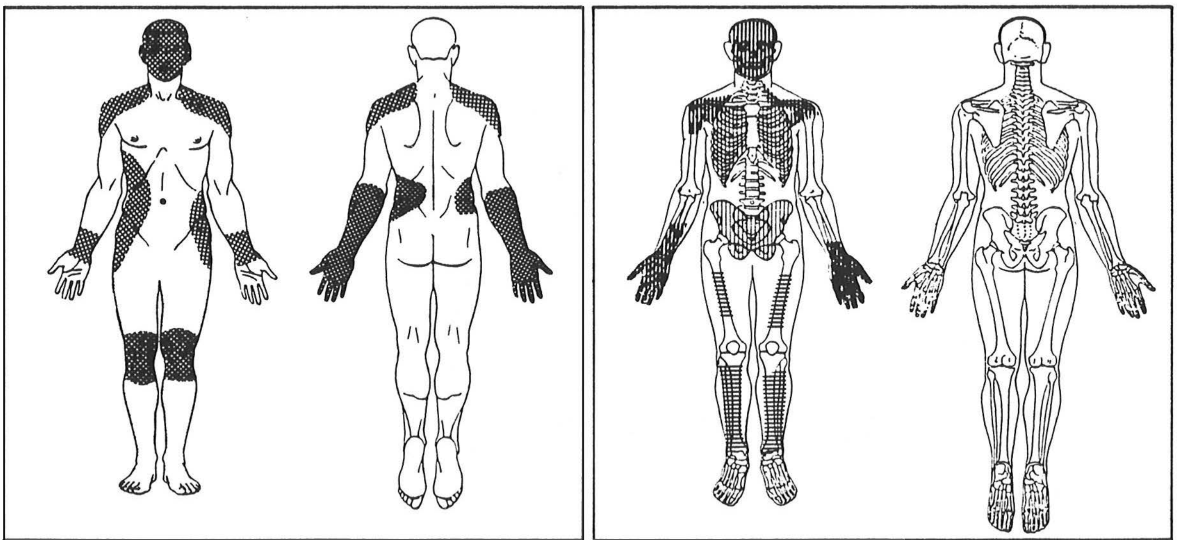
**motorized two-wheel-riders**



| injuries: | soft part | fracture | organ | vessel | |
|---|---|---|---|---|---|
| | 60.8% | 21.0% | 39.9% | - | head without helmet |
| | 5.7% | 3.3% | 0.4% | 0.4% | neck |
| | 12.5% | 9.0% | - | - | shoulder |
| | 12.3% | 8.5% | 6.3% | 1.7% | thorax |
| | 50.6% | 17.1% | - | 0.2% | arm total |
| | 10.1% | 4.2% | - | 0.2% | upper arm |
| | 13.4% | 1.7% | - | - | elbow |
| | 14.5% | 8.8% | - | - | forearm |
| | 9.9% | 1.7% | - | - | wrist joint |
| | 27.3% | 5.2% | - | - | hand |
| | 8.3% | 1.1% | 6.6% | 0.7% | abdomen |
| | 11.0% | 3.3% | 0.6% | 0.2% | pelvis |
| | 75.7% | 32.2% | - | 0.2% | leg total |
| | 25.6% | 12.9% | - | 0.2% | thigh |
| | 48.1% | 3.1% | - | - | knee |
| | 35.7% | 18.6% | - | - | lower leg |
| | 20.3% | 4.2% | - | - | ankle joint |
| | 14.9% | 3.5% | - | - | foot |

total (100%): all persons

Fig. 3: Frequency of kinds of injuries selected to injured body regions of 470 motorized two--wheel riders (100% all persons)



| body-regions with high frequency of soft part injuries | body-regions with high frequency of fractures |
|---|---|

Fig. 4: Regions of high frequency for soft-part injuries and fractures

| body-regions | | localisation of impact: road surface, soft part injury, closed | road surface, soft part injury, open | road surface, fracture/organ | passenger car, soft part injury, closed | passenger car, soft part injury, open | passenger car, fracture/organ | leather clothes |
|---|---|---|---|---|---|---|---|---|
| thorax | | 4,0% | 10,7% | 5,7% | 21,3% | 25,0% | 15,7% | yes |
| | | 10,9% | 14,3% | 6,2% | 15,7% | 15,2% | 13,1% | no |
| abdomen | | 1,0% | 4,3% | 2,3% | 7,7% | 7,7% | 6,0% | yes |
| | | 2,6% | 5,0% | 1,7% | 3,6% | 5,5% | 5,0% | no |
| pelvis | | 5,3% | 6,3% | 4,2% | 13,7% | 16,8% | 8,4% | yes |
| | | 2,8% | 6,6% | 1,6% | 3,3% | 5,8% | 2,7% | no |
| wrist joint | | 4,8% | 13,0% | 4,8% | 4,1% | 15,1% | 4,8% | yes |
| hand | | 14,4% | 29,2% | 2,3% | 7,5% | 14,1% | 3,7% | no |
| arm | | 9,7% | 24,0% | 7,0% | 12,7% | 19,0% | 11,3% | yes |
| | | 14,7% | 32,1% | 3,6% | 9,5% | 18,3% | 6,9% | no |
| ankle joint | | 1,3% | 2,5% | - | 18,8% | 25,0% | 11,3% | yes |
| foot | | 6,4% | 10,5% | 1,2% | 11,3% | 20,4% | 5,4% | no |
| leg | | 29,5% | 35,8% | - | 46,3% | 67,4% | 47,4% | yes |
| | | 22,2% | 55,1% | 3,1% | 40,7% | 77,4% | 31,4% | no |

Fig. 5: Injury frequency for body regions, with and without leather protection, divided by road- - and car impact (100% all body regions with or without leather protection)

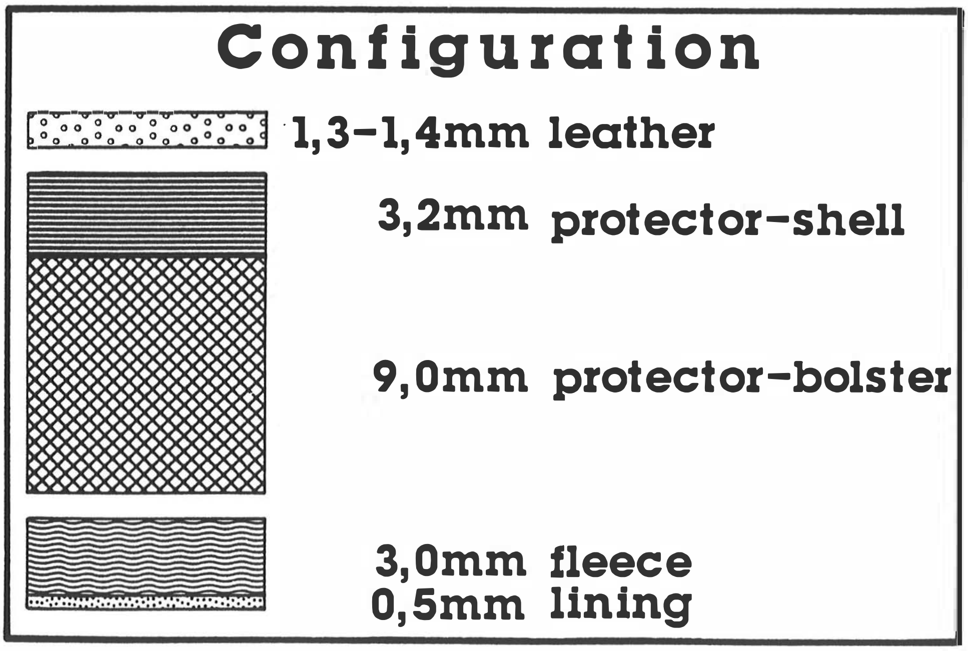



Fig. 6: System design of a hard-shell-protector

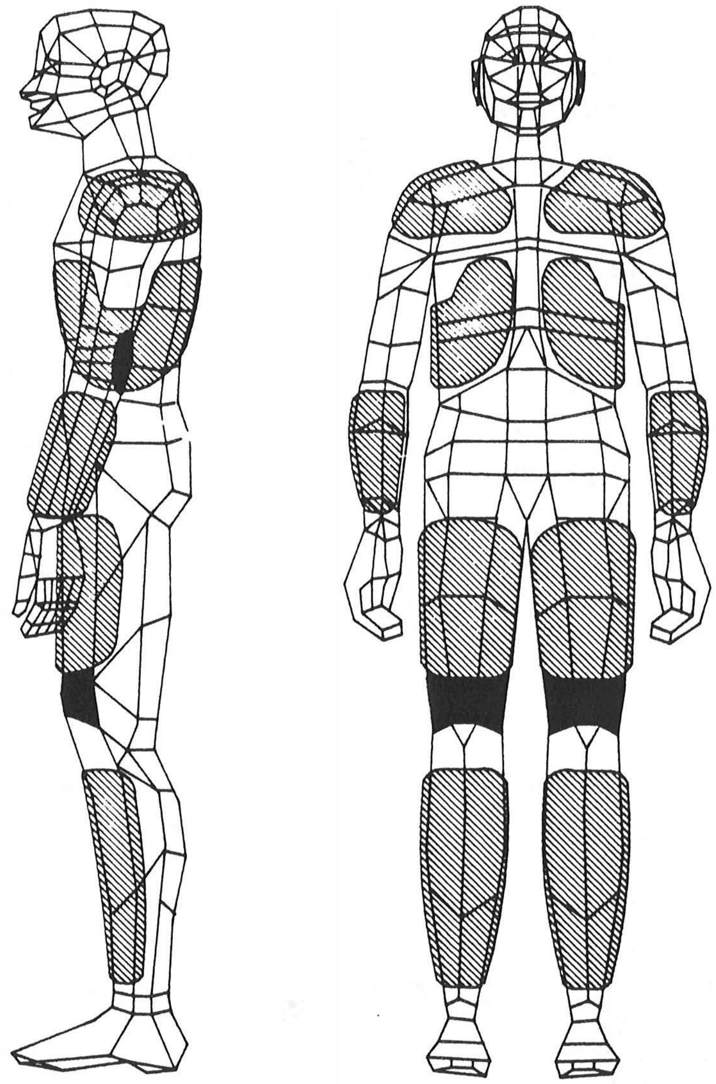


Fig. 7: Protected body regions (black:exclusive bolster/hatchin:protector plus bolster) by recommendations of the accident-field-study

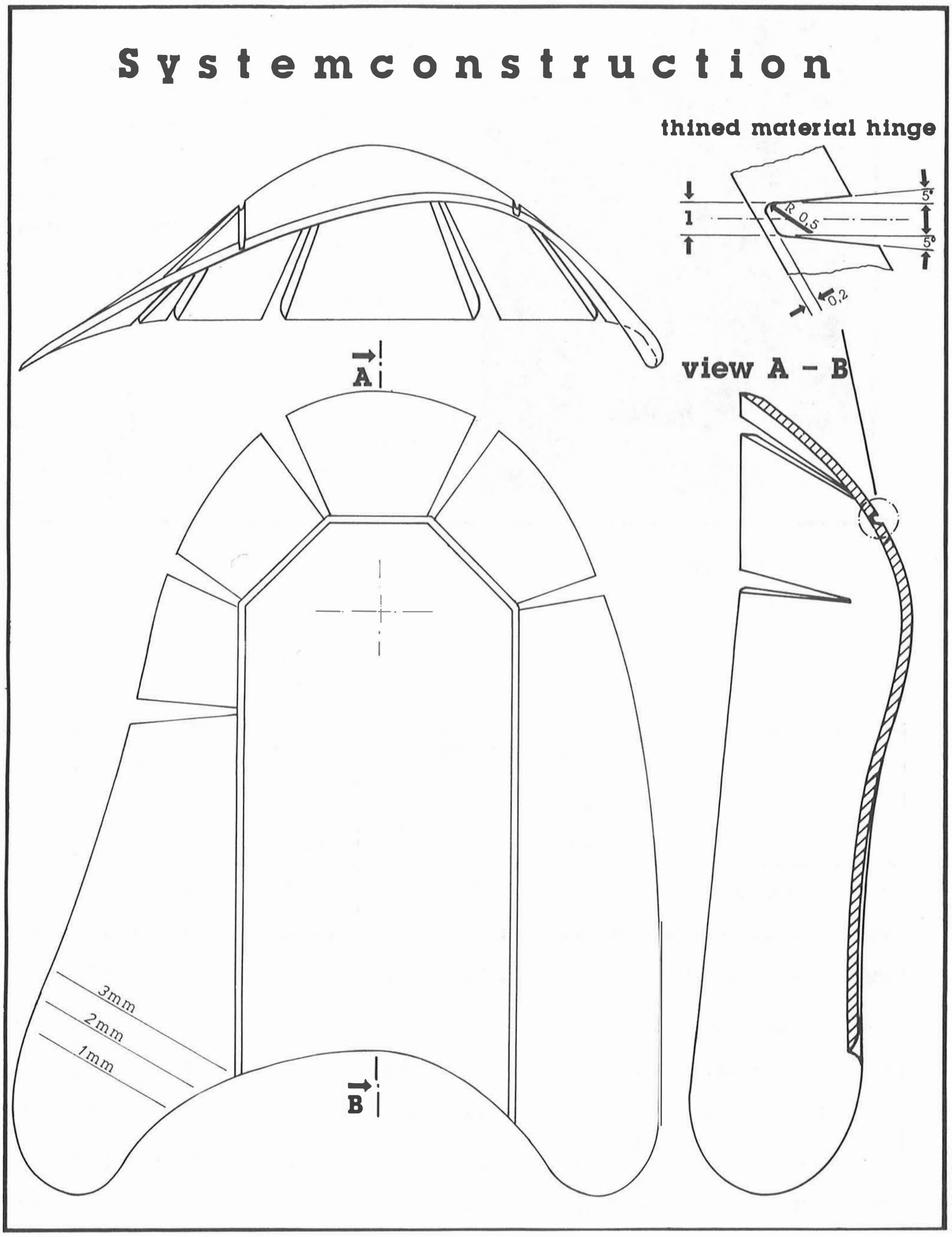



Fig. 8: Construction drawing of a shoulder protector

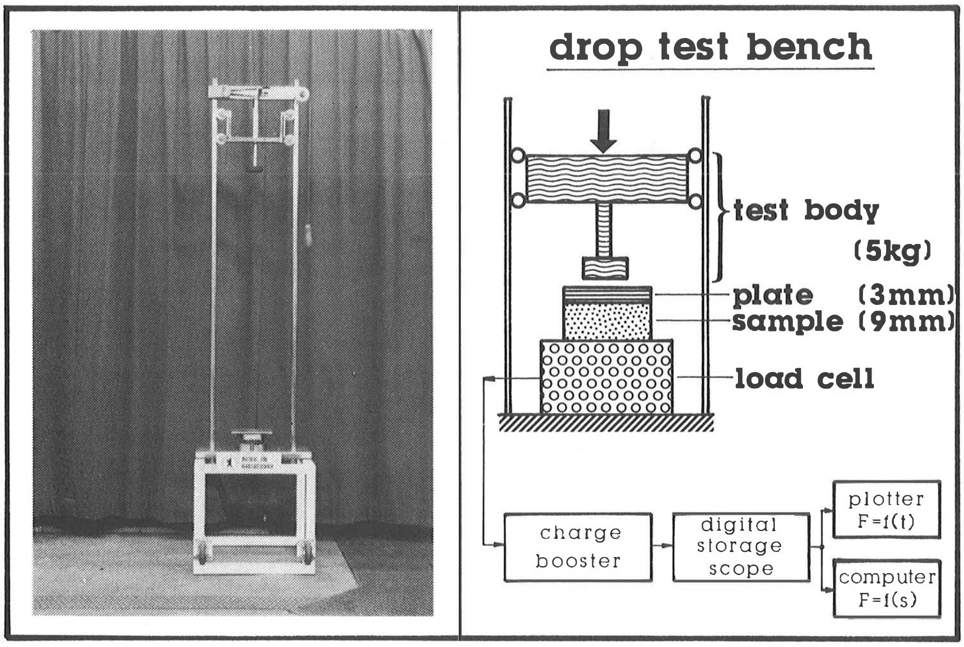



Fig. 9: Measuring apparatus and -system of a drop test bench

| | without plate | | | with plate | | | FR |
|---|---|---|---|---|---|---|---|
| | $F_{max}$ (kN) | Δt (ms) | η | $F_{max}$ (kN) | Δt (ms) | η | (%) |
| **PVC** 150 gramm/litre | 30.00 | 1.67 | 0.10 | 16.70 | 2.00 | 0.28 | 44 |
| **PVC** 250 gramm/litre | 25.77 | 1.75 | 0.13 | 14.47 | 2.30 | 0.35 | 43 |
| **PVC** 300 gramm/litre | 21.57 | 1.85 | 0.14 | 14.73 | 2.10 | 0.38 | 32 |
| **PS** 37 gramm/litre | 24.20 | 1.70 | 0.14 | 12.10 | 2.40 | 0.58 | 50 |
| **PS** 43 gramm/litre | 26.98 | 1.70 | 0.13 | 9.20 | 2.72 | 0.76 | 52 |
| **PS** 58 gramm/litre | 19.33 | 1.83 | 0.28 | 8.94 | 2.83 | 0.78 | 67 |
| **PP-fleece** | 27.75 | 1.55 | 0.11 | 22.25 | 1.93 | 0.16 | 20 |
| **PU-system 1** | 25.75 | 1.68 | 0.12 | 16.30 | 2.10 | 0.25 | 37 |
| **PU-system 2** | 23.50 | 1.70 | 0.14 | 17.80 | 1.90 | 0.24 | 24 |

$F_{max}$ maximal force
Δt duration of $F_{max}$ > 5 kN
η efficiency factor
FR force reduction by plate

Fig. 10: Results of the drop test bench measurements by selected material assays with and without hard-shell-protection

| | maximal force $F_{max}$ (kN) | duration of $F_{max}$ > 5 kN (ms) | efficiency factor $\eta$ | reduction of force transmission in relation to normal leather |
|---|---|---|---|---|
| leather 1.4mm + 3mm fleece | 34.4 | 1.6 | 0.10 | 0 |
| **knee pad:** | | | | |
| leather + 10 mm foam (very soft) | 32.0 | 0.8 | 0.03 | 7 % |
| leather + 5mm foam (soft) | 33.8 | 0.3 | 0.05 | 3 % |
| leather + 5mm foam + Kevlar | 33.9 | 0.3 | 0.05 | 3 % |
| leather + 10mm Halvarsson foam | 21.8 | 1.7 | 0.16 | 37 % |
| air-cushion-film | >35.0 | 0.6 | <0.05 | - |
| **protector-composite-system** | | | | |
| PU-foam 2 | 17.1 | 1.9 | 0.15 | 51 % |
| Halvarsson foam | 10.6 | 1.8 | 0.50 | 69 % |

Fig. 11: Special results of drop test bench measurements in comparision of material assays of commonly used leather clothes.

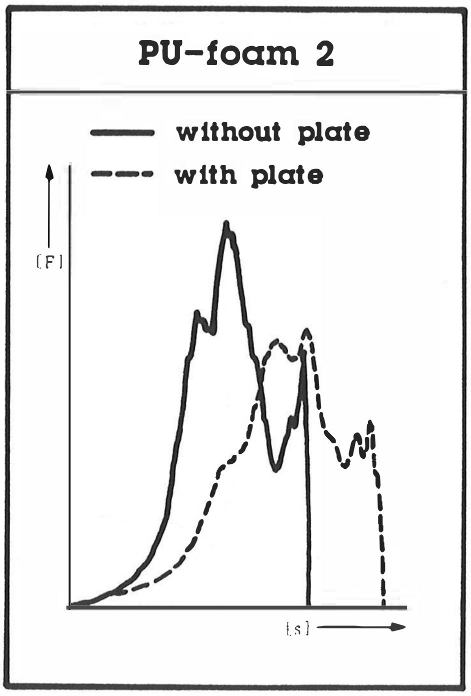



Fig. 12a: Force (F)-reduction of Polyurethan(PU)-foam No.2 by hard-shell-protection

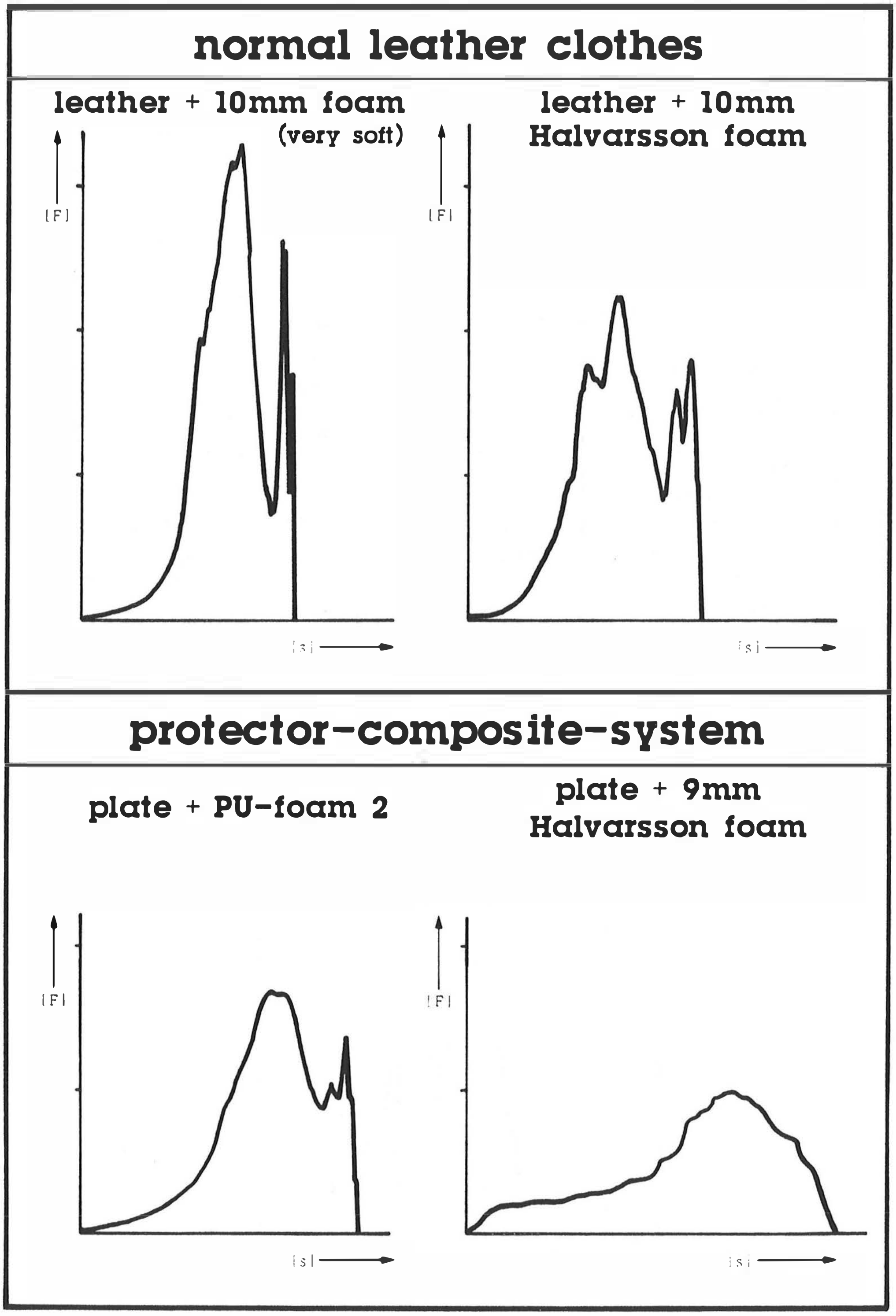



Fig. 12b: Force (F)-reduction of protection areas in "normal" leather clothes in comparision to a compound system of hard shell and shock absorbing foam