IMPACT DYNAMIC, HEAD IMPACT SEVERITY AND HELMET'S ENERGY ABSORPTION IN MOTORCYCLE/PASSENGER CAR ACCIDENT TESTS

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ABSTRACT

Starting points for this study are accident statistics and indepth accident investigation. Motorcycle/car accidents are complex and difficult to analyse, thus more tests are necessary to get a deeper understanding of this type of impact.

Statistics tell us what the most hazardous collision types are between motorcycles and passenger cars. Accident investigations and medical accident research show that many helmets used by motorcycle riders are not very efficent in head protection.

Intention of this investigation is to describe and analyse two major type of accidents, intersection and head-on collision. During impact tests with instrumented dummies, different drivers position, fuel tank shapes and handle bar types were investigated. In order to evaluate the energy absorption characteristics of helmets, high-speed films and acceleration data are used. HIC values are computed, trajectories of motorcycle riders are drawn, impact time-histories are compared and head impact locations addressed, in order to draw conclusions.

Furthermore the protection capacity of helmets was studied in more detail in pendulum impacts with dummy heads. Results will give hints to improve the damping characteristic of helmets.

CONCLUSIONS

o impact dynamic

seating position:
- "tourer" type - low probability of head/roof rail contact
- "racer" type - high probability

o head impact severity

3 impact areas addressed:
low severity - 1 hood; low severity - 2 window (glass); high severity, depending on impact location, speed and direction - 3 roof rail

o helmet's energy absorption
- current EA helmet material is too stiff - high HIC values at relatively low speed
- improvement by softer EA material with high thickness effiency (usable thickness at tolerable g-level)
- current facial impact protection - poor, due to absence of EA zones and direct facial loading (visor)

INTRODUCTION

Since 1978 the number of persons injured in road accidents is decreasing even though the number of road users is increasing. Nevertheless, the number of two-wheelers involved in accidents is increasing since 1975.

Therefore for accidental and biomechanical research, it is necessary to get more knowledge about two-wheeler accidents. In particular it seems to be important to improve impact protection for motorcycle riders, that means head impact protection in the first place, in particular the helmet.

This study provides experimental data of the two major motorcycle-car accident types, in connection with corresponding laboratory tests with helmets.

TEST PROGRAMM AND TEST SET-UP

Accident simulation

From the wide variety of real world accidents two dominant types were selected, intersection and frontal impact. Opposed to the frontal impact intersection accidents are characterized by motorcycle running into the side of a car.

Figure 1 shows combinations of vehicles, vehicle data, impact speed and impact location.

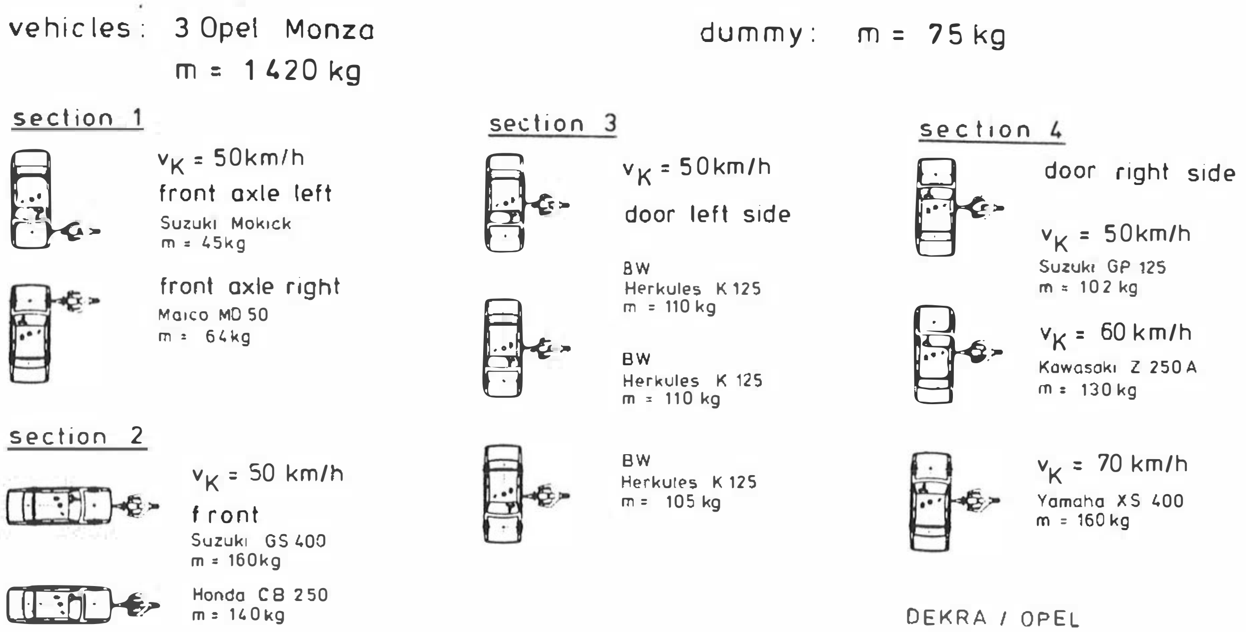

Figure 1: accident simulation matrix

All tests were conducted at the Adam Opel safety test center at Rüsselsheim. Figure 2 illustrates the motorcycle carrier developed by DEKRA. This device keeps dummy and motorcycle in position while it is accelerated to its test speed. Just before impact the carrier is stopped by a friction brake, while dummy and motorcycle continue into the test vehicle, figure 3.

Figure 2: Test set-up/motorcycle carrier

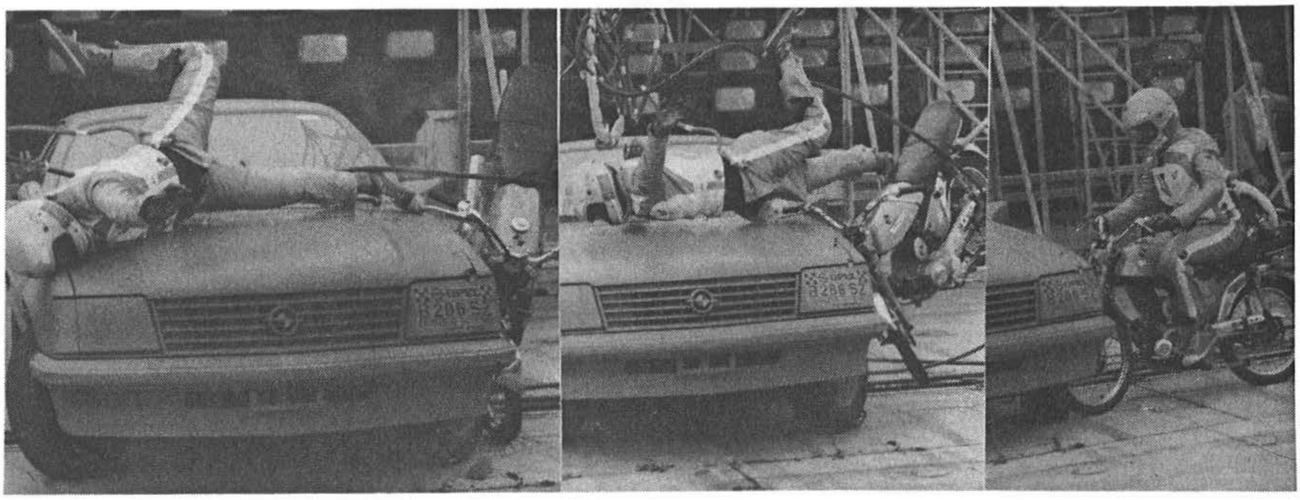

Figure 3: Example of impact kinematic

Test device is a Hydrid II pedestrian dummy (simular ATD Part 572), equipped with 3-axial accelerometers in head, chest and pelvis. The dummy is dressed with leather suit and helmet. Helmets are changed from test to test in order to assure constant test conditions.

High-speed filming provides material for film analysis. 3 cameras, 2 from the side and 1 from the top, were used to document the impact situation. Tests are conducted in 4 sections (figure 1)

Section 1 2 tests: Motorcycle impacts vehicle perpendicularly at front axle

Section 2 2 tests: Motorcycle impacts frontally at center line

Section 3 (Reproduceability-test) 3 tests: Motorcycle impacts perpendicularly at drivers door

Section 4 (impact speed variation) 3 tests: Motorcycle impacts perpendicularly at drivers door with 50, 60 and 70 km/h respectively

Laboratory tests

For investigating driver's head impact load under controlled laboratory conditions a special test set-up was designed, figure 4. A Hybrid II dummy head including neck was fixed to the top of a pendulum (ECE-design). Due to pendulum design maximum impact speed was 32 km/h, which is lower than observed in full scale testing. A rigid impact surface, covered with 10 mm ply-wood was selected. For base data one impact was conducted without helmet.

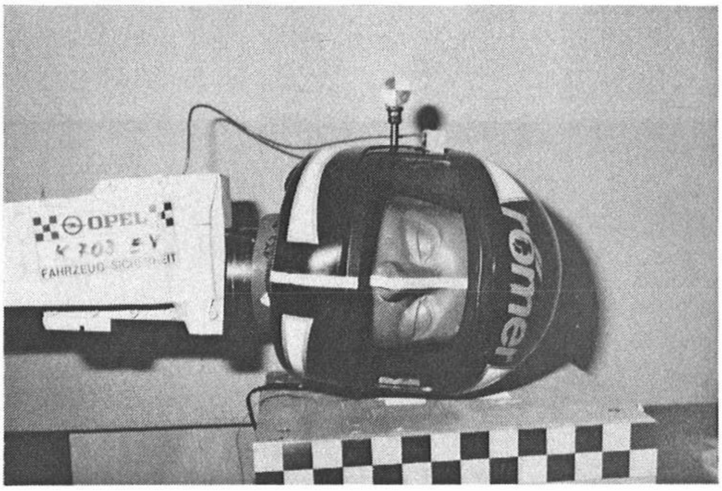

Figure 4: Test set-up pendulum with head for impact tests;
m = 9,2 kg; v = 32 km/h; type of helmet Römer RS

Two different types of pendulum helmet tests were prepared. At first facial impacts against rigid surface and a roof rail cut-out are simulated.

At second for energy evaluation purposes a series of helmets were impacted laterally on a rigid surface. Beside standard damping alternative materials were tested, figure 5.

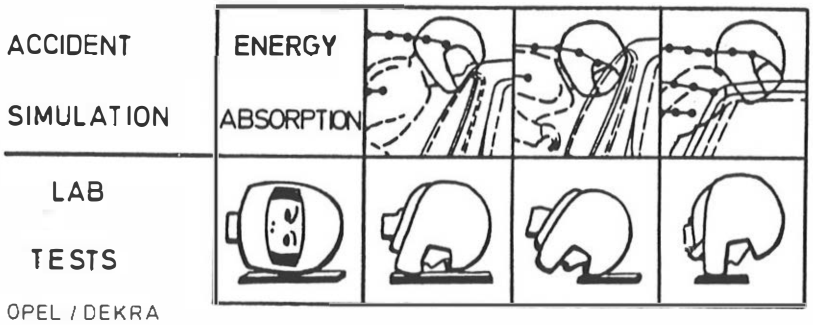

Figure 5: Lab-tests derived from full scale tests

RESULTS OF ACCIDENT SIMULATION TESTS

Event/time-history of motor cycle/vehicle collision

Even though there are different types of impact direction, certain simularities of events are found, which might just differ partly in time, see figure 6.

In the first phase after initial contact of car and compression of the cycle front tire the deformation of the front fork starts between 4 and 14 ms. The next sequence begins with wheel/engine contact, provided that impact speed is in the test range or higher and front wheel is trapped between vehicle and cycle engine. Begin of contact is between 18 and 30 ms, depending on wheel/engine clearance, fork bending stiffness, local vehicle structure and impact speed.

Between 20 and 46 ms fork and headlamp start loading the vehicle with increasing contact area.

It was noticed that the rear wheel was lifted slightly up to about 30 ms before total stop, this is at about 36 to 84 ms after start of collision. Between 54 and 120 ms the cycle comes to a complete stop and rebound begins. Rebound movement might be horizontally or with an upward rotation around the front wheel. The last two events are substantially influenced by dummy kinematic.

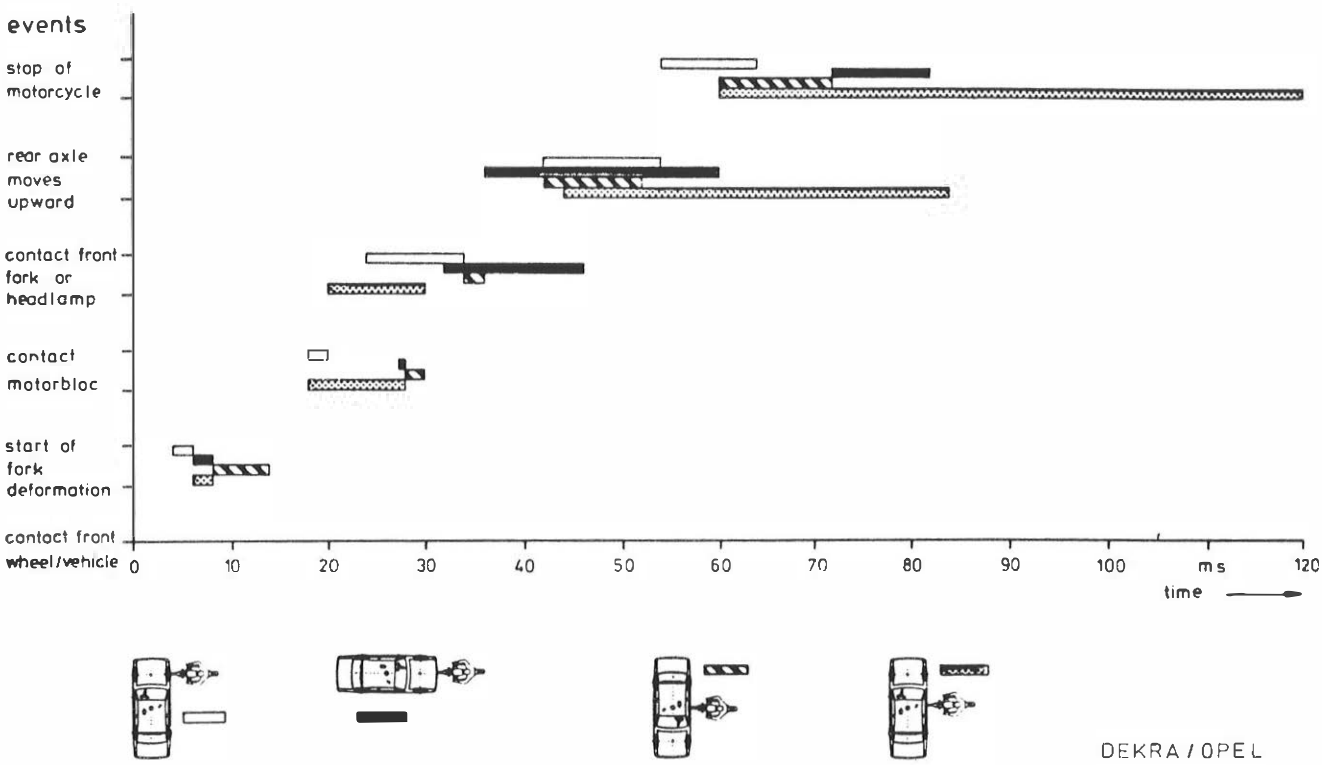

Figure 6: Time/event history of motorcycle impact

Dummy movement relative to motorcycle starts at 20 to 35 ms, when the front wheel contacts the engine bloc. When fork and headlamp hit the vehicle, the relative dummy speed is increasing due to higher cycle deceleration. Consequently the dummy feet are slipping from the foot rests and the dummy hits the fuel tank between 40 and 65 ms.

Further event sequences cannot be clearly identified. During the following time dummy hands, legs, upper body and head are hitting the vehicle at different times and locations.

There is a close time relationship between reported lift of rear wheel before stop of cycle and dummy/fuel tank interaction. Beside that, cycle deceleration occurs without dummy input. Later on during rebound of motorcycle, dummy legs are interacting with handle bars, causing the cycle to rotate. The following dummy kinematics is influenced by this interaction.

Seating position, handle bar and fuel tank - how it relates to dummy kinematic

There is a close relationship between seating position and type of handle bar, figure 7. A "tourer" type handle bar requires a more upright driver position. Henceforth upper body parts are basically in a high starting position before impact. Upper body trajectories show a minor upward direction during impact, which might be increased in real life, because the driver might support himself actively by holding handle bar firmly.

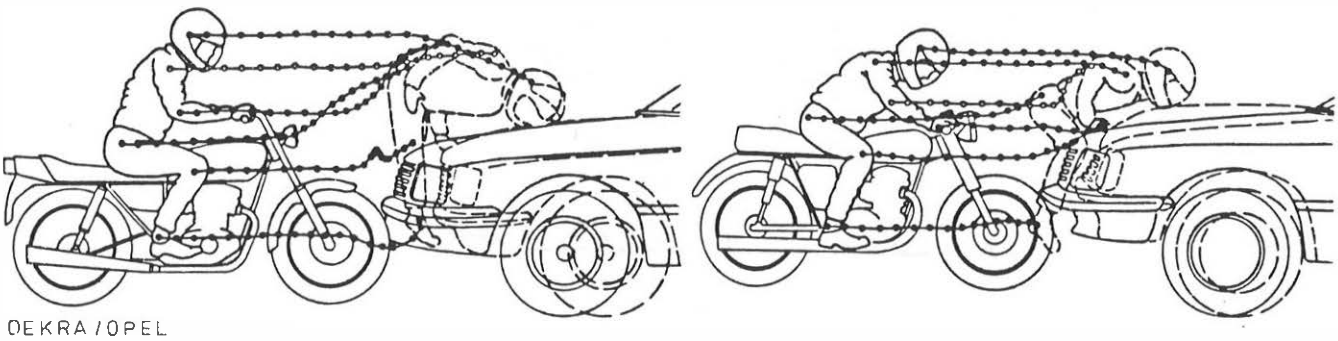

Figure 7: Influence of seating position - trajectories

In frontal or side impacts into the front end of a vehicle, driver's hands are above the vehicle without the risk of direct loading. Upright seating position leads also to a lower probability of head contact with side or roof rail of a vehicle. In that case severity is much lower especially when the head impacts the softer top of the roof instead of the rail. As a possible drawback chest impact might be more severe, but load is distributed on a larger area.

A "tourer" handle bar is negative during rebound, because relative speed between driver upper legs and rebounding handle bar is high and might cause bone fractures. Interaction forces are high, since test results show that they cause cycle rotation of significant magnitude.

At the same time these forces increase drivers upper body rotation causing higher head impact speed.

A low "racer" type seating position, caused from low, small handle bars lead to low body loading during rebound. But driver/vehicle impact is more severe than in "tourer" position, because all above mentioned advantages regarding head impact are not given.

As mentioned before dummy interacts with the fuel tank. Rear wheel lifting at the same time as a cycle's response. In addition the dummy is lifted slightly while moving forward. However a general conclusion cannot be drawn from film analysis and deceleration data of the pelvis.

Evaluation of head impact

Three different types of facial head/vehicle impact have been observed (one example is figure 8):

- chin/jaw
- visor
- forehead

and combinations. Head impact speed is always almost identical with motorcycle impact speed.

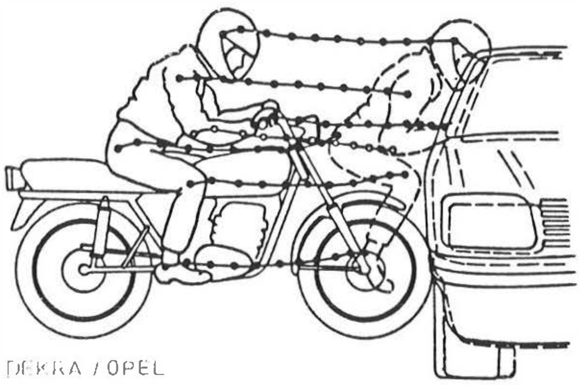

Figure 8: Example of head impact location and direction
Regarding the vehicle one can distinguish between 3 different areas:

1 - hood, top of the roof
2 - roof rail (structural member)
3 - glass windows, figure 9

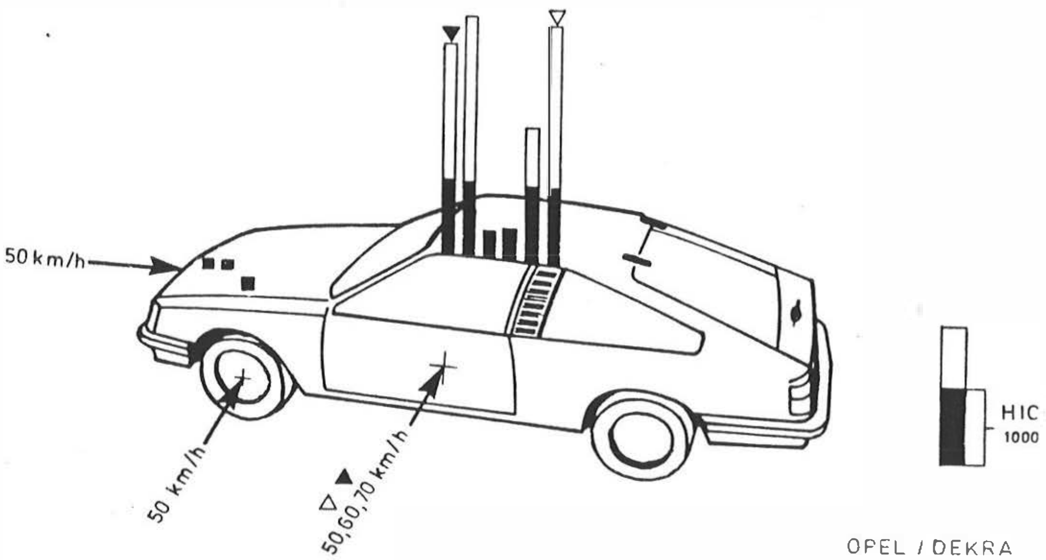

Figure 9: Head impact - location and HIC values

Hood and roof 1 is a noncritical impact zone, because of a soft stiffness characteristic. HIC values are far below the critical value of 1000.

However critically high HIC values are generated at the roof rail 2. Low HIC numbers, shown in the roof area, indicate head impact on glass of side or front window, which seems to be noncritical.

These tests show that high impact speed is not directly related to high HIC values.

Generally impact severity is characterized by impact location and direction, impact speed and the way the helmet is impacted. These various parameters are difficult to control in a complex test environment like described so far. In order to look into head impact protection more in detail additional laboratory tests have been conducted.

LABORATORY TEST RESULTS ENERGY ABSORPTION

Side impact

Side impact tests have been conducted in order to get an understanding of helmet energy absorption (EA) potential. Tests on a rigid surface show the differences of EA material used in helmets.

From tests without helmet on a rigid surface we know that HIC values of more than 5000 can be produced by a dummy head. The selected standard helmet showed a substantial reduction of HIC. In figure 10 results of 3 identical tests are summarized as a standard helmet data base (XS size). HIC values differ only little, from 2652 to 2696 with a mean value of 2639. The same applies to deceleration values. Total dynamic deformation is in the range of 28 mm. The thickness of styrofoam shell is 30 mm in size XS, but only 25 mm in XL. Under same test conditions head severity increases by 54 % (HIC), maximum deceleration by 71 %, while displacement is only 10 % more.

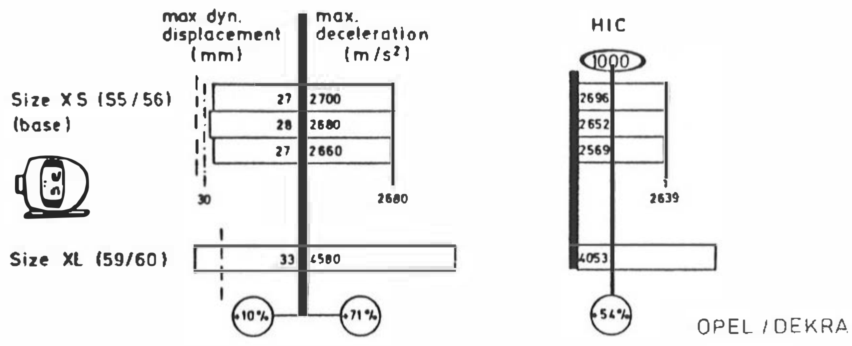

Figure 10: Energy absorption - base helmet ; side impact on rigid surface; impact speed 32 km/h; mass 9,2 kg

Rigid surface impact simulates ground , tree or guard rail contact. Tests of this kind ar helpful in evaluating EA material, because deformation is limited to the helmet.

When a head hits a car surface instead there is additional displacement by sheetmetal deformation. Lab tests with sections of a roof rail (figure 11) show HIC reduction of 33 % from the base. Maximum deceleration is 25 % less and maximum dynamic displacement 3 % higher. This displacement increase of 3 % is very minor compared to 33 % HIC reduction. But it is a hint that helmet stiffness is higher than roof rail stiffness. Thus in this test there is less helmet styrofoam deformation, but a substantial roof rail deformation. That leads to the question, whether helmets are too stiff and how to improve protection potential.

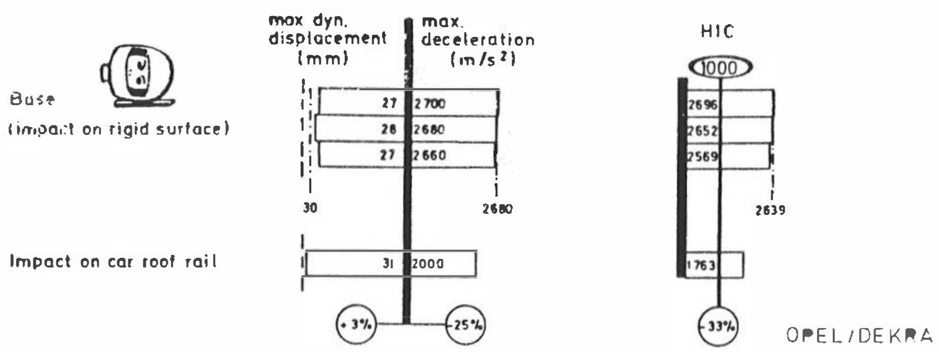

Figure 11: Energy absorption; impact on car roof rail

Figure 12 gives results of a test series with two alternative EA materials under identical test conditions. Arrows show the trend of improvement. A Hexcel* layer of 35 mm can reduce HIC value almost to the biomechanical limit of 1000. Even a different foam (PU) of only 25 mm thickness produces HIC values of 20 % less than base. To increase helmet protection, EA material of the above mentioned characteristic has to be used. Preferably a type of material like Hexcel which allows for a given thickness an almost 90 % usage for displacement at tolerable head deceleration. Styrofoam (Polystyrol), PU foam and foams in general do have a low thickness efficiency. That means in order to obtain a head deceleration below the biomechanical limit (e. g. 800 m/s^2 - 3 ms), only half of the thickness can be used because of material compression, opposed to Hexcel where the crushed material folds into the hexagonal tubes.

A "soft" EA material would provide protection for impact speed up to about 30 km/h. A second layer on top could care for higher impact energy, in order to cover at least 90 - 95 % of all field-relevant severities. Thickness of EA zone must be sized by using field data of head impact speed.

From accident statistics we know that major impact directions are from side, front and rear. Side and rear can be designed in the same manner, but the facial protection seams to create some problems.

* Hexagonal cell structure (honeycomb) made from aluminium foil.

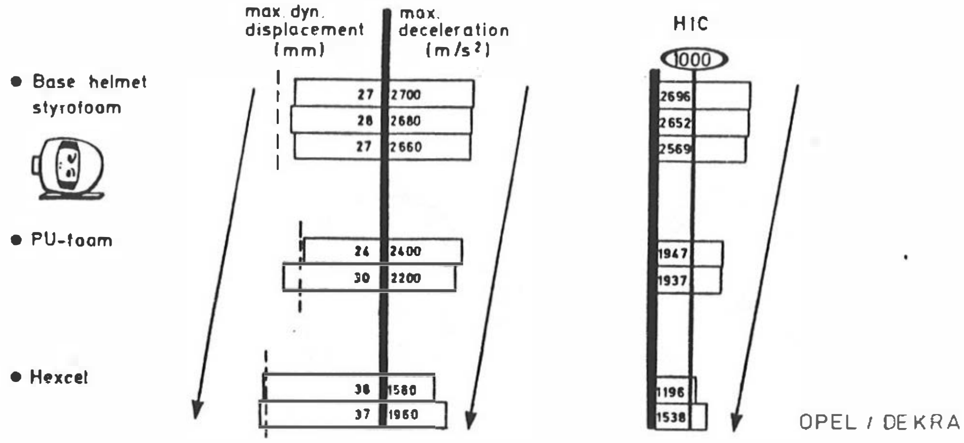

Figure 12: Energy absorption comparison

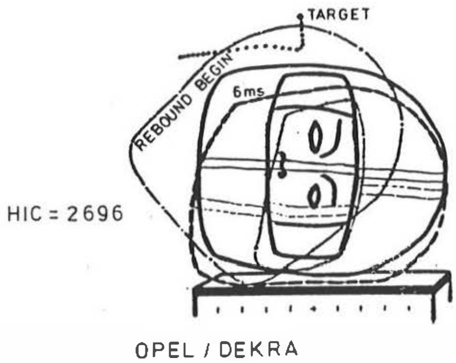

Figure 13: Side impact - impact phases and helmet deformation

Frontal impact

From full scale accident simulation tests three types of facial impacts are derived, figure 5.

They are characterized by chin/jaw, forehead and a combination of both, a full face impact. In addition there is a very critical one which is visor versus corner of roof rail. Test results of the first three are shown in Figure 14. It indicates three stage: first contact, face contact and maximum displacement. Two targets - at dummy's head and at helmet - are traced and their trajectories drawn. Chin/jaw and forehead impacts are characterized by a tremendous amount of head rotation, which gives lower accelerometer readings and conseqently HIC values, but probably high loads on cervical vertebrae. Rotation and low energy absorption of helmet impact areas lead to early face contact. Due to dummy head design nose and face skin is working as an elastic deformation zone in addition. Hence in reality severe facial injuries are possible, which cannot be concluded from HIC values.

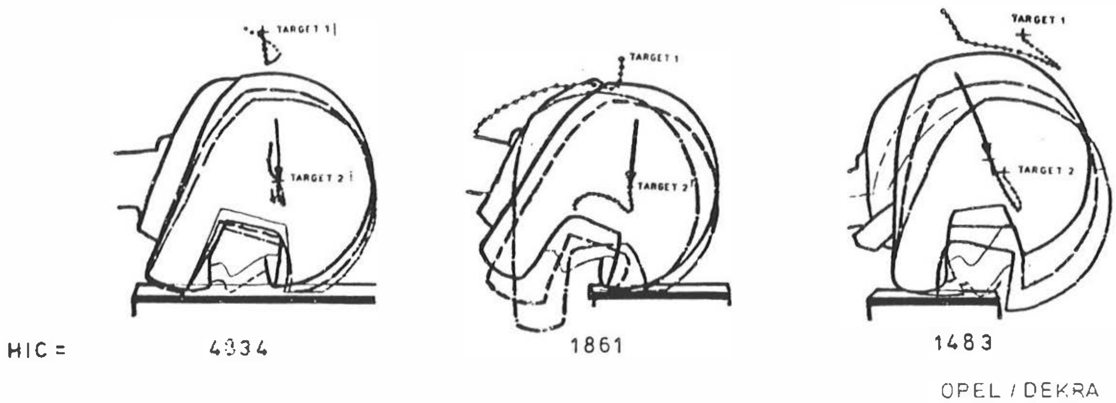

Figure 14: Facial impact - impact phases and helmet rotation

Almost the same applies to the full face impact, even though now the HIC value (4834) is very high due to only little rotation and energy absorption on a short displacement. Essentially the dummy face is absorbing energy rather than the helmet. This is even more the case when the head is impacting a car roof rail. Current visors have no protective function in the sense of energy absorption. This is the most severe case and in fact like impacting without helmet. Data are not reported here, because they do not allow any conclusions in relation to human beings.

Facial protection is the weakest point in current helmet design. Improvement is necessary because facial impacts occur very often.

FINAL REMARKS

This study investigated two major accident types of motorcycles. Insights are given to impact kinematics and head loadings. Helmets show that ECE regulation 22 produces extremely stiff EA zones, resulting in high head load. Alternative material tests indicate that there are ways to improve protection potential towards higher efficiency.

Further development work is required to get at least a minimum facial impact protection.