REPETITION OF REAL-CHILD PEDESTRIAN ACCIDENTS USING A HIGH INSTRUMENTED DUMMY

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INTRODUCTION

Biomechanical data are till now mostly determined for the group of old people. Only few results are known for middle aged persons and nearly nothing is known about biomechanical levels of the injury tolerance of children. Because of the general absence of such data, the aim of this paper will be the correlation of dummy measuring values with real injuries of children for establishing levels of injury tolerance, but on the other hand, the dummies are needed for the evaluation of safety devices.

Especially appropriate for the production of such a correlation is the repetition of real-child pedestrian accidents, because with Pontoon front contours children are not thrown onto the vehicle, but will be positioned at the primary contact areas in the impact phase with the effect of a high test reproducibility. On the other hand, there exists a large enough number of in-depth single-case analyses of real child pedestrian accidents to use a selection modus for finding out appropiate cases for repetition.

So, as to allow as much evidence as possible concerning body sequents, an Alderson VIP 6 was modified by bringing in additional measuring equipment for the neck, abdominal region, pelvis and lower extremities. All tests are worked out on a special pedestrian impact test facility. Besides the comparison of real accidents and test results, concerning the area of correlated reversible loading ranges the latter will be shown for the head and neck area.

Range value of the impact loading should be the reversible injury which means no lethal consequence and no irreversible injury, for instance no fracture. This means, it is located under an injury level of AIS 2 (1). The main point of injury models of child traffic participants is the head for unrestrained and restrained child car occupants (2), as well as child pedestrians (3) and two wheel riders. Therefore, establishing levels of injury tolerance should go in line of order with the endangering of body regions.

For child pedestrians, there result from the body regions with the injury level of AIS 2 a frequency of 31%, and for the group larger than AIS 2 of 25%. Under consideration of reversible range loading until an impact speed of 10,9 m/s there would be a reduction of 49% of injury severity groups from AIS 2 on, on the other hand of 19% from AIS 3 on.

Starting with direct comparisons of the impact tests with the real accident, it is followed by a looking out for a general comparison, this means correlation between test results and real injuries.

EXISTING RESULTS

Backaitis et al. (5) discovered that the restrained Alderson VIP 3 and 6 dummy appears to correlate fairly well with baboons on the basis of head excursions in the forward and lateral collision modes , nevertheless caused by his body segments.

The child cadaver and VIP 6 kinematic is similar during the frontal impact as restraint car-occupant (6). Also the belt load time history, as well as the course of resultant head decelerations, correspond to a great extent. The flexion behaviour of the vertebral column shows significant greater values for the cadaver and thereof, greater times of displacement. The adult dummy (Sierra Stan 50%) and cadaver kinematics are fairly similar during the initial phase of the pedestrian accident (7). Shape and size of deformation caused by the head are comparable.

The dummy has higher and shorter acceleration pulses than the cadaver (8) (9), as well as lower ground contact forces in lateral pedestrian collisions, possibly caused by a greater lateral flexion of the cadaver knee. Dummy impacts are more repeatable than cadaver impacts.

Blunt, respectively, great surface loading, is favourable for a comparison of dummy and cadaver (10). Direct comparison between dummy and cadaver, respectively living human being, taken from the literature are limited essentially to single cases and allowed general results only for kinematic and kind of vehicle damages.

Correlation setups made up to the present have not started first by direct comparison of a great number of single cases, but rather by correlation of groups of dummy tests, as well as groups of living human beings by individual calculated dependancies to a parameter of accidental severity. Contrary to the direct comparison, a great number of the trauma influencing traffic participant parameters, vehicle parameters as well as accidental parameters cannot be eliminated.

TEST APPARATUS

PEDESTRIAN DUMMY

For the repetition tests, a 50% 6 year old dummy - Alderson VIP 6 - is used with additional installed measuring gauges which are of importance especially for the pedestrian collision. Fig. 1 shows the modified dummy without soft tissues. A measuring neck was constructed and placed close to the lower end of the rubber neck and installed into the upper thorax to measure sheare forces, bending moments in the spinal cord area of C7, as well as cranial neck forces.

For the measuring of triaxial pelvis acceleration, a tube was brought into the pelvis with accelerometers positioned at a vertical height between the upper femoral joints. Because the lower extremities are a high loading area in pedestrian collisions the originals were exchanged for more resistant new ones of the same weight as well as distortional flexibility between thigh and shank. By the installed internal cables, the total mass of the dummy rises from 21.5 to 21.6 kg.

A total of 32 channels are taken from the dummy (Fig. 2). The bending moment transducers for the lower extremities are located in the proximal, medial and distal area of the upper as well as lower leg (Fig. 3). Because of the dummy rotation in the initial impact phase, caused by a walking position of the dummy, the thighs have installed two-axis bending moment transducers. Limited by the channel capacity of the amplifier , only that one of the shanks which is placed at the impact side, is plugged to the measuring system.

IMPACT TEST FACILITY

With the aim of a high reproducibility of the pedestrian collision, the main influencing accidental parameters on kinematic as well as loading of the dummy must be repeatable by the impact test facility (Fig. 4). These are impact speed of the car, braking deceleration of time of impact, primary impact point at the vehicle and dummy as well as position of upper and lower limbs. Additionally, the vehicle frontend geometry and stiffness must be equal in a test series. Therefore, after every impact, the damaged vehicle elements are changed on the basis vehicle. In addition, the joint moments of the dummy were checked before every crash. To equalize a higher stature of the accidented child, the c.g. of the dummy was lifted up to the one of the real child by using additional soles of light Polyurethan strong fixed to the shoes. The dummy was free standing at the time of collision, because an electromagnetic retaining device, which fixed the dummy in impact position, let him free just before impact. The measuring cable which leaves the dummy near his c.g. was placed at its first five meters over a cross stick, falling down after the dummy moved about one meter. Therefore its influence is drastically reduced in the primary impact phase. Through the low level of influence of walking speed on the position of the head's impact point on the vehicle (in the walking direction) due to the child's low body height, this is contrary to that of adults, it was decided to do it without a dummy own speed, for bringing about a better reproducibility of test results.

To find out clear contact areas post-crash on the dummy and vehicle, the head, as well as the impact side of the lower legs of the dummy, are painted red, respectively blue, the vehicle front is painted white. Post-crash vehicle and dummy are positioned in the initial phase of collision to find out the correlated contact areas.

REAL ACCIDENTS

For representative results, a selection modus is used to find out typical average accidents from the real crash situation (2), for example:

- 50% pedestrian (7.1 year old child) which means here stature height as well as mass near the VIP 6
- pontoon front contour (involvement 63%) (2)
- clear impact point or small area on the road, as well as impact speed
- braking at time of collision (involvement about 70%)
- vehicle frontal impact (involvement 75%) (2)
- impact speed in the area of 6.0 to 10.9 m/s (area of highest involvement)
- pedestrian lateral impact (involvement 71%) (2)

Based on 200 medically and technically in-depth-single-case analyses of real child pedestrian accidents of traffic accident research programmes (financed by the Federal Authorities of Road System, Cologne, FRG) 10 cases were selected which are most equal to the requirement list. Information of the type of real accidental data are given by (2).

Of importance for the dummy test are, as explained before, the injuries caused by vehicle contact. Only for these primary injuries can the accidental parameters be analyzed from the real accident. The separation of the injuries in primary and secondary (road) is done as follows:
injuries caused by primary collision are related by the extension and position of damaged spots on the vehicle, as well as type and position of injury
injuries caused by secondary collision are determined by type and place of injuries, degree of contamination of injuries, as well as reconstruction of the motional action.

COMPARISON REAL ACCIDENT/DUMMY TEST

A survey of the choosen real cases, as well as the worked out impact tests, is given by Fig. 6. The vehicle impact speed is varied in the ranges of the real accident with the aim to have the test at the lower as well as upper range, possibly also in the middle of the real impact speed. Also the position of the upper extremities are defined for this purpose.

Each test set consisted of more than two repetition tests designed to provide information on the consistancy of test results.

A sample of mostly resultant measuring signals for the body segments are given with Fig. 6 from impact 3.1. For the lower extremities on the impact side the first peak is caused by the bumper/shank impact, the second by the headlight surrounding/ thigh impact and the third by ground contact.

Because the head is the highest traumatized body region for children, eight cases were choosen with a Scull Brain Trauma of first degree - cerebral concussion with an unconsciousness under 15 minutes - (Fig. 7) and two cases with a second to third degree one - unconsciousness of more than 12 respectively 24 hours -. The impact direction of the head correlates well by the repetition test with the real accident. For the evaluation of the agreement of the vehicle damage from the head impact as main parameter, the depth of penetration is shown. The real depth values must be taken as approximate values. Because the local stiffness of the bonnet is influenced by the position of bracings but on the other hand a different position of the impact area means not necessarily a different stiffness, an additional information is given regarding the position to the vicinity of the bracings. As a consequence test 8.3 shows a position at the range of a bracing as well as 9.3 also near a bracing but also with greater degree of depth of penetration.

An example of high and low reproducibility regarding the resultant head acceleration is shown with Fig. 8 and 9. The variation of the HIC from 449 to 1380 shows the sensibility of the HIC despite the similarity in form of the signals, therefore the peak value shows a great influence.

Because the biomechanical loading for the human body intensity and time duration of the acceleration pulse is of importance, besides the calculation of HIC and SI also the effective resultant head acceleration (changing of speed of the head/time duration) for the direct vehicle contact, but also for the whole primary impact (direct and indirect acceleration), are calculated. In addition, the level of resultant head acceleration for a time duration of 3 m/s is also given by Fig. 7.

REPRODUCIBILITY OF TEST RESULTS

As can be seen from Fig. 5, the distribution of test results contains also the distribution followed by the wished-for changing of the impact speed in the ranges of the real accident. For test series number 9 the level of impact speeds are positioned under the range of the real case due to the maximum speed of the pedestrian impact facility.

With Fig. 7 the average percental spread in the test series is for the HIC ± 23%, for the SI ± 23% and for the a_{Hr} $\geq$ 3ms ± 15%.

CORRELATIONS

The worked out correlations are shown in this phase of the study only for the head and neck region.

HEAD AREA

Because the test impact speed was mostly in the range of real accident, all of the measuring values from a body region of a test series could be the searched correlated value, with the exception that the area of impact would not be comparable to the real accident. It follows that all loading values, not only their arithmetical mean values, are possible correlation values to the real injury.

The percental accumulative frequency of HIC and resultant head accelerations - peak value as well as for time durations $\geq$ 3 ms - related to real injuries of First Degree Scull Brain Trauma can be seen in Fig. 10.

Not included are the results of 4.1 and 4.2 because a shoulder impact occures in every test which is contrary to the real accident.

For the Head Injury Criterium 50% of the values are under 750 and for the resultant peak head acceleration under 139 g, as well as for time durations $\geq$ 3 ms under 80 g.

To find out a correlated range of reversible child head injuries, wherefrom level and time duration of loading can be taken is given by Fig. 11. Also sketched is the Wayne State University Curve for cerebral concussion (11) worked out for adults.

Because the direct head/front-end impact can be accepted as cause of the real injury, but also on the other hand the indirect head acceleration can possibly be a co-cause of the Trauma, for both groups the effective resultant head acdlerations are sketched. The consequence of calculated loading values with an ability to express only for a ranged time duration, shows that the borderline of reversible head injuries in children is reached by a lower loading, in contrast to adults. The ranged time duration is nevertheless of special importance for the layout of safety devices in pedestrian collisions.

NECK AREA

From the choosen 10 real cases there was none with a neck injury. Because the neck with children is disproportional smaller in circuit than with adults it is also of great interest to correlate these measured impact loadings.

With Fig. 12 50% of the shearing forces are located under

730 N and 50% of the bending moments - both in the area of C7 - under 95 Nm. The cranial neck forces seem to be very high with 50% of their values measured under 1970 N with a head mass of the VIP 6 of 2.5 kg and a neck mass of 0.4 kg. For example Burow (12) found out by adult cadaver tests that a shear force of 1800 ./. 2600 N can result in an injury of the condyle joint - adult head masses between 2.7 and 3.5 kg - as well as in one case he found a rupture of neck with a cranial force of 1000 N.

The arithmetic mean distribution of the measuring values in the test series is calculated to ± 21% for F_{Ns} and ± 15% for F_{Nc} as well as ± 6% for M_N.

SUMMARY

The worked out results are all dependent on the used dummy, a modified Alderson VIP 6, which means that these are correlated values. Because the dummy shows a similar kinematic behaviour to that of living human beings, the results can also give an estimation of the area of biomechanical tolerance levels of children. The repetition tests for a group of 10 selected real child pedestrian accidents shows a reproducibility of loading values for the head and neck region between ± 6 to 23%.

The following results are of special importance:

1. For the head region 50% of the HIC values are located under 750 if correlated to real injuries of First Degree Scull Brain Trauma.

2. The lower range of the effective resultant head acceleration for head/vehicle impact which is also correlated to real injuries of First Degree Scull Brain Trauma, shows in the average values of about 50 g for time durations of 15 to 20 ms. This would be a possible upper range of reversible injuries.

3. For the neck region 50% of the shearing forces in the area of C7 are found under 730 N. Bending moments in the same area are till 50% of them smaller than 95 Nm. Both are correlated to real child pedestrian accidents without a neck injury.

Conclusionary the correlated measuring values of the child dummy shows for the head area that children are injured earlier than adults at the same loading.

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1.	**Head (Cranium)**	
	Triaxial acceleration	± 750 g
2.	**Neck (C7 area)**	
	Transverse force	± 10000 N
	Anterior - posterior force	± 10000 N
	Cranial force	± 5500 N
	Transverse bending	± 500 Nm
	Anterior - Posterior bending	± 500 Nm
3.	**Chest (Thorax)**	
	Triaxial acceleration	± 750 g
4.	**Abdomen**	
	Anterior - posterior acceleration	± 750 g
	Vertical acceleration	± 750 g
5.	**Pelvis**	
	Triaxial acceleration	± 750 g
6.	**Upper Leg (Femur)**	
	Transverse bending	± 350 Nm
	Anterior - posterior bending	± 350 Nm
7.	**lower Leg (Tibia/Fibula)**	
	Transverse bending	± 300 Nm

Fig. 2: Measuring ranges of the modified VIP 6

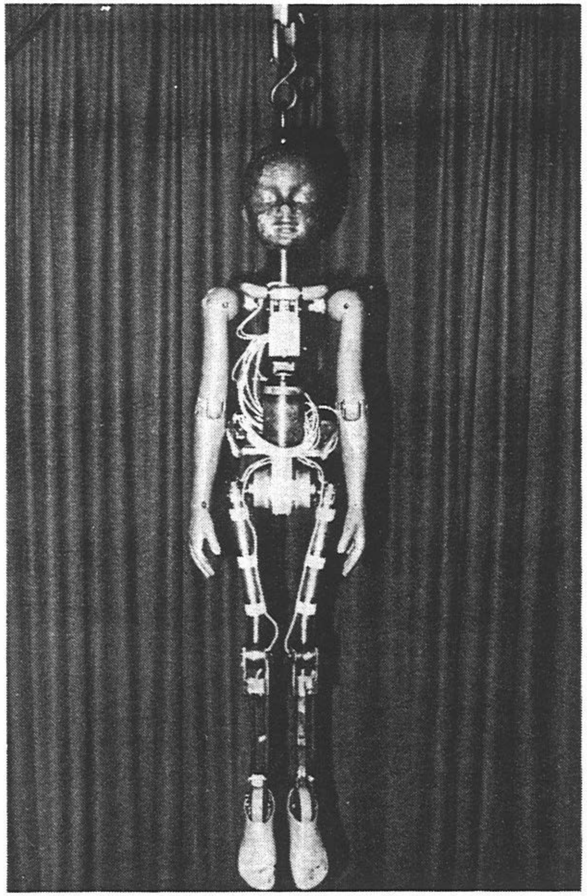


Fig. 1: Modified VIP 6

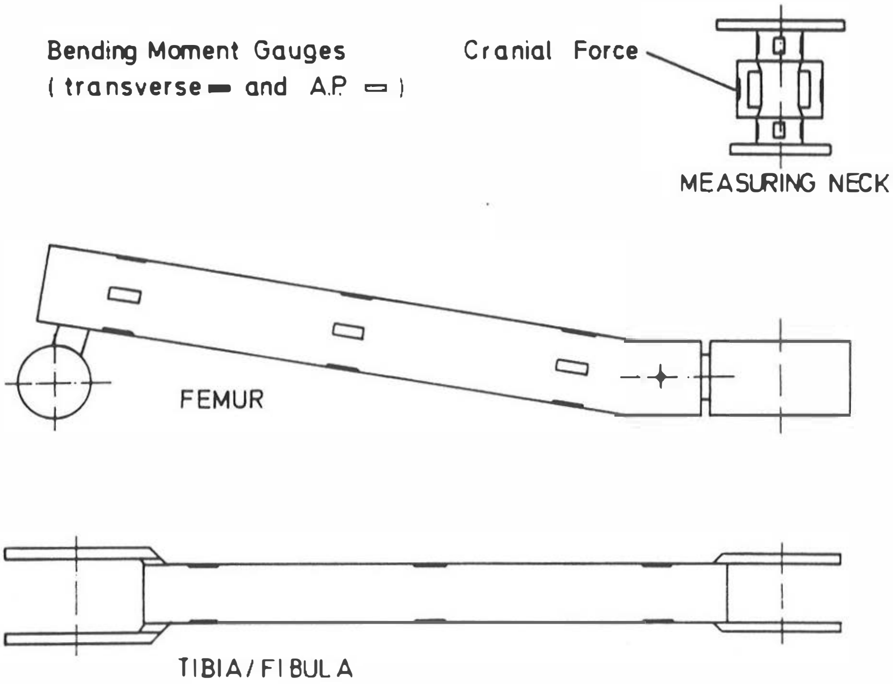


Fig. 3 Straingauge installation on the measuring neck, femur and tibia/fibula of the modivied VIP 6

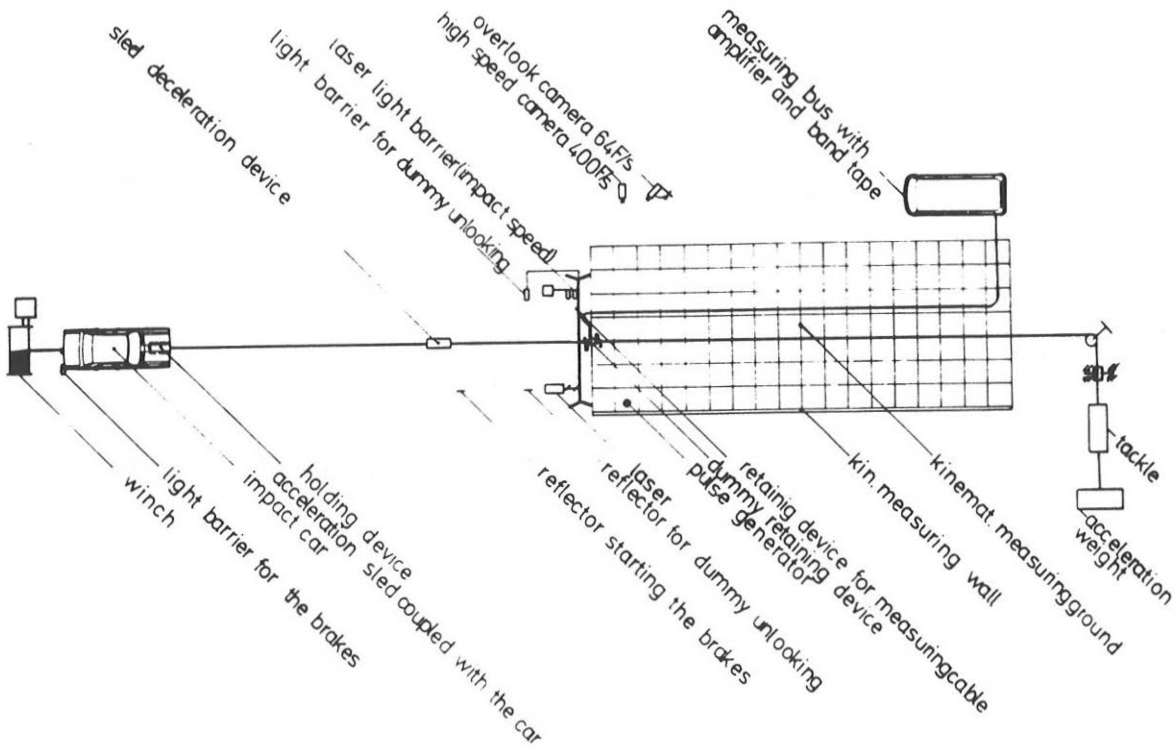
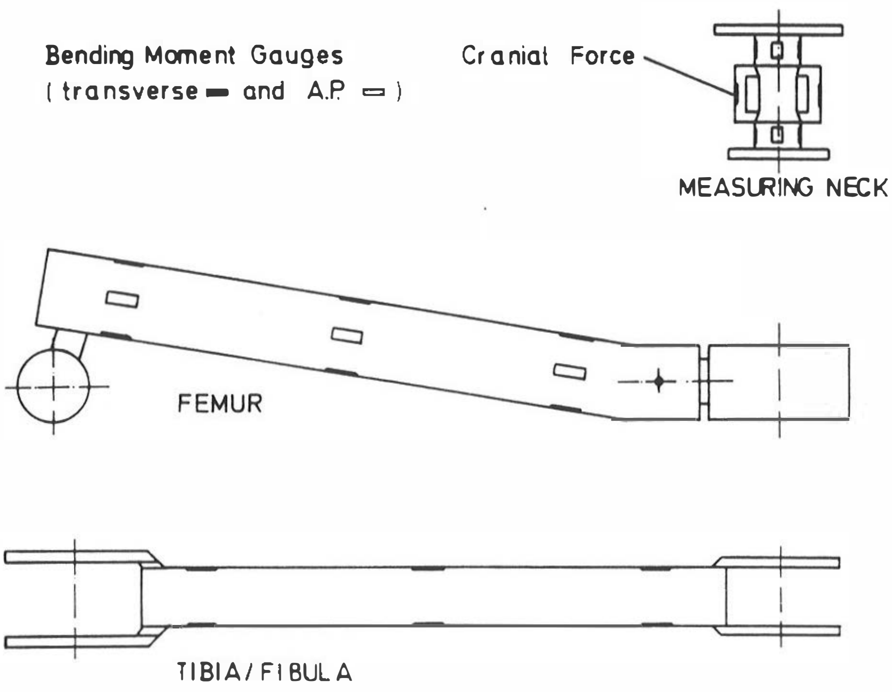


Fig. 4 Pedestrian Impact Test Facility



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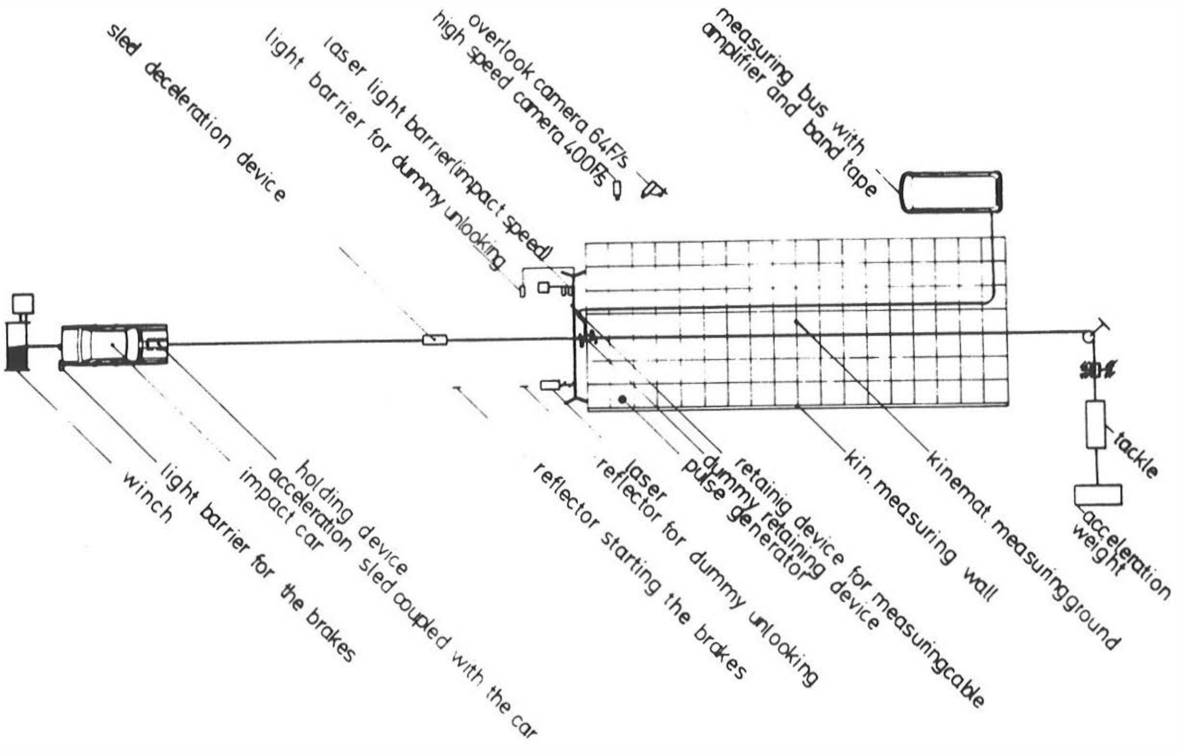

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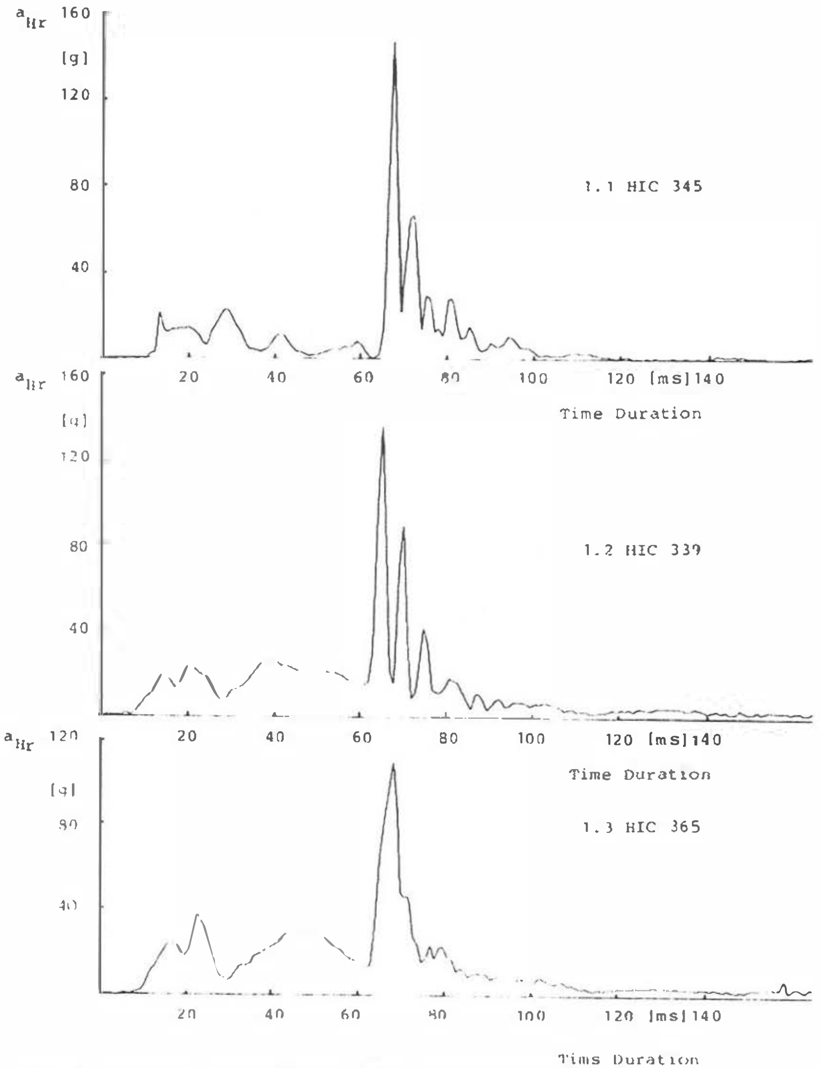

Fig. 8 Comparison of resultant head acceleration pulses of high reproducibility (1.1 - 1.3)

Case Test	Primary Head Injury	Head Imp. Dir. [Clock]	a_{Hr} Peak [g]	a_{Hr} ≥3ms [g]	a_{Hei} [g]	t_i [ms]	a_{Hev} [g]	t_v [ms]	SI	HIC	Vehicle Damage b Head Imp Depht [cm]
1	Scull Brain Trauma1	7/8									1.0med.
1.1	laceration left	7	147	67	50	13	17	75	530	345	0.3med.
1.2	paretial, Scull Cal.	7	136	73	48	15	24	77	640	339	0.3med.
1.3	Fract. left paret.	7	104	78	58	12	28	64	610	365	1.0med.
av	AIS 3		129	73					593	350	
2	Scull Brain Trauma3	9									2.5soft
2.1	Subdural Haematoma	9	66	57	52	17	38	67	840	683	2.0soft
2.2	Scull Frac.le pare.	9/10	233	102	70	18	52	56	2260	1283	2.5soft
av	AIS 5		150	80					1530	974	
3	Scull Brain Trauma1	6									3.0soft
3.1	Bruise on Scull	5	112	68	58	17	41	55	1020	764	3.3soft
3.2	occipital	5	69	59	46	19	38	55	720	613	2.6soft
3.3		5	105	73	41	24	39	62	1050	747	3.5soft
av	AIS 2		95	67					930	708	
4	Scull Brain Trauma1	12									0.5soft
4.1	Bruise with lacerat	1	50	41	27	18	20	73	220	164	1.0soft
4.2	on Forehead	12/1	45	33	22	21	19	70	180	147	0.9soft
av	AIS 2		48	37					200	156	
5	Scull Brain Trauma1	9/10									0.2med.
5.1	Bruise left lateral	9	223	121	73	17	36	70	2330	1881	0.3med.
5.2		9	182	126	59	18	31	72	1470	1134	0.3med.
av	AIS 2		203	124					1900	1508	
6	Scull Brain Trau2/3	1									0.5soft
6.1	Subdural Haematoma	1	141	98	65	13	40	57	1170	650	0.4soft
6.2	Bruise with lacerat	1	156	121	77	13	49	54	1710	1023	0.5soft
6.3	on Forehead	1	154	102	77	16	57	51	2050	1528	0.5soft
av	AIS 5		150	107					1643	1067	
7	Scull Brain Trauma1	11									0.8soft
7.1	Abraison on Fore-	11/12	194	140	56	18	31	76	1770	1380	0.5soft
7.2	head	12	138	84	45	18	24	86	780	449	0.2soft
av	AIS 2		166	112					1275	914	
8	Scull Brain Trauma1	11									1.0med.
8.1	Bruise on Forehead	11	108	76	73	15	46	70	1590	1131	0.3med.
8.2	Lost of one Incisor	11	141	120	64	15	51	51	1660	1023	0.3med
8.3		11	204	137	87	14	65	52	3140	2191	0.7hard
av	AIS 2		151	111					2130	1448	
9	Scull Brain Trauma1	5/6									0.5soft
9.1	Bruise on Scull	5/6	218	98	94	12	55	56	2780	1552	0.9soft
9.2	occipital	5/6	283	103	96	12	60	55	3690	1826	0.8soft
9.3		5	330	186	133	11	67	58	6330	4103	1.1med.
av	AIS 2		177	129					4267	2493	
10	Scull Brain Trauma1	12/1									0.7soft
10.1	Laceration on For-	10	124	77	54	18	39	57	1120	622	1.3soft
10.2	head	10/11	146	84	51	15	33	52	970	572	1.0soft
av	AIS 2		135	81					1045	597	

a_{Hei} effective resultant head acceleration by direct contact

a_{Hev} effective resultant head acceleration by the whole veh. impact

t_i , t_v puls time durations

Fig. 7 Comparison of test measuring values with real injuries for the head region

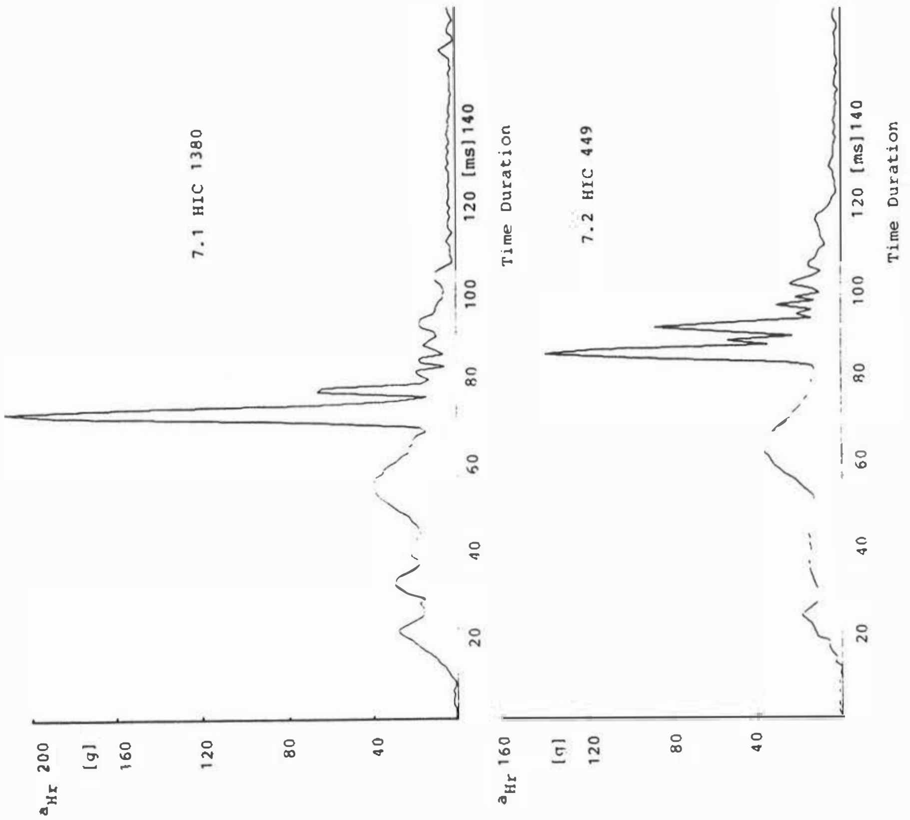

Fig. 9 Comparison of resultant head acceleration pulses of low reproducibility (7.1 , 7.2)

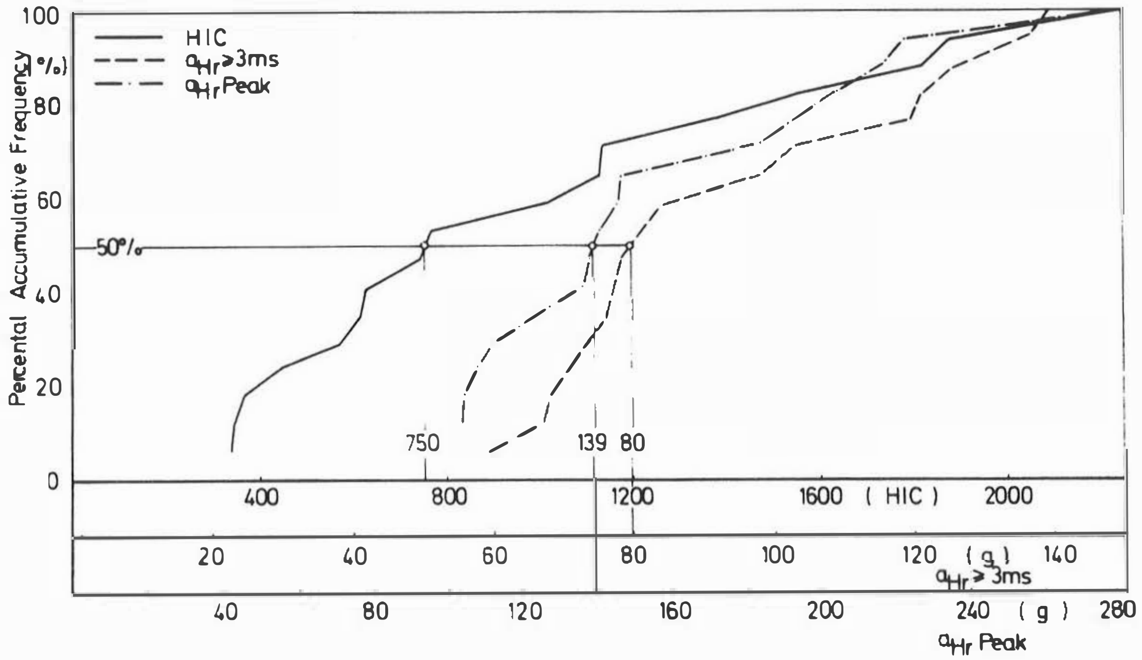

Fig. 10 Percental accumulative frequency of HIC and resultant head acceleration (a_{Hr} peak) as well as for time durations $\geq$ 3ms for the modified VIP 6 related to real injuries of First Degree Scull Brain Trauma

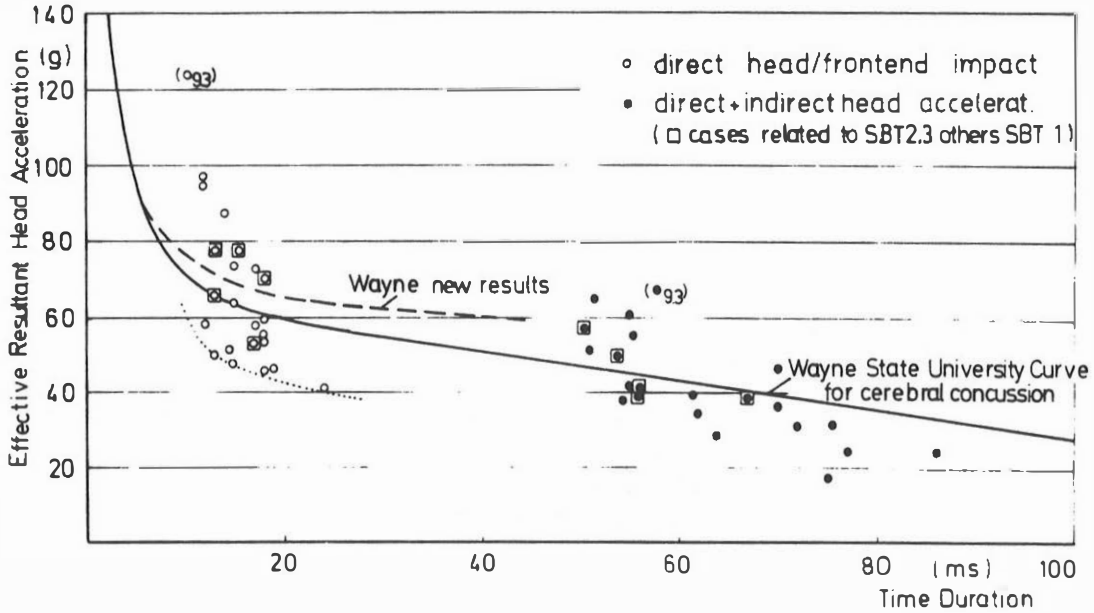

Fig. 11 Effective resultant head c.g. acceleration and pulse time of dummy direct vehicle frontend impact as well as regarding the whole vehicle impact

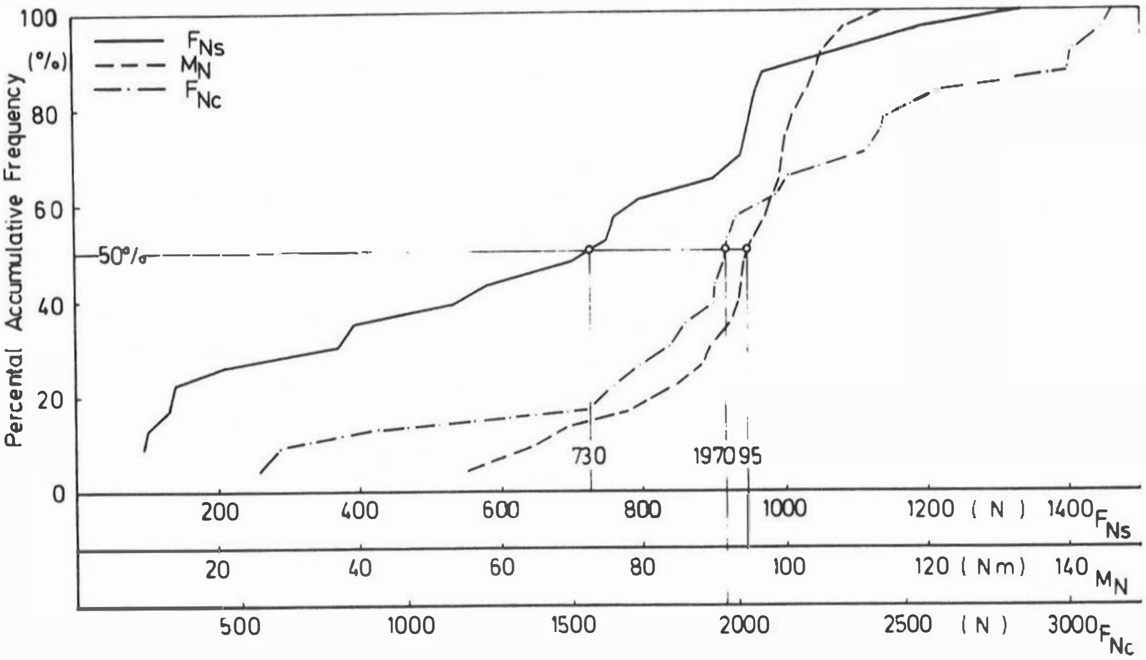

Fig. 12 Percental accumulative frequency of maximal sharing forces (F_{Ns})and bending moments (M_N) in the lower neck area as well as cranial neck forces (F_{Nc}) for the mod.VIP 6 related to cases without resulting neck injuries