EXPERIMENTAL STUDY OF PEDESTRIAN KINEMATICS AND INJURIES

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Two years ago we started a joint research on improvement pedestrian safety in case of car to pedestrian traffic accident. This study involves together CITROEN Car Factory, Anatomical Laboratory of the Marseille's Medical University (secteur Nord) and the Crash test Laboratory of ONSER.

In a previous paper (1) we presented the aims and the method of this research. This study uses results obtained from tests with fresh cadavers and with anthropomorphic dummies. Tests are performed with an impact speed varying from 10 km/h to 40 km/h, and the pedestrian is hit either on his profile or on his face in the axis of the striking vehicle.

Tests are conducted with a scale 1 car model whose front end is identical to the front end of the chosen vehicle.

1. TESTS DESCRIPTION

For this study we performed 16 tests with a ONSER 50 percentile dummy and 31 tests with umbalmed cadavers. Tables 1 and 2 include the main characteristics of the tests.

The previsionnal test programme of this study includes several tests conducted under the same conditions of speed, crash configuration, car model. For each crash condition we performed 3 or 4 tests. The test programme of 39 km/h impact speed is not yet completed and ut to date, we have performed only 2 tests for each crash condition at this impact speed. In the same way, due to the absence of injury, we performed few tests at 10 km/h impact speed. The results analysed for this study are those of the 3 tests performed with fresh cadavers. All the tests planned are not yet completed and especially we have to perform tests at 32 km/h impact speed, which is intermediate between 25 and 39 km/h.

In the same way we have introduced a new front end (Citroen GSA) with which we will conduct comparative tests under the same conditions as those chosen for the tests with the first vehicle (Citroen Visa). This vehicle was used with two contours of profile : on one hand the profile of the mass production car, and in the other hand with a modified profile in order to a simultaneous contact on the bumper and on the bonnet (fig. 1) This modification changes neither the vehicle length nor the stiffness of

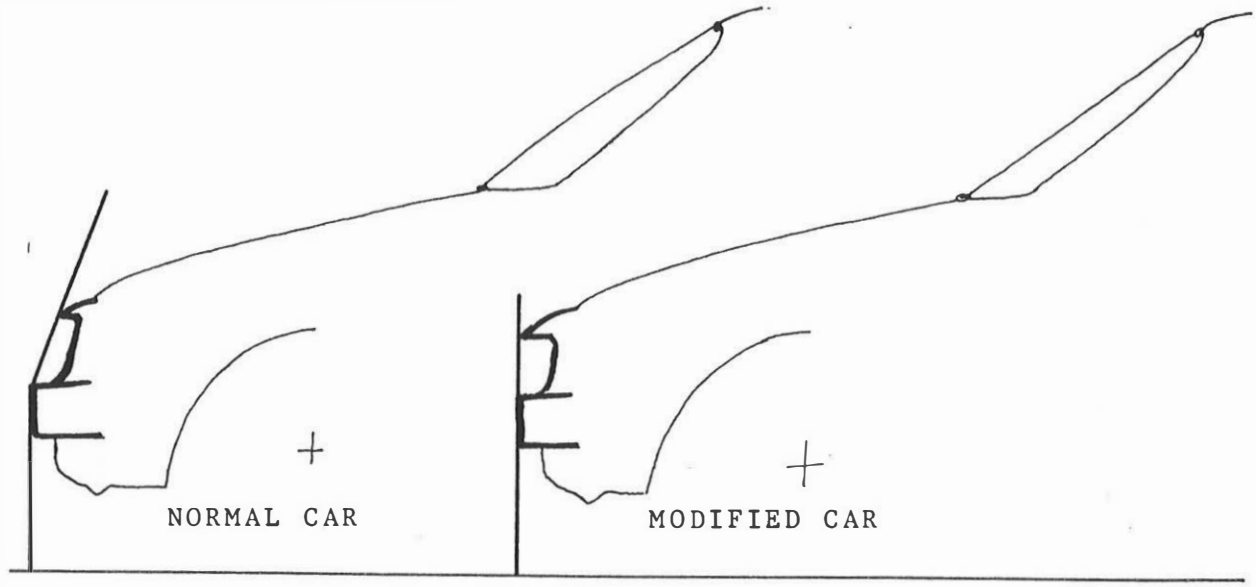

Fig.N° I: COUNTOUR OF CITROEN VISA

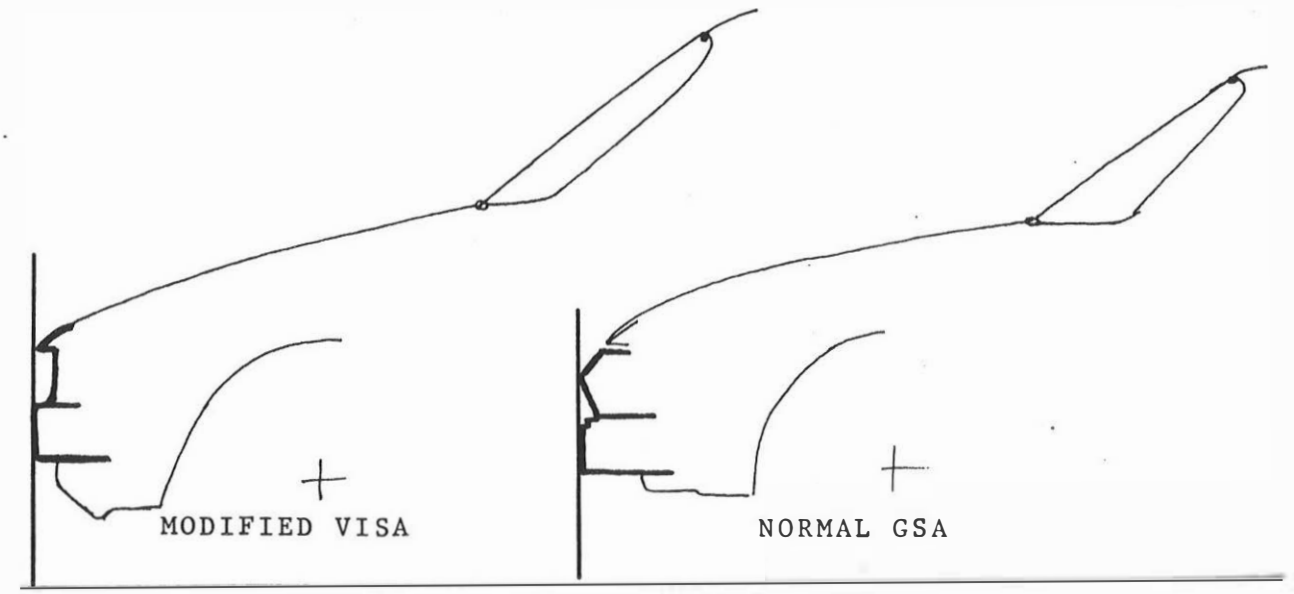

Fig.N° 2: COUNTOUR OF CITROEN VISA AND GSA

Impact speed	Position	Vehicle	Modification	Number of tests
20	face	Visa	no	4
20	profile	Visa	no	4
25	face	Visa	no	2
25	face	Visa	yes	2
25	profile	Visa	no	2
25	profile	Visa	yes	2

Table 1 : Main characteristics of dummy tests

Impact speed	Position	Vehicle	Modification	Number of tests
10	face	Visa	no	2
10	profile	Visa	no	2
20	face	Visa	no	3
20	profile	Visa	no	3
25	face	Visa	no	4
25	face	Visa	yes	3
25	profile	Visa	no	3
25	profile	Visa	yes	3
39	face	Visa	no	2
39	face	GSA	no	2
39	profile	Visa	no	2
39	profile	GSA	no	2

Table 2 : Main characteristics of cadaver tests

contacted elements.

The profile of the second car (Citroen GSA) was approximately identical with the profile of the modified first car ; nevertheless its windscreen is more away from the front extremity (fig. 2). But their structures have a different stiffness, which is specific of the chosen vehicle.

2. OVERALL RESULTS

Analysis of results is made by associating for each test injuries of cadaver (description and severity) with the crash conditions (impact speed and impact configuration). The results of tests are detailed in appendix. Analysis of these tables allows to precise the level of injury production as a function of impact speed and pedestrian crash configuration.

In 10 km/h impact speed tests, we never observe any injury, the pedestrian being either facing or in profile. However we performed only 4 tests (2 for each crash configuration) at this impact speed.

In 20 km/h impact speed tests, all the three pedestrians hit facing sustained injuries mainly to the head and for to the lower limbs. These injuries are not severe and are generally wounds or fractures at the knee level, face wounds and fractures of facial bones (nose and mandible). The severity of these injuries is never higher than AIS 2.

The 3 pedestrians hit on their profile at the same speed sustained injuries of various severities. Two of them showed severe injuries (AIS 4) whereas the third one did not sustain any injury which could be displayed by a cadaver. The two injured subjects sustained lesions to the impacted side lower limb at the knee level, associated for one of them with a femoral neck fracture; with pelvic rami fracture and with a C6 body vertebra fracture ; for the other one the right leg fracture was associated with a liver perforation with mechanism is unusual (perforation of liver parenchyma by the xyphoid process).

For the 25 km/h tests we have the results of 7 tests facing and of 6 tests in profile. All the cadavers hit facing sustained injuries shown by autopsy and or by X ray. The severity of these injuries goes from AIS 1 to AIS 5.

It is noticeable that 2 out of the 7 subjects did not sustain lower limb injuries. The most severe injuries were cervical spine fracture at C5/C6 level (1 case) and a skull fracture in the temporal area (1 case).

All the 6 subjects hit in profile at 25 km/h impact speed were injured. The severity of these injuries goes from AIS 2 to AIS 5 and on an average injuries are more severe than those sustained in facing impacts at the same speed.

At the lower extremities, one subject did not sustain lower limb injuries whereas 3 out of 6 sustained severe injuries of lower limbs (AIS 3). At the

Test number	Car impact speed Vo (m/s)	Head impact speed Vta (m/s)	Vta/Vo	Cadaver height L (cm)	Contact length l (cm)	L/l
9.3	2.83	3.90	1.38	161	103	0.64
11.1	2.81	4.76	1.69	163	104	0.70
14.4	5.55	6.45	1.16	165	158	1.04
17.4	5.55	6.4	1.15	182	172	0.95
20.4	5.56	6.3	1.13	178	185	1.05
22.3	6.97	7.38	1.06	178	197	1.11
26.1	6.97	8.80	1.26	162	179	1.10
43.1	6.93	9.65	1.39	172	166	0.97
43.4	6.94	8.55	1.23	170	166	0.98
46.3	6.89	10.36	1.50	187	207	1.11
FOC.04	7.14	9.5	1.33	160	152	0.95

Table 3 : Head impact speed and location in facing tests

Test number	Car impact speed Vo (m/s)	Head impact speed Vta (m/s)	Vta/Vo	Cadaver height L (cm)	Contact length l (cm)	L/l
9.1	2.75	3.75	1.36	157	100	0.64
14.5	5.64	6.47	1.15	174	159	0.91
17.5	5.55	5.41	0.97	160	152	0.95
22.4	6.92	5.88	0.85	164	166	1.01
26.2	6.98	6.80	0.97	163	171	1.05
43.2	6.89	6.39	0.93	165	166	1.01
46.5	6.96	8.0	1.15	170	173	1.02
26.3	6.94	6.32	0.91	170	154	0.91
FOC.02	7.08	7	0.99	170	178	1.05
FOC.03	7.08	5.9	0.79	185	215	1.16

Table 4 : Head impact speed and location in profile tests

thoraco-abdominal level, the more severe injuries sustained by the cadavers hit in profile at 25 km/h impact speed were a multiple ribs fracture associated with a rupture of spleen and of coronary ligament of liver (1 case) and fracture of 2 ribs associated with pulmonary injuries.

8 tests were conducted at 40 km/h impact speed, 4 facing and 4 in profile. The 4 subjects hit facing were seriously injured (3 cases AIS 5, 1 case AIS 4). All of them sustained multiple severe injuries : they were injured at least at 2 different body regions with AIS 3 injury severity.

The typical injury association is skull fracture and lower limb fractures, injuries to which are added sometimes multiple rib fractures.

The 4 subjects hit in profile at 40 km/h impact speed were approximately as severely injured as in facing tests (3 cases AIS 5, 1 case AIS 3) but the injuries are more various.

Two out of the 4 subjects hit in profile at 40 km/h impact showed after impact severe skull fractures, associated for one of them with multiple rib fractures with a liver tear, and with multiple pelvic and leg fractures. Severe thoracic injuries were found on half of subjects hit in these conditions.

3. HEAD IMPACTS

Head injuries are frequent and severe especially in high speed tests (40 km/h). These injuries seem to be produced by contact against the vehicle but they are significantly reduced if a ground protection device is provided. To propose a protection, it is necessary to have a better knowledge of pedestrian head impacts, in terms of impact speed and impact location. The results of head impact speed and location of tests are listed in tables 3 & 4.

3.1. Head impact speed

By analyzing the high speed films we have determined the head impact speed against the vehicle for all the tests except the 40 km/h tests.

The head impact speed increases as the car impact speed. The head impact speed is always higher than the car impact speed when the pedestrian is hit facing whereas in profile tests, there are in a same order of magnitude.

In facing tests, the head impact speed is notably higher than the car impact speed. The ratio of head impact speed versus car impact speed is lower at 20 km/h test and increases again with the impact speed. It seems that, at 10 km/h impact speed the influence of the car impacting the pedestrian is weak and the head impact speed is mainly due to the acceleration gravity : the cadaver is thrown out of balance by the car front end and fall down on the bonnet during the car braking.

In profile tests, the ratio between the head impact speed and car impact speed does not seem to change with impact speed.. In 2 out of the 12 tests, there were no head impact on the vehicle because the cadaver placed his right arm between his head and the car bonnet.

3.2. Head impact location

The severity of head injuries sustained by pedestrians can be related with head impact speed and head impact location : indeed, each component of the car body has its own stiffness and if the head hit a rigid element, the risk of head injury is increased.

In tables 3 and 4 are listed the head impact speed and head impact location related to cadaver height. The head contact length is the curved distance between the ground and the head impact point on the car, following the car outline in its middle. It is noticeable that the ratio of the cadaver height versus head contact length is almost equal to 1 except at 10 km/h tests in which this ratio is lower. This means that it is possible to predict the head impact area on the car at impact speed up to 25 km/h. The lower value of this ratio in 10 km/h tests confirms the effect of gravity at low impact speed which is more important than the impact itself.

4. INFLUENCE OF THE CAR SHAPE MODIFICATION

Some tests were conducted with a modified Citroën Visa. This modification described in the first part of this paper, gives an initial contact on the pedestrian at a higher level than with the normal Citroën Visa. As there is few tests conducted with the modified car, it is impossible to precise the influence of the modification in terms of injuries and head impact speed. However, this modification brings the head impact area closer to the front end of the car. Indeed, the ratio of cadaver height versus contact length is not changed by the car modification and the contact length to reach a chosen point on the bonnet is longer with the modification than without..

The modified Visa need a higher impact speed than the normal Visa to allow the pedestrian head to hit the windscreen area.

5. CONCLUSION

Analysis of these 31 tests involving fresh cadavers as pedestrians pointed out that there is a risk of severe injuries at impact speed as low as 20-25 km/h as well in profile configuration as in facing configuration.

The head impact speed against the car increases with the car impact speed and for a same car impact speed, head impact speed is higher in facing than in profile. The head impact area on the car is influenced by the cadaver height. The modification of the Citroën Visa shape which gives a simultaneous contact on the thigh and on the leg seems to change the head impact area on the bonnet but not the injuries.

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A P P E N D I X

In the following pages are the detailed results of the 31 cadaver pedestrian tests.

	Test	Sex	Height cm	Weight kg	OAIS	LESIONS
10 km/h face	9/3	F	161	80	0	
	11/1	F	163	55	0	
20 km/h - face	14/4	M	165	34	2	right tibial plateau fracture and right patella fracture (AIS 2)
	17/4	M	182	67	2	forehead abrasion with fracture of the nose and of the left mandibule (AIS 2) erosions of the knees (ais 1)
	20/4	M	178	74	2	frontal abrasion (AIS 1) knees and legs contusions, internal right knee condyle fracture (AIS 2)
10 km/h Profile	9/1	F	157	49	0	
	11/2	M	174	46	0	
20 km/h - Profile	14/5	M	175	58	0	
	17/5	F	160	52	4	forehead erosions (AIS 1) liver superficial perforation (AIS 4) knees contusion, right head fibula fracture (AIS 2)
	20/3	F	162	56	4	nose abrasion (AIS 1) fracture of C6 (AIS 3) fractures of the right os pubis rami, internal right knee condyle fracture (AIS 3)

	Test	Sex	Height cm	Weight kg	OAIS	LESIONS
25 km/h - face	22/3	M	178	77	5	nose abrasion with fracture (AIS 2) fracture of C4 and C6 (AIS 5) fractures of right and left 5th and 6th ribs (AIS 3) fractures of internal right tibial plateau, rupture of the right ligamentum collaterale tibiale (AIS 3)
	26/1	F	172	55	1	forehead abrasion (AIS 1)
	43/1	M	172	65	2	forehead abrasion with nose fracture (AIS 2) left 5th and 6th ribs fracture (AIS 2) knees contusion (AIS 1)
	43/4	M	170	45	4	scalp and forehead contusion with right temporal fracture (AIS 4) right fibula fracture (AIS 2)
	46/3	M	187	87	1	forehead abrasion (AIS 1)
	FOC/02	M	170	70	2	forehead contusion with nose fracture (AIS 2) left fibula fracture with rupture of the ligamentum collaterale fibulare (AIS 2)
	FOC/04	F	160	49	2	forehead contusion with nose fracture (AIS 2) right fibula fracture, fracture of the external tibial plateau with rupture of the ligamentum collaterale fibulare (AIS 2)

	Test	Sex	Height cm	Weight kg	OAIS	LESIONS
25 km/h - Profile	22/4	F	164	60	2	forehead abrasion + nose fract. (AIS 2)
	26/2	F	163	58	5	forehead abrasion (AIS 1) fracture of the 6th to the 10th left ribs, spleen rupture, rupture of the ligamentum coronarium hepatis (AIS 4) right fibula fracture with rupture of the ligamentum collaterale tibiale, rupture of the left ligamentum collaterale fibulare (AIS 3)
	26/3	M	170	87	3	frontal abrasion (AIS 1) rupture of the left ligamentum collaterale fibulare and fracture of the left head fibula (AIS 3)
	43/2	F	165	57	2	right scalp and face abrasion (AIS 1) right fibula neck fracture, left fibula fracture (AIS 2)
	46/5	M	170	67	3	open comminuted fracture of the third upper part of the right tibia, fracture of the neck of the right fibula (AIS 3)
	FOC/03	M	185	80	4	right temporal abrasion (AIS 1) fracture of the 4th and the 6th left ribs with lung laceration (AIS 4) fracture of the head of the fibula (AIS 2)

	Test	Sex	Height cm	Weight kg	OAIS	LESIONS
40 km/h - Face	FOC/05	M	166	54	5	nose and supra-orbital ridge contusion with right occipito-parietal fracture (AIS 4) right internal tibial plateau fracture with rupture of the ligamentum collaterale tibiale, left tibial plateau fracture (AIS 3
	FOC/07 (with ground protection device)	F	160	66	4	forehead abrasion (AIS 1) left 1st to 5th ribs fractures, right 2nd, 3rd and 8th ribs fractures, sternal fracture at the 3rd upper part (AIS 4) right external tibial plateau fracture with rupture of the ligamentum collaterale tibiale avulsion of the tubercle of the tibia and rupture of the ligamentum cruciatum anterius (AIS 3)
	FOC/09	M	172	49	5	nose fracture and fracture of the base of the skull (AIS 5) fracture of the two condyles of the right femur, fracture of the shafts of the right tibia and fibula, open fracture of the shafts of the left tibia and fibula, left tibia plateau fracture with rupture of ligamentum cruciatum anterius (AIS 4)
	FOC/11	F	169	36	5	nose and orbitale plate fracture (AIS 5) fracture of 3rd to 6th right ribs left femoral neck fracture, left and right tibial plateau fracture, left and right tibia and fibula fracture (AIS 4)

	Test	Sex	Height cm	Weight kg	OAIS	LESIONS
40 km/h - Profile	FOC 06	M	176	50	5	forehead abrasion (AIS 1) flail chest of 2nd to 10 th right ribs and 5th to 7th left ribs (AIS 5) right fibula third upper part fracture left tibia tubercle fracture (AIS 2)
	FOC/08 (with ground protection device)	M	180	63	3	nose abrasion (AIS 1) right 6th and 7th rib fracture (AIS 2) right tibia and fibula comminuted fracture with rupture of the ligamentum collaterum fibulare, left tibial plateau and semi lunar cartilage fractures (AIS 3)
	FOC/10	M	167	55	5	temporal bone fracture involving petrous bone (AIS 5) dislocation of C5/C6 (AIS 3) 2nd to 6th right ribs fracture, liver laceration (AIS 4) right os pubis rami fracture, right shaft femur fracture, right tibial plateau and fibula head fractures associated with rupture of ligamentum cruciatum anterius left tibial and fibula fracture, external left malleolus fracture rupture of the ligamentum collaterum fibulare (AIS 4)
	FOC/12	M	185	74	5	nose and scapl abrasions, nose fracture, right complex skull fracture involving frontal, parietal and temporal bones, radiating to petrous bone (AIS 5) right tibial plateau fracture right fibula head fracture rupture of the ligamentum cruciatum anterius (AIS 3)