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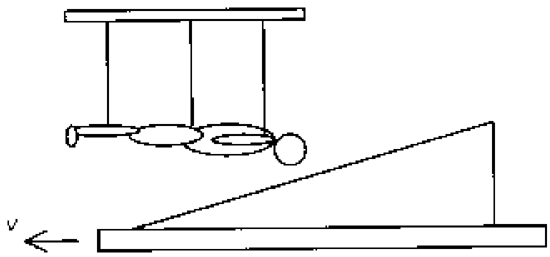
Chin Strap Forces in Bicycle Helmets

SP
Swedish National Testing and Research Institute
Mechanics
SP REPORT 1993:42

Abstract

The objective of this experimental investigation was to find out what dynamic forces bicycle helmets retention systems are subjected to when head impact accidents take place. The results were quantitative data of the retention system forces. Different helmet models were subjected to simulated accidents, of the type with the head first (with vertical and horizontal velocity) against a rigid asphalt surface. See figure below. The chin strap forces developed in the accident simulations of the present study are low compared to the requirements of most of the existing standards for bicycle helmets. Arithmetic mean values of the chin strap peak forces of all impacts were 42 N.



Three types of helmets were investigated, one hard-shell helmet, one non-shell helmet and one ribbed helmet (large ventilation holes), with hard-shell. A six-year old child test dummy, a car crash test facility with a piece of inclined asphalt road on the carriage was the main ingredient in the study. The test dummy was suspended from the ceiling and was being hit by the piece of asphalt road mounted on the stiff car crash track carriage. Some different single type accidents were simulated. All impacts were carried out with the helmeted dummy's head impacting the asphalt layer first. The types of accidents simulated were all meant to be the case when the bicycle is blocked in one way or another and the rider continues with a certain horizontal and vertical velocity.

As a subsidiary result it was discovered that the rotational effects of the tested helmets differed a lot. The shell helmets did not grip the asphalt layer at all and did not rotate, which implies that nor did the head form rotate. The non-shell helmets gripped the asphalt layer in each impact, rotated and transferred this rotation to the head form.

The stability of children helmets should be regarded to be more important for the helmet's ability to stay on the wearer's head than buckles that withstand high force levels. The helmet design in itself could result in different chin strap forces in accidents. One of the key factors is probably the helmet's area of coverage and its fit to the head. This study of the chin strap forces developed in bicycles' retention systems in single type accidents indicates that chin strap buckles with self-release function for children are applicable.

Keyword: Bicycle helmet, chin strap, head rotation, oblique impact, helmet testing, force, acceleration.

Sveriges Provnings- och Forskningsinstitut

SP RAPPORT 1993:42
ISBN 91-7848-427-8
ISSN 0284-5172

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SP REPORT 1993:42

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Acknowledgements

The present study was supported and funded by:

- **The Swedish Transport Research Board**
- **The Swedish National Board for Consumer Policies**
- **The Ministry of Children and Family and Affairs, Norway**
- **The Swedish National Road Administration**
- **The National Institute of Public Health, Sweden**
- **Bilatlas AB, Sweden**
- **Etto AB, Sweden**
- **Hamax A/S, Norway**
- **SLG ProdukterAB, Sweden**

The Swedish National Testing and Research Institute also thank Mr Anders Slätis for his valuable assistance with the project regarding the supply of background information.

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1 Introduction

In the years to come the use of helmets will probably increase. This will benefit the safety of the individual bicycle rider. However, with more helmets involved in accidents and everyday use, the weak points of today's helmet design will be revealed. One such weak point has been proved to be the hazard of chin strap suffocation.

The purpose of a chin strap is to keep the helmet on the wearer's head (especially during accidents), and thus the design is normally intended to give the straps strength and durability. However, it could be an advantage if the helmet can release automatically from the head in certain situations. Five fatal accidents have occurred in Sweden and one in Norway when playing children have been caught by the chin strap.

The protective properties of a bicycle helmet should be to:

- Absorb linear shocks during accidents.
- Prevent too heavy angular impulses during accidents.
- Distribute concentrated forces during accidents.

A prerequisite for the protective properties of a helmet is to:

- Stay on the head during accidents.

A not desirable property of a helmet is to:

- Increase the risk of a child to be caught by the head in playground equipment etc.

There exist a number of national bicycle helmet standards, and also a draft European standard [CEN prEN 1078/1079/1080] has been prepared. The first and the third protective property is covered by the part "Determination of shock absorbing capacity" (impact against flat anvil and kerbstone anvil) in the CEN draft.

The fourth desired property (to stay on the head) is taken care of by "Retention system testing: Retention system strength and Retention system effectiveness" in the CEN draft.

It is to be noted that one of the protective properties (to minimize angular accelerations) cannot be found in any of the bicycle helmet standards of today. Rotational aspects are discussed, but for technical reasons (concerning relevant test method), no requirements for angular acceleration have been implemented.

The ability to stay on the wearers' head and the risk of a child to be caught by the head in playground equipment are together the reason for the current study. The object has been to measure chin strap forces during the conditions described in part 3.

A non-exhaustive literature study has been made in order to give some background to the bicycle accident mechanisms. Some of the papers are discussed in part 8.

2 Method

A six-year old child test dummy, a car-crash test facility, three different types of bicycle helmets and an inclined asphalt layer were the main ingredients. Similar investigations have been carried out before, for example in the USA by Hogson, and in Sweden by Aldman et al. with the purpose to investigate angular acceleration or neck forces. In most of the earlier projects the accidents have been simulated by moving the test dummy against an obstacle. To set the test dummy in motion is the natural way to proceed.

We have tried to develop new concept. Instead of having the dummy in motion as in real life and drop it to the ground or let it hit an obstacle, we have let the dummy hang motionless down from the ceiling and it was being hit by a piece of asphalt road. The piece of asphalt road was mounted on a stiff carriage at our car crash test track. See figure 1.

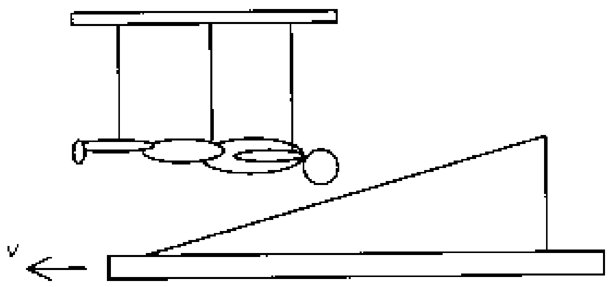

Figure 1. Carriage with "asphalt ground" hitting the dummy.

The buckles of the helmets' retention systems were replaced by a force transducer.

The method gave good control of the whole collision. The advantages (vs. moving the test dummy) were reproducibility, reliability and also more accurate and consistent measurements even for rather high speeds.

The speed of the carriage at impact was either 23 km/h, 34 km/h or 41 km/h and the angle from the horizontal plane to the plane of the asphalt layer was 28°, in all cases.

The two simulated velocity components for the dummy are then calculated as
$v(hor) = v(carr) \cdot \cos 28°$ and $v(fall) = v(carr) \cdot \sin 28°$, which gives the following three different cases:

v(carr) = 23 km/h *v(hor) = 20 km/h and v(fall) = 11 km/h*
v(carr) = 34 km/h *v(hor) = 30 km/h and v(fall) = 16 km/h*
v(carr) = 41 km/h *v(hor) = 36 km/h and v(fall) = 19 km/h*

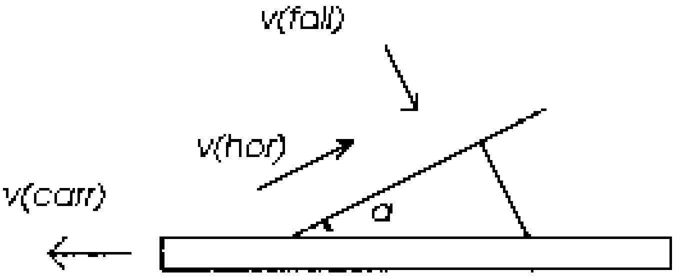

Figure 2. The velocity components.

Equipment:

- A 30 m long car crash test track with a free rolling distance of 12 m and possibilities to reach velocities up to 80 km/h.
- A carriage with the mass of 1100 kg including the piece of asphalt road.
- A TNO six-year old test dummy. Mass: 22 kg.
- A tridirectional accelerometer, Endevco 7267A, mounted in the centre of test dummy head (A in figure 3).
- A force transducer of parallelogram type with strain gages (range: 0 to 200 N), supplied by Load Indicator (B in figure 3).
- A measuring system (HBM amplifiers and Ericsson sampling computer) with a frequency response in accordance with channel frequency class 1000 of ISO 6487: 1987. Sampling rate was 10 000 samples per second. A low pass filter with a cut-off frequency of 1650 Hz was within the amplifiers. (C, D in figure 3).
- High speed cameras used at 1 000 shots per second.
- Means for analysing the raw signals and for calculation of HIC.

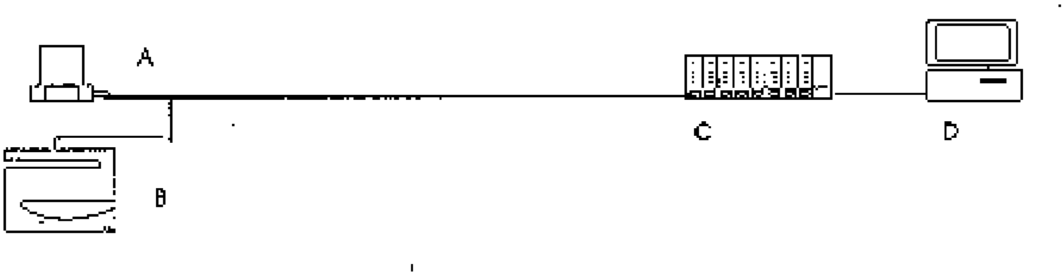

Figure 3. Sketch of the measuring assembly.

3 Accident mechanism

Some different single type accidents have been simulated in the current study. All impacts were carried out with the dummy's head impacting the asphalt layer first. The types of accident simulated were all meant to be the case when the bicycle is blocked in one way or another and the rider continues with a certain horizontal and vertical velocity, hitting the asphalt with the head first.

The following parameters need a further clarification:

- Horizontal velocity component
- Vertical velocity component
- Type of test dummy
- Body orientation of test dummy
- Impact sites on helmeted dummy head
- Helmet's position on dummy head
- Friction between dummy head and helmet
- Measurement location
- Chin strap pre-tension
- Comfort pads inside helmet
- Climatic conditions
- Ground
- Helmet types

Horizontal velocity component ("rider's speed")
The values can be considerably high when riding modern bicycles and also for children in downhill slopes. The velocity range of 10 to 50 km/h probably covers normal bicycling. In this investigation the velocities of 20, 30 and 36 km/h have been examined.

Vertical velocity component ("rider's fall height")
The drop height in different bicycle helmet standards varies between one and two metres (corresponding to 15.9 km/h and 22.5 km/h) and probably so also in reality. For six-year old children one metre is probably more accurate than two metres and furthermore the main interest of this project was to simulate high tangential forces on the helmet surface rather than large forces perpendicular to the surface. A vertical velocity component of 11, 16 and 19 km/h respectively has been examined, which was considered to cover the possible range well enough.

Test dummy
A TNO-six-year old dummy was used. The dummy was found to be robust and reliable. The neck is flexible although it is not as sophisticated as in the Hybrid III dummy. However, the Hybrid III does not seem to be available in a six-year old version and further more the purpose of the study was not to measure neck forces nor head rotation.

The dummy body orientation
This parameter is closely connected to the impact sites. The difference is that an impact site as for example at the forehead can be impacted with the body, legs or arms in different positions. Two dummy body orientations were investigated, called x and y. Both orientations with the "head first". Both orientations had the coronal plane horizontally. The x-orientation had the mid-sagittal plane parallel to the median plane of the carriage (e.g. the car crash track). The y-direction had the mid-sagittal plane in an angle of 20° to the median plane of the carriage.

Impact site on helmeted dummy head
A number of filed investigation and epidemiological research. For example "Bicycle Accidents in Gothenburg" by Per-Olof Kroon, point out that the forehead is the part of the head that is impacted most frequently in single accidents, whereas the rear part seems to be impacted most frequently in fatal accidents according to "Skall- och ansiktsskador hos cyklister med avseende på möjlig effekt av hjälmanvändning" (Bicycle driver's head and face injuries regarding possible effects of helmet use") by Ulf Björnstig et al. It was decided to include tests with front impact, side impact and rear impact.

Helmet's position on test dummy head
In this investigation only one alternative was regarded, which was according to manufacturers' instructions or so called normal use.

Friction between dummy head and helmet
Also for this parameter it was decided to test one alternative only. In some way the skin friction of the rubberised test dummy head form had to be reduced as it seemed to be much higher than for a human head. A fresh paper towel was put between the head form and the helmet at each test as this seemed to be more in accordance with the real life. It provided good repeatability as well.

Measurement location
The buckles were replaced by a force transducer, which determined the measurement location. Two steel rods reinforced the outer part of the chin of the test dummy in order to get the force transducer on the side of the face in spite of the fact that most of the children have to place the buckle beneath the chin.

Chin strap pre-tension
The pre-load on the chin strap varied at random between 1 and 6 N.

Comfort pads inside helmet
It was decided to use the comfort padding as supplied by the manufacturers.

Climatic conditions
Different climatic conditions such as cold, rain and heat have been disregarded. For practical reasons the tests were carried out in normal laboratory conditions.

Ground
A piece of massive asphalt layer similar to that used on paved roads was used in all tests.

Helmet type
Three types of helmets were investigated. One hard-shell helmet (type A), one non-shell helmet (type B) and one ribbed helmet (large ventilation holes) with hard shell (type C). All three models are of modern design with chin strap attachment both at the sides and at the rear part of the helmet.

This leaves us the following investigated variables:

- Velocity (3 alternatives)
- Impact site (3 alternatives)
- Body orientation (2 alternatives)
- Helmet type (3 alternatives)

4 Preliminary tests

Preliminary tests were made in order to make it possible to design accurate force transducers. No force measurements were made, instead three different buckles with self-release function for predetermined force levels were used. Twenty-two different helmets of various types were tested. All the collisions were filmed with a high-speed camera. The findings from the preliminary tests are presented here as a separate part of the study.

1. Eleven helmets of child's size and a TNO six-year-old dummy were tested:

- Three of them were provided with buckles releasing at approximately 50 N. They all released.
- Three of them were provided with buckles releasing at approximately 75 N. They did not release.
- Three of them were provided with buckles releasing at approximately 100 N. They did not release.
- Two of them were provided with buckles releasing at not less than approximately 1000 N, in other words ordinary chin strap buckles. These two helmets were tested for reference purpose. They did of course not release during the simulated accidents.

2. Eleven helmets of adult's size and an OGLE male test dummy were tested:

- Six of the helmets were provided with buckles releasing at 150 N. One of them did release.
- Five of the helmets were provided with ordinary buckles for reference purpose. They did not release.

5 Results

In total 57 impacts were made.

- Arithmetic mean value of the chin strap peak forces of all impacts: 42 N.

- Arithmetic mean of the peak forces at: 23 km/h: 33 N
  34 km/h: 47 N
  41 km/h: 48 N

- Arithmetic mean of the peak forces of: type A (hard shell) helmets: 43 N
  type B (non-shell) helmets: 48 N
  type C (ribbed, hard shell) helmets: 35 N

- Arithmetic mean of the peak forces for: front impact: 40 N
  side impact: 45 N
  rear impact: 42 N

The peak forces, the resultant peak accelerations and the calculated HIC-values are presented in different tables in the appendix. The first table presents the values of all 57 impacts and the following tables present the same values in different combinations.

A number of diagrams for different combinations are also presented in the appendix, which hopefully can help the reader to get an overview of the results.

6 Observations and considerations concerning chin strap forces

In the end of the appendix three of the force and acceleration curves are presented. Here it is worth nothing that for some impacts the peaks of the force pulses did not coincide in time with the peaks of the acceleration pulses, but appeared some milliseconds later.

The chin strap was always initially stretched in one way or another, depending on the impact direction, when the helmeted head was impacted with the inclined piece of asphalt road. For all helmets the liner was compressed (as supposed to) during the impact, which seemed to reduce the tension in the chin straps after the initial impact.

For the hard-shell helmet type the helmet could in some cases bounce against the head and due to the mass of the helmet stretch the chin straps once again, which could explain the force peak delays. The non-shell helmet type did not seem to bounce, but on the other hand grabbed the asphalt layer and twisted the whole head form. This could explain the force peak delays in some impacts for the non-shell helmets.

The peak force arithmetic mean value of all impacts is 42 N in this investigation, which must be considered to be quite low. The existing self-release buckles open for values between 45 and 80 N. The origin for this range is simply the weight of children.

Note that at 23 km/h carriage speed, 5 of the 21 trials recorded peak force levels of more than 45 N. Thus it should be clear that the forces developed, although low in general, were not negligible. In the draft European standard prEn 1080 Protective helmets for young children, the corresponding requirement is that the chin strap shall open for values between 60 an 90 N.

The peak forces seem to increase for higher velocity, but only to a certain extent. Here we must keep in mind that we tested helmets of a design with chin strap attachments both at the sides and at the rear part of the helmet. We could not discover any instability when studying the high speed films and if the helmets would have rolled off, the chin strap forces would probably have become more dispersed for high velocities.

When studying the different types of helmets, the values indicate that the non-shell helmet type recorded some higher peak force levels. The fact that the non-shell helmets grab the asphalt does obviously not increase the chin strap forces very much. The tangential forces on the non-shell helmets are transmitted directly to the head and do not stretch the chin strap more as compared to the shall helmets but instead rotates the head.

The helmet design in itself could naturally result in different chin strap forces in accidents. One of the key factors is probably the helmets' area of coverage and its fit to the head. The stability of children helmets should be regarded to be as important for the helmet's ability to stay on the wearer's head as buckles that withstand high force levels. Therefore, the development of an infant test head form is valuable for designing children helmets in the future.

7 Other observations - head rotation

The forces transmitted to the head at oblique impact are different in character for non-shell helmets compared to shell helmets. This was not revealed when measuring chin strap forces nor linear head acceleration, but our high speed films clearly showed the difference.

The shell helmets slided against the asphalt surface and there was only a slight angular movement of the head when the head was pushed upwards. This angular movement could not be measured at the high speed film shots. The neck was compressed during the impact, but not bent.

The non-shell helmet did in all trials grab the asphalt surface, which rotated the head together with the helmet. The consequences were in addition to the rotating of the head, a heavily bent and compressed neck, transmitted on through the whole test dummy body after the impact.

The high-speed film analysis for one non-shell helmet at rear impact (34 km/h carriage speed) gave the following measured values:

Head rotation the first 3 milliseconds during the impact were 0 rad - the helmet was compressed.
Head rotation between 3 and 8 ms was 0.26 rad.
Head rotation between 8 and 13 ms was 0.38 rad.
Head rotation between 13 and 18 ms was 0.16 rad.
Head rotation between 18 and 23 ms was 0.10 rad.

Assume that the torque was constant during the 5 ms intervals. This gives an average angular acceleration of 20800 rad/s^2 for rotating the head from 0 to 0.26 rad during the 5 ms. Löwenhielm proposes 4500 rad/s^2 to be the maximum angular acceleration that can be tolerated for a limited time period, which also is suggested by Gilchrist and Mills.

The high speed film analysis for one non-shell helmet at front impact (34 km/h carriage speed) gave the following measured values:

Head rotation the first 3 milliseconds during the impact were 0 rad - the helmet was compressed.
Head rotation between 3 and 8 ms was 0.35 rad.
Head rotation between 8 and 13 ms was 0.11 rad.
Head rotation between 13 and 18 ms was 0.16 rad.
Head rotation between 18 and 23 ms was 0.12 rad.

The average angular acceleration for rotating the head from 0 to 0.35 radians during 5 ms is 28000 rad/s^2!

In one single impact it is possible to carry out several different standard tests at the same time. We achieved an interesting mixed test procedure as we simultaneously were able to determine the shock absorption features (both for linear and angular acceleration pulses), the roll-off effects and the strength of the retention system. In other words the total helmet behaviour, accomplished by analysing the dynamic response of the dummy. This kind of full test could actually replace many of today’s individual test procedures. The angular acceleration or neck forces have not been measured directly in this investigation, but the technique is available.

8 Other relevant studies - comparisons

Hodgson's study "Skid tests on a selected group of bicycle helmets to determine their head-neck protective characteristics" indicates that the angular acceleration impulses and neck forces for non-shell helmets compared to shell helmets, are not much higher in peak levels but have longer durations. Our findings are not similar for the chin strap forces - the durations are quite the same, but the peak levels slightly higher. For the angular acceleration and the neck forces, however, our belief is that also the peak values are larger for non-shell helmets than shell helmets for **high** impact velocities. Hudson's investigation used a test dummy speed of around 10 km/h, while in the current investigation the tests started at 20 km/h. More research within this field is needed especially for velocities of more than 20 km/h. Different impact surfaces should be regarded.

Martin Williams and his research group in Australia evaluated the protective performance of 64 helmets, which had sustained impacts in real accidents, in 1989. Some interesting information for the chin strap forces investigation can be outlined:
39% of the accidents involved a single bicycle. A high proportion of helmets sustained more than one impact. Four helmets were pulled off the riders' heads in similar circumstances during the accident. These helmets did not seem to pass a stability test, e.g. to resist fore-and-aft motion when on the riders head.

Williams recommends the following concerning chin straps:

- The webbing of retention systems should be installed in such a manner that it cannot be removed from buckles and earpieces.
- Components of the retention systems or other fittings of a helmet that can come into contact with a wearer's shin should not have sharp edges.
- A dynamic helmet stability test should be developed that reflects the circumstances of accidents known to be capable of removing a helmet from a wearer's head.

Our conclusion from Williams investigation together with the current investigation is that the resistance to fore-and-aft motion and general stability is more important for a child helmet than a buckle that resists high force levels.

Another investigation, by Ulf Björnstig et al., was also studied. This investigation concerns bicycle helmets´ injury reducing potential. Some Swedish fatal and non-fatal injuries for riders who did not wear helmets in the accidents were analysed. 843 injured riders were involved and 105 of them had died as a consequence of severe accidents. 321 cases involved head injuries. A summary of interesting information for the current study is the following:

- Non-fatal head injuries: 14% of the accidents involved a collision with motor vehicles. 10% involved a collision with other riders. In 76% of the accidents no vehicles were involved other than the bicycles of the riders themselves.
- Fatal head injuries: 91% of the accidents involved a collision with a motor vehicle.

Motor vehicles seem to be involved in fatal accidents. In accidents involving motor vehicles anything can happen and the chin strap forces could probably reach values far beyond the human tolerance. The same thing will happen when impacting kerbstones etc in very high speed, whereas it's not the chin strap forces that will exceed the human tolerance, but the neck forces. Also single bicycle accidents may result in fatal injuries and other severe injuries, and the helmets potential to reduce injuries is considered to be important. In this perspective we believe that investigations of chin strap forces developed in single bicycle accidents for adults and not only for children must be meaningful and needed.

9 Conclusions

The chin strap forces developed in the accident simulations are low compared to the requirements of most of the existing standards for bicycle helmets.

The rotational effects of the tested helmets differ a lot. The shell helmets do not grip the asphalt layer at all and do not rotate, which implies that neither the head form rotates. The non-shell helmets grip the asphalt layer in each impact, rotate and transfer this rotation to the test dummy head form.

The method used in this investigation is probably applicable as an oblique impact test and might prove effective for testing several properties of a bicycle helmet; whereas today's recognized standards use different methods for testing different properties of the helmet. Different accident types can easily be simulated and extensive measurements could be carried out.

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APPENDIX

Impact site	Dummy	Helmet	Peak force (N)	Peak acc (g)	HIC
Front	Orient. x	Type A	*71*	*48*	*68*
Front	Orient. x	Type B	*30*	*91*	*233*
Front	Orient. x	Type C	*14*	*62*	*111*
Front	Orinet. y	Type A	*15*	*68*	*122*
Front	Orient. y	Type B	*17*	*84*	*155*
Front	Orient. y	Type C	*14*	*53*	*91*
Side	Orient. x	Type A	*27*	*95*	*134*
Side	Orient. x	Type B	*101*	*106*	*205*
Side	Orient. x	Type C	*14*	*124*	*135*
Side	Orient. y	Type A	*20*	*77*	*98*
Side	Orient. y	Type B	*59*	*107*	*266*
Side	Orient. y	Type C	*48*	*98*	*159*
Rear	Orient. x	Type A	*18*	*117*	*240*
Rear	Orient. x	Type B	*41*	*126*	*304*
Rear	Orient. x	Type C	*17*	*99*	*213*
Rear	Orient. y	Type A	*18*	*91*	*179*
Rear	Orient. y	Type B	*40*	*102*	*252*
Rear	Orient. y	Type C	*24*	*66*	*135*
Rear	Orient. y	Type A	*22*	*88*	*195*
Front	Orient. y	Type A	*67*	*52*	*65*
Front	Orient. y	Type B	*14*	*91*	*181*
Front	Orient. x	Type A	*89*	*88*	*239*
Front	Orient. x	Type B	*41*	*126*	*652*
Front	Orient. x	Type C	*45*	*83*	*143*
Front	Orient. y	Type A	*27*	*101*	*344*
Front	Orient. y	Type B	*31*	*122*	*497*
Front	Orient. y	Type C	*22*	*111*	*273*
Side	Orient. x	Type A	*73*	*144*	*359*
Side	Orient. x	Type B	*36*	*113*	*323*
Side	Orient. x	Type C	*52*	*132*	*415*
Side	Orient. y	Type A	*55*	*93*	*285*
Side	Orient. y	Type B	*19*	*85*	*287*
Side	Orient. y	Type C	*37*	*122*	*456*
Rear	Orient. x	Type A	*44*	*140*	*534*
Rear	Orient. x	Type B	*108*	*179*	*912*
Rear	Orient. x	Type C	*54*	*92*	*347*
Rear	Orient. y	Type A	*28*	*133*	*531*
Rear	Orient. y	Type B	*61*	*127*	*436*
Rear	Orient. y	Type C	*29*	*129*	*326*
Front	Orient. x	Type A	*63*	*134*	*552*
Front	Orient. x	Type B	*59*	*131*	*539*
Front	Orient. x	Type C	*44*	*138*	*457*
Front	Orient. y	Type A	*78*	*136*	*511*
Front	Orient. y	Type B	*36*	*134*	*558*
Front	Orient. y	Type C	*27*	*137*	*450*
Side	Orient. x	Type A	*35*	*146*	*497*
Side	Orient. x	Type B	*55*	*128*	*986*
Side	Orient. x	Type C	*50*	*131*	*648*
Side	Orient.y	Type A	*36*	*144*	*580*
Side	Orient. y	Type B	*47*	*156*	*904*
Side	Orient. y	Type C	*39*	*151*	*508*
Rear	Orient. x	Type A	*49*	*140*	*706*
Rear	Orient. x	Type B	*62*	*169*	*1960*
Rear	Orient. x	Type C	*41*	*151*	*658*
Rear	Orient. y	Type A	*30*	*176*	*889*
Rear	Orient. y	Type B	*58*	*152*	*861*
Rear	Orient. y	Type C	*62*	*151*	*750*
Mean value:			***42***	***115***	***420***
Min value:			***14***	***48***	***65***
Max value:			***108***	***179***	***1960***

Table 1. All 57 impacts.

Impact site	Dummy	Helmet	Peak force (N)	Peak acc (g)	HIC
Front	Orient. x	Type A	*71*	*48*	*68*
Front	Orient. x	Type B	*30*	*91*	*233*
Front	Orient. x	Type C	*14*	*62*	*111*
Front	Orient. y	Type A	*15*	*68*	*122*
Front	Orient. y	Type B	*17*	*84*	*155*
Front	Orient. y	Type C	*14*	*53*	*91*
Side	Orient. x	Type A	*27*	*95*	*134*
Side	Orient. x	Type B	*101*	*106*	*205*
Side	Orient. x	Type C	*14*	*124*	*135*
Side	Orient. y	Type A	*20*	*77*	*98*
Side	Orient. y	Type B	*59*	*107*	*266*
Side	Orient. y	Type C	*48*	*98*	*159*
Rear	Orient. x	Type A	*18*	*117*	*240*
Rear	Orient. x	Type B	*41*	*126*	*304*
Rear	Orient. x	Type C	*17*	*99*	*213*
Rear	Orient. y	Type A	*18*	*91*	*179*
Rear	Orient. y	Type B	*40*	*102*	*252*
Rear	Orient. y	Type C	*24*	*66*	*135*
Rear	Orient. y	Type A	*22*	*88*	*195*
Front	Orient. y	Type A	*67*	*52*	*65*
Front	Orient. y	Type B	*14*	*91*	*181*
Mean value:			***33***	***88***	***169***
Min value:			***14***	***48***	***65***
Max value:			***101***	***126***	***304***

Table 2. 23 km/h carriage speed only.

Impact site	Dummy	Helmet	Peak force (N)	Peak acc (g)	HIC
Front	Orient. x	Type A	*89*	*88*	*239*
Front	Orient. x	Type B	*41*	*126*	*652*
Front	Orient. x	Type C	*45*	*83*	*143*
Front	Orient. y	Type A	*27*	*101*	*344*
Front	Orient. y	Type B	*31*	*122*	*497*
Front	Orient. y	Type C	*22*	*111*	*273*
Side	Orient. x	Type A	*73*	*144*	*359*
Side	Orient. x	Type B	*36*	*113*	*323*
Side	Orient. x	Type C	*52*	*132*	*415*
Side	Orient. y	Type A	*55*	*93*	*285*
Side	Orient. y	Type B	*19*	*85*	*287*
Side	Orient. y	Type C	*37*	*122*	*456*
Rear	Orient. x	Type A	*44*	*140*	*534*
Rear	Orient. x	Type B	*108*	*179*	*912*
Rear	Orient. x	Type C	*54*	*92*	*347*
Rear	Orient. y	Type A	*28*	*133*	*531*
Rear	Orient. y	Type B	*61*	*127*	*436*
Rear	Orient. y	Type C	*29*	*129*	*326*
Mean value:			***47***	***118***	***409***
Min value:			***19***	***83***	***143***
Max value:			***108***	***179***	***912***

Table 3. 34 km/h carriage speed only.

Impact site	Dummy	Helmet	Peak force (N)	Peak acc (g)	HIC
Front	Orient. x	Type A	*63*	*134*	*552*
Front	Orient. x	Type B	*59*	*131*	*539*
Front	Orient. x	Type C	*44*	*138*	*457*
Front	Orient. y	Type A	*78*	*136*	*511*
Front	Orient. y	Type B	*36*	*134*	*558*
Front	Orient. y	Type C	*27*	*137*	*450*
Side	Orient. x	Type A	*35*	*146*	*497*
Side	Orient. x	Type B	*55*	*128*	*986*
Side	Orient. x	Type C	*50*	*131*	*648*
Side	Orient. y	Type A	*36*	*144*	*580*
Side	Orient. y	Type B	*47*	*156*	*904*
Side	Orient. y	Type C	*39*	*151*	*508*
Rear	Orient. x	Type A	*49*	*140*	*706*
Rear	Orient. x	Type B	*62*	*169*	*1960*
Rear	Orient. x	Type C	*41*	*151*	*658*
Rear	Orient. y	Type A	*30*	*176*	*889*
Rear	Orient. y	Type B	*58*	*152*	*861*
Rear	Orient. y	Type C	*62*	*151*	*750*
Mean value			***48***	***145***	***723***
Min value			***27***	***128***	***450***
Max value			***78***	***176***	***1960***

Table 4. 41 km/h carriage speed only.

Impact site	Dummy	Helmet	Peak force (N)	Peak acc (g)	HIC
Front	Orient. x	Type A	*71*	*48*	*68*
Front	Orient. y	Type A	*15*	*68*	*122*
Side	Orient. x	Type A	*27*	*95*	*134*
Side	Orient. y	Type A	*20*	*77*	*98*
Rear	Orient. x	Type A	*18*	*117*	*240*
Rear	Orient. y	Type A	*18*	*91*	*179*
Rear	Orient. y	Type A	*22*	*88*	*195*
Front	Orient. y	Type A	*67*	*52*	*65*
Front	Orient. x	Type A	*89*	*88*	*239*
Front	Orient. y	Type A	*27*	*101*	*344*
Side	Orient. x	Type A	*73*	*144*	*359*
Side	Orient. y	Type A	*55*	*93*	*285*
Rear	Orient. x	Type A	*44*	*140*	*534*
Rear	Orient. y	Type A	*28*	*133*	*531*
Front	Orient. x	Type A	*63*	*134*	*552*
Front	Orient. y	Type A	*78*	*136*	*511*
Side	Orient. x	Type A	*35*	*146*	*497*
Side	Orient. y	Type A	*36*	*144*	*580*
Rear	Orient. x	Type A	*49*	*140*	*706*
Rear	Orient. y	Type A	*30*	*176*	*889*
Mean value			***43***	***111***	***356***
Min value			***15***	***48***	***65***
Max value			***89***	***176***	***889***

Table 5. Type A helmets only.

Impact site	Dummy	Helmet	Peak force (N)	Peak acc (g)	HIC
Front	Orient. x	Type B	*30*	*91*	*233*
Front	Orient. y	Type B	*17*	*84*	*155*
Side	Orient. x	Type B	*101*	*106*	*205*
Side	Orient. y	Type B	*59*	*107*	*266*
Rear	Orient. x	Type B	*41*	*126*	*304*
Rear	Orient. y	Type B	*40*	*102*	*252*
Front	Orient. y	Type B	*14*	*91*	*181*
Front	Orient. x	Type B	*41*	*126*	*652*
Front	Orient. y	Type B	*31*	*122*	*497*
Side	Orient. x	Type B	*36*	*113*	*323*
Side	Orient. y	Type B	*19*	*85*	*287*
Rear	Orient. x	Type B	*108*	*179*	*912*
Rear	Orient. y	Type B	*61*	*127*	*436*
Front	Orient. x	Type B	*59*	*131*	*539*
Front	Orient. y	Type B	*36*	*134*	*558*
Side	Orient. x	Type B	*55*	*128*	*986*
Side	Orient. y	Type B	*47*	*156*	*904*
Rear	Orient. x	Type B	*62*	*169*	*1960*
Rear	Orient. y	Type B	*58*	*152*	*861*
Mean value			***48***	***123***	***553***
Min value			***14***	***84***	***155***
Max value			***108***	***179***	***1960***

Table 6. Type B helmets only.

Impact site	Dummy	Helmet	Peakforce (N)	Peakacc (g)	HIC
Front	Orient. x	Type C	*14*	*62*	*111*
Front	Orient. y	Type C	*14*	*53*	*91*
Side	Orient. x	Type C	*14*	*124*	*135*
Side	Orient. y	Type C	*48*	*98*	*159*
Rear	Orient. x	Type C	*17*	*99*	*213*
Rear	Orient. y	Type C	*24*	*66*	*135*
Front	Orient. x	Type C	*45*	*83*	*143*
Front	Orient. y	Type C	*22*	*111*	*273*
Side	Orient. x	Type C	*52*	*132*	*415*
Side	Orient. y	Type C	*37*	*122*	*456*
Rear	Orient. x	Type C	*54*	*92*	*347*
Rear	Orient. y	Type C	*29*	*129*	*326*
Front	Orient. x	Type C	*44*	*138*	*457*
Front	Orient. y	Type C	*27*	*137*	*450*
Side	Orient. x	Type C	*50*	*131*	*648*
Side	Orient. y	Type C	*39*	*151*	*508*
Rear	Orient. x	Type C	*41*	*151*	*658*
Rear	Orient. y	Type C	*62*	*151*	*750*
Mean value			***35***	***113***	***349***
Min value			***14***	***53***	***91***
Max value			***62***	***151***	***750***

Table 7. Type C helmets only.

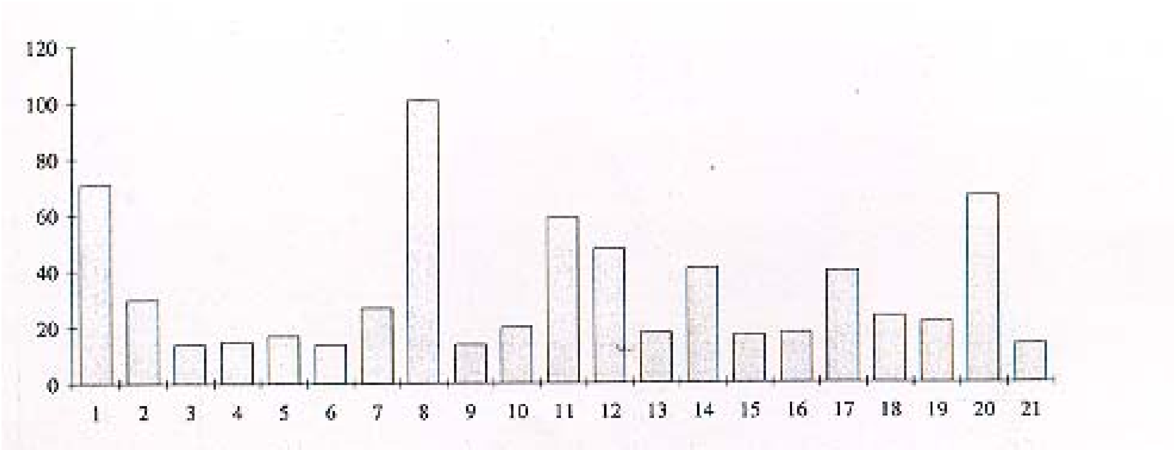


Diagram 1. Measured chin strap peak forces (N) 23 km/h carriage speed.

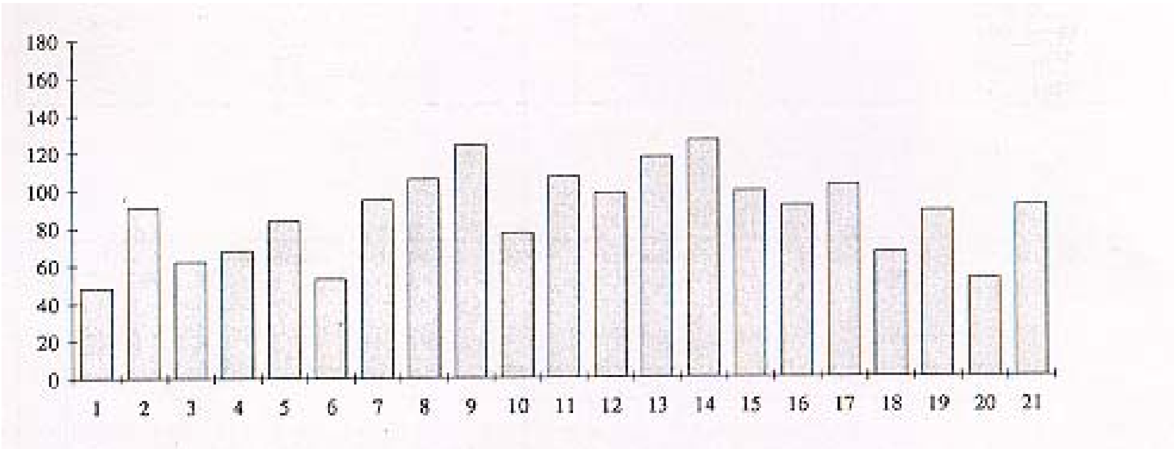


Diagram 2. Measured head peak acceleration (g) at 23 km/h carriage speed.

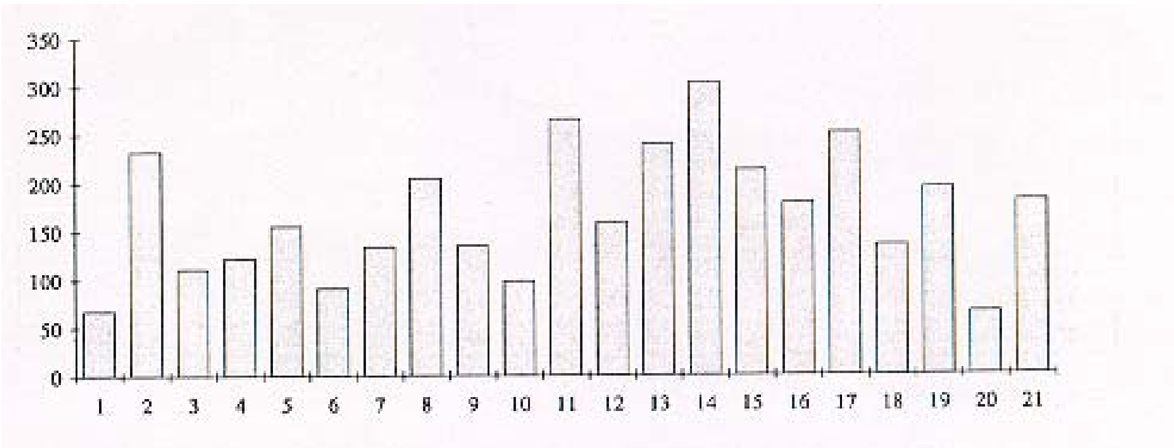


Diagram 3. Calculated head injury criterion (HIC) at 23 km/h carriage speed.

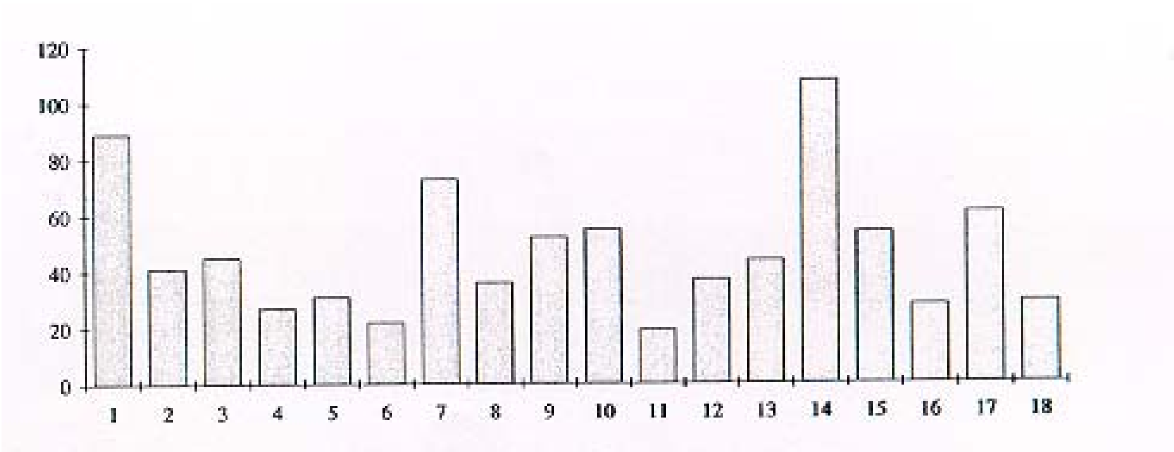


Diagram 4. Measured chin strap peak forces (N) at 34 km/h carriage speed.

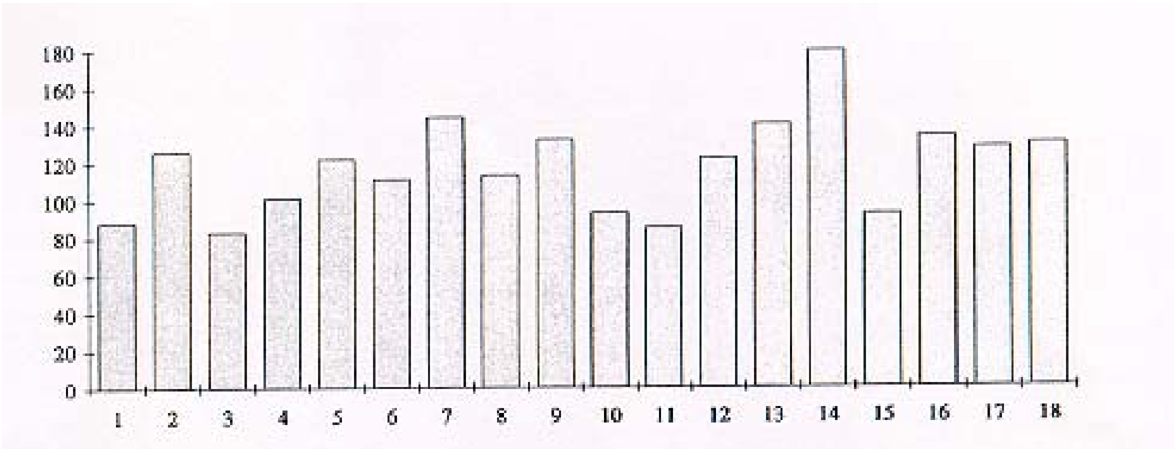


Diagram 5. Measured head peak acceleration (g) at 34 km/h carriage speed.

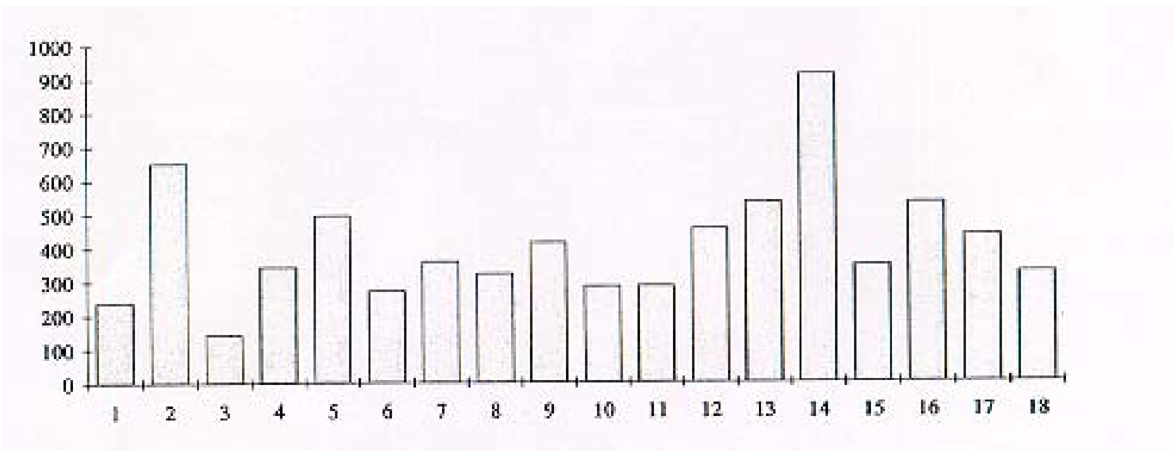


Diagram 6. Calculated head injury criterion (HIC) at 34 km/h carriage speed.

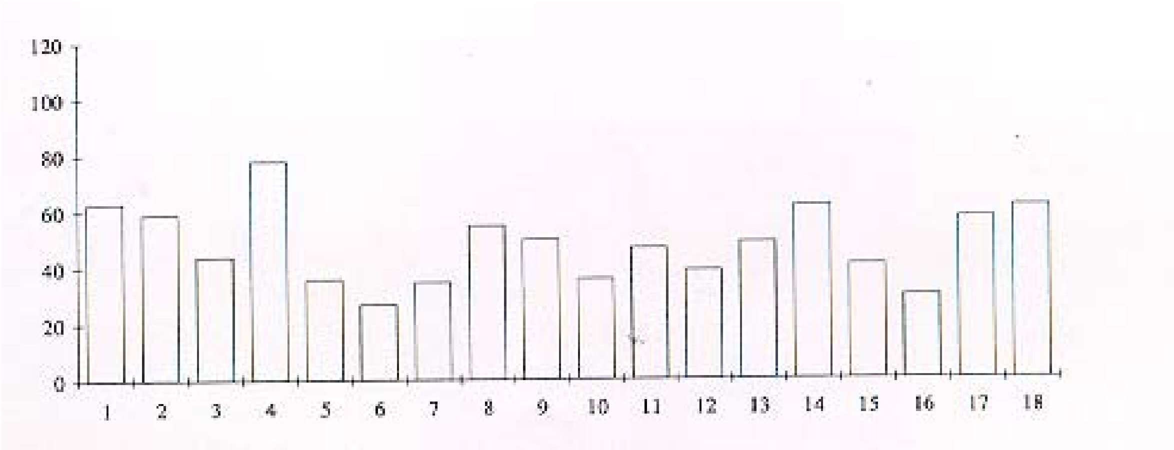


Diagram 7. Measured chin strap peak forces (N) at 41 km/h carriage speed.

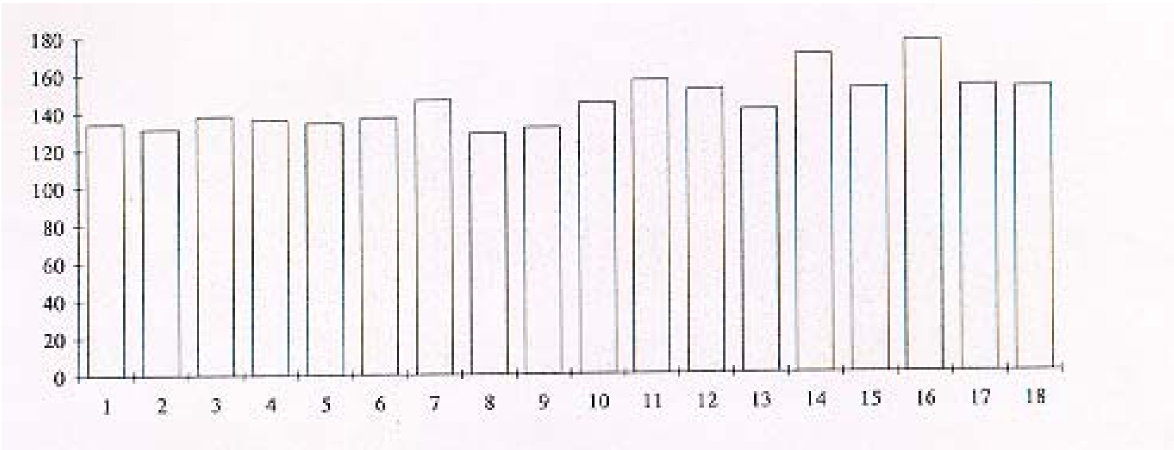


Diagram 8. Measured head peak acceleration (g) at 41 km/h carriage speed.

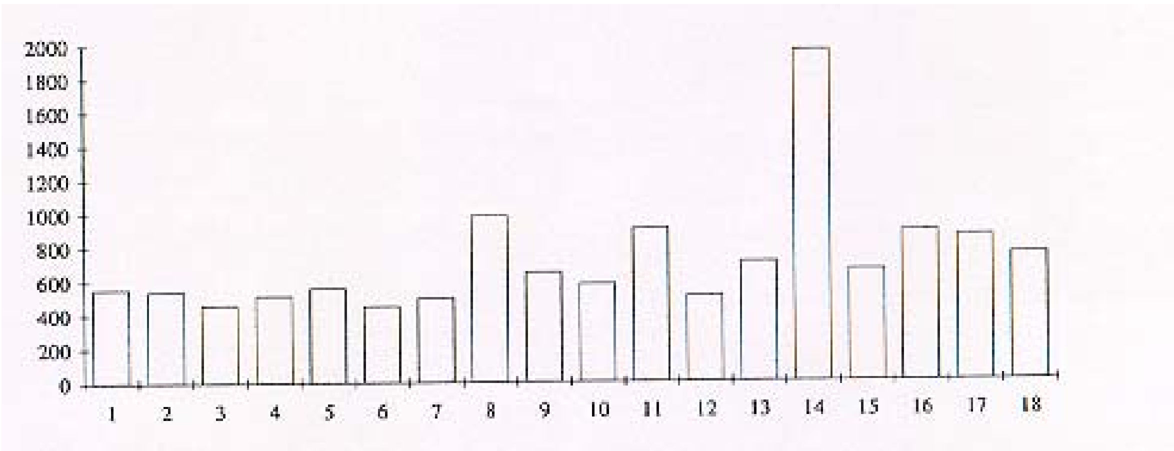


Diagram 9. Calculated head injury criterion (HIC) at 41 km/h carriage speed.

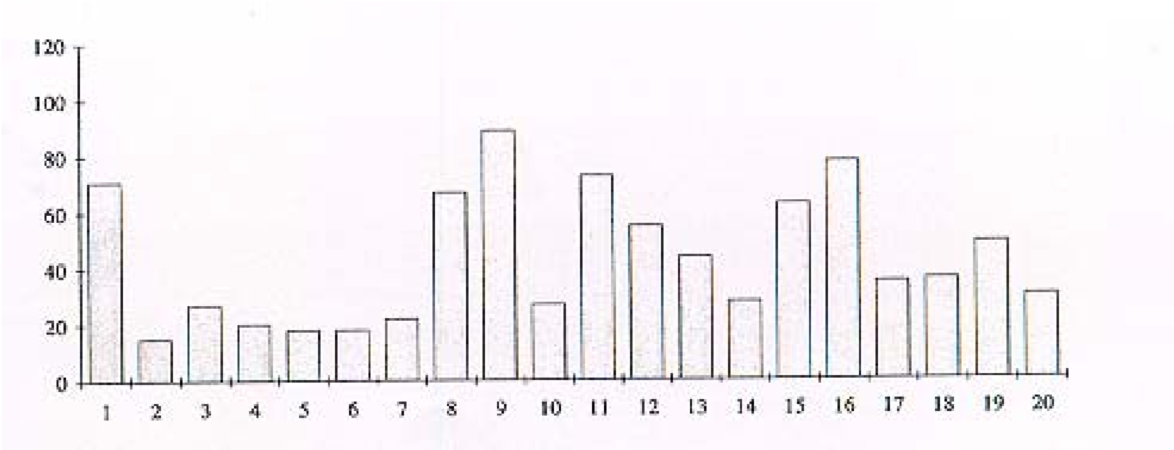


Diagram 10. Measured chin strap peak forces (N) for type A helmet.

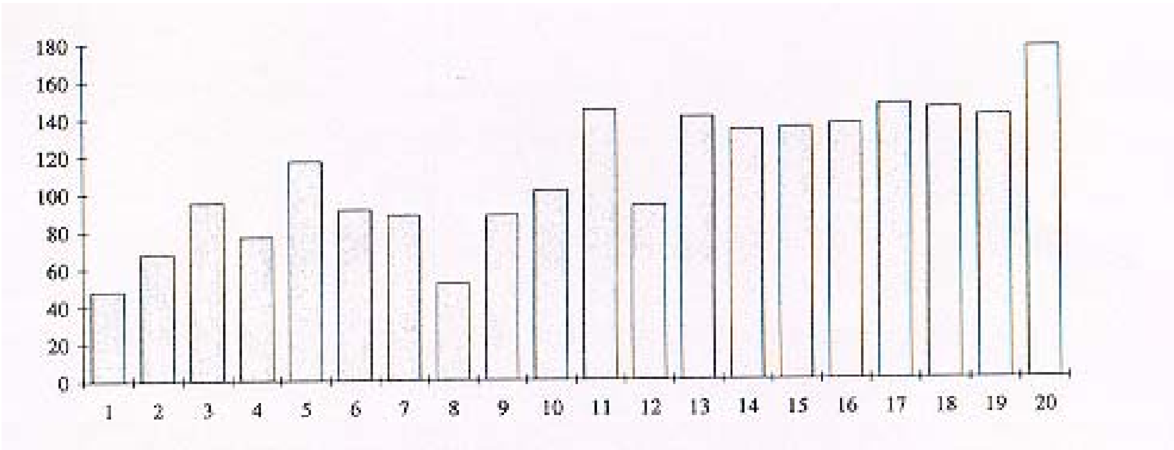


Diagram 11. Measured head peak acceleration (g) for type A helmet.

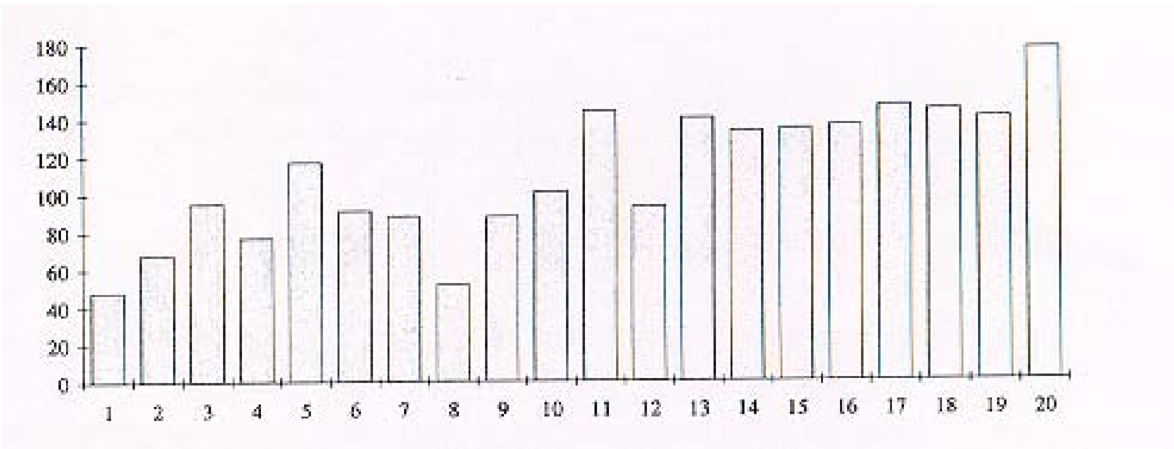


Diagram 12. Calculated head injury criterion (HIC) for type A helmet.

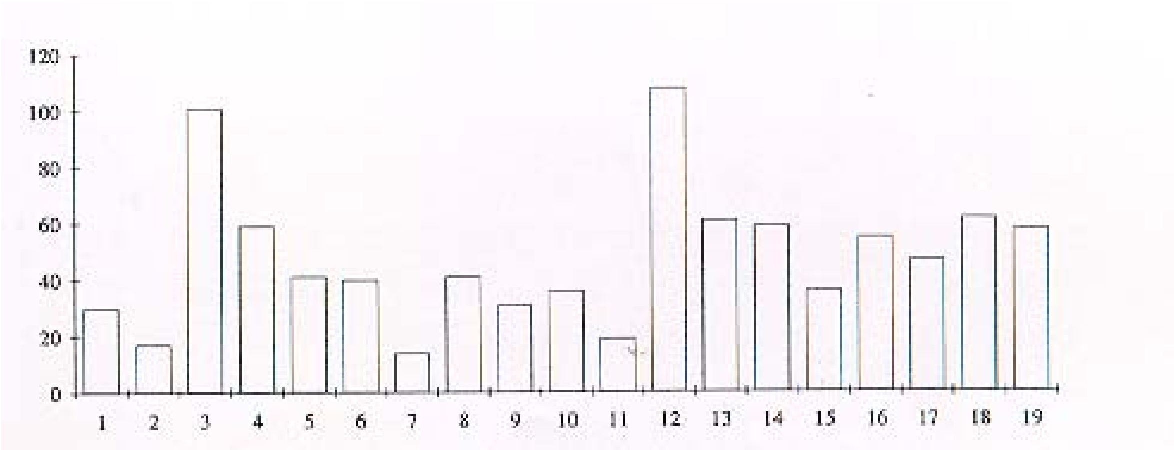


Diagram 13. Measured chin strap peak forces (N) for type B helmet.

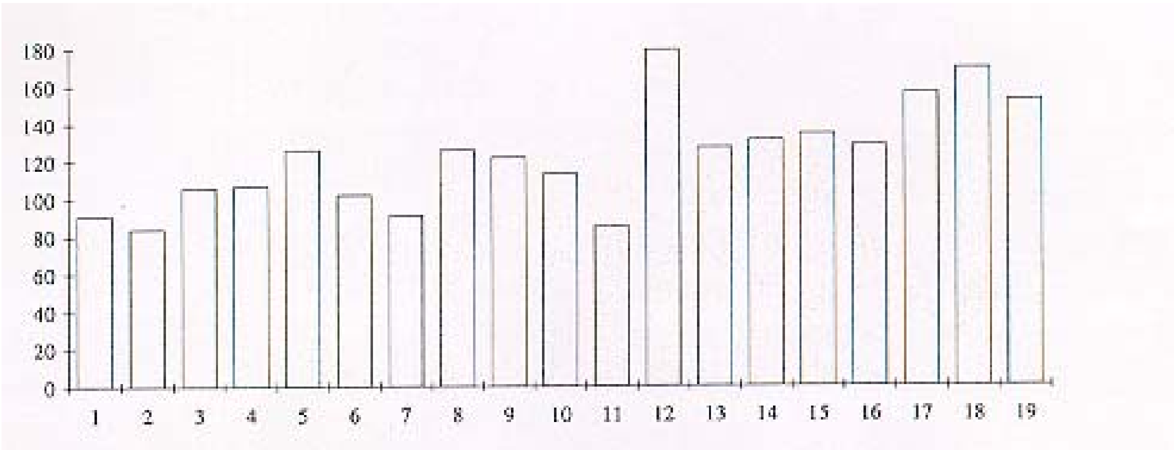
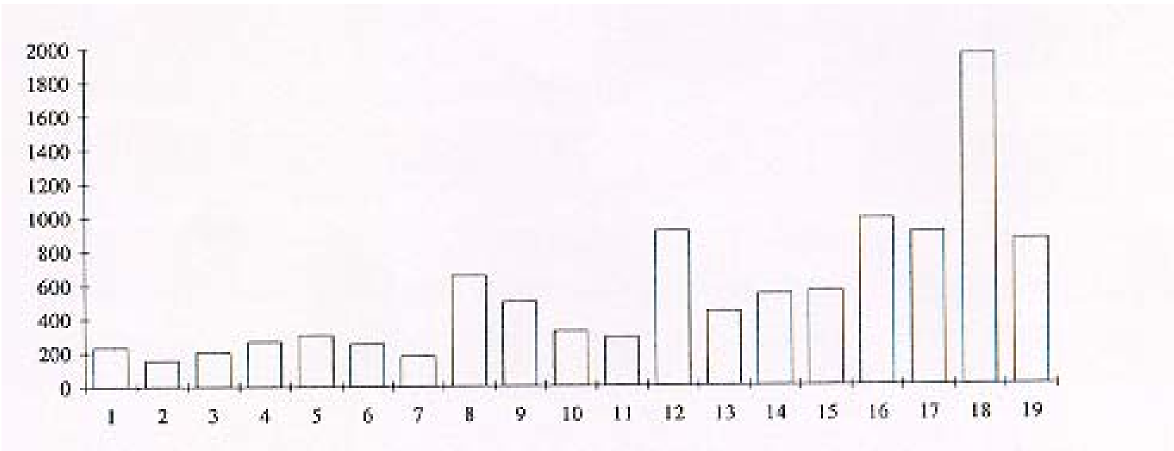


Diagram 14. Measured head peak acceleration (g) for type B helmet.



Digram 15. Calculated head injury criterion (HIC) for type B helmet.

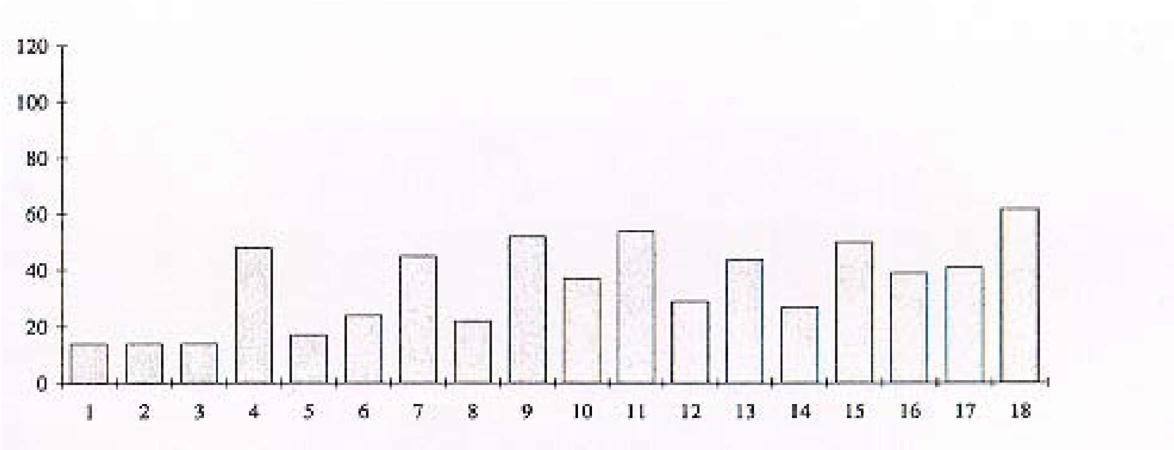
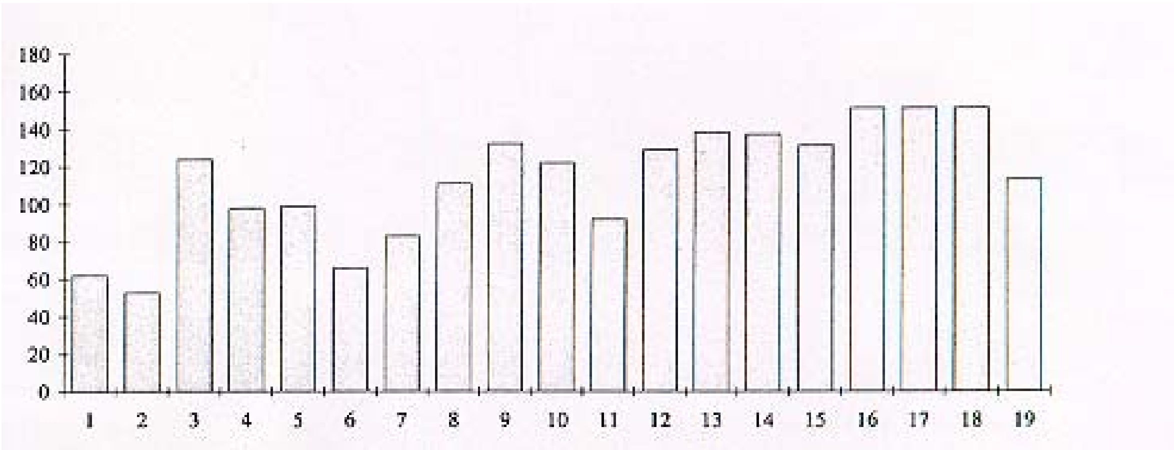


Diagram 16. Measured chin strap peak forces (N) for type C helmet.



Digram 17. Measured head peak acceleration (g) for type C helmet.

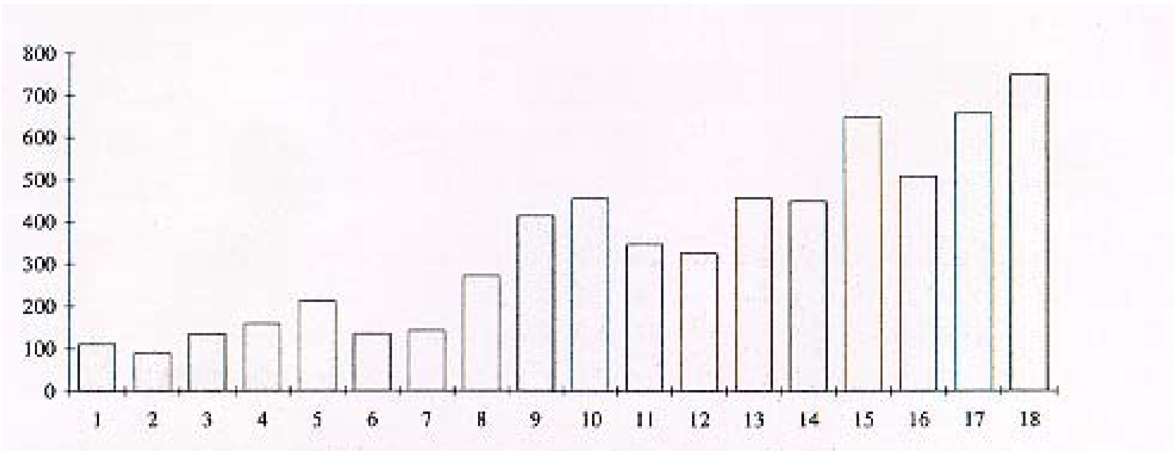
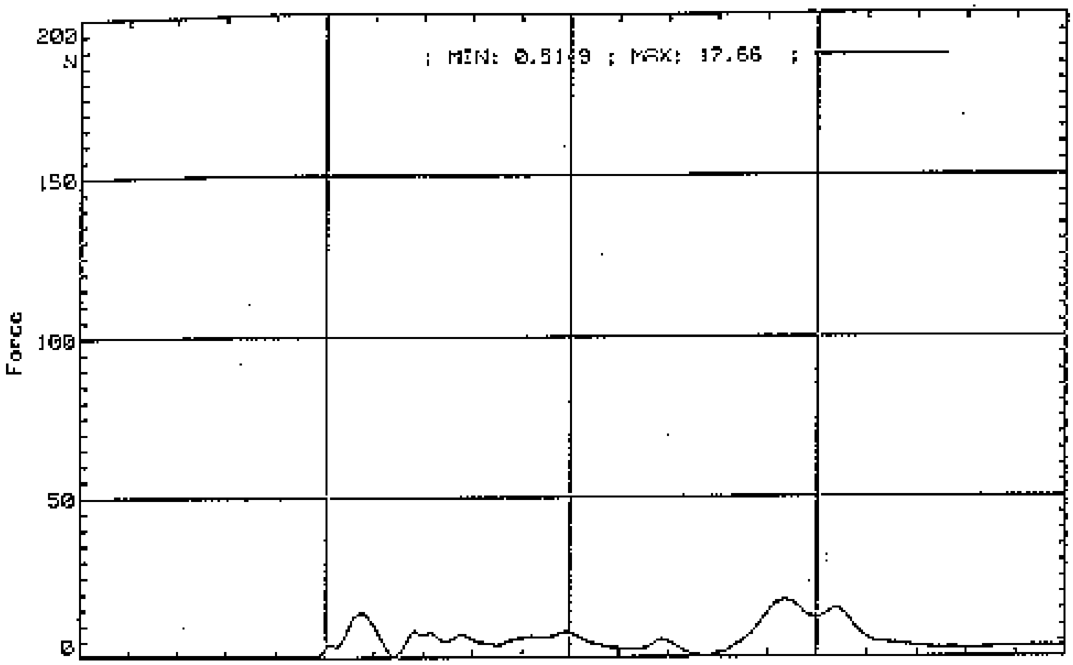


Diagram 18. Calculated head injury criterion (HIC) for type C helmet.

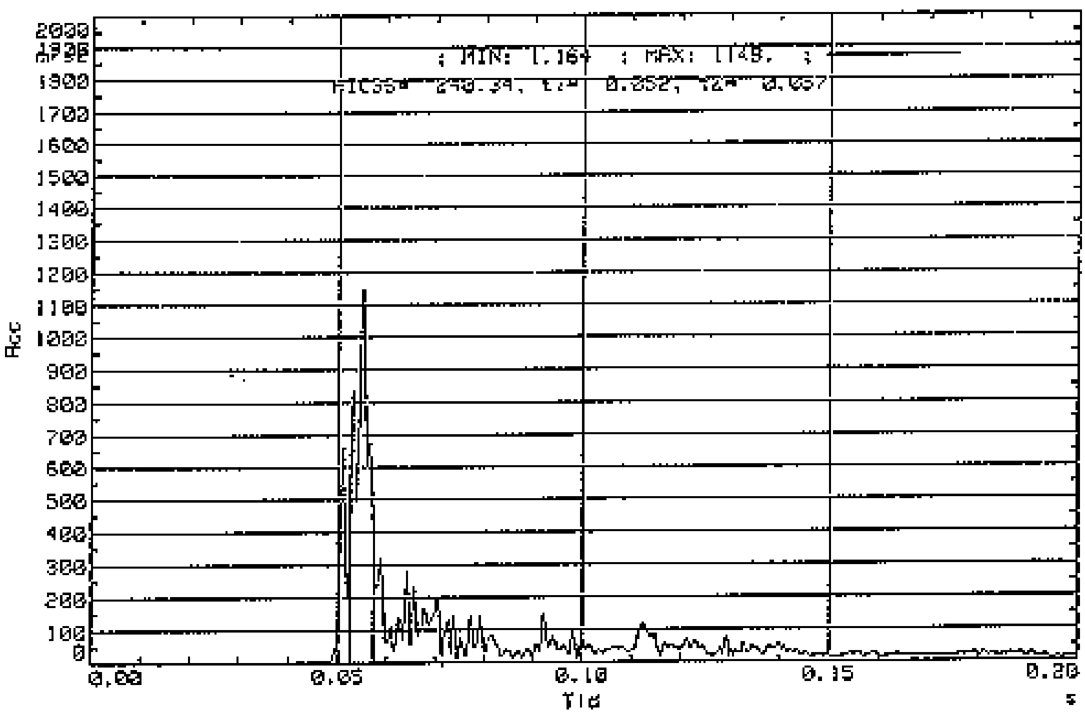
CHIN STRAP FORCES
TEST 13

DAT 930505

Force



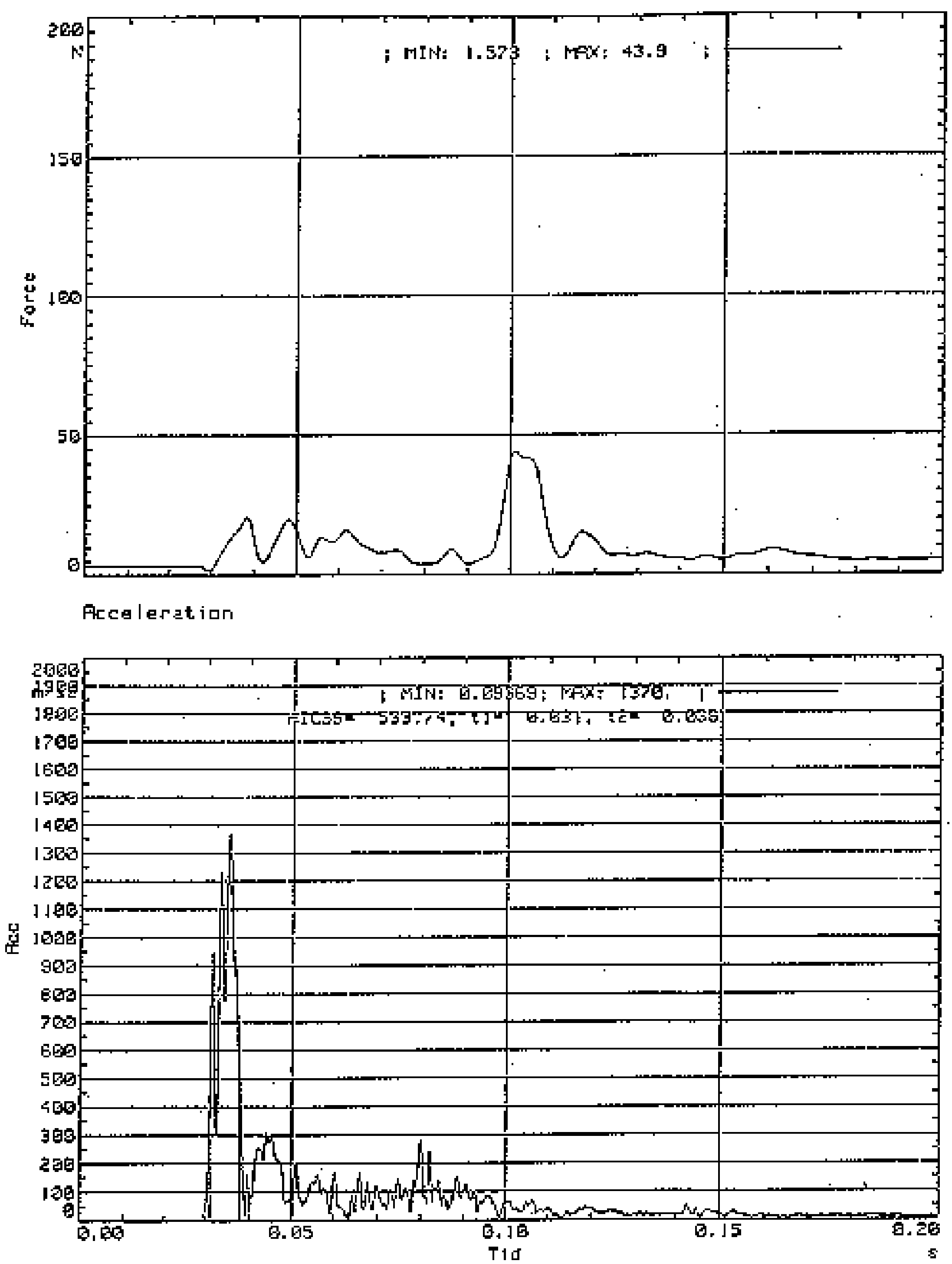
Acceleration



CHIN STRAP FORCES
TEST 34

DAT 930430

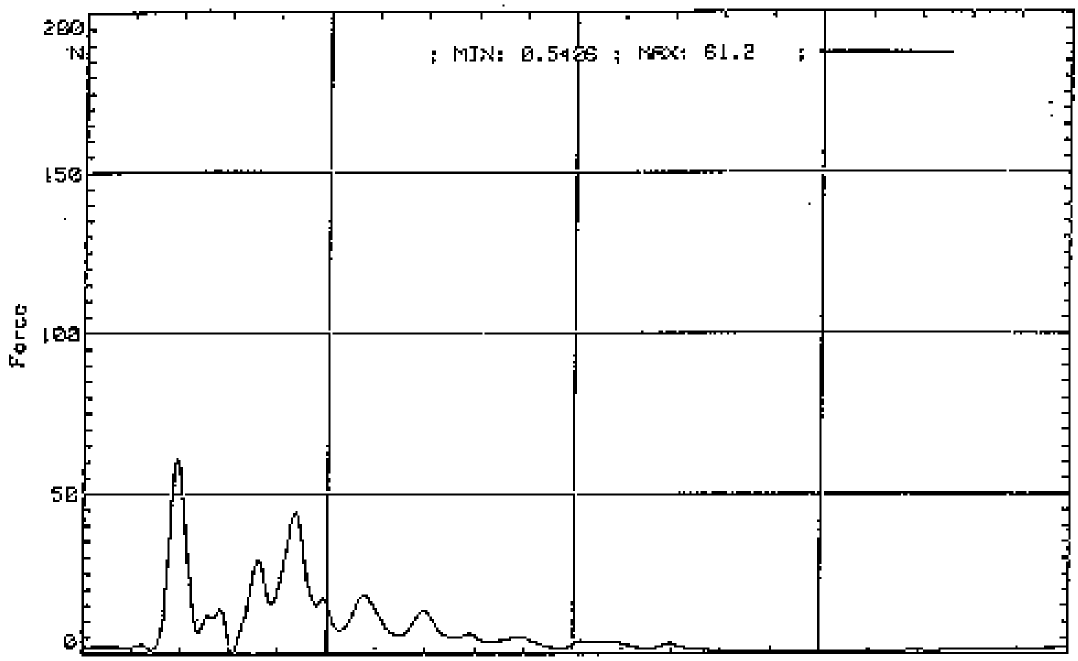
Force



CHIN STRAP FORCE
TEST 38

DAT 930503

Force



Acceleration