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SIMULATION OF A COLLISION BETWEEN PASSENGER CAR AND CHILD PEDESTRIAN

ABSTRACT

The Department of Forensic Experts in Transportation at the Faculty of Transportation Sciences performed a second set of dynamic passive safety tests of a passenger car (M1 category - Škoda Octavia II) in a child pedestrian collision. The initial and test conditions were similar to those of the first set of tests in September 2009 (Škoda Roomster). The deformations of the contact zones on the frontal vehicle surface were analyzed by a 3D scanning technology (3D handy scanner). Head, thorax and pelvic resultant acceleration, acceleration of knee joint in sagittal direction and contact force on the femoral structure of the dummy (P6 dummy, 1.17m; 22kg) were measured. The aim of these tests is to provide a detailed description of pedestrian kinematics and comparison of primary and secondary impact seriousness.

KEY WORDS

passenger car, child pedestrian, primary and secondary impact, dummy instrumentation, injury criteria, 3D scanning

1. INTRODUCTION

Pedestrian safety is nowadays one of the very important criteria in case of the vehicle safety evaluation. Vehicle certification standards are based on the vehicle frontal part testing with impactors which represent certain body parts of an adult pedestrian. The risk of the impact consequences for children is only tested by the head impactor test [1]. The reason for this stems from many different scientific studies. They proved that the head is the most frequently injured body part in adults as well as in child pedestrians. This conclusion is more significant in case of child pedestrians as it is demonstrated by the two independent sources in *Table 1*. A head injury within the frame of polytrauma is usually a predictive injury from the fatality rate point of view. This fact is the predictive factor for the current child pedestrian passive safety certification methodology.

In order to obtain more information on the child pedestrian injury spectrum, a detailed analysis of patients hospitalized at the Anaesthetic Resuscitation Clinic in Motol´s Faculty Hospital in Prague in the period from 1996 to 2007 was performed, and contributed to ascertaining the rate and injury seriousness of other children's body parts (see *Table 1*). Based on the forensic expert's experience, cases which caused similar consequences were selected.

The Faculty of Transportation Sciences performed the second set of three dynamic passive safety tests of a passenger car (category M1 – Škoda Octavia II) vs. child pedestrian collision. The tests were performed at different impact speeds (10; 20; 30 kmph), analogous to the first set of tests made in September 2009 with Škoda Roomster. The deformations of the contact zones on the frontal vehicle surface were analyzed by 3D scanning technology. Head, thorax and pelvic resultant acceleration were measured on a child dummy P6. The dummy was modified due to the demand on higher number of measuring areas than in the case of the original P6 dummy, which is intended for child restraints testing. The left upper leg was equipped with two strain-gauge halfbridges on the femoral skeleton for the contact force measurement. One uniaxial accelerometer was installed in the knee area for the measurement of acceleration in the sagittal direction.

The initial and test conditions were similar to those of the tests in 2009. The acceleration measuring was made by new equipment.

Table 1 - Pedestrian injury distribution with respect to certain body region [2, 3]

	Source (1)		Source (2)	Source (3)
	Adults	Children	Adults	Children
Head	30.9%	56.4%	31.3%	42.1%
Neck	4.3%	0.0%	1.3%	4.8%
Thorax	12.8%	7.7%	10.2%	14.0%
Upper extremities	7.4%	12.8%	8.1%	3.6%
Abdomen	1.1%	0.0%	5.6%	8.5%
Pelvic	5.3%	0.0%	6.3%	10.5%
Lower extremities	38.3%	23.1%	32.4%	16.5%

Source (1) GIDAS/German In-depth Accident Study, file range N = 188
Source (2) IHRA/PS Accident Data
Source (3) Clinical study made by author, patients of Anaesthetic Resuscitation Clinic in Motol´s Faculty Hospital between years 1996 – 2007, Range of patients file N = 146
Note: Source (3): A total of 479 injuries

2. EXPERIMENT

2.1 Conditions

With respect to the technical specifications and the possibility of the comparability with the previous measurement, the following initial conditions were formulated:

a) collision of a passenger car (M1 category),
b) P6 dummy, (6 years; 1.17m; 22kg) which was adapted for the test – mentioned above. (Note: There is no child dummy which is specified for full-scale pedestrian – vehicle crash tests).
c) dummy position: the dummy was facing the approaching vehicle, heel standing in the longitudinal axis of the vehicle (see *Figure 1*),
d) proposed collision speeds: 10; 20; 30 kmph,
e) the vehicle is starting to break at the moment of the crash contact.

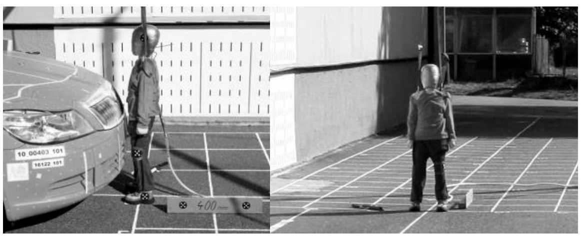

Figure 1 - Initial dummy position

Measured quantities

- real vehicle speed, vehicle acceleration (3D),
- acceleration time flow of the dummy (according to the dummy instrumentation),
- contact force time flow in femur,
- high speed video recording,
- dimensional characteristics of the process (initial and final location of colliding object),
- 3D scanning of contact zones after collision and car damage.

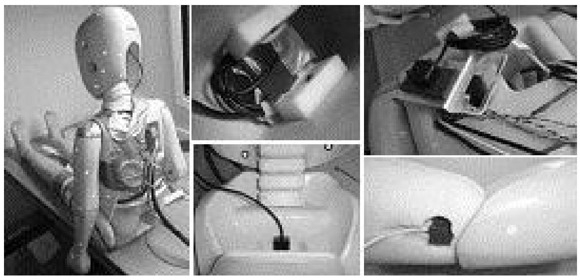

Figure 2 - Dummy instrumentation

Dummy instrumentation (see Figure 2)

- head: 3-axis accelerometer, directions x, y, z, 1,000g range,
- thorax: 3-axis accelerometer, directions x, y, z, 1,000g range,
- pelvic region: 3-axis accelerometer, directions x, y, z, 500g range,
- knee joint: 1-axis accelerometer, direction x, 500g range,
- upper leg: femoral skeleton – two strain-gauge halfbridges, uniaxial state of stress.

Passenger car Škoda Octavia II, 1.4 MPI

- maximum power: 59kW
- total displacement: 1,390cm [3]
- curb weight: 1,255kg
- the car was equipped with an antireflection coating and impact zones on the bonnet due to the 2003/102/EC directive [4]

3. TIME COURSE OF THE EXPERIMENT

Three tests at the real impact speed of 12.2 kmph (test No. 101), 22.4 kmph (test No. 201) and 30.6 kmph (test No. 301) were made.

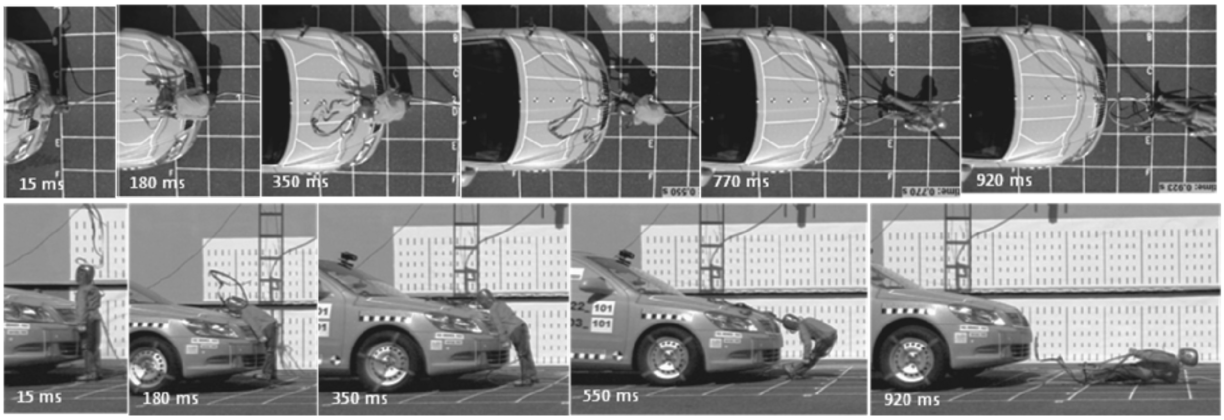

Figure 3 - Test No. 101- video sequence

3.1 Test No. 101, impact speed 12.2 kmph

Time of the first contact of the dummy with the vehicle: t_{s101} = 15ms.

3.2 Impact speed 22.4kmph

Time of the first contact of the dummy with the vehicle: t_{s201} = 9ms.

3.3 Impact speed 30.6 kmph

Time of the first contact of the dummy with the vehicle: t_{s301} = 3ms.

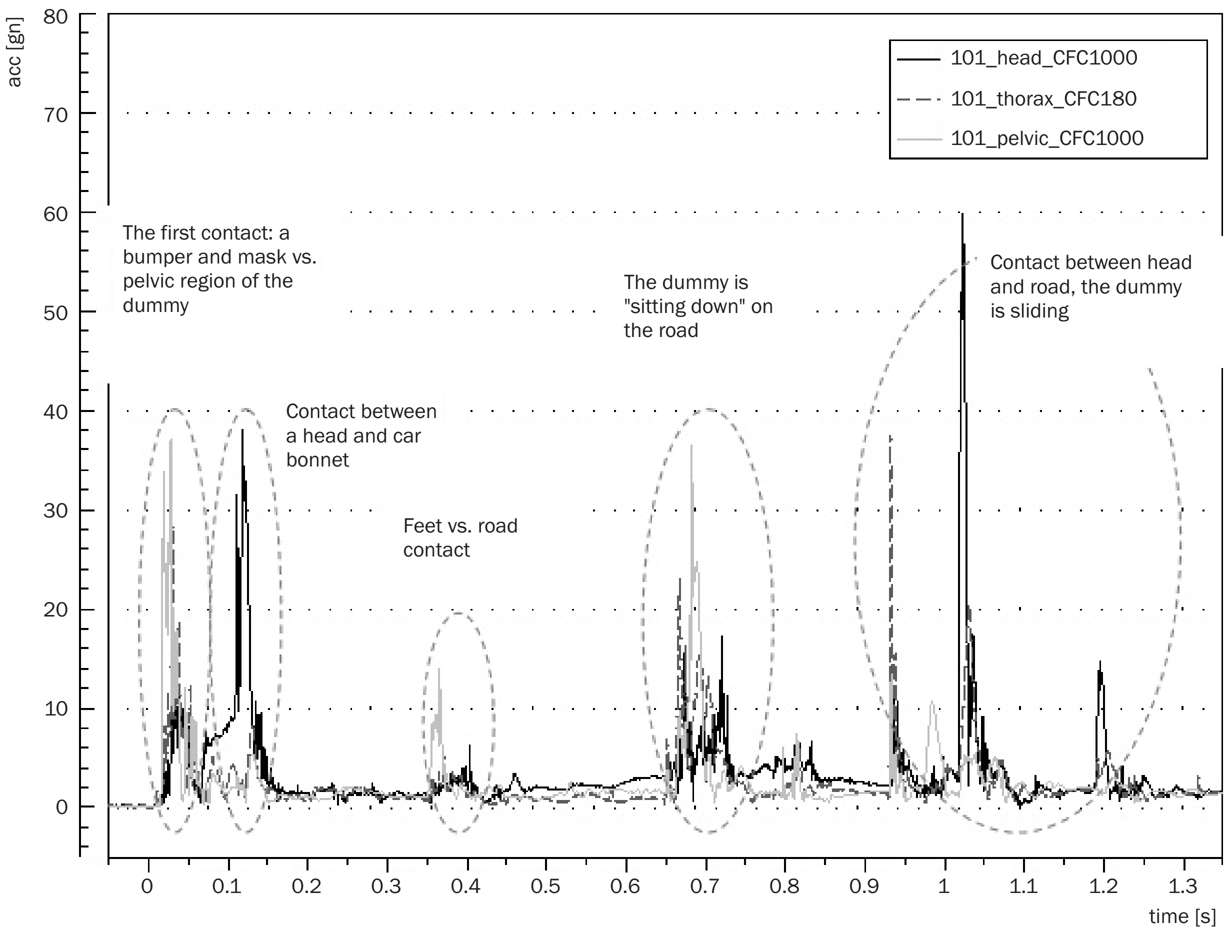

Figure 4 - Test No. 101 – measured acceleration for head (black solid), thorax (dashed) and pelvic (gray solid)

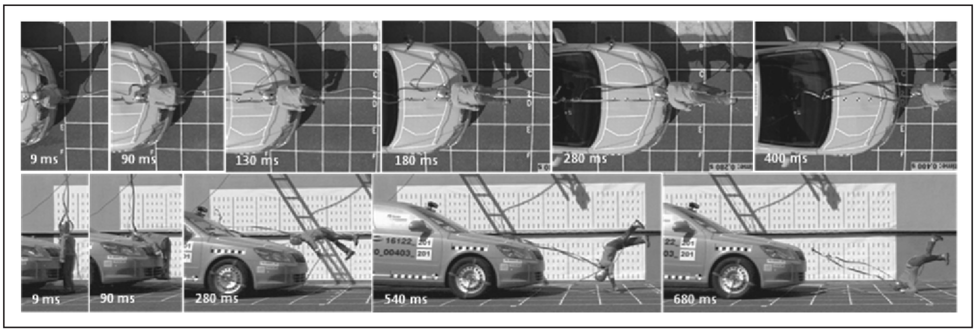

Figure 5 - Test No. 201- video sequence

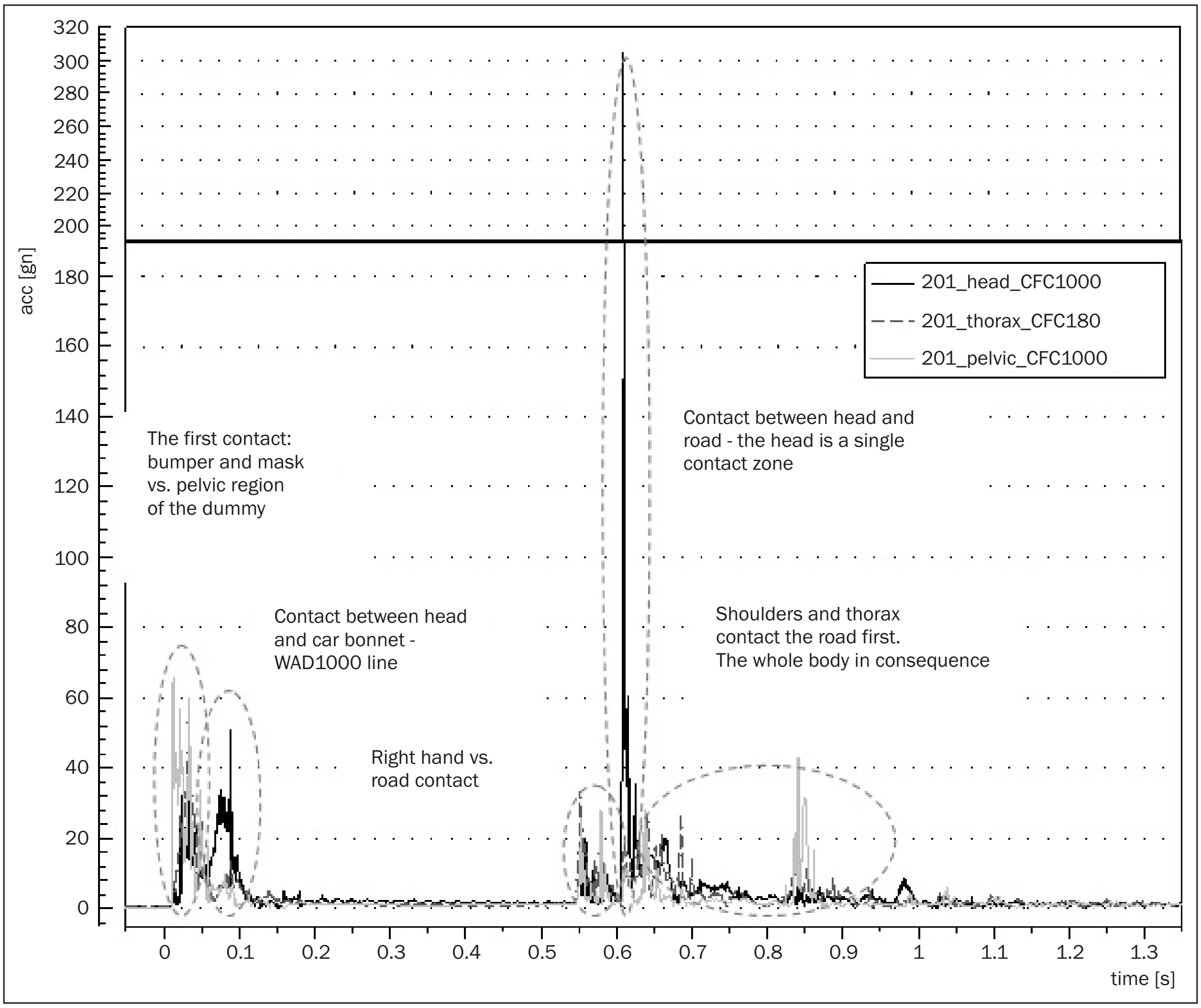

Figure 6 - Test No. 201 – measured acceleration for head (black solid), thorax (dashed) and pelvic (gray solid)

4. RESULTS

4.1 Biomechanical criteria values [5]

Injury criteria - head: HPC and 3ms

The head performance criterion is defined by the following formula:

$$HPC = \left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a.dt\right]^{2.5} (t_2 - t_1) \quad (1)$$

where a = resultant acceleration in g, t_1 a t_2 = time points, which determine the beginning and end of a time interval, where the *HPC* value is maximal. *HPC* limit value is 1,000. According to the US standard FM-VSS 208 "Occupant crash protection" HPC_{15} limit val-

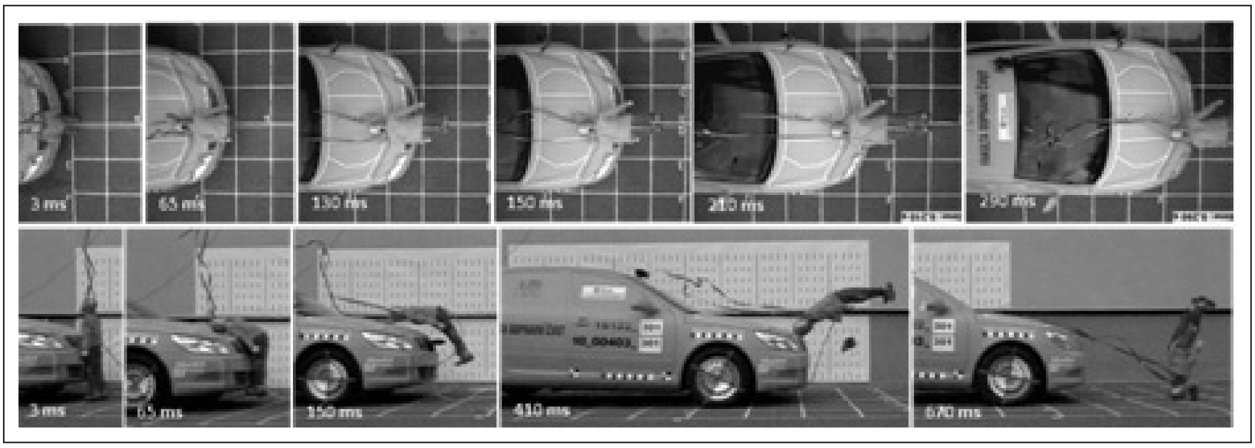

Figure 7 - Test No. 301- video sequence

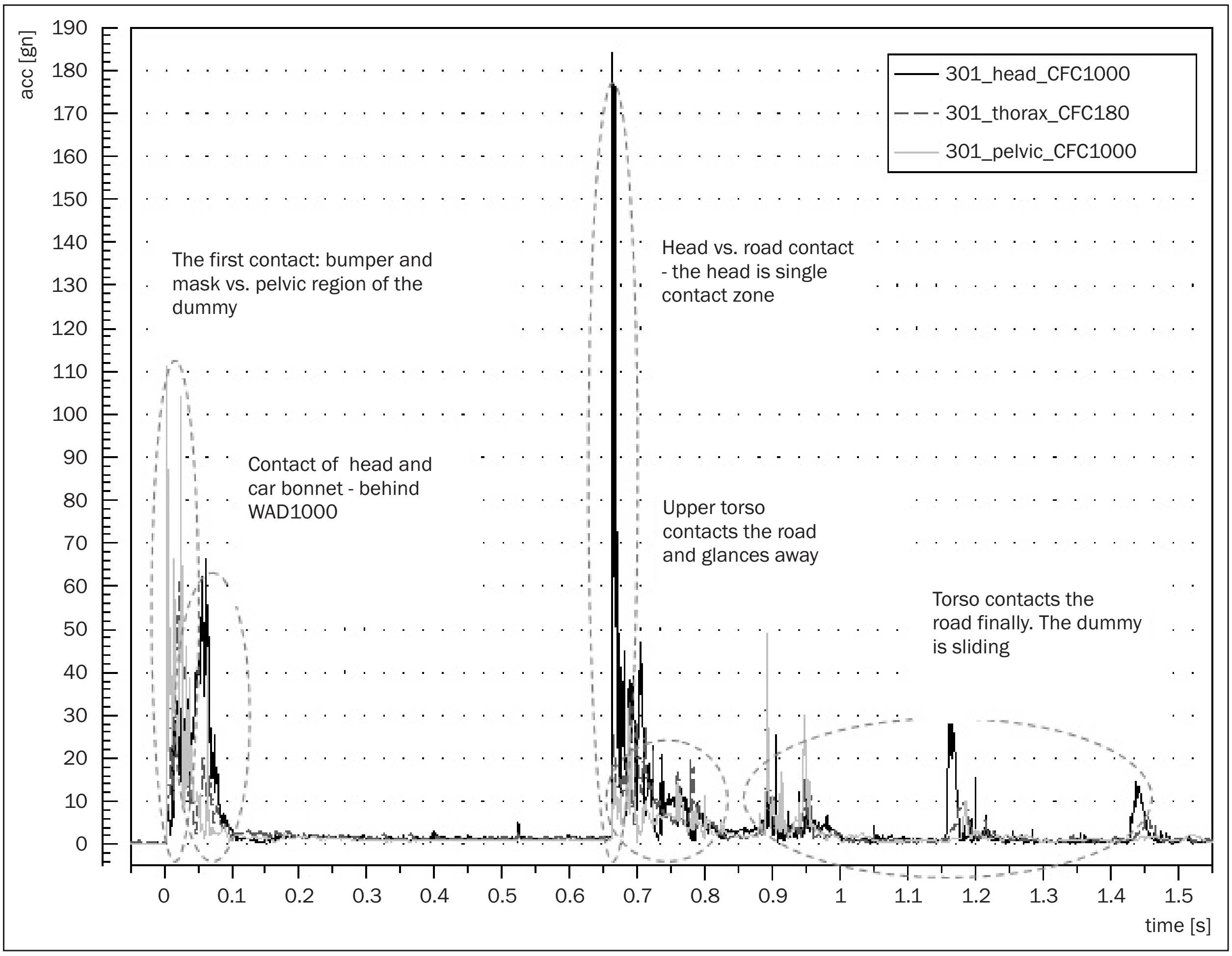

Figure 8 - Test No. 301 – measured acceleration for head (black solid), thorax (dashed) and pelvic (gray solid)

ue in case of a 6-year-old child reaches 700 [6]. *HPC* measured values are presented in *Table 1*.

The 3ms criterion is applicable not only to the head performance, but also to other body segments. The limit value for head is 80g. Criterion interpretation: Acceleration higher than 80g must not act longer than 3ms.

According to the US standard FMVSS 208 "Occupant crash protection" HPC_{15} limit value in case of a 6-year-old child reaches 60g [6]. 3ms measured values (see *Table 2*):

3ms injury criteria – thorax

The limit value of this criterion in case of thorax is 60g. According to standard ECE 44 "Child restraints

Table 2 - Head performance criterion (HPC) and 3ms criterion

test no:	velocity	Primary impact		Secondary impact		Primary impact		Secondary impact	
		HPC_{15}		HPC_{15}		a3ms		a3ms	
	[kmph]	[-]	limit	[-]	limit	[g]	limit	[g]	limit
101	12.2	58.2	1,000/700	135.6	1,000/700	33.7	80/60	52.8	80/60
201	22.4	58.3	1,000/700	554.8	1,000/700	26.1	80/60	49.7	80/60
301	30.6	251.3	1,000/700	862.7	1,000/700	46.6	80/60	88.7	80/60

systems” limit value in case of a 6-year-old child reaches 55g [7]. Measured values (see *Table 3*):

Table 3 - 3ms criterion - thorax

test no:	velocity	Primary impact		Secondary impact	
		a3ms		a3ms	
	[kmph]	[g]	limit	[g]	limit
101	12.2	13.6	60/55	19.3	60/55
201	22.4	38.9	60/55	21.7	60/55
301	30.6	50.9	60/55	22.9	60/55

a_{max} *injury criteria – pelvic*

The maximum acceleration value must not exceed 130g (see *Table 4*).

Table 4 - 3ms criterion - pelvic

test no:	velocity	Primary impact		Secondary impact	
		a_{max}		a_{max}	
	[kmph]	[g]	limit	[g]	limit
101	12.2	37.1	130	36.6	130
201	22.4	65.9	130	44.2	130
301	30.6	111.4	130	39.1	130

Femur injury criterion – contact force

The bending femur tolerance is not strictly defined. In case of adult femur the following bending limits are frequently published: 1.5kN to 4kN. Levine (2002) [5] published the bending limit value till rupture 3.92kN

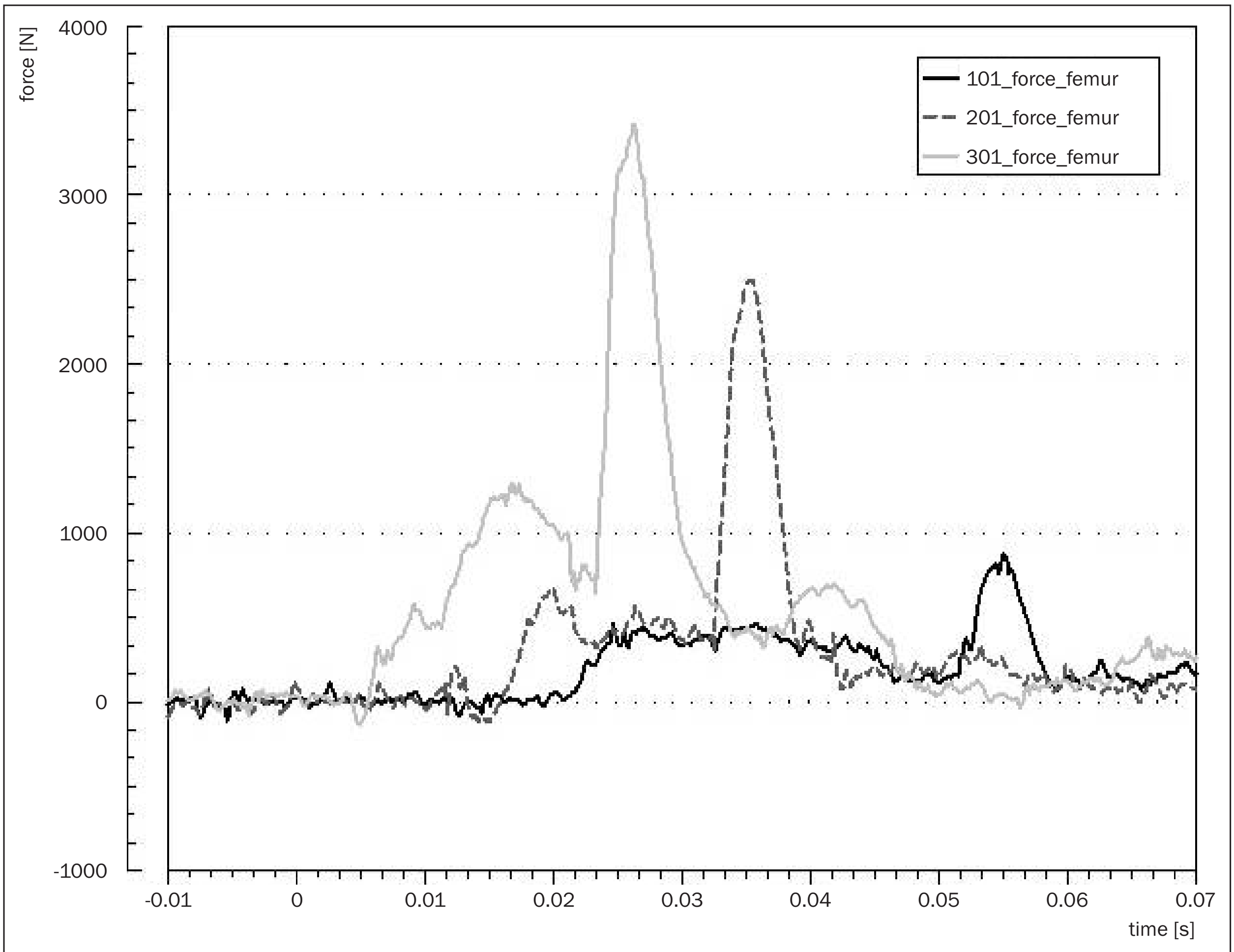

Figure 9 - Femur contact force time course

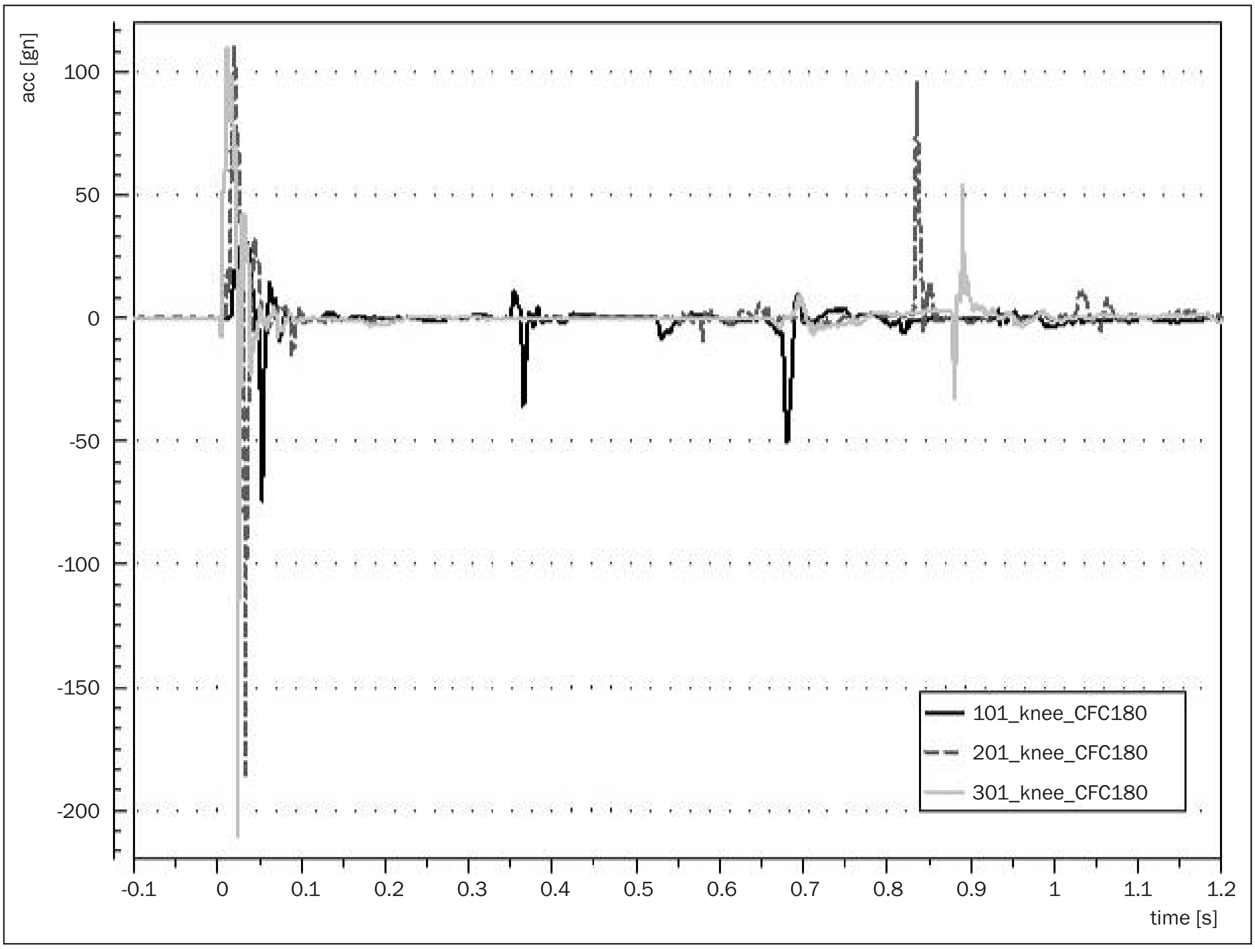

Figure 10 - Knee acceleration time course in x direction

for men and 2.58kN for women. Yamada (1970) published the maximum bending limit till specimen rupture in relation to the donor's age [8, 9]. In the group from 20 to 39 years the limit is ca. 2.8kN in case of 260mm [2] femur cortical bone cross-sectional area and bending strength 212N/mm [2]. In children group of around 6 years Yamada published the same level of bending strength, femur has higher level of plasticity and is able to absorb more energy till rupture, cross-sectional area of cortical bone is smaller [8, 10]. For the measured values see *Figure 9*.

Table 5 - Maximum femur contact force

test no:	Primary impact	
	F_{max}	
	[N]	t [ms]
101	877	55
201	2,497	35.5
301	3,418	26.2

Knee acceleration

Maximum acceleration value must not exceed 170g. The measured values are presented in *Table 6*.

Table 6 - Maximum knee acceleration in x direction

test no:	Primary impact		Secondary impact	
	a_{max}		a_{max}	
	[g]	limit	[g]	limit
101	74.6	170	50.5	170
201	186.8	170	96	170
301	210.4	170	54.2	170

4.2 3D scanning – 3D data digitalization

3D scanning is a process of data digitalization; the goal is to express the real object in a virtual (mathematical) way. This method of digitalization is able to record space or solid effectively.

The result of 3D digitalization is "a point cloud" where the position of every single point is detected by a 3D scanner. This type of application in connection to a formulated task allows to record car body damage after a crash test.

Method requirements: mobility of device, limited time for scanning (max. 15 minutes for one scanning series), scanning accuracy (in 0.01mm), reliability of the device, data quality, non-contact scanning, out-

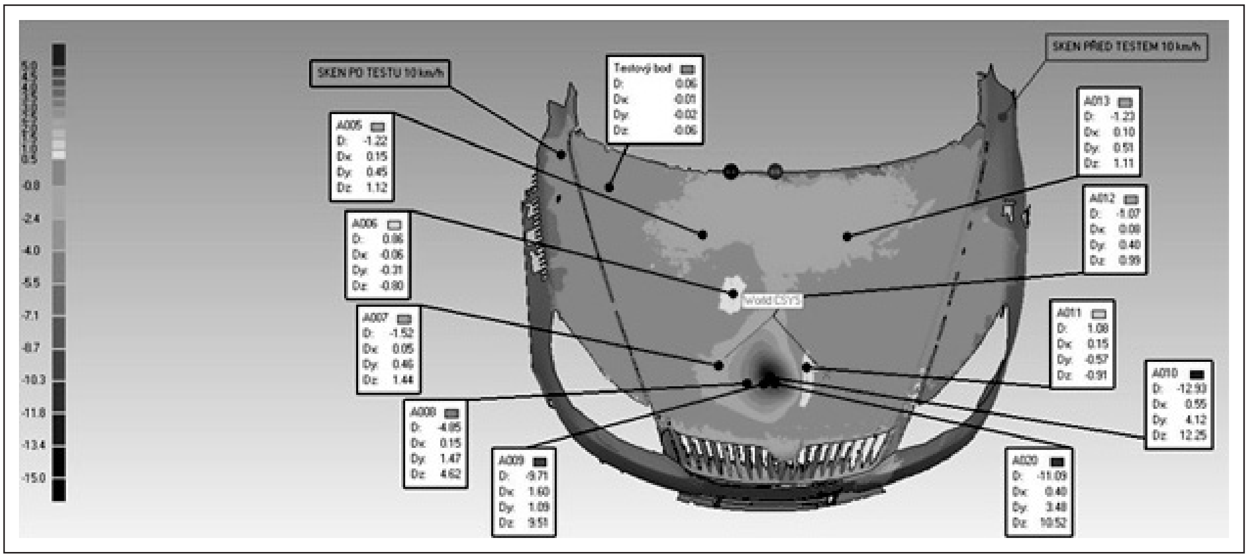

Figure 11 - 3D analysis and deformation map for test 101 - 12.2kmph

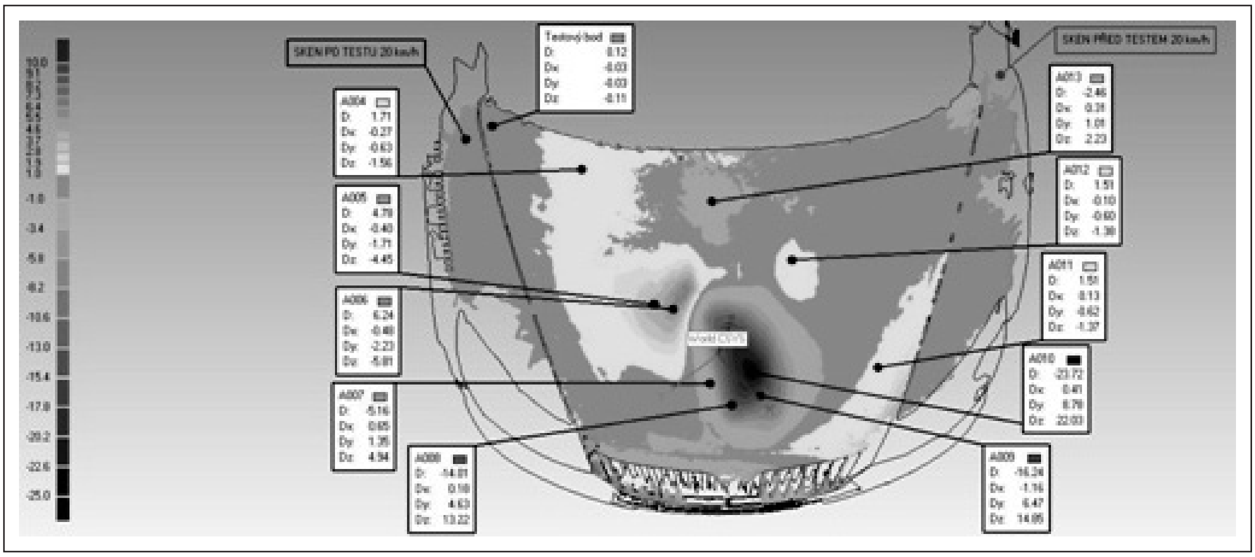

Figure 12 - 3D analysis and deformation map for test 201 - 22.4kmph

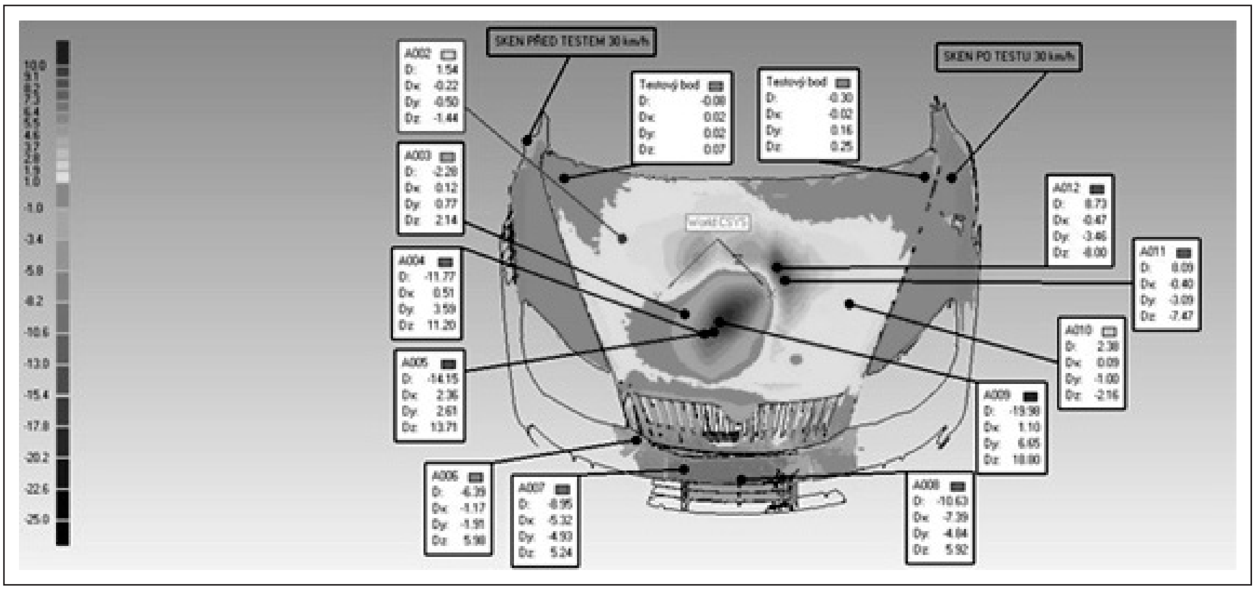

Figure 13 - 3D analysis and deformation map for test 301 – 30.6kmph

door performance, variable lightning conditions, availability of scanned object position change, scanning interruption, "easy" data processing, real time result visualization (data verification).

With respect to the facts mentioned above, Handyscan type MAXScan from CreaForm was chosen for this application. The advantage of this type of scanner is the possibility of a relative motion of the scanner and the scanned object. The scanner identifies the position markings on the scanned object and two cameras record the laser intersection, which is projected on the object.

In case of the car body deformation scanning, parts on vehicle front (bumper, hood, fenders, front grill) were covered with reflex targets. The original vehicle frontal parts were fitted appropriately and scanned because of the consequent comparison with those that were damaged by the crash test. The 3D analysis is based on the 3D surfaces comparison.

The results from test 101/201/301 (12.2 kmph/22.4 kmph/30.6 kmph) show, that the dummy head impact caused plastic deformation of the hood of 13.2 mm/23.7mm/20mm (depth), rear central part of the hood was deflected in test 101 on the average by 1.5mm. Dummy head contact point is demonstrated by the dark area on the deformation map, lifted area of the hood in test 201/301 reached a maximum of 6.7 mm/8.8mm.

5. DISCUSSION

5.1 Head injuries

Neither Head Performance Criteria (HPC), nor 3ms injury criteria limit value was exceeded in the primary head impact for all the performed tests. The head contacted the car bonnet behind the WAD1000 line.

The values of the biomechanical criteria are several times higher for the secondary impact than for the primary one. The limit value for the secondary impact was only exceeded in case of test No. 301 (30.6 kmph); the 3ms criterion was in this case exceeded by 10%. According to the US standards (FMVSS 208 "Occupant crash protection"), the value of HPC15 exceeded also the defined limit (limit 700) for a 6-year-old child.

Based on the test and video analysis, and the analysis of the secondary contact with the road surface, it is obvious that neither HPC value nor the 3ms criteria represent objectively the seriousness of the secondary impact. The reason for this lies probably in the mechanism of dominating flexion and extension motion in the neck spine and head skidding on the road surface. This conclusion corresponds with the previous experiments made in 2009 and with literature cited below [9, 11].

5.2 Thorax injuries

The limit value of 3ms criteria for a 6-year-old child thorax (55g according to EHK 44) was not exceeded in any performed test. This value is close to the limit in test No. 301 for the primary impact. For the secondary impact, there is no critical acceleration because of the kinematics of the pedestrian after the collision. The secondary contact took place mostly via head and neck.

5.3 Pelvic area injuries

The maximal acceleration limit amax 130g was not exceeded in any performed test for the primary or for the secondary impact. The pelvic area is the point of the first contact with the car front end, which can be clearly seen from the graphic presentation of the acceleration and video records made by a high-speed camera. The highest acceleration values for the pelvis area were measured at the primary contact. There is a presumption of abdominal organs contusion and risk of pelvic fracture (symphysis pubic). The pelvic and knee area were the most loaded parts of the body within the experimental series.

5.4 Knee injuries

The limit value of the maximal acceleration for knee (170g) was exceeded in test No. 201 and 301 (primary impact). Injury of knee joint or a fracture of a crus (on epiphysis or metaphysis) can be expected.

5.5 Femur contact force

The limit value of the maximum contact force on the femoral skeleton is not exactly defined [10, 12]. On the basis of the research, we can say that the average biomechanical limit for the contact force was exceeded at the primary impact in test No.301. In this case a femur fracture can be predicted. The impact force on the femoral skeleton was calculated from the axial strain with the knowledge of the material properties.

5.6 Secondary impact remarks

HPC seems to be an indicator of the secondary impact seriousness regarding the fact that in all the tests it reached higher values than in the primary contact with the vehicle frontal part. An interesting observation is that in case of other body parts the results were inverse – the primary impact was the one with the more serious consequences regarding the biomechanical criteria values calculated for the dynamic impacts of certain body parts in the direct interaction with the vehicle frontal part.

6. CONCLUSION

The CTU in Prague, the Faculty of Transportation Sciences performed the second set of dynamic passive safety tests of a passenger car (Škoda Octavia II) collision with a P6 dummy. Particular conclusions and findings are in the discussion part of this paper.

The performed tests show that the head biomechnical criteria were not exceeded within the head contact with the vehicle frontal part. In case of the secondary collision, the head biomechanical criteria based on the linear acceleration detection are not a sufficient predictor for the serious injury occurrence, therefore, angular acceleration should be detected as well.

There is no high risk of thorax serious injury. In case of pelvic, we can expect serious injury occurrence especially in the primary contact above 30kmph. The knee region is threatened by the primary contact with the vehicle frontal part as well as femur. From the measured data we can predict high risk of femoral fracture in contact speed above 30kmph.

Nevertheless, from the results it is obvious that it is necessary to focus on action of force on the upper and lower leg at the primary contact and the necessity of the force moment and acceleration measurement on the neck of the dummy – for the reasons of analysing the secondary impact seriousness. It is a very complex issue which requires further research, for example to identify the factors that can significantly influence the post-crash kinematics and the secondary impact and perform the numerical analysis of the response to factors variation.

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ABSTRAKT

SIMULACE KOLIZE OSOBNÍHO VOZIDLA S DĚTSKÝM CHODCEM

Ústav soudního znalectví v dopravě Fakulty dopravní provedl již druhou sérii dynamických testů pasivní bezpečnosti dětského chodce při kolizi s osobním vozidlem (kategorie M1 - Škoda Octavia II). Počáteční podmínky testů byly obdobné jako v případě první série testů, která byla provedena v září 2009 s vozidlem Škoda Roomster. Kromě výsledného zrychlení hlavy, hrudníku a pánve, bylo detekováno i jednoosé zrychlení kolene v sagitálním směru a kontaktní síla na stehenní skelet figuríny (figurína typu P6, 1,17m, 22 kg) a byla analyzována i velikost deformace přídě vozidla pomocí 3D scanneru. Účelem těchto testů není pouze poskytnout detailní popis kinematiky chodce a porovnání závažnosti primárního a sekundárního nárazu, ale také poskytnout data pro matematickou simulaci nehodového děje.

KLÍČOVÁ SLOVA

osobní vozidlo, dětský chodec, primární a sekundární náraz, instrumentace, kritéria poranění, 3D skenování.

LITERATURE

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