COLLISION DYNAMICS IN EXPERIMENTAL SIMULATIONS OF 90° MOTORCYCLE COLLISIONS AGAINST THE SIDE OF MOVING PASSENGER CARS

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ABSTRACT

Accident simulations involving the 90° collision of motorcycles against the side of moving passenger cars have been conducted and evaluated in cooperation between DEKRA and Winterthur-Versicherungen. In contrast to motorcycle collisions against stationary passenger cars, the tests involving collisions against moving passenger cars revealed a multitude of collision sequences corresponding to what really happens in an accident. In order to show this comprehensively, the overhead views of collision configurations, final positions and centre-of-mass paths have been selected for each individual case; to further illustrate the spatial complexity, side views have been provided of some collisions in the form of sequences of still pictures. Motion paths, velocities and impact events recorded by manual film evaluations, in connection with the vehicle damage thereby incurred, provide important information on collision dynamics.

INTRODUCTION

Experimental accident simulations are of great importance for the gaining of deeper knowledge of the dynamics of real collisions. Within the framework of continuously conducted series of tests, there were, first of all, collisions of moving passenger cars against stationary passenger cars /1/. Following the further development of the test equipment, it was possible also to conduct collisions involving two moving passenger cars. Accident simulations with passenger cars and motorcycles were performed analogously.

The following describes results from fourteen tests involving the 90° collision of the motorcycle against the side of moving passenger cars in the area of the front axle, door and rear axle.

Initial results concerning the sequence of collisions as far as the impact of the helmeted head of the motorcycle occupant, under particular consideration of the effect of protective helmets, as well as the safety of motorcycle designs have already been published /2,3/. The further evaluation covered the entire collision sequence as far as the reaching of the final positions of motorcycles and motorcycle occupants as well as the standstill positions of the passenger cars.

TEST SETUP AND PROCEDURE

By means of a towing vehicle, passenger car and motorcycle together with occupants represented by the dummies were accelerated by cables guided via loose and fixed pulleys to just before the place of collision at a constant velocity ratio. The motion of the motorcycle was stabilized by a sled. Just before the collision, there was an abrupt retardation of the motorcycle-guiding sled with release of the cable connection at a predetermined shearing section, whereafter the vehicles moved freely up to collision.

The passenger car was braked before or after the collision by a compressed-air brake triggered by release cord. The passenger cars that were unbraked at collision were travelling at approximately half the collision velocity of the motorcycle. In the case of collisions with braked passenger cars, it was also possible to achieve collision-velocity ratios between motorcycle and passenger car in the region of 4:1 by means of suitable cable guides.

The velocity of the motorcycle shortly before the collision was measured by means of a photo-electric light barrier. As a result of the constant velocity ratio that was influenced only slightly as a result of different elongations of the towing cables, the collision velocity of the passenger car was thus also known. The sequence of motions was documented by several high-speed and motor-driven still-picture cameras. High-speed film shots from horizontal and vertical directions of view onto the collision were used for the subsequent determination of positions, distances and velocities by means of fixed reference marks on the road surface and on the vehicles. Accident marks on the road surface, on the vehicles and on the dummy or its overall and protective helmet were measured after each test and were photographically documented.

For the tests with pre-collision braking of the passenger cars, the dummy representing the motorcycle occupant was a special design corresponding to a 50% male in terms of dimensions and weight distribution. In the tests involving collisions against unbraked passenger cars, use was made of a 50% hybrid II pedestrian dummy (ATD Part II) made available by the motor-vehicle manufacturer Adam Opel AG.

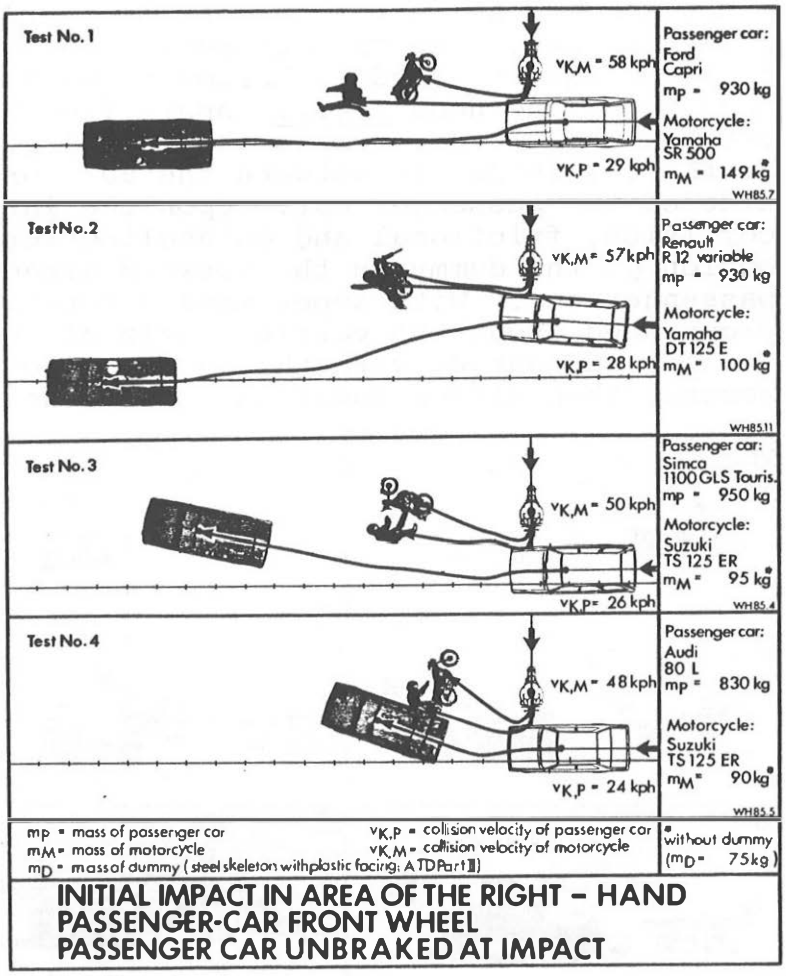
TEST RESULTS

Motion sequences

Initial impact in area of front axle of passenger-car

In four tests the motorcycle impacted against the right-hand front wheel of an unbraked passenger car at approximately twice the velocity of the latter, Fig. 1.

Fig. 1:
Overhead view of impact configurations, final positions and centre-of-mass paths in tests nos. 1 to 4



The ratio of the collision momentum of motorcycle and dummy in relation to the collision momentum of the passenger car was 1:2.1 (test no. 1) to 1:2.9 (test no. 3).

The directions of motion of the passenger cars after collision up to subsequent braking and reaching of the final positions are non-uniform. In the case of an eccentric impact on the front wheel of the passenger car, and in all cases during subsequent collision-induced rolling, different steering motions are caused by impact forces and by forces in the wheel suspension gear.

The motions of dummy and motorcycle exhibit typical aspects in common. The beginning is characterized by the deflection of the front wheel of the motorcycle in the forward direction of travel of the passenger car; the left-hand side of the front wheel of the motorcycle is then in contact with the fender/front-door area of the passenger car. Frictional, impact and entangling forces cause the other parts of the motorcycle likewise to follow the motion to the right. The inertia motion of the dummy is virtually undisturbed until it slides over the tank of the already decelerated motorcycle. Approximately 0.1 seconds after the start of collision, the dummy impacts against the front-door area of the still-moving passenger car. The thereby occurring impact of the helmet against rigid roof edges harbours the danger of hypercritical loading of the head /2,3/. Apart from head, neck and chest, another endangered area is the left leg, which, in the course of the collision, is between the 90° turned motorcycle and the side of the passenger car. Upon the intensive contact of collision, frictional and entangling forces redirect the motion of the dummy in the forward direction of travel of the passenger car. With superimposed rotations, particularly pronounced about the vertical axis of the body, the dummy remains in contact with the passenger car for fractions of a second, then slides downward and reaches the final position.

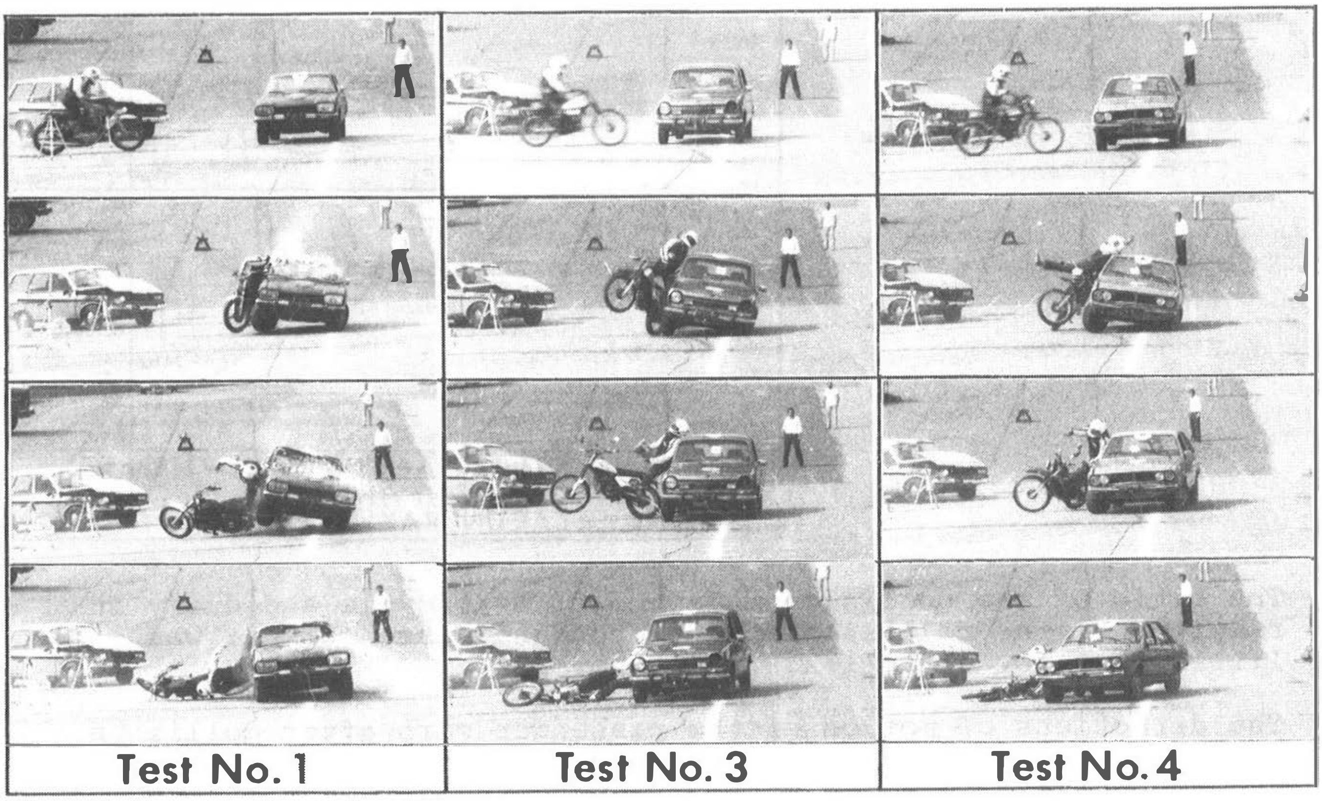


Fig. 2: Side view of collisions with initial impact in area of right-hand front wheel of unbraked passenger cars (frame rate 3.6 1/s)

For purposes of further illustration, Fig. 2 shows stills of three collisions with horizontal viewing direction.
The collision dynamics are characterized by a succession of jolts, Fig. 3. The considerable change of motion of the passenger car takes place after the impact of the dummy and of the side of the motorcycle. Both impact events can be assigned the effect of the maximum impact forces.

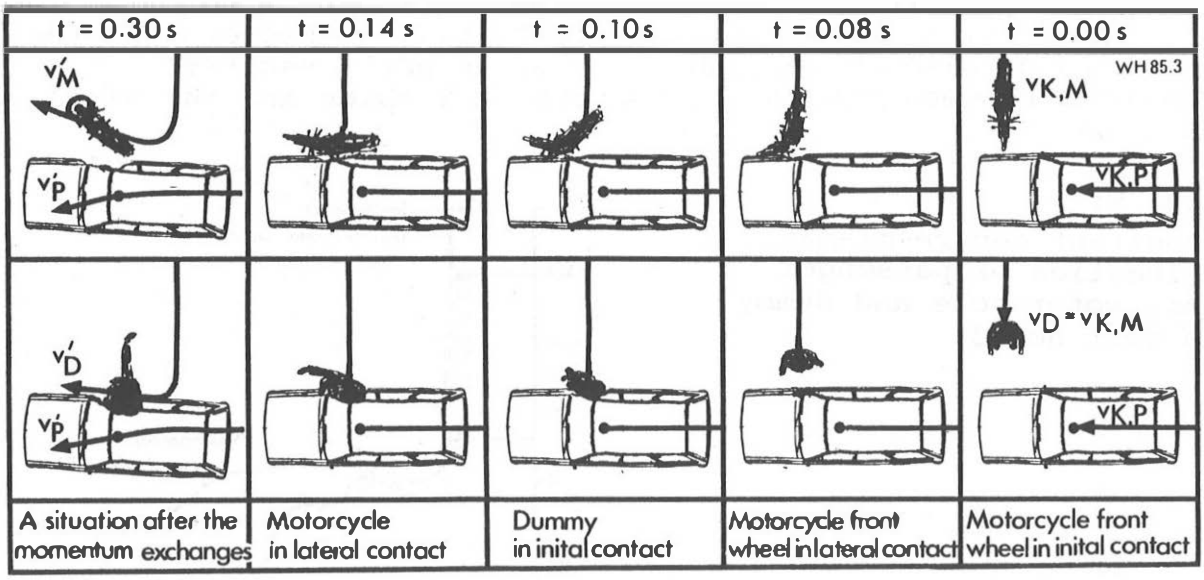
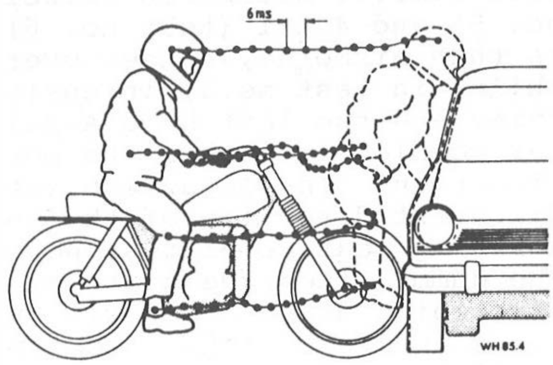


Fig. 3: Synchronized overhead views of sequence of motions of motorcycle and passenger car (top) as well as of dummy and passenger car (bottom) during collision in test no. 3

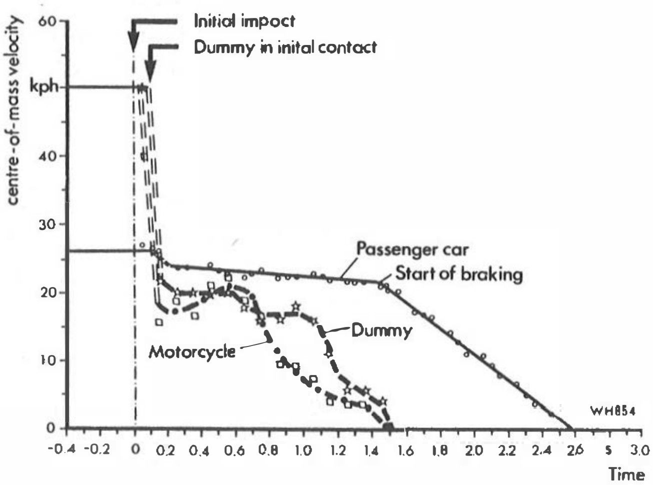
The motion of the dummy in relation to the motorcycle begins approximately simultaneously with the contacting of the deflected front wheel of the motorcycle. Until it impacts against the passenger car, the head virtually retains its original velocity, whereas the centre of mass of the body is decelerated earlier as it slides over the motorcycle tank and as a result of impacts of the extremities, Fig. 4.

Fig. 4:
Side view of dummy trajectories in collision phase up to impact of head in test no. 3



The precise delimitation of decisive momentum-exchange phases, particularly the determination of corresponding momentum directions, is not possible by means of manual film evaluations. For a quantitative description, the magnitudes of the centre-of-mass velocities were established, Fig. 5. After termination of the collision impacts, a velocity loss of the passenger car in the order of magnitude of between 3 and 7 kph is detectable. The dummy reaches approx. 70 to 100% of the velocity of the passenger car after the collision. The motorcycle is, in tendency, equally fast as or slower than the dummy, which also corresponds to the, in part, shorter distances between the position of the collision and the final position.

Fig. 5:
Resultant centre-of-mass velocities of passenger car, motorcycle and dummy in test no. 3



In three tests, the motorcycle impacted against the left-hand front wheel of the already braked passenger car, Fig. 6. The corresponding side views are shown in Fig. 7.

Despite virtually identical collision velocities as in test no. 4, the dummy in test no. 7 does not impact in the area of the front door but falls onto the engine hood of the passenger car, while the motorcycle performs basically the same motion as in tests 1 to 4.

With similar collision velocities in the ratio 3.8:1 (test no. 5) and 4.1:1 (test no. 6), in test no. 6 the dummy, which is then airborne, slides over the hood of the passenger car, while, in test no.5, intensive contact between the back of the dummy and the left-hand A-pillar of the same-model passenger car completely brakes the motion of the dummy in its original direction. In comparison with all the other tests, the different direction of the rotations of the motorcycle are a striking feature of test no. 6. In this test, the motion of the dummy after the start of collision is characterized by a stretching of the legs with raising of the buttocks after the knees and lower legs have impacted against the motorcycle handlebars and against the passenger-car fender, respectively. With the vertical axis of the body virtually horizontal when turning onto the right-hand side, the dummy then slides across the engine hood, flies approx. 7.5 m and then slides into the final position. The take-off velocity is approx. 30 kph.

Fig. 6:

Overhead view of impact configurations, final positions and centre-of-mass paths in tests nos. 5 to 7

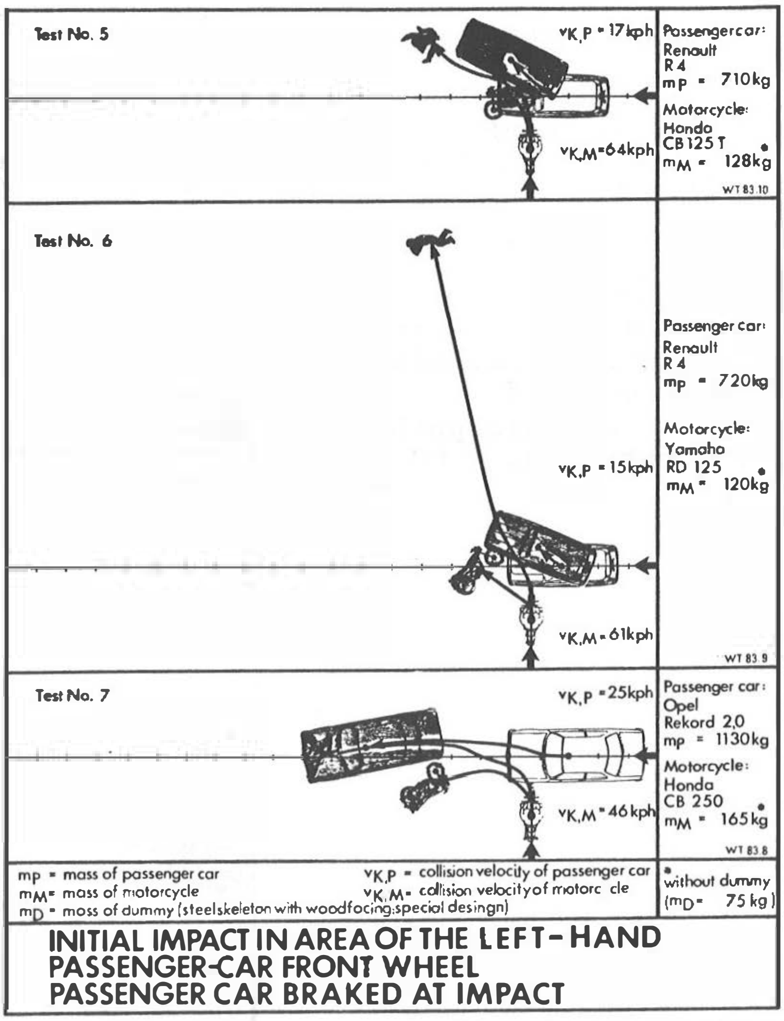
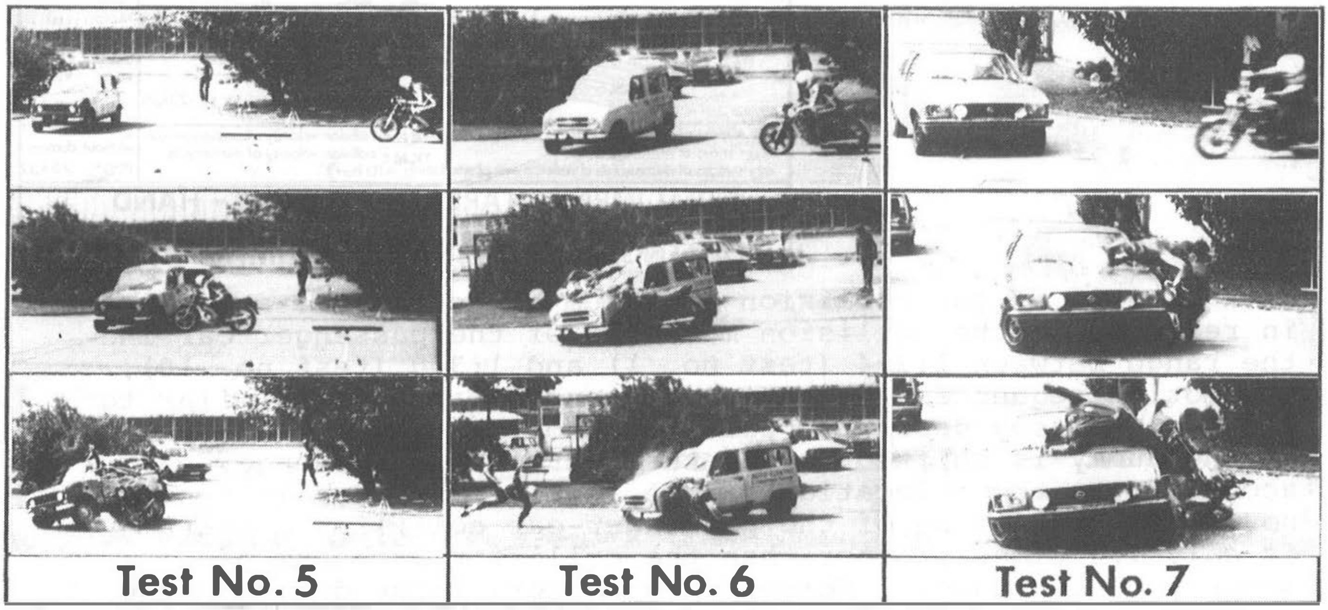


Fig. 7:

Side view of collisions with initial impact in area of left-hand front wheel of braked passenger cars (frame rate 3.125 1/s)

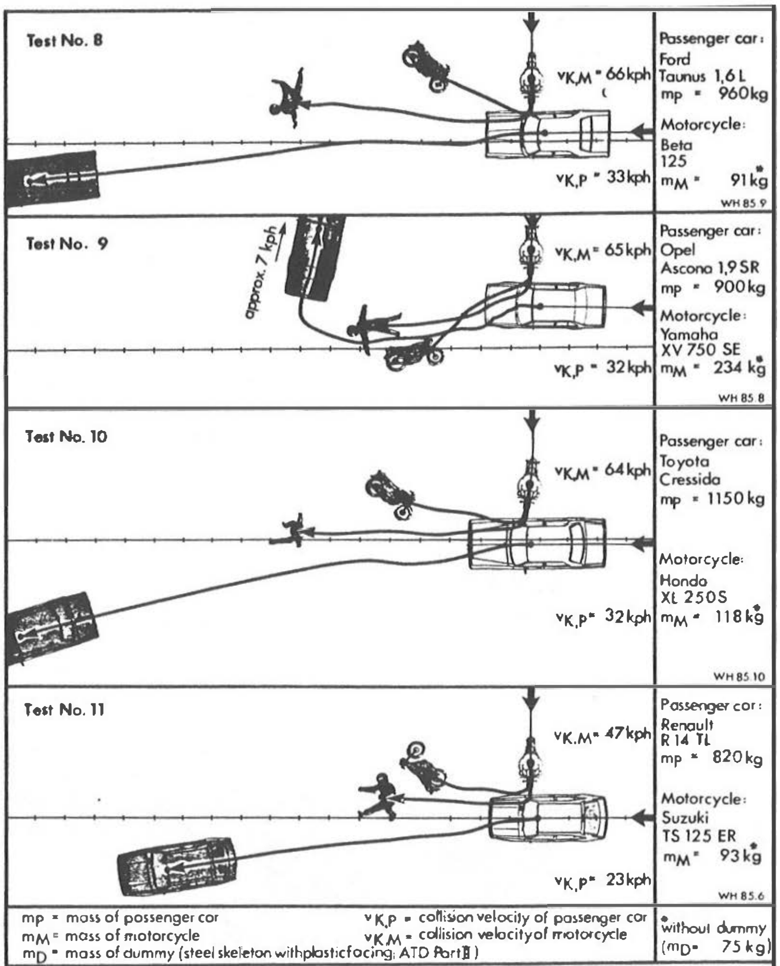


It was not possible in tests nos. 5 to 7 to establish a post-collision loss of velocity of the passenger car superimposed on the braking deceleration.

Initial impact in area of front door of passenger car

In five tests, the motorcycle impacted against the front door of the passenger car at a velocity ratio $v_{K,M} : v_{K,P} = 2:1$. In four tests, the passenger car was unbraked during the collision, Fig. 8; in one test, it was braked, Fig. 9.

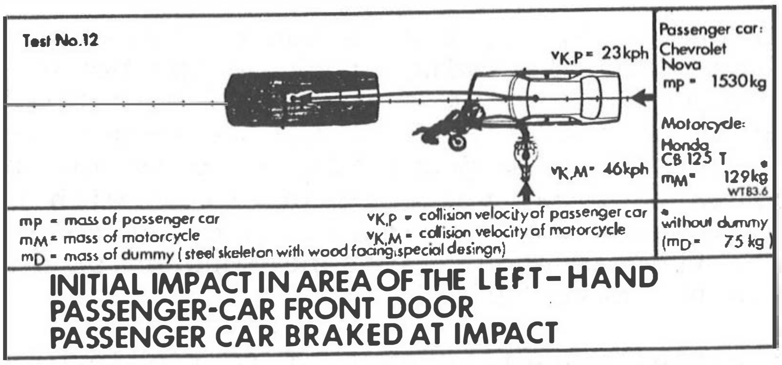
Fig. 8:
Overhead view of impact configurations, final positions and centre-of-mass paths in tests nos. 8 to 11



INITIAL IMPACT IN AREA OF THE RIGHT - HAND PASSENGER-CAR FRONT DOOR
PASSENGER CAR UNBRAKED AT IMPACT

With a ratio of the collision momentum of motorcycle and dummy in relation to the collision momentum of the passenger car in the range between 1:2.4 (test no. 1) and 1:3.0 (test no. 10), the motion sequences in tests 8, 10 and 11 are very similar to those previously described for tests nos. 1 to 4. The impact of the dummy is shifted toward the rear of the passenger car according to the relocation of the initial impact. In test no. 9, the magnitude of the passenger-car collision momentum is only 1.4 times greater than the collision momentum of motorcycle and dummy. Forces upon impact of the dummy in the

Fig. 9:
Overhead view of impact configurations, final positions and centre-of-mass paths in test no. 12

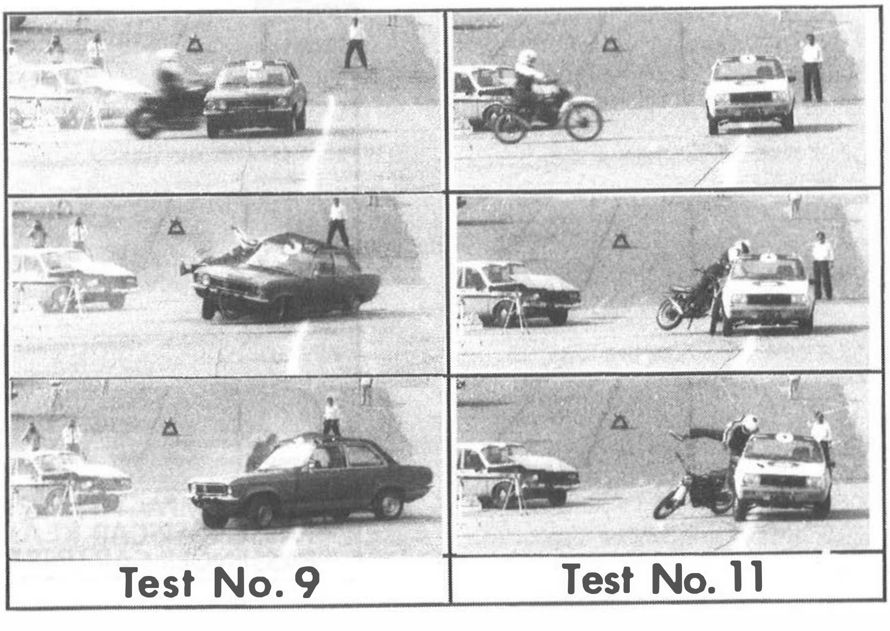


area of the B-pillar cause a pronounced rotation of the passenger car about its vertical axis with yaw angles up to approx. 100°. The passenger car, which is quickly decelerated by large slip angles, thus impedes the motions of the motorcycle and, in particular, of the dummy which were deflected in the original forward direction of travel of the passenger car, with motorcycle and dummy reaching their final positions at a comparatively short distance from the place of collision.

In tests nos. 8, 10 and 11, it is possible by means of manual film evaluation to detect a collision-induced loss of velocity of the passenger car in the range between 1 and 3 kph. In this connection, the dummy and the motorcycle reach approx. 90 to 100% and approx. 50 to 75%, respectively, of the velocity of the passenger car directly after the collision.

In test no. 9, it was not possible to detect a collision-induced loss of velocity of the passenger car superimposed on the slip-angle-induced deceleration. The velocities of dummy and passenger car are virtually identical directly after the collision; the velocity of the motorcycle is approximately half as much at this point in time. For purposes of further illustration, Fig. 10 shows side views of two collisions.

Fig. 10:
Side view of collisions with initial impact in right-hand front-door area of unbraked passenger cars (frame rate 3.6 1/s)



In test no. 12, the motion of the dummy severely is impeded by its thighs becoming stuck on the motorcycle handlebars after the motion of the dummy has been deflected in the forward direction of travel of the passenger car. After the collision, the dummy reaches only approx. 45% of the passenger-car velocity and falls with the tipping motorcycle into the final position. A collision-induced loss of velocity of the passenger car superimposed on the braking deceleration is not detectable.

Initial impact in area of rear axle of passenger car

In two tests, the motorcycle impacted at approximately double the velocity of the passenger car against the right-hand rear wheel of the unbraked passenger car, Fig. 11. The corresponding side views are shown in Fig. 12.

Fig. 11:
Overhead view of impact configurations, final positions and centre-of-mass paths in tests nos. 13 and 14

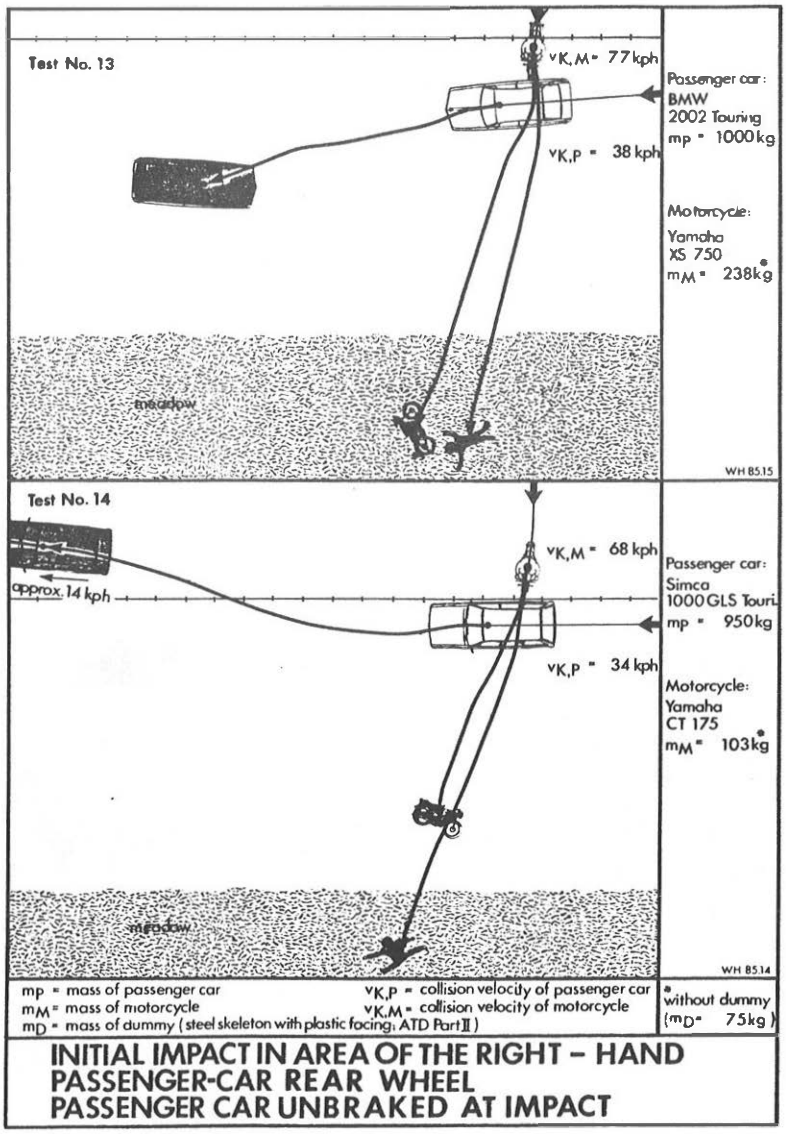
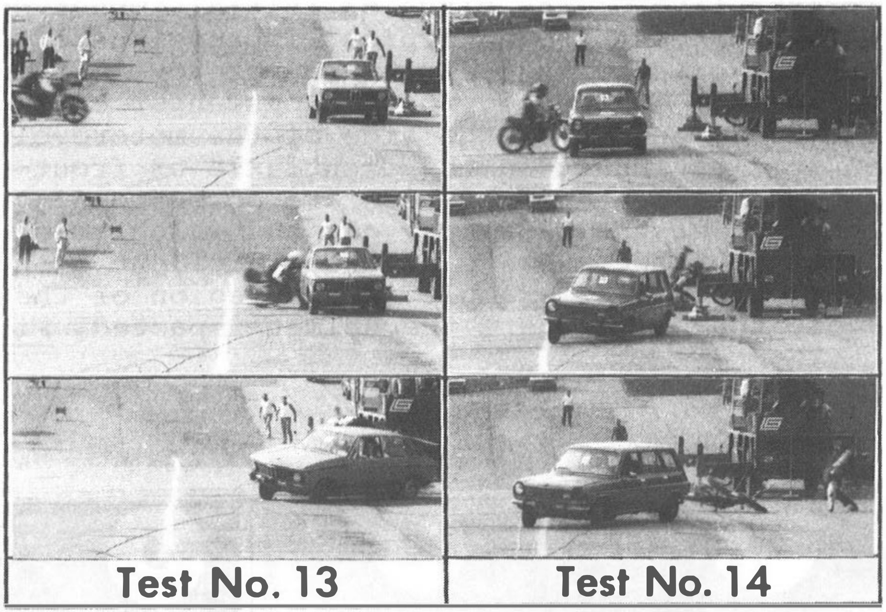


Fig. 12:

Side view of collisions with initial impact in area of right-hand rear wheel of unbraked passenger cars (frame rate 3.6 1/s)



As a result of the relocation in relation to the front-wheel impact of the motorcycle after the deflection of the motion of the motorcycle in the forward direction of travel of the passenger car, the dummy contacts the body of the estate car in the area of the C-pillar. In both cases, there is a chest and shoulder impact as well as a predominantly glancing helmet impact. With thereby initiated rotations about the transverse and longitudinal axes of the body with the upper body in a virtually horizontal position, the dummy flies directly after the collision at a velocity of about 40 khp into an adjoining meadow. In test no. 13, the motorcycle is just as fast as the dummy after the collision; in test no. 14, the motorcycle is approx. 35% slower.

Due to the very eccentric impact in test no. 13, there is a yawing rotation of the passenger car through approx. 190° until it reaches the final position. A collision-induced loss of velocity superimposed on the slip-angle-induced deceleration is not detectable.

In test no. 14, there is an initial yawing rotation of the passenger car up to approx. 40° which again decreases in the further course of motion due to steering motions of the front wheels. The collision-induced velocity loss of the passenger car is approximately 3 kph.

Vehicle damage

Damage to passenger car

The impact events are reflected by the indentations and abrasion marks on the passenger car. With knowledge of anticipated motion sequences, it is possible to find details with precision when securing the marks of a real accident.

Irrespective of the place of initial impact on the passenger car, the tests showed typical impressions of tyre, rim, front upright or steering head (when motorcycle front wheel deflected) in the body of the passenger car. The impact of the dummy and/or of the side of the motorcycle that follows an initial impact in the front-axle or front-door area produces indentations which are correspondingly offset toward the rear of the passenger car and which point, visually at first, to the severity of these accident events. Details of damage show, for example in the region of the edge of the roof, the place where the helmet impacted, Fig. 13.

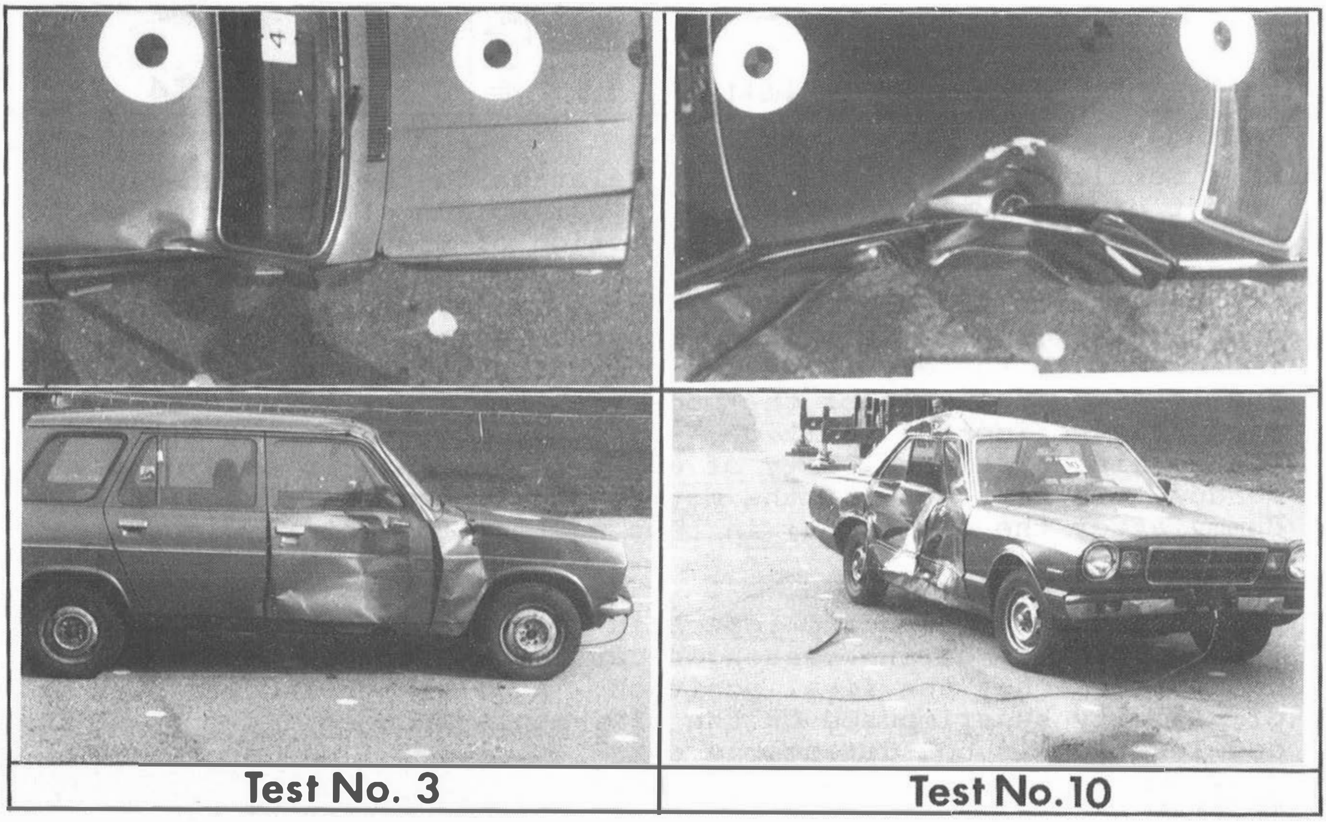
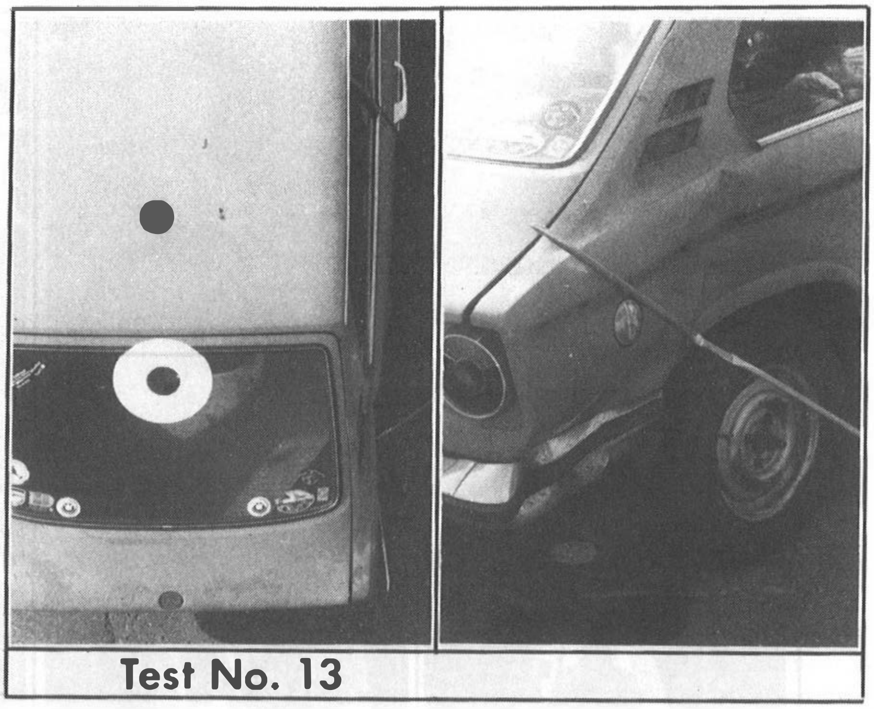


Fig. 13: Overhead and side views of passenger-car damage with initial impact in front-axle/front-door area

If the dummy leaves the place of collision, airborne, there are none of the typical body-contact indentations which are otherwise produced if the dummy is completely braked in its original direction of motion, Fig. 14.

Fig. 14:
Overhead and side views of passenger-car damage with initial impact in rear-axle area



Damage to motorcycle

The damage to the motorcycle once again makes it possible clearly to detect the dynamics of the collision. Upon initial impact, the front fork is first of all jolted back. There is a correspondingly superimposed deformation of the fork as a result of the deflection and contacting of the side of the front wheel. Twists or deformations on the handlebars additionally illustrate what happened at the start of the collision, Fig. 15.

In some tests, when the dummy slid over the motorcycle tank, there were heavy impacts of the trunk and thighs. Typical indentations of the motorcycle tank are asymmetrical as a result of the motion of the motorcycle being deflected in the forward direction of travel of the passenger car, Fig. 16.

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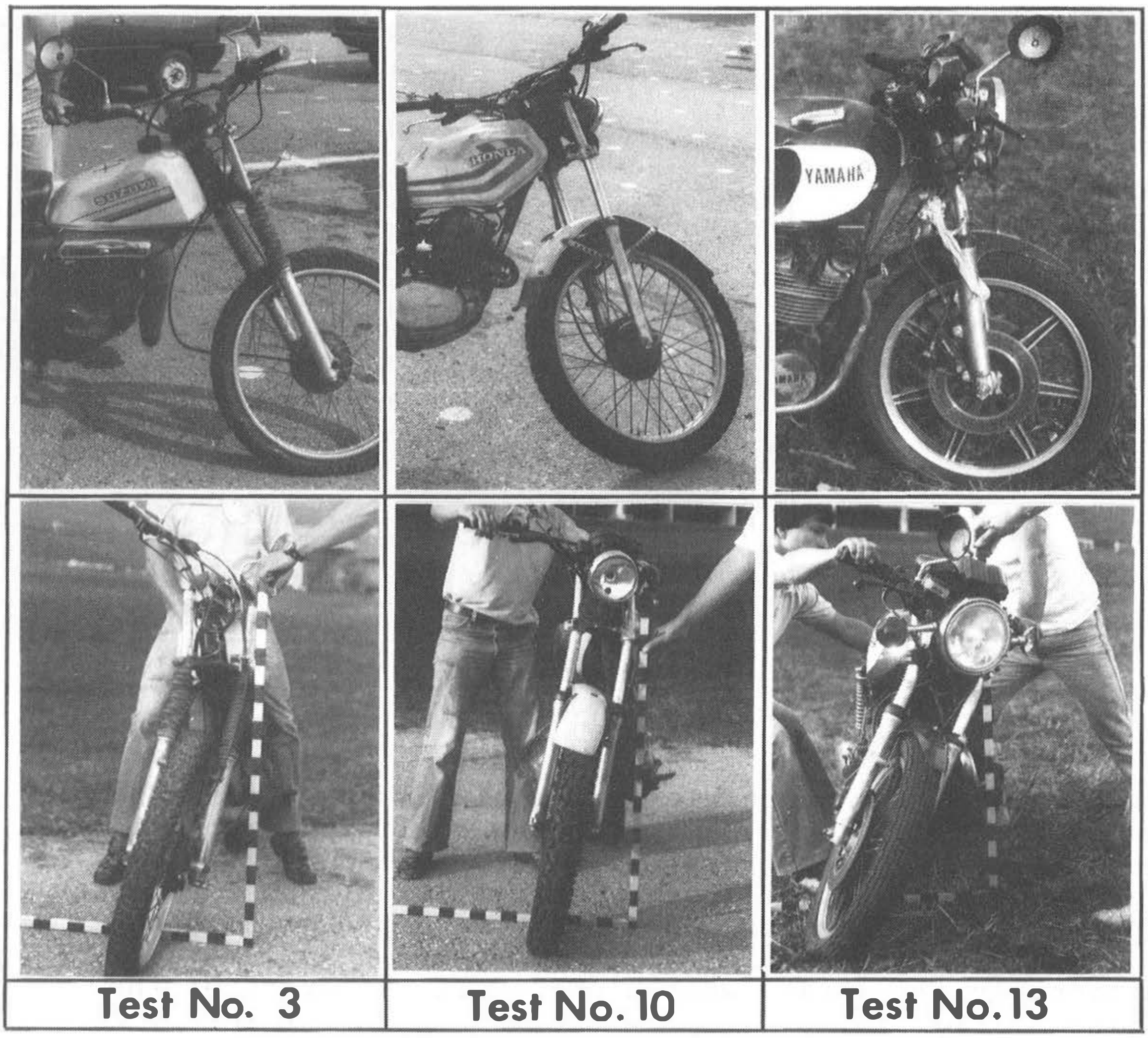

Fig. 15: Damage in front area of motorcycle

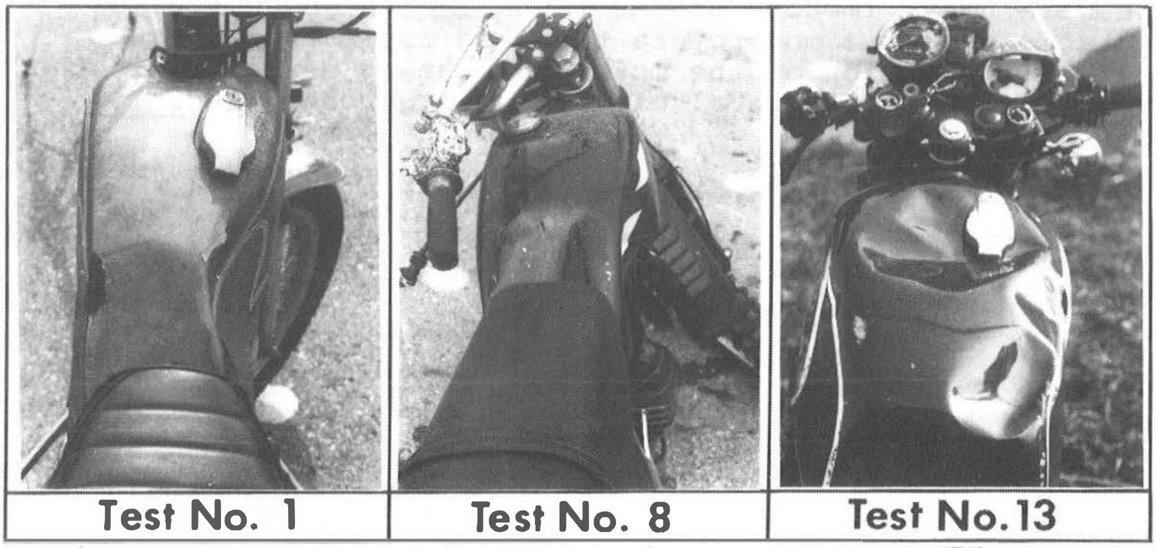

Fig. 16: Indentations in motorcycle tank resulting from impact of trunk/thigh of dummy