CYCLISTS IMPACTED BY SIMULATED VEHICLE FRONTS

E.G. Janssen and C.G. Huijskens

Research Institute for Road Vehicles TNO, Delft, The Netherlands

ABSTRACT

Twenty full-scale tests are performed, in which a dummy-cyclist was laterally impacted by simulated vehicle fronts, made of poly-urethane foam. The vehicle geometry, the vehicle impact speed and the vehicle stiffness, as well as the initial position of the dummy's legs, were varied.
These tests were performed in the framework of a long-term research programme, aimed to compare vehicle-cyclist and vehicle-pedestrian accidents, and to give recommendations for test methods in future regulations.
The trajectories of the cyclist observed in these tests are quite similar to those of pedestrians published in literature. Head/windshield contact seems to be more likely for cyclists than for pedestrians.

INTRODUCTION

Pedestrians and cyclists form a significant proportion of road accident casualties. In the Netherlands the bicycle is very popular and more cyclists than pedestrians are killed or severely injured [1]*.
In the past years international research has focussed mainly on pedestrian safety. Studies show that passenger cars are in most cases the opponent for the pedestrian casualties (65-90%); the pedestrian is struck by the front of the car in about 75% of the car-pedestrian accidents [2]. An increase of pedestrian safety can be expected by improvement of the vehicle design, for instance with respect to geometry and local dynamic stiffness of the vehicle front [2]. Based on such studies, various recommendations for the front structure design of passenger cars are being developed now by research institutes and international organizations, like EEVC. Cyclist safety, however, should be included in the discussions about future international regulations in this field. Research on vehicle-cyclist accidents is necessary to show the influence of vehicle front design parameters on cyclist injuries and to analyse differences between cyclists and pedestrians in this respect.

The Research Institute for Road Vehicles TNO has started a long-term research programme on this topic. The final aim of this research programme is to recommendate methods to assess the aggressiveness of passenger cars striking pedestrians or cyclists. A research programme is planned, partly based on international co-operation, in which mathematical models, component and full-scale tests are incorporated.

This paper shows the results of twenty full-scale tests, performed in the first phase of the research programme, in which a dummy-cyclist was laterally impacted by a simulated vehicle front. The specific aims of these tests are:

---

* Numbers in parentheses designate references at end of paper.

- Development and evaluation of a test set-up based on accident analysis.
- Analysis of the influence of several test parameters on the test results.
- Generating a database for mathematical model validation and comparison with pedestrian tests.

TEST METHOD

GENERAL

The vehicle speed, as well as the vehicle front geometry and vehicle front stiffness were varied in these tests. A specific combination of these parameters was chosen as reference. After the initial tests a standard bicycle pedal position, which resulted in an almost pure lateral motion of the dummy, was defined. Considering the specific aims of the first phase of the research programme, this 2-D motion of the dummy is preferable to the 3-D motion observed in tests with another pedal position.
On the basis of a defined standard test (8303/8306 in Table 1), each variation was tested twice.

Table 1 Variations of testparameters (see also Fig. 1).

Test number	Pedal position*	Vehicle front geometry (cm)			Padding density (kg/m^3)			Vehicle impact speed (km/h)
		A	B	C	1	2	3	
8301	H	55	80	10	50	50	50	20
8302	H	55	80	10	50	50	50	30
8303	V	55	80	10	50	50	50	30
8304	V	55	80	10	50	50	50	30
8305	V	55	80	10	50	50	50	30
8306	V	55	80	10	50	50	50	30
8307	V	55	80	10	35	35	50	30
8308	V	55	80	10	35	35	50	30
8309	V	55	80	10	50	50	50	20
8310	V	55	80	10	50	50	50	20
8311	V	55	80	10	50	50	50	40
8312	V	55	80	10	50	50	50	40
8313	V	55	80	20	50	50	50	30
8314	V	55	80	20	50	50	50	30
8315	V	35	80	10	50	50	50	30
8316	V	35	80	10	50	50	50	30
8317	V	35	60	10	50	50	50	30
8318	V	35	60	10	50	50	50	30
8319	V	35	60	20	50	50	50	30
8320	V	35	60	20	50	50	50	30

* H = Horizontal pedal position; foot on impact side backwards.
V = Vertical pedal position; foot on impact side downwards (see Fig. 3).

VEHICLE FRONT

The test set-up is based on analysis of vehicle-cyclist accidents [1] and is selected to enable a direct comparison with vehicle-pedestrian tests [2]. With regard to the vehicle, important parameters are the geometry and dynamical stiffness of the vehicle front. To determine the influence of variation of one parameter, e.g. bumper height, the other parameters should not change. Therefore it was decided to use a moving barrier on which different simulated vehicle fronts can be built, instead of real passenger cars. The vehicle front consists of 3 sections simulating the bumper, the grill and the hood (see Fig. 1). The sections are made of homogeneous poly-urethane foams (PUR) with densities of 35 kg/m^3 and 50 kg/m^3. The dynamical force-deflection characteristics of these PUR-foams were determined using a rigid spherical-impactor (D=168 mm, m = 6.8 kg).

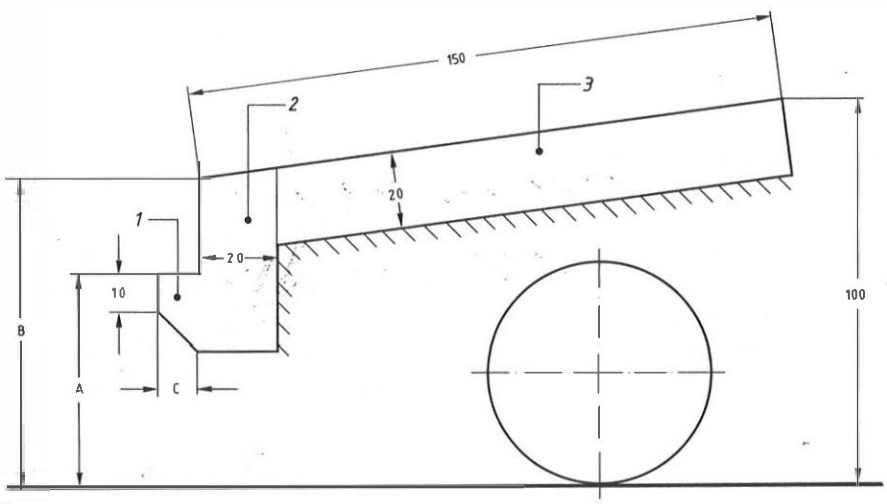

Fig. 1. Vehicle front consists of bumper (1), grill (2) and hood (3) section. Vehicle geometry (dimensions in cm) is changed by variation of the bumper height (A), hood-edge height (B) and bumper protrusion (C), see Table 1.

The results of a 30 km/h impact perpendicular to the foam surface, are shown in Fig. 2. The foam sections are thick enough (20 cm) to fully absorb the impact energy. The bumper foam is covered with a perforated aluminium sheet of 1 mm thickness, to avoid unrealistic penetration of sharp bicycle parts. This did not influence the force-deflection characteristics of the foam very much. The characteristics of a hood-section and bumper-section of a real car are also shown in Fig. 2. The real car is initially stiffer, caused by inertia effects and a greater deforming contact-area.
The width of the vehicle front and the length of the hood are 150 cm. The bumper width is 10 cm. The other dimensions, i.e. bumper height, hood-edge height and bumper protrusion, are varied in these tests. These variations are based on published vehicle-pedestrian accident studies. A low vehicle front, i.e. a hood-edge height of 70 cm and a bumper height of 35 cm, is reported to have a positive effect on legs and pelvis injuries of pedestrians in comparison with a higher vehicle front, e.g. a hood-edge height of 80

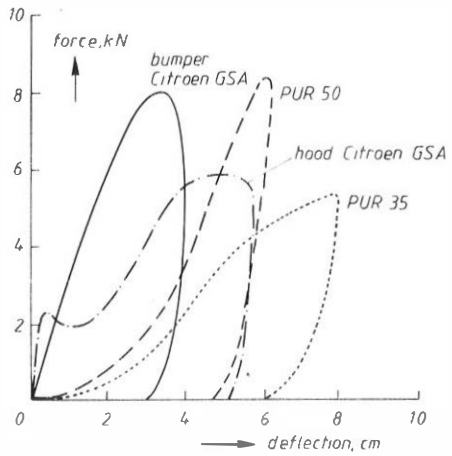

Fig. 2. Dynamical force-deflection curves of PUR-foams (50 kg/m^3 and 35 kg/m^3) obtained from ECE-R21 impactor tests (v = 30 km/h), compared to curves of a Citroën GSA [3] (hood impactor: m = 5.25 kg, D = 200 mm, v = 30 km/h; bumper-impactor: m = 10 kg, width =101.5, v = 23.5 km/h).

cm and a bumper height of 55 cm [4]. On the other hand, a lower vehicle front appears to have a negative effect on head and thorax injuries due to a larger rotational velocity of the pedestrian [5]. To determine the influence of the height of the vehicle front on the kinematics and accelerations of a cyclist, two bumper heights (35 and 55 cm) and two hood-edge heights (60 and 80 cm) were chosen. To vary the front slope of the vehicle, also two bumper protrusions (10 and 20 cm) were chosen, so that dependent on the combination of dimensions a front slope of 78, 68 or 51 degrees results (see also Table 1 and Fig. 1).

DUMMY AND BICYCLE

In this first phase of the research programme the cyclist was represented by a 50th percentile anthropomorphic male dummy. The Standard Part 572 dummy was chosen because it is a well defined dummy and is often used as a pedestrian dummy, in spite of its disadventages (e.g. not sufficient lateral flexibility and not representative as 50th percentile injured pedestrian). In order to use this dummy as pedestrian dummy, some modifications were necessary. The range of motion in the hip joint was increased by cutting away some buttocksflesh. The knees, lower legs and feet of the Standard Part 572 dummy were replaced by special pedestrian body parts, supplied by Humanoid Systems. These body parts are reinforced and easily replaceable. Furthermore the ankels have a lateral flexion possibility and accelerometers can be mounted into the knees and feet.
The bicycles are standard Dutch men's bicycles (frame height 58 cm, wheel-diameter 28") but without chain, mudguards, lighting, etc. The remaining bicycle mass was 12.5 kg.
The dummy was sitting in a defined standard position on the stationary bicycle and was supported by a, vertically adjustable, cable fixed to the neck-bracket. An electro-magnetic release-system, activated by the moving barrier, interrupted this support approximately 10-15 ms before cyclist/ vehicle contact.

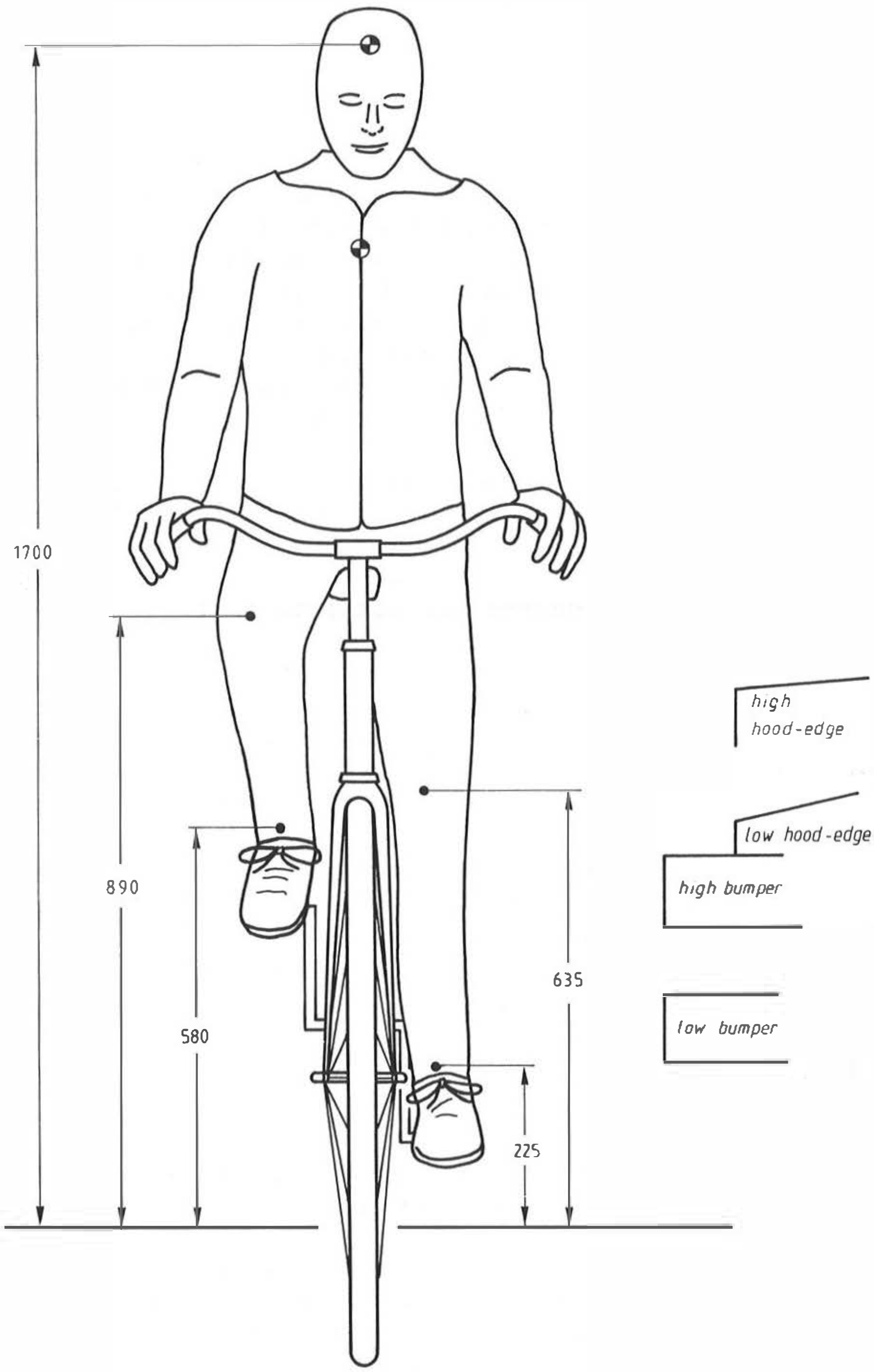

Fig. 3. Defined standard height of head, knees and ankles of the dummy (with a vertical pedal crank position), compared to the variations in bumper height and hood-edge height.

The position of the legs was varied by fixation of the pedal cranks in either a horizontal position (impacted foot backwards) or in a vertical position (impacted foot downwards). Figure 3 shows the height of knees and ankles in the vertical crank position, compared to bumper and hood-edge height.

IMPACT DIRECTION AND SPEED

In the Netherlands the passenger car is the most frequent collision partner for the killed (62%) and severely injured (69%) cyclist [1]. In 60-65% of these cases the cyclist was laterally (left more than right) impacted by the front of the car [1]; the impact direction selected here is therefore 90 degrees (from the left side). The centre of the bicycle is located in the symmetrical plane of the simulated vehicle.
From accident analysis it is known that many vehicles brake before striking a pedestrian [2]. Furthermore, the safety benefits to be expected from improvements in vehicle design seem to be most important for the speed range up to 40 km/h [2]. In the Netherlands most vehicle-cyclist accidents occur inside built-up areas where a speed limit of 50 km/h or less exists. Therefore the vehicle impact speeds in these cyclist tests are selected at 20, 30 and 40 km/h .
The moving barrier with the simulated vehicle front (total mass 930 kg) was braked when bumper/leg contact occurred (vehicle deceleration during braking approximately 0.7 g). The moving barrier doesn't "dive" during braking, because it is constructed without any suspension. So the vehicle front height is maintained during the complete test.

INSTRUMENTATION

The dummy was instrumented with triaxial accelerometers in the c.g. of the head, thorax and pelvis. Additionally, triaxial accelerometers were mounted into the knees and uniaxial accelerometers into the feet (lateral direction).
Two unaxial accelerometers were mounted on the moving barrier to measure the braking and impact deceleration.
Eight high-speed film cameras were used to measure and analyse the motions of the dummy and bicycle during the impact.

TEST RESULTS

GENERAL

In identical tests, the acceleration-time histories of the head, thorax and pelvis, as well as the overall kinematics of the dummy, reproduced very well.
The acceleration-time histories of the knees and feet, however, were sometimes disturbed by high-frequency vibrations, caused by metal-to-metal contacts in the joints and between joint bolts and bicycle frame.
The initial position of the left arm (= impacted side) has a great influence on the kinematics of the dummy. In three tests (8304, 8305 and 8316) this arm was not stretched enough in the initial position and therefore the elbow penetrated into the foam of the hood, instead of sliding over the hood. Due to this, head/hood contact was disturbed or didn't occur at all in these tests.
Especially the permanent deformations of the vehicle front and the bicycle, and the locations of these deformations, but also the throwing distance of the dummy and bicycle, reproduced very well.
The dummy accelerations, vehicle decelerations and throwing distances of dummy and bicycle are summarized in the Appendix.

To extend the analysis of the tests, an imaginary windshield, consisting of a target-plane for high-speed film analysis, was added to the vehicle front (see Fig. 4). The chosen length of the hood (dimension D) leads to a head impact approximately on the centre of the imaginary windshield.
Table 2 shows the impact velocity of the head on the imaginary windshield

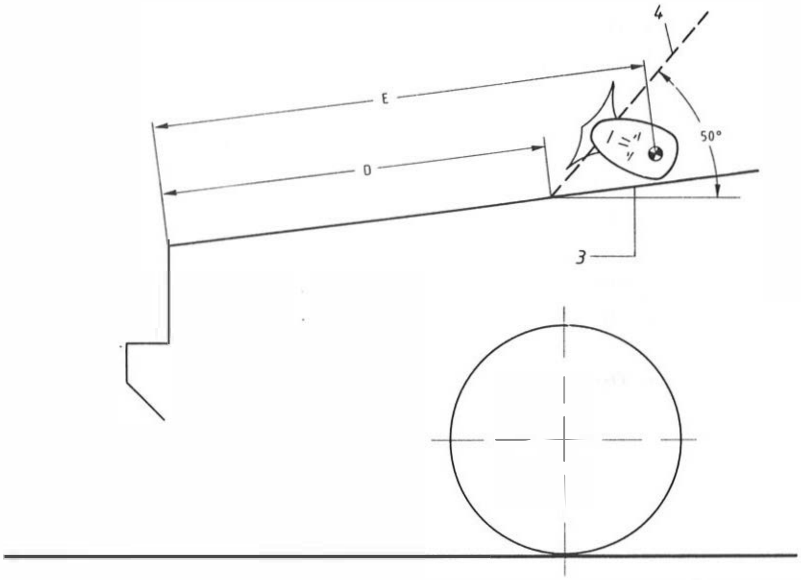

Fig. 4. For film analysis an imaginary windshield (4) is added to the vehicle front. See Table 2 for the dimension of the hood length D. Distance E gives the impact location of the head on the hood.

and the distance between hood-edge and head impact location on the hood (dimension E in Fig. 4).
Considering the realistic hood lengths (1.00-1.28 m), head/windshield contact is most likely in real accidents.

PEDAL POSITION

The impact locations of the bumper and grill on the dummy's leg are located in or close to a vertical plane through the dummy's c.g. and parallel to the vehicle direction of motion, in the tests where the pedal cranks are fixed in the vertical position and the impacted leg is stretched downwards (see also Fig. 3). Therefore the motion of the dummy is an almost pure lateral one in this vertical plane, without rotation around the dummy's longitudinal axis. The vehicle front impacts the left leg, which is compressed between bicycle and vehicle front. Then the bicycle starts rotating and strikes the right leg. The cyclist rotates around the hood-edge and successively the left side of the hip, the left arm, the left shoulder and finally the left upper side of the head strike the hood. When the legs are horizontal, the bicycle starts moving away from the dummy and vehicle. Due to the braking of the vehicle the dummy slides over the hood and falls on the ground. This second impact was not analysed in detail, however, acceleration-time histo-

Table 2 Results of full-scale cyclist-vehicle tests; head impact on imaginary windshield and hood.

Test number	Hood length D 1) (m)	Head/windshield impact velocity (km/h)	Distance E 1) (m)
8303	1.00	42	1.14
8306	1.00	40	1.12
8307	1.00	37	1.10
8308	1.00	44	1.11
8309	1.00	2)	0.90
8310	1.00	2)	2)
8309	0.80	24	0.90
8310	0.80	21	2)
8311	1.00	61	1.24
8312	1.00	62	1.24
8313	1.00	43	1.10
8314	1.00	45	1.12
8315	1.00	43	1.13
8316 3)	1.00	-	-
8317	1.28	48	1.45
8318	1.28	49	1.45
8319	1.28	58	1.43
8320	1.28	58	1.48

1) See Fig. 4.
2) No head contact occurred.
3) Head kinematics disturbed by elbow/shoulder impact.

ries sometimes showed high peak values for this impact.
If the pedal cranks are fixed in a horizontal position, both knees are in a forward position. So in that test set-up the impact locations of the (high) vehicle front on the dummy's leg are located in front of the vertical plane through the dummy's c.g. and parallel to the vehicle direction of motion. Therefore also a rotation around the dummy's longitudinal axis could be observed in these tests; the posterior part of the dummy's head and thorax impacted the hood.
Results from accident analysis studies concerning the influence of the pedal position on the kinematics of the cyclist weren't available.

VEHICLE SPEED

The influence of the vehicle speed can be determined by comparing the results of the tests 8309/8310 (20 km/h), 8303/8306 (30 km/h) and 8311/8312 (40 km/h). Other parameters weren't changed in these tests (see Table 1).
Figure 5 shows the influence of the vehicle impact speed on the throwing distance of the dummy and bicycle, compared to the braking distance of the moving barrier. These curves are quite similar to what is known about throwing distances of pedestrians.

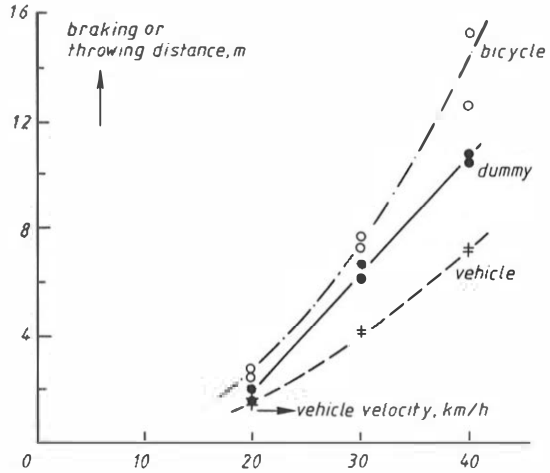

Fig. 5. Influence of the vehicle impact velocity on the throwing distance of dummy and bicycle, compared to the braking distance of the vehicle.

The trajectories of the head, thorax and ankles of the cyclist, relative to the vehicle, are shown in Fig. 6. In the 20 km/h tests the dummy just falls

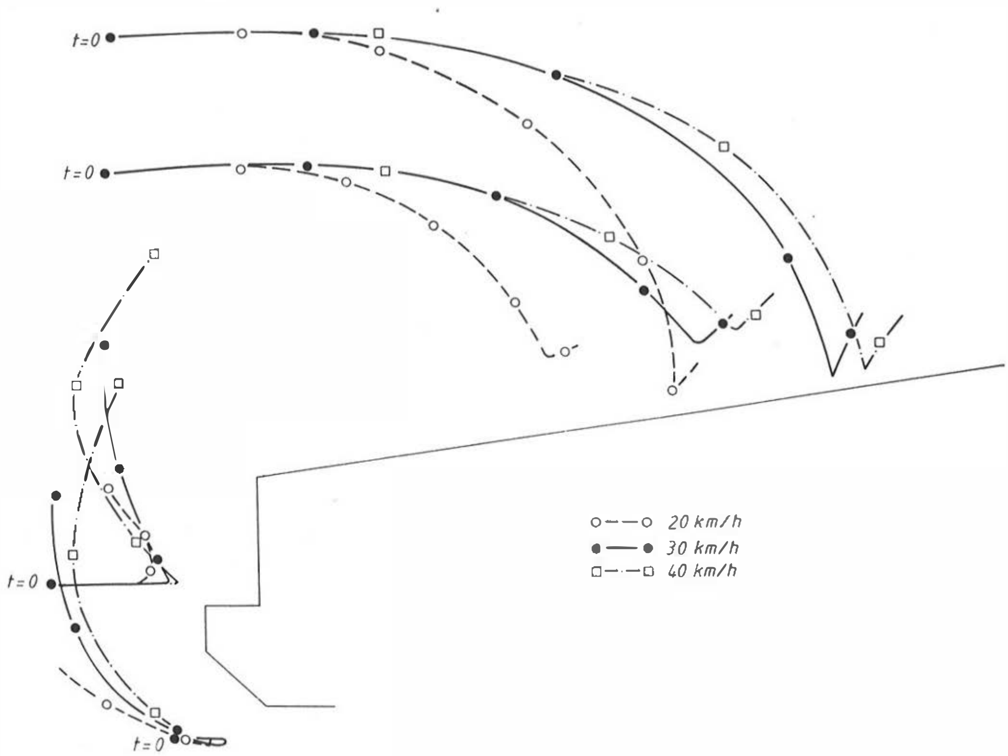

Fig. 6. Influence of the vehicle impact velocity on the trajectories of head, thorax and ankles of the dummy-cyclist (vehicle front geometry A/B/C = 55/80/10 cm). Time intervals of 50 ms are shown.

on the hood. In one 20 km/h test there was no head/hood contact and in the other one there was only a slight contact. The head impact location on the hood in this 20 km/h test almost coincided with this location obtained from wrapping the cyclist's height around the vehicle front (see Fig. 7). So in this test set-up and using this dummy, there will probably be no head/hood contact if the vehicle speed is decreased below 20 km/h. In the 30 and 40 km/h tests the impact locations of the head and thorax are located much more towards the windshield (see Fig. 6).
In the 20 km/h tests the imaginary windshield was shifted forward to realize a head/windshield contact comparable to the other test (see Table 2). The impact velocity of the head on the imaginary windshield increases strongly if the vehicle speed increases; approximately 22 km/h in the 20 km/h tests to approximately 62 km/h in the 40 km/h tests.
The accelerations of the c.g.'s of head, thorax and pelvis are strongly influenced by the vehicle speed. The HIC, e.g., is increased by a factor 3 to 6, while the SI of thorax and pelvis are doubled, if the vehicle speed increases from 30 to 40 km/h. The average acceleration of the left knee, caused by the bumper impact in the 20, 30 and 40 km/h tests, is approximately 475, 700 and 950 m/s^2 respectively. The maximum accelerations caused by knee-bicycle contacts, however, showed peak values up to 3100 m/s^2 and ankle joint-stops even up to 5400 m/s^2.

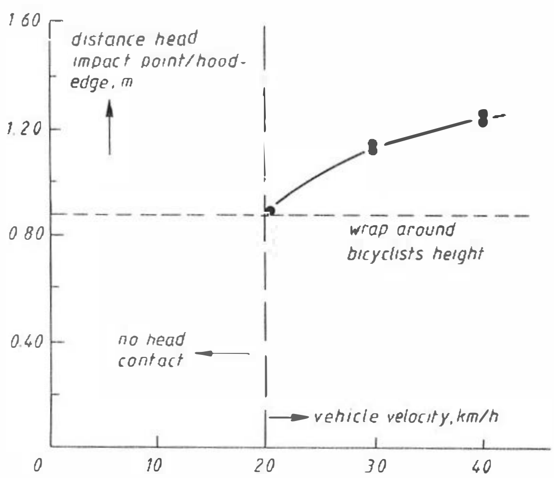

Fig. 7. Influence of the vehicle impact velocity on the head impact location on the hood, compared to this location obtained from wrapping the cyclist height around the vehicle front (A/B/C = 55/80/10 cm).

VEHICLE GEOMETRY

The hood-edge height appears to have a predominant influence on the kinematics of the cyclist. The variations in bumper height and bumper protrusion didn't influence the head impact location on the hood (compare testno. 8303/8306, 8313/8314, 8315/(8316) in Table 2). The distance between head impact location and hood-edge, however, is strongly increased when the hood-edge

height is decreased (compare testno. 8315/8316 and testno. 8317/8318 in Table 2). The same holds for the impact velocity of the head on the imaginary windshield (see Table 2).
Fig. 8 shows the trajectories of the dummy, struck by a high and a low vehicle front. The lower body is less translated in horizontal direction, when struck by a low vehicle. The right leg slides over the hood-edge, in stead of being horizontally accelerated by the vehicle front. Therefore the rotational motion of the upper body is less restricted.
First analysis of pedestrian tests, in which the dummy is laterally (90°) impacted by identical simulated vehicle fronts (second phase of the research programme), indicates that the trajectories of pedestrians and cyclists are quite similar (see also Fig. 9). The distance between head impact location on the hood and hood-edge ("E" in Fig. 4), however, is approximately 30 cm greater for the cyclist, due to its higher c.g. position.
Maximum head accelerations and HIC increase when bumper protrusion is increased, or when bumper height and/or hood-edge height are decreased. Maximum chest accelerations and SI increase when bumper height and/or hood-edge height are decreased. Increasing bumper protrusion of a high vehicle has no influence on the chest accelerations. Increasing bumper protrusion of a low

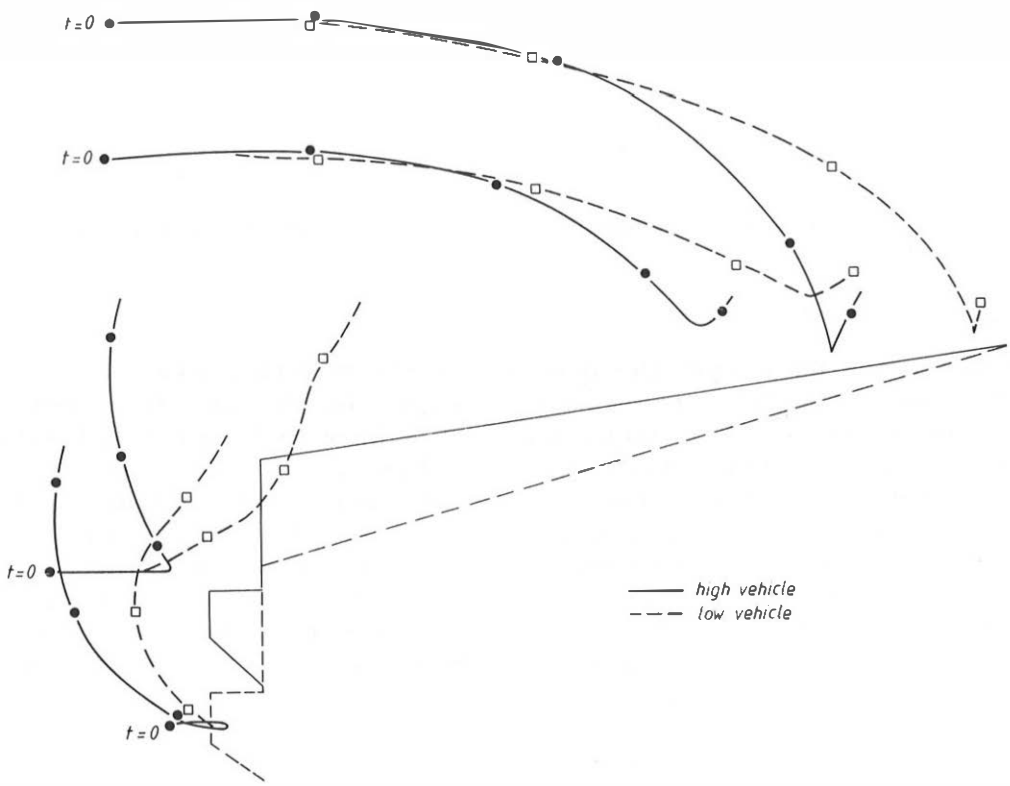

Fig. 8. Influence of the vehicle front height on the trajectories of the head, thorax and ankles of the dummy-cyclist (vehicle speed = 30 km/h). Time intervals of 50 ms are shown.

vehicle decreases the chest accelerations (probably caused by lateral/vertical shoulder impact). Maximum pelvis accelerations decrease when bumper height and/or hood-edge height are decreased. Increasing bumper protrusion of a high vehicle or a low vehicle leads to a decrease or increase of the maximum pelvis accelerations respectively.
The impact location of the bumper on the lower leg of the cyclist depends on the position of the leg. In this test set-up the impacted leg is in the most downward position and the bumper impacts the leg just above the ankle or just below the knee (see also Figure 3). Initial accelerations are therefore higher at the impacted joint, but high-frequency vibrations disturbed the measurements. Lateral flexion of the left ankle was higher in the variations with a high bumper.

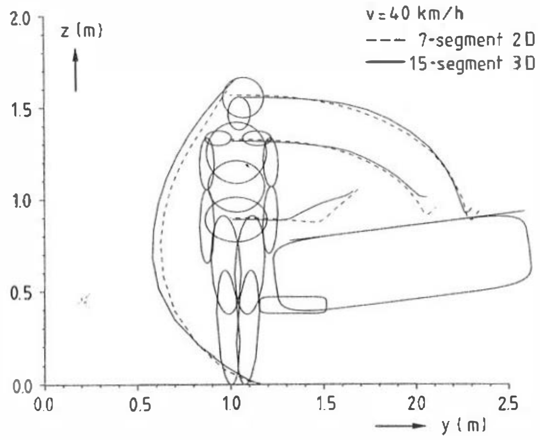

Fig. 9. Mathematical simulation of a vehicle-pedestrian accident [6].

VEHICLE STIFFNESS

In the tests 8307/8308 the density of the PUR-foam simulating the bumper and grill was 35 kg/m^3, instead of 50 kg/m^3 in the standard tests (8303/8306). The influence of this variation on the knee and foot acceleration-time histories is not clear, because these histories were disturbed by metal-to-metal contacts. The influence on the acceleration-time histories of the head, thorax and pelvis, however, was only minor. The trajectories of the head and thorax also were not influenced by this variation.
The vehicle stiffness also will be varied in the mathematical models, which will be developed in the next phase of the research programme. These models can contribute to a better understanding of the effects of vehicle stiffness variations.

DISCUSSION AND CONCLUSIONS

Pedestrians as well as cyclists, are among the most vulnerable traffic participants. The aggressiveness of passenger cars striking pedestrians or cyclists can be reduced by improvement of the vehicle design.
Twenty full-scale tests are performed, in which a dummy-cyclist is laterally impacted by a simulated vehicle front. Dependent on the position of the dummy's legs an almost pure lateral motion of the dummy can occur. The vehicle geometry, especially the hood-edge height, influences the kinematics and the accelerations of the dummy-cyclist. Maximum head accelerations and HIC are increased by a factor 1.5 up to 2 if the front height is decreased by 20 cm. These changes can also result in different head impact locations on the vehicle; e.g. plus 30 cm on the hood if the front height is decreased from 80 to 60 cm. This makes head/windshield contact more likely.
The impact speed of the braked vehicle also strongly influences the kinematics and accelerations of the dummy-cyclist. In future the influence of the bicycle speed on the test results will be determined also. The difference in density of the used PUR-foams, however, doesn't influence the test results very much.
The kinematics of pedestrians and cyclists, laterally struck by identical vehicle fronts, are very much alike. The position of the legs, however, influences the kinematics in both cases. The head impact location on the hood seems to lie further away from the hood-edge for the cyclist, due to the higher position of its c.g.
The performance of the modified Standard Part 572 dummy was satisfactory for the first phase of the research programme. More representative human substitutes will be used later on in the research programme. Concerning dummies, it is probably better to assess the severity of leg impact by consideration of the bending moments in the bones and knee joint, in stead of accelerations.
The research programme will be continued by performing identical full-scale tests with dummy-pedestrians. This makes comparison of kinematics and "injuries" of pedestrians and cyclists, struck by identical vehicles, possible. The programme will be extended in future by using other human substitutes (e.g. cadavers, child dummies) and real passenger cars, while in conjunction with this experimental research, mathematical models of both pedestrian and cyclist impacts will be formulated with the MADYMO CVS program package. These models can contribute to the insight in this complex impact situation and they can be extended to conditions for which no tests are available. International co-operation is strongly recommended for successfully attacking the problems in this research field.

ACKNOWLEDGEMENTS

The authors would like to thank the Experimental Section of the Department of Injury Prevention for conducting the experiments and the Dutch Government for sponsoring the research programme.

REFERENCES

1. J.J.W. Huijbers:
"A description of bicycle and moped rider accidents aimed to indicate priorities for injury prevention research", International IRCOBI Conference, Delft, September 1984.

2. European Experimental Vehicles Committee:
"Pedestrian injury accidents", 9th ESV Conference, Kyoto, November 1982.

3. C. Huss:
"Messung der lokalen Steifigkeit von äusseren Fahrzeugteilen", Diplomarbeit, Wuppertal, 1982.

4. S.J. Ashton and G.M. Mackay:
"Benefits from changes in vehicle exterior design-field accident and experimental work in Europe", SAE P-121 Pedestrian Impact Injury & Assessment, Detroit, 1983.

5. J.E. Fowler and J. Harris:
"Practical vehicle design for pedestrian protection", 9th ESV Conference, Kyoto, 1982.

6. J. van Wijk, J. Wismans, J. Maltha and L. Wittebrood:
"MADYMO Pedestrian Simulations", SAE P-121 Pedestrian Impact Injury & Assessment, Detroit, 1983.

APPENDIX. Results of full-scale cyclist-vehicle tests; throwing distances and accelerations

Testnumber		8301	8302	8303	8304	8305	8306	8307	8308	8309	8310
Impact SPEED.	(km/h)	20.0	30.0	30.2	30.5	30.0	30.0	30.0	30.5	19.6	19.8
Throwing distances.											
DUMMY	(m)	-.-	6.8	6.3	5.8	7.1	6.7	6.4	6.0	1.6	2.0
BICYCLE	(m)	-.-	12.8	7.4	6.0	8.9	7.7	7.1	6.1	2.7	2.8
SLED	(m)	-.-	4.5	4.2	3.9	4.1	4.1	4.1	3.9	1.6	1.7
Max. HEAD Res. Acc	(m/sec2)	135	1248	1061	350	480	990	1076	1247	262	221
Time	(msec)	199	188	180	178	151	169	170	167	237	240
Time	(msec)	124	184	175	90	84	165	166	164	223	226
HIC		14	779	581	130	170	515	619	751	41	16
Time	(msec)	240	192	183	234	204	172	174	171	240	240
Max. 3msec	(m/sec2)	111	132	955	327	314	86	60	144	174	52
Time	(msec)	200	154	178	176	149	27	35	110	255	84
					*	*					
Max. CHEST Res. Acc.	(m/sec2)	198	360	286	260	312	328	323	339	258	282
Time	(m/sec)	198	191	167	176	125	155	153	150	223	237
SI.		12	114	77	61	76	89	83	97	38	33
Max. 3msec	(m/sec2)	94	157	216	210	282	271	87	85	223	179
Time	(msec)	196	177	182	135	130	154	185	182	223	228
Max. PELVIS Res. Acc.	(m/sec2)	167	377	673	496	622	888	808	744	582	474
Time	(msec)	47	29	20	18	18	19	18	18	22	20
SI.		12	63	106	61	98	156	127	121	45	37
Max. 3msec	(m/sec2)	71	99	258	148	211	173	147	171	114	128
Time	(msec)	38	54	19	35	27	39	17	17	20	40

Testnumber		8311	8312	8313	8314	8315	8316	8317	8318	8319	8320
Impact SPEED.	(km/h)	40.5	40.4	29.8	29.9	29.9	29.8	29.9	30.0	29.9	29.9
Throwing distances.											
DUMMY	(m)	10.7	10.5	6.5	5.9	6.2	6.3	6.2	5.8	5.1	4.8
BICYCLE	(m)	12.7	15.4	7.5	9.1	9.2	6.6	6.3	7.1	6.9	6.1
SLED	(m)	7.3	7.4	4.1	4.1	4.4	4.0	4.3	4.3	4.3	4.2
Max. HEAD Res. Acc	(m/sec2)	1731	2365	1243	1393	1241	588	1190	1460	1462	1564
Time	(msec)	140	137	178	175	178	177	187	185	191	199
Time	(msec)	136	133	175	171	174	87	179	182	187	195
HIC		1840	3271	711	1024	681	212	1003	1267	1560	1410
Time	(msec)	144	139	181	178	180	185	190	189	196	203
Max. 3msec	(m/sec2)	213	2079	1104	1241	1087	283	73	1316	96	1409
Time	(msec)	75	135	177	174	176	145	112	184	205	197
							*				
Max. CHEST Res. Acc.	(m/sec2)	356	523	324	332	373	316	550	526	488	374
Time	(m/sec)	145	128	163	162	164	141	167	170	171	179
SI.		130	176	83	88	99	42	201	193	140	106
Max. 3msec	(m/sec2)	331	334	246	307	198	184	144	482	377	320
Time	(msec)	145	140	167	162	178	140	190	170	175	178
Max. PELVIS Res. Acc.	(m/sec2)	861	995	656	611	512	563	343	406	442	512
Time	(msec)	17	17	19	18	35	12	9	11	9	10
SI.		253	288	92	80	130	126	91	93	99	109
Max. 3msec	(m/sec2)	287	280	176	230	321	275	238	225	236	245
Time	(msec)	21	25	18	17	34	34	136	135	136	140

* Head kinematics disturbed by elbow/shoulder impact.

(Appendix continued)

APPENDIX Results of full-scale cyclist-vehicle tests (continued)

			8301	8302	8303	8304	8305	8306	8307	8308	8309	8310	8311	8312	8313	8314	8315	8316	8317	8318	8319	8320
Max LEFT KNEE Res	Acc		(1000 Hz)																			
		(m/sec2)	809	2431	1553	1706	1583	1951	1752	2048	1790	2007	2107	2414	2231	2037	1897	2287	1442	2291	1372	2147
Time		(msec)	23	7	13	30	16	29	16	16	19	16	12	13	30	15	5	10	7	78	9	7
Max LEFT KNEE Res	Acc		(180 Hz)																			
		(m/sec2)		2456	1586	1692	1507	1972	1761	1914	1657	2029	2111	2365	2215	2057	2004	2195	1437	227?	1365	2188
Time		(msec)		8	14	30	16	29	15	16	17	16	14	13	31	15	5	10	7	78	9	7
Max RIGHT KNEE Res.	Acc		(1000Hz)																			
		(m/sec2)	999	2177	1929	1510	1144	2244	732	977	765	432	1957	3119	2453	1034	925	1319	594	528	365	661
Time		(msec)	47	31	33	31	32	30	32	32	44	46	26	26	31	32	54	21	17	30	27	18
Max RIGHT KNEE Res.	Acc		(180 Hz)																			
		(m/sec2)		2196	1891	1484	1174	2194	738	976	753	439	1904	3023	2491	1029	916	1250	612	520	367	680
Time		(msec)		31	33	31	32	30	32	32	45	46	26	26	31	33	54	21	17	30	27	18
Max. LEFT FOOT Acc. (lateral)			(1000Hz)																			
	(+)	(m/sec2)								5366	4562	1672					2638			1343		
Time		(msec)								12	17	17					13			15		
	(-)	(m/sec2)	1959	2883	2935	926	3969	1169	5678	4928	4892	2962	5456	4892	5959	6133	1289	1397	1427	1397	1271	1781
Time		(msec)	13	18	13	13	11	20	13	12	16	14	11	12	13	12	4	9	9	8	6	7
Max. LEFT FOOT Acc (lateral)			(180 Hz)																			
	(+)	(m/sec2)				2369				5366	4154						2644			1367		
Time		(msec)				11				12	17						13			15		
	(-)	(m/sec2)			2978	782	3969	1139	5678	4928	4940	2932	5360	4916	5881	5857	1295	1259	1517	1433	1301	1763
Time		(msec)			13	12	11	20	13	12	16	14	11	12	13	12	4	9	8	8	6	7
Max. RIGHT FOOT Acc. (lateral)			(1000Hz)																			
	(+)	(m/sec2)									516							1475	1109	1283	654	1061
Time		(msec)									41							26	23	29	26	24
	(-)	(m/sec2)	1180	2178	2206	1127	3255	3867	4113	3765	432	432	3831	3861	3855	1505	1571	1283	785	875	618	701
Time		(msec)	41	18	29	29	27	28	30	31	55	44	23	23	30	31	22	39	35	21	19	20
Max. RIGHT FOOT ACC. (lateral)			(180 Hz)																			
	(+)	(m/sec2)																	1127	1253	624	1079
Time		(msec)																	23	29	26	24
	(-)	(m/sec2)			2211	1127	3255	3843	4113	3765	432	450	3783	3825	3843	1517	1565	1253	803	863	606	695
Time		(msec)			29	29	27	29	30	31	55	44	23	23	30	31	22	39	35	21	20	20
Max SLED Decelerations																						
Left side.		(m/sec2)	14.0	7.0	17.1	18.7	18.0	16.2	16.2	18.0	11.7	11.5	16.2	18.0	15.7	16.4	16.6	[illegible]	10.7	12.1	12.1	11.7
Right side.		(m/sec2)			13.6	-.-	14.0	12.8	12.1	14.0	9.6	7.9	12.6	14.1	12.2	12.4	12.9	13.3	9.0	10.9	9.7	9.2