CORRELATION OF DUMMY-LOADINGS WITH REAL INJURIES OF CHILDREN BY REPETITION TESTS

G. Stürtz

Daimler-Benz AG*
(Germany)

Introduction

Hitherto, biomechanical data have been determined mostly for older adults. Only few results are known for middle-aged persons and almost nothing is known about biomechanical levels of the injury tolerance of children. Because of the general absence of such data, which is contrary to the increasing need for an efficient layout of exterior vehicle elements as well as restraint systems, the aim of this paper is the correlation of dummy-load values with real injuries of children for establishing levels of the injury tolerance, but on the other hand those dummies are needed for the evaluation of safety devices. Finally biomechanical critical load values as well as protection criteria are derived for different body regions of children.

This method has advantages especially for the childrens group, thinking on repetition tests of real traffic accidents with child pedestrians as well as restrained child car occupants:

- during the primary collision, children up to middle sized ones are not thrown onto pontoon-shaped vehicles, but remain positioned on the primary contact areas, with the contributing effect of a high test reproducibility.
- child restraint systems for small-sized children, which reduce the child mass forces by energy absorbtion in a frontal deformable table with area contact, have the advantage in frontal collision modes, that these deformations in repetition tests can be compared to those found in real cases.
- on the other hand, there exists a large enough number of in-depth single-case analyses of real accidents with children to use a selection modus for finding out appropriate cases for repetition.

Biomechanical critical limit of the impact loading should be the reversible injury - strain or compression damage of a cell -, which

* This paper was worked out at the Technical University Berlin

means no lethal consequence and no irreversible injury - destruction of a cell - , for instance no fracture. This signifies, that the limit is located under an injury severity degree of AIS 2 (1).* As an example for pedestrians a frequency of 31 % results for the body regions with an injury level of AIS 2, and only one of 25 % from AIS 3 upward. This means also, that if this load limit isn't exceeded up to a vehicle impact speed of 11 m/s - under which about 60 % of all injured pedestrians are found (2) - , a reduction of 49 % of AIS 2 and only one of 19 % from AIS 3 upward would then be possible.

With the aim of a high efficiency establishing levels of injury tolerance should be in line of order with the real endangering of body regions. The main point in the injury model of child traffic participants shows the head for unrestrained and restrained child car occupants (2), as well as child pedestrians (2) and two-wheel riders (3). Therefore the primary selection criterion of cases with child pedestrians - also considering AIS 2 - is the presence of a cerebral concussion with unconsciousness less than 15 minutes - first degree "Scull Brain Trauma" (SBT 1) by "TÖNNIS" - .

Starting with direct comparisons of pedestrian impact tests with the real accident - for child occupants only final results are given - this is followed by a general comparison, which means the correlation of test results with real injuries.

Existing Results

A summary of results with relevance to this topic is given by (4) in which also first results of this analysis are shown with regard to the childish head and neck region. In conclusion it can be said, as follows:

- the kinematic behaviour of the restrained Alderson VIP 3c and 6c child dummy correlates fairly well with baboons on the basis of head excursions, respectively the VIP 6c kinematic is similar to cadavers during frontal impacts when restrained as car occupant.
- dummies show higher and shorter acceleration pulses than cadavers as well as lower ground contact forces in lateral pedestrian collisions.
- blunt, respectively great surface loading, is favourable for a comparison of dummy and cadaver.
- other correlation setups made up to the present have not started first with direct comparisons of a greater number of single cases, but rather by correlation of groups of dummy tests, as well as groups of living human beings by individual calculated dependencies to a parameter of accidental severity. Contrary to a basis of direct comparisons, a great number of the trauma

* Numbers in parentheses designate References at end of paper.

influencing traffic participant or vehicle or accidental parameters cannot be eliminated then.

Child Pedestrian Accidents

Test Apparatus - So as to allow as much evidence as possible concerning body segments, an Alderson VIP 6c anthropometric dummy, Figure 1, was modified by bringing in additional measuring gauges which are also of importance, especially for pedestrian collisions, see also (4). With the aim of a high reproducibility, the main influencing accidental parameters on kinematic as well as loading of the dummy - for instance: impact speed of car, breaking deceleration at time of impact, primary impact point at vehicle and dummy, position of upper and lower limbs - were reached to be repeatable by the impact test facility. Because of the low influence of walking speed on the position of child's head/bonnet impact - due to it's low stature height - the latter was not simulated either in order to achieve a better reproducibility of test results. Post-crash vehicle and dummy are positioned in the initial phase of collision to find out the correlated contact areas.

Real Accidents - Based on 200 medically and technically in-depth single case analyses of real child pedestrian accidents, 10 cases were selected which correspond to a requirement list. As the head is the most traumatised body region for child traffic participants, of the cases selected eight show a primary first degree Scull Brain Trauma (SBT 1) of the child and two one of a second to third degree (SBT 2 to 3).

Comparison of Real Accident/Dummy Test - A survey of the selected real cases, as well as the worked out impact tests, is given by Figure 2. The vehicle impact speed is varied in the testseries within the range of the real accident with the aim to have the test carried out at the lower, as well as the upper limit possibly also at the mean value of the real impact speed. Each test set consists of more than two repetition tests designed to provide information on the consistency of results.

A detailed comparision of real accident data with those of the repetition tests regarding the head region is shown in Figure 3. The peak value of resultant head acceleration (a_{Krmax}), the maximum resultant value for time durations greater or equal 3 ms (a_{Krg} ($\geqq$ 3 ms)) and the Head Injury Criterion (HIC) were taken from the measured signals.

The impact directions of the head show a good correspondence. For the evaluation of the correspondence of the vehicle damage due to the head impact, as main parameter, the depth of penetration is shown in the right column. The real depth values must be taken here as approximated values. As the local stiffness of the bonnet is influenced by the position of bracings, an additional information is given regarding its position relative to the vicinity of bracings.

Reproducibility of Test Results - The distribution of test results contains also the distribution as consequence of the desired vehicle impact speed changes. The average spread in the test series is found for the HIC to ± 15 %. Together with other body regions, the average spread of load characteristic values in the test series - their reproducibility - is as follows:

head	± 15 to 23 %
neck	± 6 to 15 %
thorax	± 10 to 19 %
abdomen	± 12 to 23 %
pelvis	± 10 to 23 %
lower extremities	± 10 to 12 %

Correlations - As the test impact speed was mostly in the range of the real accident, all recorded maximum load characteristic values of a body region within a test series could be the searched correlated value, with the exception that area and type of impact wouldn't be comparable to the real accident. Should there be only two instead of three accepted cases in a test series, then their arithmetic mean value is taken as an additional third value for an equal consideration of each series.

Head Region - The type of the chosen load characteristic values of a body region, for instance HIC and a_{Krg} (≧ 3 ms) are of great influence on the resulting statements. Therefore effective load values (a_e) are also calculated and related to the pulse time duration.

The found correlations are shown here for all relevant body regions, but in greater detail for the most important head region. The percental accumulative frequency of HIC, a_{Krg} (≧ 3 ms) and a_{Krmax} correlated to real injuries of SBT 1 is shown in Fig. 4. Not included are the results of test 4.1 and 4.2, because a shoulder impact occurs in every test which is contrary to the real accident. For the HIC 50 % of the values are located under 840 and for a_{Krg} (≧3 ms) under 83 g, as well as for a_{Krmax} under 143 g.

The arithmetical mean values of the test series show a biomechanical distribution with a standard deviation of ± 50 % for HIC=1031, ± 23 % for a_{Krg} (≧ 3 ms)=95 g and ± 32 % for a_{Krmax}= 161 g.

A method fo find out a correlated range of reversible child head injuries, wherefrom level - effective (average) acceleration - and time duration of loading can be taken, is shown in Figure 5 including a regression function for SBT 1 as well as single data of SBT 2 to 3. Also drawn is the Wayne - State - University - Curve for cerebral concussion with first scull fracture (AIS ≅ 2) (5) (6). As the direct head/front impact can be accepted as cause of the injury, but on the other hand the indirect head acceleration can also be a factor of the trauma, the effective resultant head acceleration is shown for both groups.

The consequence of calculated load values restricted to a limited time duration shows that the regression curve of children is positioned at a lower niveau in contrast to adults. Also as tendency the border line of irreversible head injuries - 50 g, 12 to 15 ms - with children is reached by a lower direct loading, contrary to adults. The limited impulse time duration is nevertheless of special importance for the layout of safety devices in pedestrian collisions.

Neck Region - Among the 10 real cases, there is none with a neck injury. As children's necks are disproportionally smaller in diameter than these of adults, it is also of great interest to correlate these with measured impact loadings.

In Figure 6,50 % of the maximum resultant shearing forces in the neck spine area of C 7 are located under $F_{HsC7rmax}$=825 N and 50 % of the maximum resultant bending moments are under $M_{HC7rmax}$=92 Nm. The maximum cranial neck forces seem to be very high with a median value of $F_{HcC7max}$=1930 N considering a head mass of the VIP 6c of 2,5 kg and a neck mass of 0,4 kg. As a comparison, Burow (7) discovered through adult cadaver tests that a shear force of 1800 - 2600 N can result in an injury of the condyle joint (range of the adult head masses: 2,7 to 3,5 kg). Moreover he found in one case a rupture of the neck with a cranial force of 1000 N. On the other hand Simons and Herting (8) found out that a cranial force of approximately 9000 N having caused in two cases a neck rupture. The measured child shear forces are higher with adults by the factor 1,5 to 2,1 when compared with the highest average value of a test series (6.1 - 6.3).

The arithmetic mean values of the test series show a biomechanical distribution with a standard deviation of ± 29 % for $F_{HsC7max}$= 810 N, ± 14 % for M_{HC7max}=90 Nm and ± 27 % for $F_{HcC7max}$ = 1978 N.

Thoratic Region - In the cases selected, three children suffered an injury of the thorax, one of the type of a lung contusion and - bleeding (AIS 3, case 2), one of a small lung haematomas up to diameters of 3 cm (AIS 3, case 6), as well as one of a clavicular fracture (AIS 2, case 8).

For the cases without thoratic injuries - not using series 4 as well as test 9.3, Figure 7, the median values are SI_T=300, a_{Trg} (≧ 3 ms) = 58 g and a_{Trmax}= 54 g. As for the group with irreversible thoratic injuries (AIS 2 - 3) only nine tests are worked out, a trend analysis gives median values of SI_T=980, a_{Trg}(≧ 3 ms)= 94 g and a_{Trmax}=154 g.

The arithmetic mean values of the group without injuries show a biomechanical distribution with a standard deviation of ± 123 %(!) for SI_T=572, ± 54 % for a_{Trg} (≧ 3 ms) = 67 g and ± 75 % for a_{Trmax}=83 g. Adequate results for the children's group with irreversible injuries are ± 22 % for SI_T=1051, ± 12 % for a_{Trg}(≧ 3 ms)=

103 g and $\pm$ 18 % for a_{Trmax}=146 g.

Abdominal Region - Among the selected real cases, there are four that show high irreversible abdominal injuries of AIS 4 to 5 of the type of organ ruptures with the necessity for each of them to receive an intensive medical treatment.

For cases without abdominal injuries, Figure 8, the median values are SI_A=370, a_{Arg}($\geq$ 3 ms) = 57 g and a_{Armax}= 73 g. For cases with abdominal injuries (AIS 4-5) the median values are SI_A=2430, a_{arg}($\geq$ 3 ms) = 136 g and a_{Armax}=221 g.

The arithmetic mean values of the uninjured group show a biomecanical distribution with a standard deviation of $\pm$ 42 % for SI_A=371, $\pm$ 30 % for a_{Arg}($\geq$ 3 ms) = 53 g and $\pm$ 20 % for a_{Armax}=79g. For the group with irreversible injuries the adequate values are $\pm$ 30 % for SI_A=2331, $\pm$ 9 % for a_{Arg}($\geq$ 3 ms) = 130 g and $\pm$ 19 % for a_{Armax}=208 g.

Pelvic Region - Among the selected cases there are only two in which children suffered an injury of the pelvis, one by a fracture of the right "os ilium" (AIS 2, case 6) caused by the headlight surrounding and another by an infracture of the upper pubis branch (AIS 2, case 10), also caused by the headlight surrounding.

For cases with pelvis injuries, Figure 9, the median values are SI_B=710, a_{Brg}($\geq$ 3 ms) = 86 g and a_{Brmax}=118 g. As for the group with irreversible injuries only 5 tests have been worked out, a trend of median values with SI_B=1285, a_{Brg}($\geq$ 3 ms) = 93 g and a_{Brmax}=108 g can be given here only. The arithmetic mean values of the test series taken from the group of uninjured children show a biomechanical distribution with a standard deviation of $\pm$ 86 % for SI_B = 1214, $\pm$ 52 % for a_{Brg}($\geq$ 3 ms) = 100 g and $\pm$ 50 % for a_{Brmax}= 143 g.

Lower Extremities - Among the selected cases there are seven where the loaded leg was uninjured, three with an injury severity degree of AIS 1, two with one of AIS 2 and three with one of AIS 3, whereby the latter are of the type of dislocated femur shaft fractures.

Position and value of the maximum bending moments (M_{Emax}), as well as maximum impact force in the femur or tibia are found, as follows:

- graphical connection of the maximum bending moments at different levels of the measuring gauges, as for instance in the medial as well proximal and distal area of the femur considering also position of joints.
- calculating the impact force by means of the known mass of the lower and upper leg, as well as total body mass and location of the maximum bending moment. $F_{Esä}$ means the resultant static force which causes the same maximum bending moment and

F_{Esmax} the appraised dynamic value.

For cases with injury severity degrees of AIS <2, Figure 10, the median values are $F_{Esä}$=1385 N and M_{Emax}=211 Nm. As the medial areas of the femur, as well as the tibia/fibula, are most endangered, because of their small cross-sectional area, additional distributions are set up for the appropriate bending moments. The median values therefore are as follows: M_{Fmrmax}=139 Nm (middle of femur) as well as $M_{T/Fmax}$=116 Nm (middle of tibia/fibula).

For cases with irreversible injuries of the lower extremities (AIS 2 to 3) the median values are $F_{Esä}$=3930 N and M_{Emax}=533 Nm. As there was no fracture in the test series, the dummy-bones could reach a high bending moment and therefore especially these median values must be clearly higher than the real fracture moment.

The arithmetic mean values of the test series with group AIS 2 show a biomechanical distribution with a standard deviation of ± 64 % for F_{Esmax}=1613 N, ± 52 % for M_{Emax}=248 Nm, ± 63 % for $\overline{M}_{Fmrmax}$=174Nm and ± 31 % for $M_{T/Fmmax}$=129 Nm. For the group AIS 2 to 3 the adequate results are ± 69 % for F_{Esrmax}=4499 N and ± 50 % for M_{Emax}=504 N.

Comparing these results with others taken from literature, the following is of special importance:

- first fracture with $F_{Esä}$=1285 N as well as M_{Emax}=222 Nm in an area of a percental height of 32 % of the femur. The average value for both cases of AIS 2 is $F_{Esä}$=2874 N, as well as M_{Emax}=405 Nm.
- half of the fractures are located and the medial area of the femur, respectively tibia/fibula.

Child Occupant Accidents

The real cases with child occupants used here for repetition on a hydropneumatic catapult are taken from three groups of documentation consisting of 93 children using restraints (2). These groups are made up from traffic accident research programs in Hanover and Berlin (2), supplemented by police reports from the city of Hanover (2), as well as the traffic accident documentation of Römer - Britax (9).

All cases selected are close to a used Alderson VIP 3c anthropometric dummy also with regard to frontal impact directions and documented deformations of the contact-table of a child restraint system. Among these cases there was only one with an injury of AIS 1 (case 11), from type of a blunt abdominal trauma without consequences.

50 % of the correlated reversible loadings (AIS <2) are lower than SI_{Ard}=92 - values are related to the mass of the real child ($_{rd}$) -,

resp. a maximum abdominal unit pressure p_{Admax} of 9,5 N/cm^2, resp. a maximum resultant abdominal force F_{Admax} of 1385 N as well as a maximum resultant abdominal acceleration $a_{Arrdmax}$ of 26 g (SK0). 75 % of the values are lower than SI_{Ard}=176, p_{Admax}=14,2 N/cm^2, F_{Admax}=2180 N and $a_{Arrdmax}$=31 g (SK1).

Biomechanical Critical Load Limits

A summary of the correlated dummy load values, - including regressions of effective ones - Figure 11, shows that for the head region there are only results regarding "irreversible" injuries and for the neck area there are only "reversible" ones. The other body regions, however, show results for both groups of injury severity.

For the definition of biomechanical protection criteria against irreversible injuries, the upper limit of reversible loadings is searched for, but as a result it can be seen that both distributions are overlapping. Therefore two different types of protection criteria can be defined:

- SK0 gives complete protection against irreversible injuries, only reversible injuries are allowed.
- SK1 with an accepted portion of for instance 25 % irreversible injuries.

For some body regions of children in the selected cases there are either none or only a small number of reversible injuries, and for other body regions either all injuries are irreversible ones or only a small number of high respectively low level ones. Therefore the frequency of irreversible injuries must be deduced out of the load distribution of reversible correlated injuries on defined load levels. The body regions best suited for this are the thorax or the lower extremities. The irreversible injuries from AIS 2 and 3 which are located at the lower limit of irreversible injury degrees, show that for the thorax 84 % of the AIS 2 values are lower than an SI of 754 and 25 % of the irreversible injuries, respectively their correlated dummy load values are also lower than this level. For the lower extremities there are 64 % of reversible injuries respectively 25 % of irreversible ones ranging under $F_{Esä}$=1550 N.

Therefore, protection criteria for body regions seem to be meaningful which cover 75 % of the correlated reversible injuries and thereby accepting about 25 % of irreversible injuries (SK1). On the other hand those criteria which cover about 50 % of reversible injuries and whereby no irreversible injuries are expected (SK0) are also shown in Figure 11. To find the load values for SK0, partly the lower limit of irreversible injuries is taken for the neck, thorax and abdominal region, including also 50 % of the correlated reversible injury degrees.

The observed upper limit of reversible injuries resulting from direct frontal abdomial surface loading can be estimated from case 11 with F_{Admax}=2380 $\pm$ 5 % (N), p_{Admax}=16,2 $\pm$ 11 % (N/cm^2),

$a_{Arrd}=44 \pm 11$ % (g), $a_{Aerd}=25{,}0 \pm 16$ % (g) as well as $SI_{Ard}=377$.

Conclusions

The obtained results are all dependent on the dummy used, a modified Alderson VIP 6c and 3c, which means that these are correlated values. As these dummies show 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, but on the other hand, those dummies can be used for a better qualitative valuation of safety devices, too.

As dummy measuring values show on the average higher and shorter signals compared to those of living human beings, the correlated biomechanical load values are in their overall level somewhat higher than the real ones.

References

(1) "The Abbreviated Injury Scale (AIS) - 1976 Revision". Grove, Illinois, USA, 1976

(2) "Biomechanik des Kindes, Anforderungen an die Innere und Äußere Sicherheit von Kraftwagen". Technical University Berlin, Institute of Automotive Engineering, Rep. No. 265, 1979

(3) Stürtz, G. Suren, E.G.: "Kinematic of Real Pedestrian and Two-Wheel-Rider Accidents and Special Aspects of the Pedestrian Accident". Proc. 2nd Int. Meeting on Biomechanics of Injury to Pedestrians, Cyclists and Motorcyclists, IRCOBI, Amsterdam, Sept. 1976

(4) Stürtz, G.: "Repetition of Real-Child Pedestrian Accidents using a High Instrumented Dummy". Proc. 3rd Int. Meeting on Simulation and Reconstruction of Impacts in Collisions, IRCOBI, Lyon, Sept. 1978

(5) Hodgson, L. M. et al.: "Testing the Validity and Limitations of the Severity Index". Proc. 14th Stapp Car Crash Conf. Ann Arbor, Michigan, USA, Nov. 1970

(6) Patrick, L. M. : "Human Tolerance Impact - Basis for Safety Design". SAE-pap. 650171

(7) Burow, K. : "Zur Verletzungsmechanik der Halswirbelsäule". Technische Universität Berlin, Inaugural Dissertation D83, 1974

(8) Simons, C. F., Herting, D. N.: "Strength of the human neck". North American Aviation Inc. Space and Information System Division. Accession No. 09233-65 SID 65-1180, 1965

(9) "Accident Reports of Römer - Britax". Inc., Ulm, 1977

Case Test	Passenger Car	Vehicle Impact Speed [m/s]	Braking Deceler. at Imp. [m/s²]	Body Stat [m]	Ped Imp Dir [Clock]	Pedestr Impact Speed [m/s]	Position of lower Extrem.
1	Opel Kadett B	8.4-10.0	7.3-8.9	1.29	8	slow run	RL f LL
1.1		9.2	7.8	1.21	8	standing	"
1.2		8.4	7.3	1.21	8	"	"
1.3		8.5	7.2	1.21	8	"	"
2	Opel Kadett B	8.2-10.9	5.0-6.0	1.25	9	running	unknown
2.1		10.1	6.6	1.21	9	standing	LL f RL
2.2		10.2	6.6	1.21	9	"	"
3	Renault R 4	11.3-12.5	7.1-8.0	1.10	3	running	RL f LL
3.1		11.3	6.3	1.21	3	standing	"
3.2		11.8	5.9	1.21	3	"	"
3.3		12.4	5.8	1.21	3	"	"
4	Renault R 4	7.8- 9.5	7.1-8.7	1.33	9	running	RL f LL
4.1		9.1	6.6	1.21	9	standing	"
4.2		9.0	6.9	1.21	9	"	"
5	Opel Rekord C	7.5-10.0	5.0-6.5	1.21	9	running	RL f LL
5.1		9.3	7.6	1.21	9	standing	"
5.2		7.7	6.6	1.21	9	"	"
6	Opel Rekord C	10.1-11.[illegible]	7.1-8.0	1.20	3	slow run	LL f RL
6.1		10.7	7.4	1.21	3	standing	"
6.2		11.0	7.1	1.21	3	"	"
6.3		11.8	7.1	1.21	3	"	"
7	Renault R 16	7.6- 8.7	7.1-8.7	1.18	3	running	LL f RL
7.1		9.4	8.1	1.21	3	standing	"
7.2		8.7	8.1	1.21	3	" "	"
8	VW K 70	11.8-13.0	7.3-8.9	1.12	10	slow run	RL f LL
8.1		12.2	7.4	1.21	10	standing	"
8.2		11.8	7.5	1.21	10	"	"
8.3		12.7	7.4	1.21	10	"	"
9	VW K 70	13.4-15.4	7.3-8.9	1.12	3	running	RL r LL
9.1		12.7	7.7	1.21	3	standing	"
9.2		13.0	7.5	1.21	3	"	"
9.3		13.1	7.3	1.21	3	"	"
10	Opel Kadett A	11.2-12.4	7.1-8.0	1.28	9	running	RL f LL
10.1		11.9	8.3	1.21	9	standing	"
10.2		11.8	7.9	1.21	9	"	"

Fig. 2 - Accidental data of the real child pedestrian accidents as well as of the carried out repetition tests

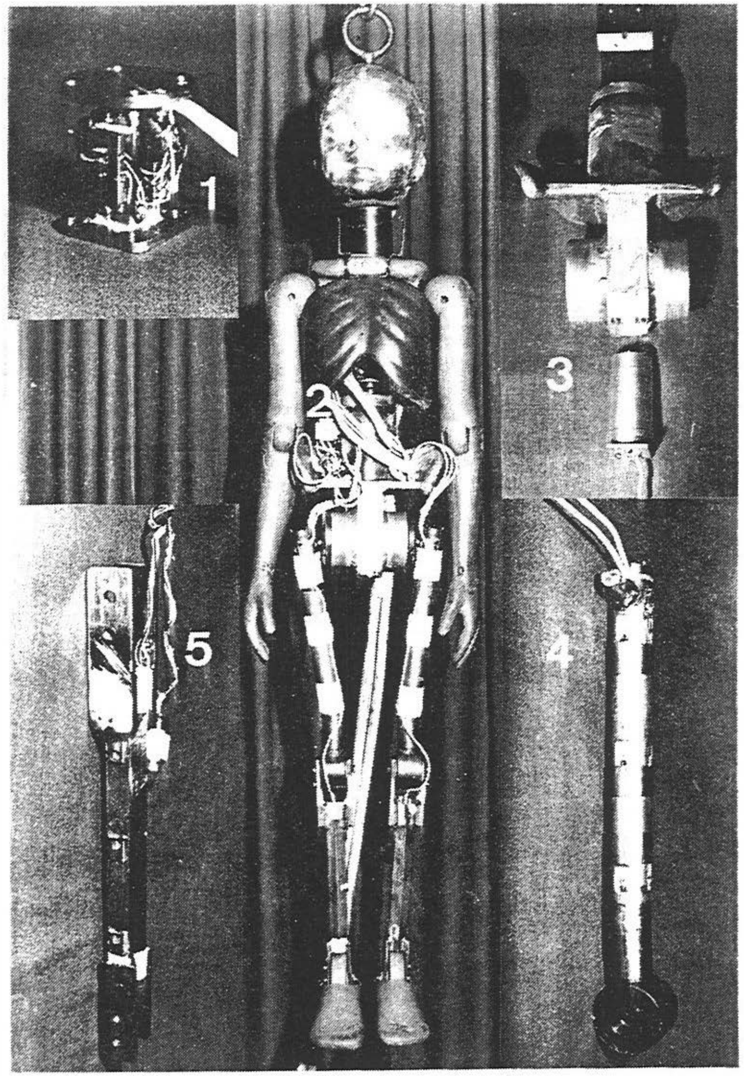

Fig. 1 - Modified Alderson VIP 6c : 1 measuring neck, 2 abdominal accelerometers, 3 tube for pelvis accelerometers, 4 femur, 5 tibia/fibula

Case Test	Primary Head Injury	Head Imp. Dir. [Clock]	a_{Kr} Peak [g]	a_{Kr} >3ms [g]	a_{Kei} [g]	t_i [ms]	a_{Kev} [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	parietal, 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	62	970	572	1.0soft
av	AIS 2		135	81					1045	597	

a_{Kei} effective resultant head acceleration by direct contact

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

t_i , t_v puls time durations

Fig. 3 - Comparison of test results with data of the real child pedestrian accidents regarding the head region

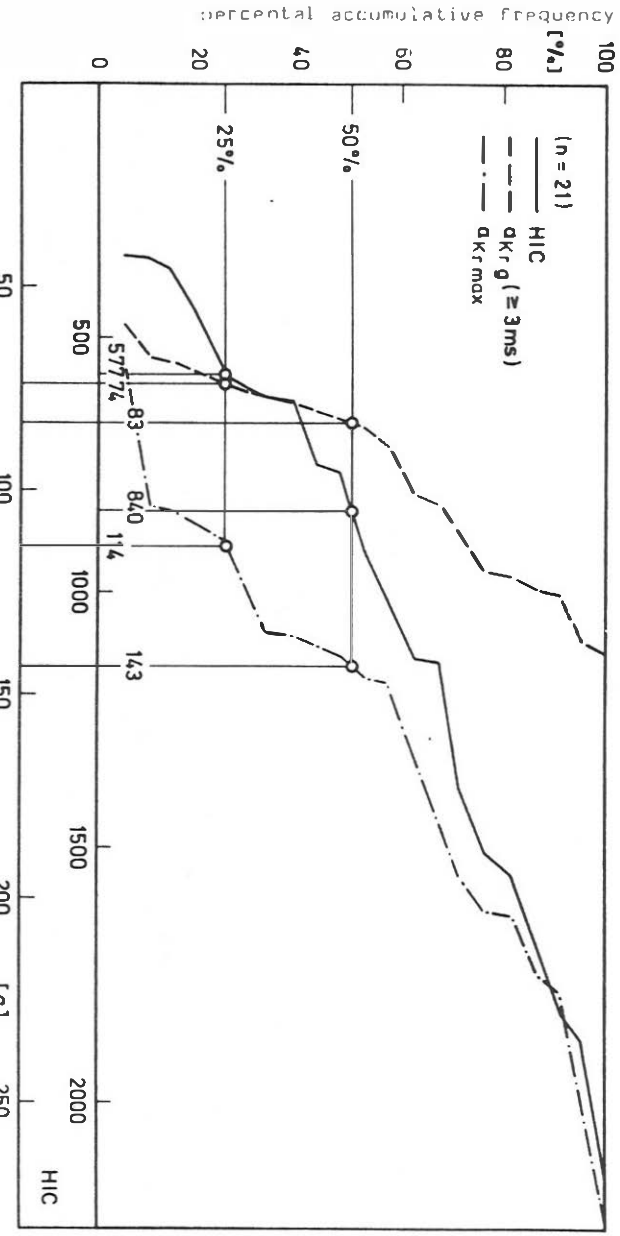

Fig. 4 - Percental accumulative frequency of HIC and maximum resultant acceleration (a_{Krmax}) as well as for time durations ≧ 3 ms for the head region of the modified VIP 6c correlated to real injuries of first degree S. B. Trauma

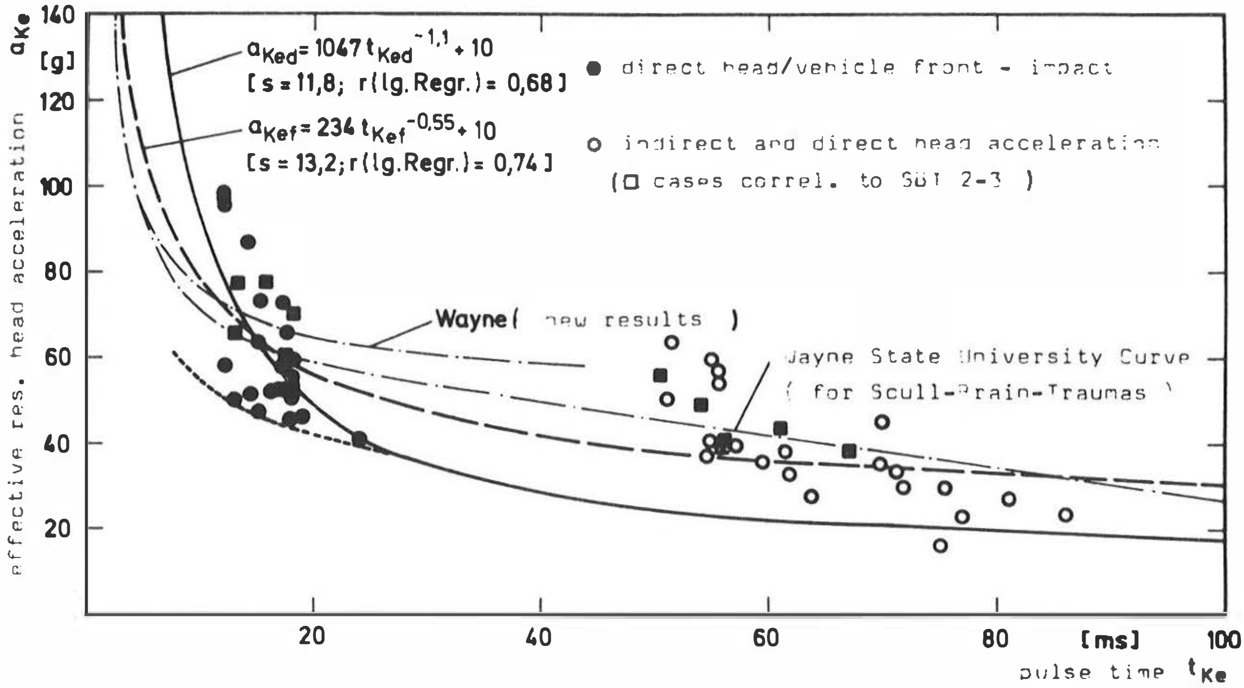

Fig. 5 - Effective resultant head acceleration versus pulse time for the direct dummy (VIP 6c) head/vehicle frontend impact as well as for the direct + indirect phase of the whole vehicle impact (o● first degree Scull Brain Trauma)

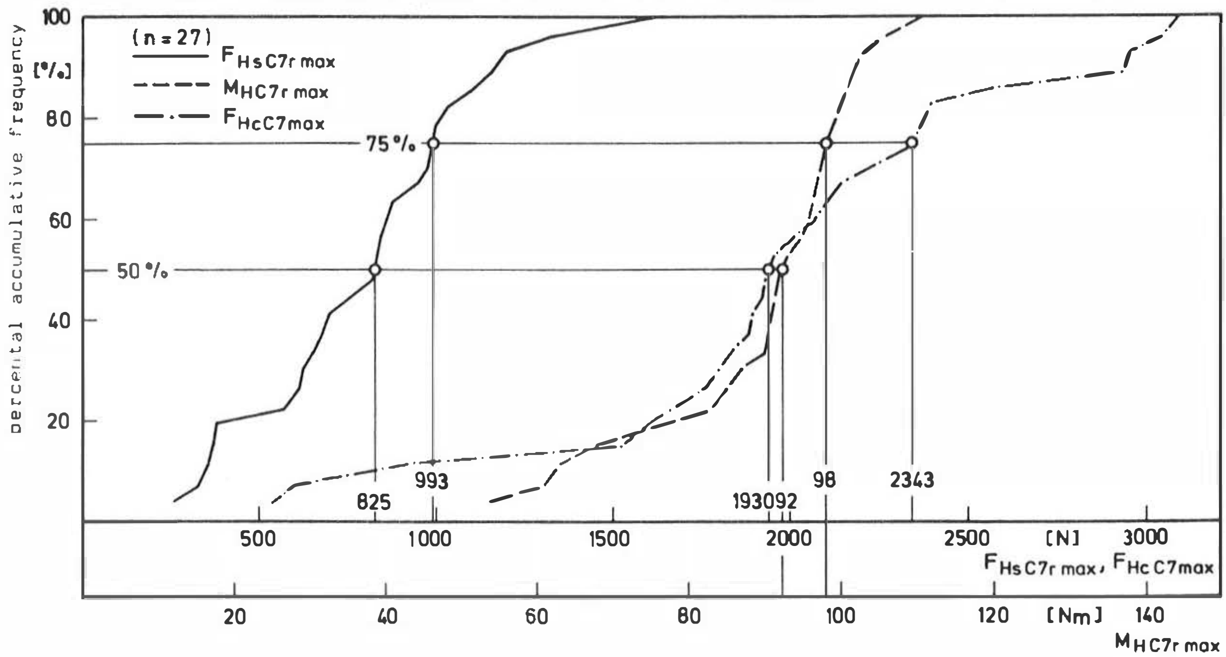

Fig. 6 - Percental accumulative frequency of maximum resultant shearforce ($F_{HsC7rmax}$) and maximum resultant bending moment ($M_{HC7rmax}$) as well as maximum cranial force ($F_{HcC7max}$) in the neck spine area of C7 of the VIP 6c correlated to real loadings without injury consequence

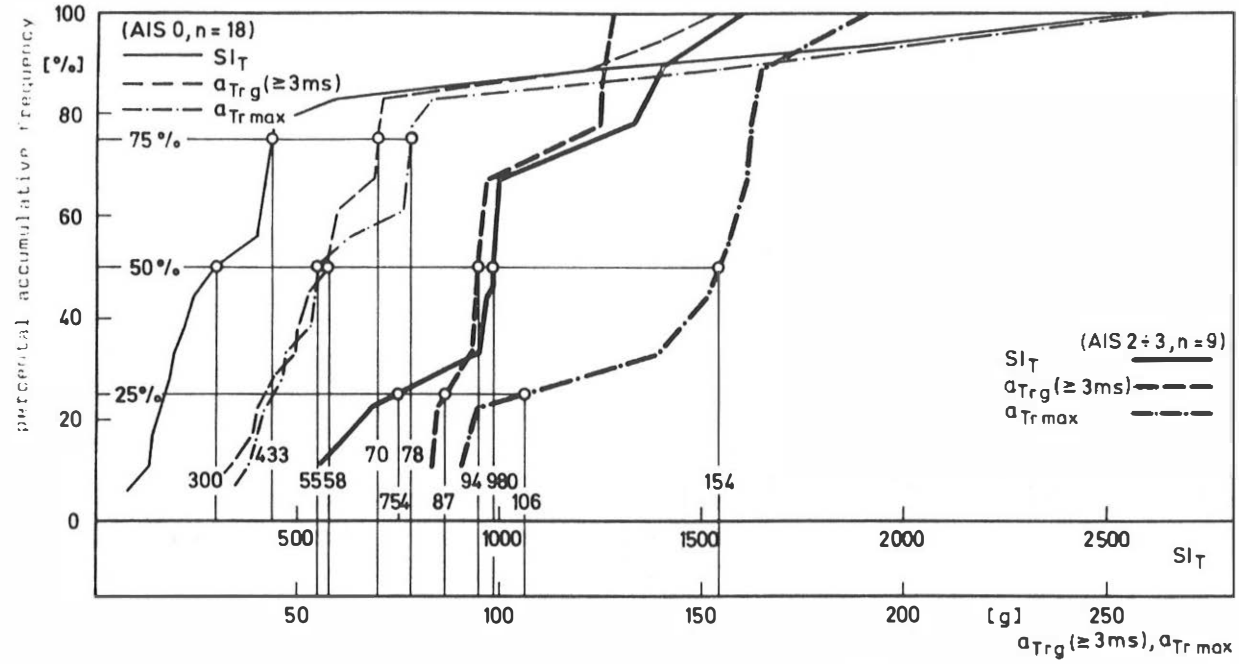

Fig. 7 - Percental accumulative frequency of SI_T and maximum resultant acceleration (a_{Trmax}) as well as for time durations ≧ 3 ms for the thoracic region of the VIP 6c correlated to injury severity degrees of AIS 2-3 respectively loadings without injury consequence

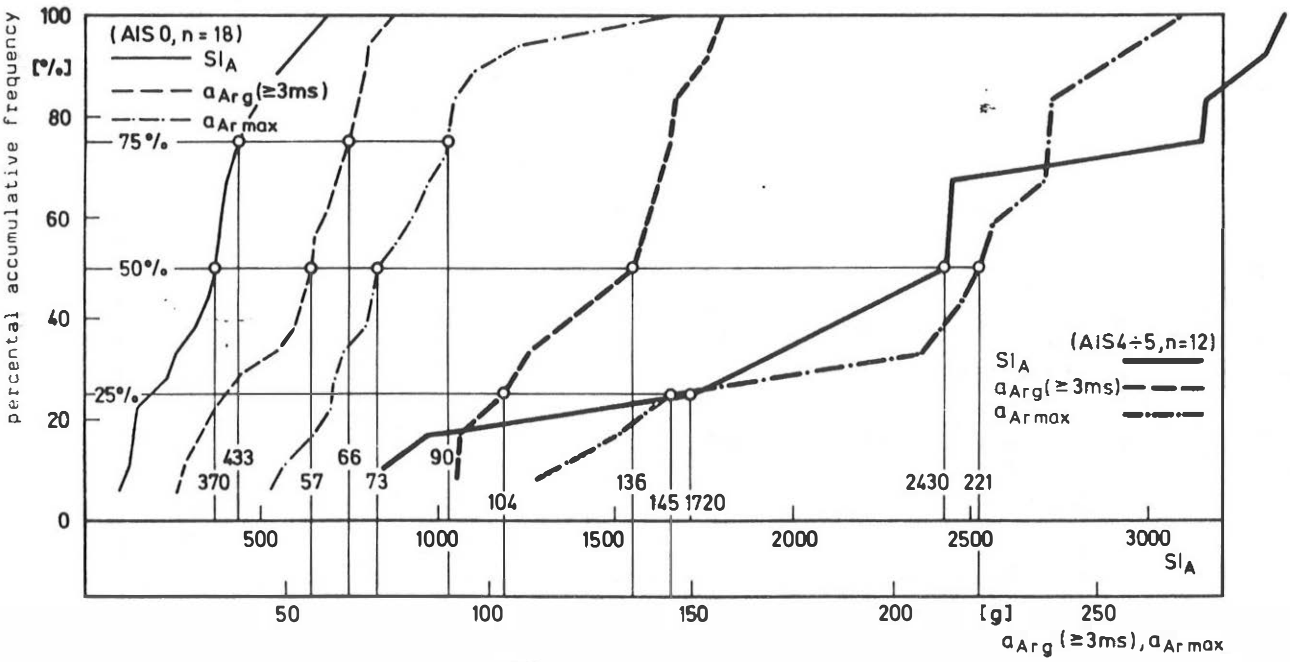

Fig. 8 - Percental accumulative frequency of SI_A and maximum resultant acceleration (a_{Armax}) as well as for time durations ≧ 3 ms for the abdominal region of the VIP 6c correlated to AIS 4-5 resp. loadings without injury consequence

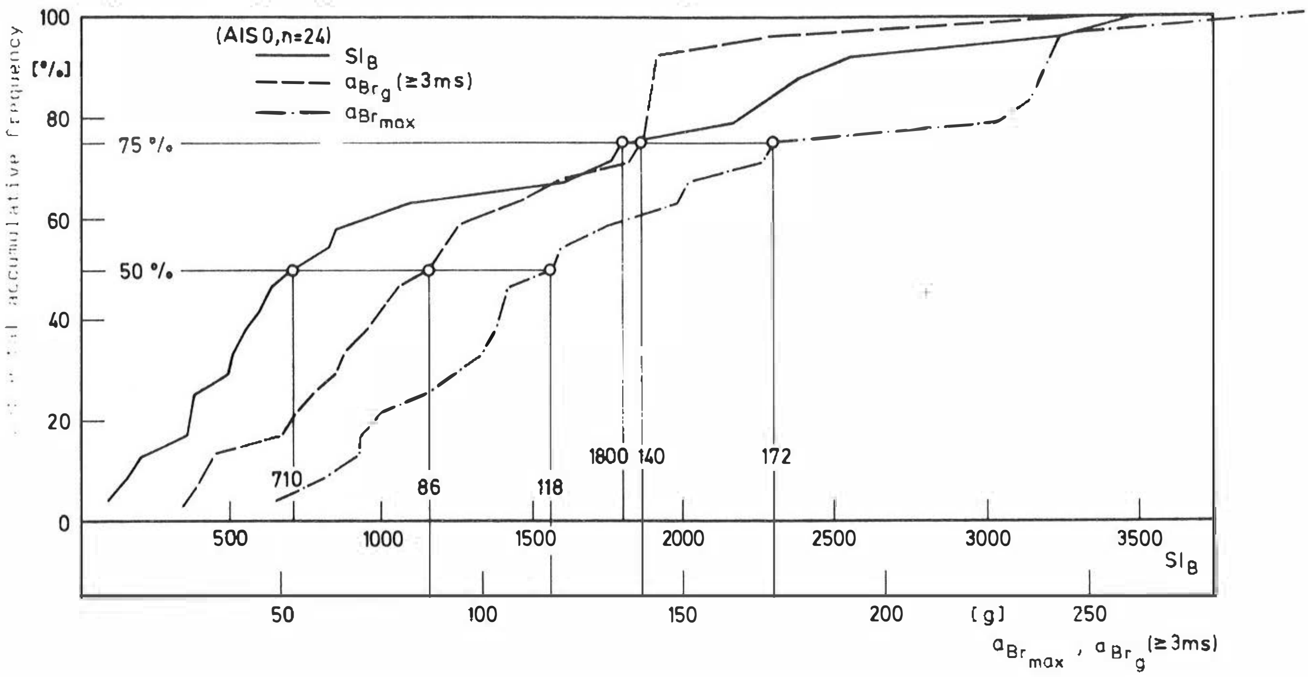

Fig. 9 - Percental accumulative frequency of SI_B and maximum resultant acceleration (a_{Brmax}) as well as for time durations ≧ 3 ms for the pelvis region of the VIP 6c correlated to loadings without injury consequence

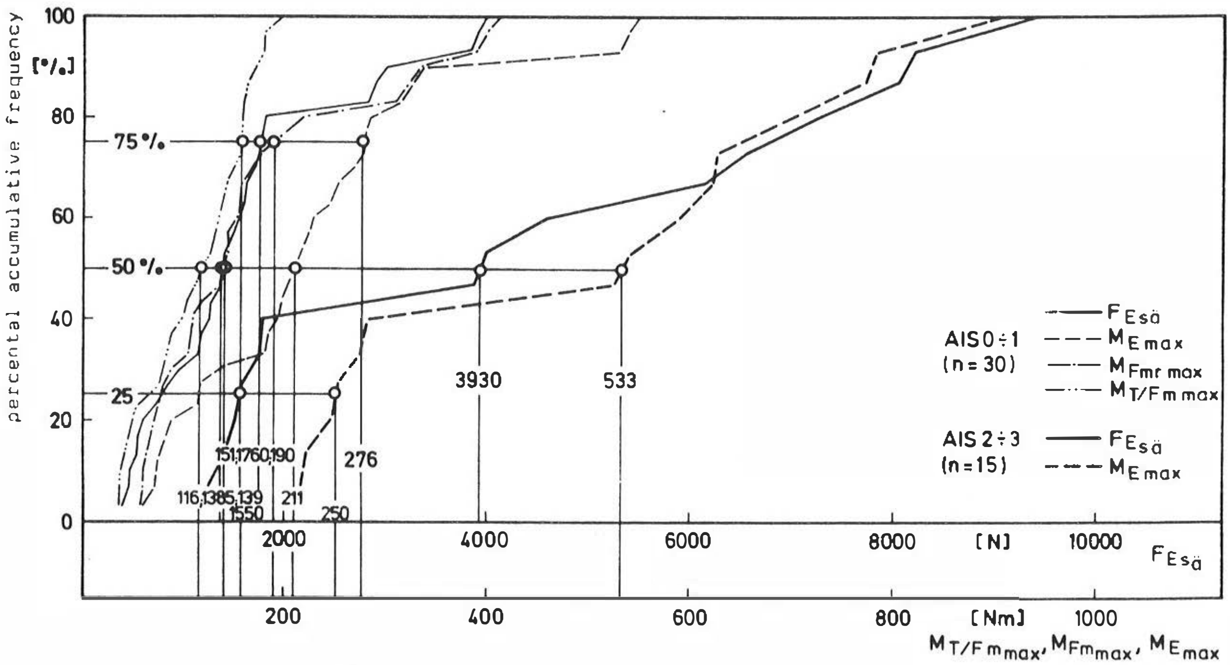

Fig.10 - Percental accumulative frequency of load values for the lower extremities correlated to AIS 2-3 as well as AIS< 2

body region	loading charact. value	reversible injuries number n	reversible injuries $\sum H$ 50	reversible injuries $\sum H$ 75	reversible injuries av. value $\bar{x}$	reversible injuries stand. dev s	irreversible injuries number n	irreversible injuries $\sum H$ 25 %	irreversible injuries $\sum H$ 50 %	irreversible injuries av. value $\bar{x}$	irreversible injuries stand. dev s	protection criteria SK1	protection criteria SK0
head	type and sever. of injury			-			7		SHT1				
	HIC						21	$\boxed{577}$	840	1031	517	600	350
	$a_{Kr\ g}$ (≥3 ms) [g]						"	$\boxed{74}$	83	95	22	70	60
	$a_{Kr\ max}$ [g]						"	$\boxed{114}$	143	161	52	110	70
	$a_{Ke} = f(t_{Ke})$						$a_{Ked} = 1047\ t_{Ked}^{-1,10} + 10$ [g]				11,8 g		
							$a_{Kef} = 234\ t_{Kef}^{-0,55} + 10$ [g]				13,2 g		
neck	injury severity degree	9		AIS 0					-				
	$F_{HS\ C7\ max}$ [N]	27	825	$\boxed{993}$	810	312						990	880
	$M_{H\ C7\ max}$ [Nm]	"	92	$\boxed{98}$	90	13						100	90
	$F_{Hc\ C7\ max}$ [N]	"	1930	$\boxed{2343}$	1978	541						2300	1900
	$F_{HSe} = f(t_{HSe})$	"		-									
thorax	injury severity degree	6		AIS 0			3		AIS 2 ÷ 3				
	SI_T	18	300	433	573	707	9	$\boxed{754}$	980	1051	226	750	300
	a_{Trg} (≥3 ms) [g]	"	58	70	67	36	"	$\boxed{87}$	94	103	12	85	55
	$a_{Tr\ max}$ [g]	"	59	78	83	62	"	$\boxed{106}$	154	146	26	105	55
	$a_{Te} = f(t_{te})$	$a_{Te} = 174\ t_{te}^{-0,62} + 10$ [g]				15,6 g	$a_{Te} = 457\ t_{te}^{-0,78} + 10$ [g]				6,7 g		
abdomen	injury severity degree	6		AIS 0			4		AIS 4 ÷ 5				
	SI_A	18	370	$\boxed{433}$	371	156	12	1720	2430	2331	693	400	350
	a_{Arg} (≥3 ms) [g]	"	57	$\boxed{66}$	53	16	"	104	136	130	12	65	55
	$a_{Ar\ max}$ [g]	"	73	$\boxed{90}$	79	16	"	145	221	208	39	90	70
	$a_{Ae} = f(t_{Ae})$	$a_{Ae} = 724\ t_{Ae}^{-1,07} + 10$ [g]				6,9 g	$a_{Ae} = 2399\ t_{Ae}^{-1,26} + 10$ [g]				7,9 g		
pelvis	injury severity degree	8		AIS 0			2		AIS 2				
	SI_B	24	$\boxed{710}$	1800	1214	1041	6	-	1285	1184	316	700	500
	a_{Brg} (≥3 ms) [g]	"	$\boxed{87}$	140	100	52	"	-	93	95	36	85	60
	$a_{Br\ max}$ [g]	"	$\boxed{118}$	172	143	72	"	-	108	118	38	115	85
	$a_{Be} = f(t_{Be})$	$a_{Be} = 2570\ t_{Be}^{-1,35} + 10$ [g]				7,8 g							
lower extremities	injury severity degree	10		AIS 0 ÷ 1			5		AIS 2 ÷ 3				
	$F_{Esä}$ [N]	30	1385	1760	1613	1039	15	$\boxed{1550}$	3930	4499	3104	1600	1400
	$M_{E\ max}$ [Nm]	"	211	276	248	129	"	$\boxed{250}$	533	504	251	250	220
	$M_{Fmr\ max}$ [Nm]	"	139	$\boxed{190}$	174	109	"	-	-	-	-	190	140
	$M_{T/Fm\ max}$ [Nm]	"	116	$\boxed{157}$	129	40	"	-	-	-	-	160	115
	$F_{Eqe} = f(t_{Eqe})$	"		-			$F_{Eäe} = 3,24 \cdot 10^3 t_{Ee}^{-1,85} + 250$ [N]				923 N		

$\boxed{}$ originonal values for the determination of SK1

Fig. 11 - Summary of correlated VIP 6c dummy load values as well as derived or recommended protection criteria against irreversible injuries