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**TNO report**

**TNO-DV 2008 A379**

**Blast performance of commercially available  
demining footwear: a summary of experimental  
trials on surrogate legs**

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# Experimenteel onderzoek naar beschermende werking van schoenen tegen anti-personeelsmijnen

Het KPU-bedrijf heeft behoefte aan inzicht in de beschermende werking van schoenen tegen anti-personeelsmijnen. Er zijn een zevental commercieel verkrijgbare beschermende schoenen getest. De onbeschermde standaard gevechtslaars is als referentie getest. De testen zijn uitgevoerd met surrogaat onderbenen, waarbij de ontstane letsels door een traumachirurg geanalyseerd zijn. De meeste schoenen bieden onvoldoende bescherming tegen een AP mijn, met amputatie tot gevolg.



## Probleemstelling

Er zijn diverse schoenen op de markt die claimen bescherming te bieden tegen een anti-personeels (AP) mijn. Echter objectieve meetresultaten zijn vaak niet beschikbaar. Het KPU bedrijf heeft de wens uitgesproken inzicht te krijgen in de beschermende werking van commercieel verkrijgbare AP mijnschoenen.

## Beschrijving van de werkzaamheden

Na een korte literatuurstudie en overleg met zowel medewerkers van Defence Research & Development Canada en de Webrtechnische Dienststeltte 91 in Duitsland is besloten de testmethode voor AP-mijnschoenen zoals beschreven door

een NATO werkgroep te volgen. Er zijn twee verschillende surrogaat onderbenen beschikbaar voor de AP mijnschoenen testen: het in Canada ontwikkelde onderbeen CLL en het in Australië ontwikkelde FSL. Beide typen zijn voor dit project gebruikt. Er zijn in totaal acht schoentypes getest, waaronder de onbeschermde gevechtslaars van de Nederlandse Krijgsmacht. De blastbelasting van de AP mijn was respectievelijk 25, 50 en 75 gram. Tijdens de testen zijn zowel krachten in het onderbeen, als ook de verticale verplaatsingen gemeten. De letsels zijn geanalyseerd middels röntgenfoto's en een autopsie door een trauma chirurg. De schade aan de schoenen is gerapporteerd.

## Resultaten en conclusies

In totaal zijn er 19 testen uitgevoerd. In overeenstemming met bevindingen van andere onderzoeksgroepen blijkt dat de beschermende werking van de schoen niet te voorspellen is op basis van een nauwelijks beschadigde schoen. Een aanvullend letselonderzoek, zoals binnen dit project is uitgevoerd, is noodzakelijk. De letsels, voorspeld met de verschillende typen onderbenen, zijn vergelijkbaar. Het CLL is praktischer in gebruik in verband met de versimpelde geometrie van dit surrogaat been. De testresultaten laten zien dat de meeste schoenen onvoldoende beschermende werking bieden tegen een AP-mijndreiging.

## Toepasbaarheid

De testmethode kan gebruikt worden voor het evalueren van de beschermende werking van andere AP-mijnschoenen.

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## Contents

	<b>Managementuittreksel .....</b>	<b>3</b>
	<b>Abbreviations .....</b>	<b>7</b>
<b>1</b>	<b>Introduction .....</b>	<b>9</b>
<b>2</b>	<b>Mine boot testing and evaluation using two different surrogate legs.....</b>	<b>11</b>
<b>3</b>	<b>Signature .....</b>	<b>23</b>
	<b>Appendices</b>	
	A Test set-up	
	B General results	
	C Measurement results	
	D Medical results	



## Abbreviations

AIS	Abbreviated Injury Scale
AP	Anti Personnel
ATD	Anthropomorphic Test Device
BKA	Below Knee Amputation
CLL	Canadian Lower Leg
FSL	Frangible Surrogate Lower Limb
MOD	Ministry of Defence
MTS	Mine Trauma Score
NATO	North Atlantic Treaty Organization
TNO	Netherlands Organization for Applied Scientific Research

In Appendix D a list of medical definitions is given.



# 1 Introduction

One of the hazards faced by soldiers on the battlefield is injury due to anti personnel mines (AP-mines). Detonation of an AP mine typically can follow after stepping on the mine while it is buried in the ground. The primary damage mechanism of AP mines is the blast effect. Severe damage to the flesh and skeletal structure of the impacted leg can be the result, which can end in amputation [Brown, 2001]. Many attempts have been made at designing mine protective footwear that reduces this trauma. Several international projects were defined to evaluate this footwear using biomechanical surrogates or even cadaver legs [Anderson, 2004; Bass, 2004; Griffin, 1999].

The Clothing and Personal Equipment Department of the Dutch Ministry of Defence tasked TNO Defence, Security and Safety to perform AP mine shoe tests to study the protection level and injury response of several boots using different surrogate legs.

The goal of this report is to describe the results of these tests and to compare the results with test results as presented in literature.

The main body of this report is a copy of the paper 'Mine boot testing and evaluation using two different surrogate legs'. The paper will be presented at the Personal Armour Systems Symposium October 2008 in Brussels.

The paper summarizes the most important topics of the tests. More background can be found in the appendix. The test set-up is presented in Appendix A. The test results are summarized Appendix B and the measurement results and medical reports are presented in Appendices C and D.



## 2 Mine boot testing and evaluation using two different surrogate legs

This chapter is a copy of the paper to be published in Proceedings of Personal Armour Systems Symposium, October 2008 Brussels.

### Abstract

This paper describes tests of protective footwear (i.e. mine boots) against anti personnel blast mines. The objective of this study is to compare the performance of eight different boots looking at several parameters using two types of surrogate legs, i.e. the Frangible Surrogate Lower Limb (FSSL) and the Canadian Lower Leg (CLL). Analyses of the surrogate legs have been conducted by means of autopsy by a surgeon in the Dutch Armed Forces. Force and displacement measurements were taken for a better understanding of the phenomena. It was found that none of the footwear tested, except one, could prevent amputation of the lower leg for charge sizes of either 25, 50 or 75 grams. The results agree with findings in literature. The CLL and FSSL tests showed similar results, although it should be mentioned that the CLL is more practical in use.

*Keywords: AP mine, test, boot, surrogate leg.*

### Introduction

One of the hazards faced by soldiers on the battlefield is injury due to anti personnel mines (AP-mines). Detonation of an AP mine typically can follow after stepping on a buried mine. The primary damage mechanism of AP mines is the blast effect. Severe damage to the flesh and skeletal structure of the impacted leg can be the result, which can end in amputation [5]. Many attempts have been made at designing mine protective footwear that reduces this trauma. Several international projects were defined to evaluate this footwear using biomechanical surrogates or even cadaver legs [2, 3, 4, 6].

The Clothing and Personal Equipment Department of the Dutch Ministry of Defence tasked TNO Defence, Security and Safety to perform AP mine boot tests to study the protection level and injury response of several boots using different surrogate legs. The goal of this paper is to describe the results of these tests and to compare the results with test results as presented in literature.

There are two main types of demining boots: conventional boots and platform boots. A conventional boot looks like a standard combat boot with a thicker sole. Some boots are designed using material to damp the blast of the detonation. The platform boot designs focus more on creating a distance between the threat (explosive material) and the foot which minimizes the effect of the detonation inflicted on the lower extremities. However, this has negative effects on the ergonomics. The focus of the current paper is on the injury prevention only.

### Materials and methods

The experiments were carried out in the large calibre test facilities of the Laboratory for Ballistics Research of TNO using the Australian-designed Frangible Surrogate Leg (FSSL) and the Canadian Lower Leg (CLL). The test has been conducted in accordance

to the report written by the NATO Human factors and medicine 089 task group 024 [8]. The test set-up and the legs are presented in Figure 1.

The test rig consists of a long piston which can only move in a vertical direction. Wheels have been used for supporting the piston and minimizing the friction (disturbance) for a free vertical movement. The piston represents the upper leg of a person in a standing position. The mass of the piston is 25 kg. Both FSSL as the CLL were connected to the piston using an adapter constructed at TNO.

For the trials charge sizes (25 g, 50 g, or 75 g) of Composition 4 (C4) were used (cylindrical shaped tablet without casing), each having a height-to-diameter ratio of 35% based on a review of AP mine geometries. The C-4 tablet was positioned under the heel which is considered to be worst case. The charge was placed 20 mm under the surface (sand on top of it). A steel sand container was used with dimension 700 mm x 630 mm and a height of 310 mm. The charges were bottom-initiated with DM42 detonators.

The displacement of the leg has been monitored by means of a displacement transducer (AE sensors, type WS10-1000-R1K-L10-HG) and high speed video recordings (1000 fps). Furthermore a force transducer (Denton type 3115) was placed directly above the connection of the surrogate leg and the beam, which measured the compression forces (see Figure 1).

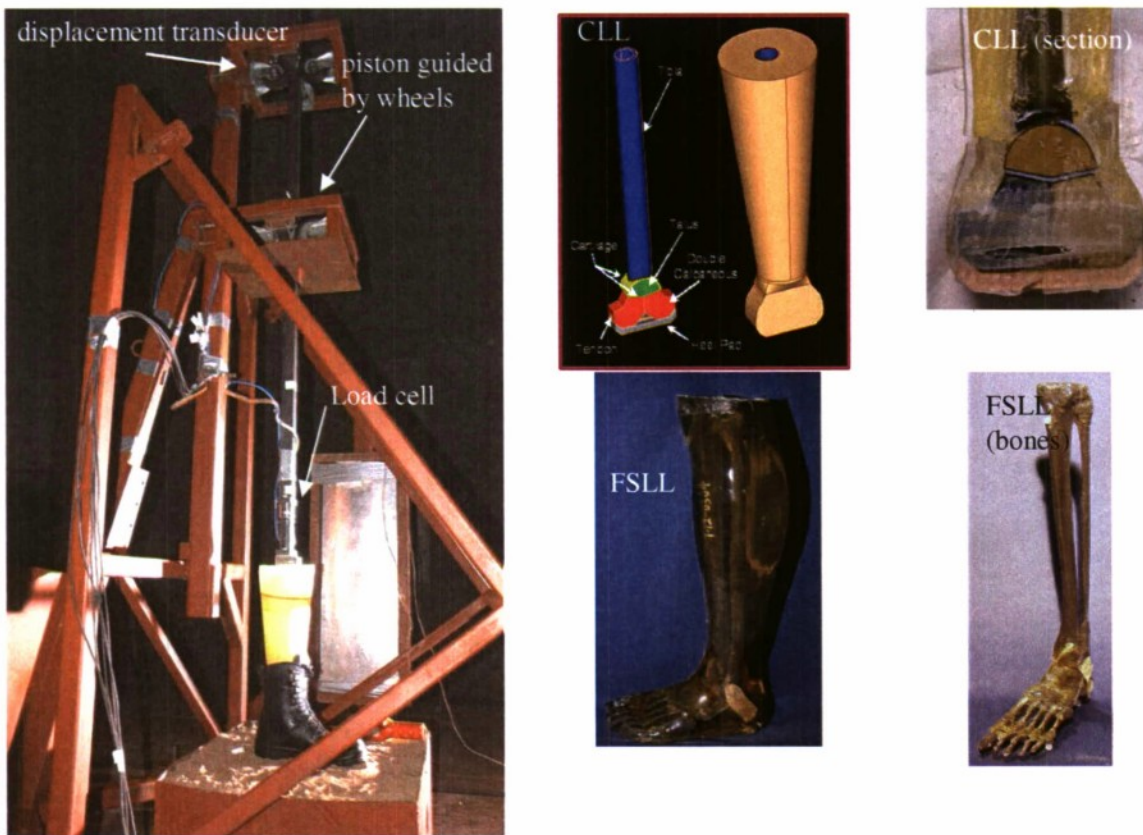


Figure 1 Left: test set-up of AP mine boot test with CLL. Right: CLL and FSSL.

Eight boot types were selected for testing, with the spiderboot as a typical example of a platform boot. Whereas the others are more or less conventional boots, including the Combat Boot of the Dutch army which was used as a reference (see Figure 2).



Figure 2 Pictures of the eight mine boots used including the Dutch army combat boot.

The CLL and FSLL both consist of a bony structure in combination with gelatine. From a practical point of view the 10% gelatine recipe was used for both legs. To preserve the ballistic gelatine, all legs were maintained at 4°C in a cooling unit until just prior to the test.

The CLL is designed with a double calcar bone without a forefoot, since damage to the calcar bone is the key indicator in performance and it makes it also easier to fit in a boot (see Figure 1). During the tests the forefoot of the boot was left empty. The FSLL consists of the foot/ankle and lower leg that are rigidly connected (see Figure 1). This makes it nearly impossible to fit into the mine boots without damaging the gelatine/bone structure at ankle location. Therefore, for the FSLL tests, the boots were cut near the tongue of the boot when necessary.

The test results were documented with digital photographs before and after each test. Post X-ray images were taken of all legs. After detonation, the boot was removed and each leg (including separate pieces if the specimen was disintegrated) was examined. Each leg was evaluated by the same examiner who was blinded to charge size and boot type. Standard physical measurements of each specimen were documented using the MTS score (see Table 1) and the Abbreviated Injury Score (AIS) which ranges from 0 (no injury) to 6 (lethal injury) [1]. Contamination was considered present when any foreign material (sand, boot fragments, soot) was present in the wound (gelatine). The boots were examined separately and the damage was described.

Table 1 Mine trauma score [8].

MTS Score	Injury	Medical assessment
0	Minimal	No major injury
1	Closed	Surgery required and limb is salvageable
1a	Open contained	
1b	Open contaminated	
2	Closed	below knee amputation (BKA) (= trans-tibial amputation)
2a	Open contained	
2b	Open contaminated	
3	Open contaminated	Trans-tibial/trans-femoral amputation
4	Open contaminated	trans-femoral amputation

NOTES:

**Closed injury:** any injury to the lower extremity that does not violate the skin, thereby minimizing the risk of infection.

**Open contained injury:** any injury to the lower extremity that violates the skin (lacerations, tears), but is not contaminated by the outside environment because the inner footwear was not compromised.

**Open contaminated injury:** any injury to the lower extremity that does violate the skin and has contamination of the soft tissues and bones from the environment where the blast occurred.

## Results

During the tests it became obvious that for the 50 g tests the boots already showed poor protection, and tests at higher masses would not provide more insight. Therefore only two tests at 75 g were performed. The test results are summarized in Table 2. The high speed video provided insight into the overall event and showed that after detonation of low mass blast mine of 25 g a high deformation of the leg/boot is witnessed. Examples of the visual results are shown in Figures 3 and 4. The MTS scores for the 25 g and 50 g tests are shown in Table 2 as well as in Figure 5.

Table 2 Test results summarized.

No.	Boot	Leg	Explosive <sup>#</sup> mass	MTS	AIS	Treatment
1	Combat Boot Dutch army	CLL	25 g	2b	3	Below knee amputation (BKA)
2	Spiderboot (combined with CB*)	CLL	25 g	1a	2	Be aware of possible arterial lesions
3	Anonymate	CLL	50 g	2b	3	BKA <sup>§</sup>
4	Forceware	CLL	50 g	2b	3	BKA
5	Mile Dragic	CLL	50 g	2b	3	BKA <sup>§</sup>
6	Aigis	CLL	50 g	2b-3	3	BKA <sup>§</sup>
7	ZEMAN	CLL	50 g	2b	3	BKA <sup>§</sup>
8	Spiderboot (combined with CB)	CLL	75 g	1	2	Conservative; probably temporarily external fixation
9	Aigis	CLL	25 g	2a	3	BKA
10	Rubber block (SA) (combined with CB)	CLL	50 g	2a	2	BKA**
11	Forceware	CLL	25 g	2b	3	BKA
12	Spiderboot (combined with CB)	FSSL	75 g	1b	2	Debridement and external fixation of ankle
13	ZEMAN	FSSL	50 g	2b	4	BKA
14	Aigis	FSSL	25 g	2b	3	BKA
15	Combat Boot Dutch army	FSSL	25 g	2b	3	BKA
16	ZEMAN	CLL	25 g	2b	3	BKA
17	ZEMAN	FSSL	25 g	2b	3	BKA
18	Anonymate	FSSL	25 g	2b	3	BKA
19	Anonymate	FSSL	25 g	2b	3	BKA

<sup>#</sup> Explosive material C4.

\* CB = Combat Boot (Dutch Army).

<sup>§</sup> If degloving is the real mechanism, than above knee amputation would be needed. However it is assumed that the degloving (loosening of the soft tissue) can be seen as a result of the test set-up (gelatine just for lower leg part, whereas in reality the human skin and muscles of the entire leg are holding together). Therefore the degloving as seen in a few tests is assumed not to be a realistic injury mechanism.

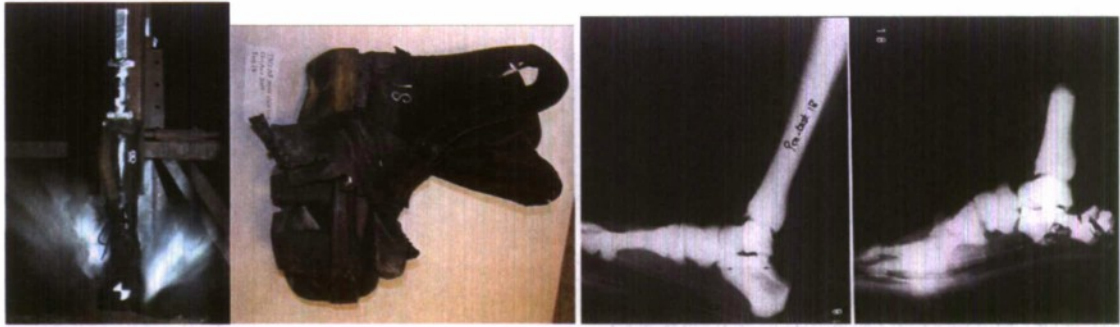


Figure 3 An example (test 18). Test, boot damage, X-ray pre-and post test. From the post test X-ray findings a traumatic amputation of lower leg at boot level and fractures in upper ankle joint were diagnosed. Also damage of the mid tarsal joint complex (Chopart) and the tarsometatarsal joint complex (Lisfranc), middle foot and soft tissue injuries were noted.



Figure 4 An example (test 5). Boot damage, CLL visual injury assessment. The leg and foot, inspecting the CLL, appear not to be damaged significantly. However when the latex confinement is removed the real severe injury is revealed. The calcar bone, with heel pad and tibia is cracked and fragmented. The foot is amputated. There is soft tissue damage in the lower leg part, just above the ankle. Besides, there is a severely damaged ankle joint. The talus was broke into two main fragments. The calcar bone (rear and front) were both broken into two main fragments and small pieces. The foot sole of the CLL was damaged.

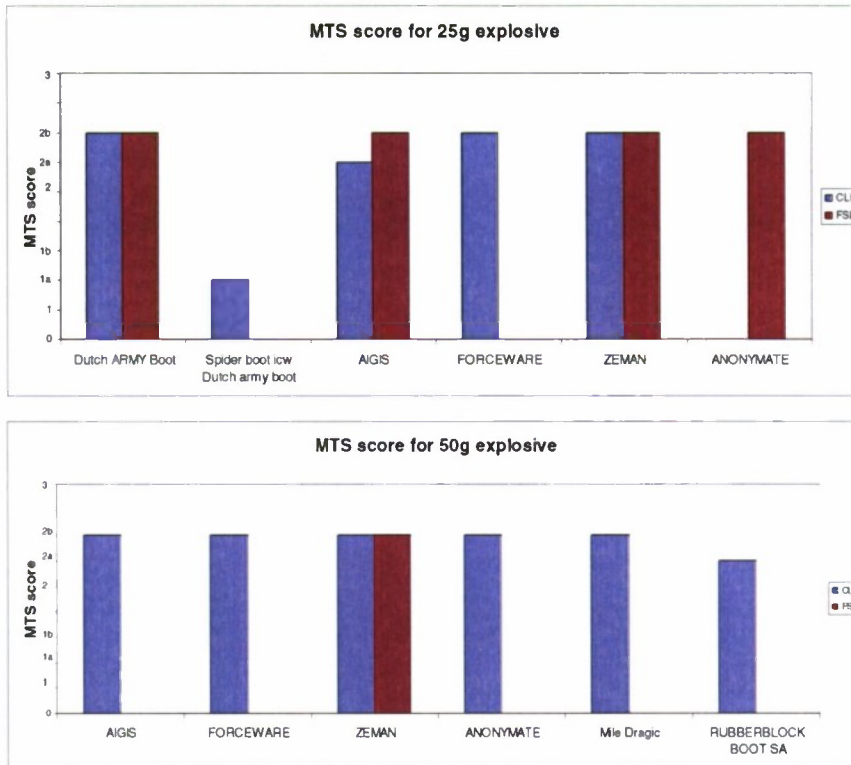


Figure 5 MTS scores for 25 g and 50 g tests.

Finally, the reference force transducer (Figure 6) and displacement sensor (Figure 7) are used as data source. In most cases a higher force correlates with a higher MTS score. Or better when the mine boot is constructed in a manner that the force on the piston is minimized a lower MTS score can be expected. The spider boot showed a relative low force and also the injury score was the lowest of all mine boot concepts tested. Remarkable is the fact that the forces measured with the FSL were significant higher than the tests with the CLL even with a lower explosive mass.

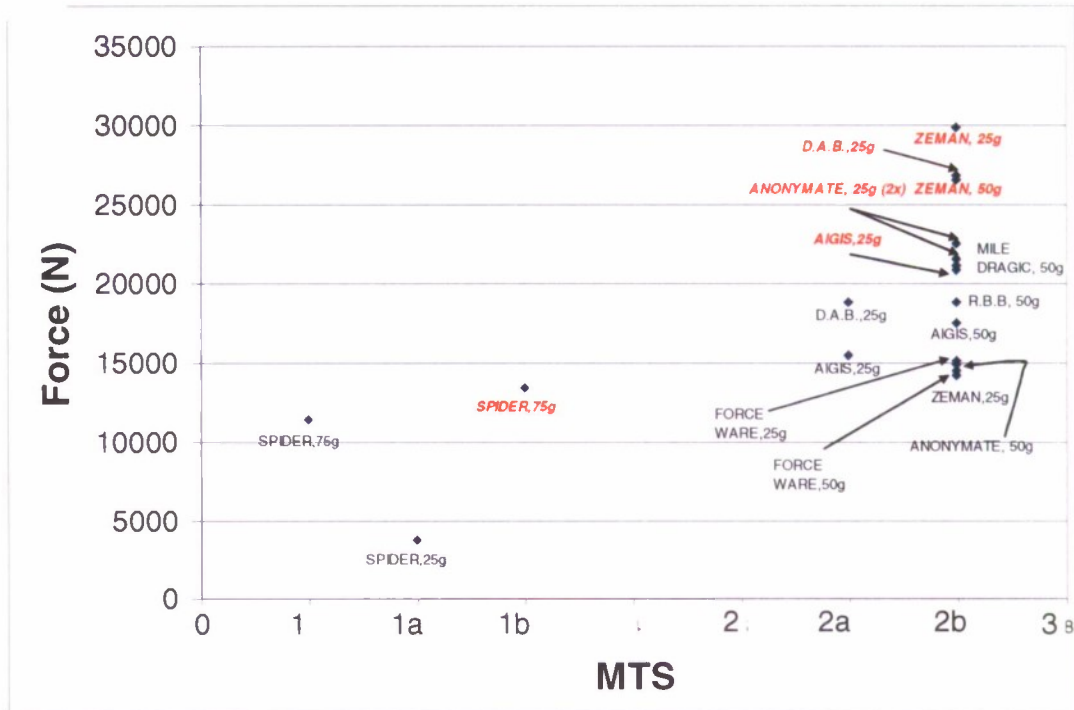


Figure 6 Piston force versus MTS. The descriptions in red italic text are the experiments were the FSLIs were used.

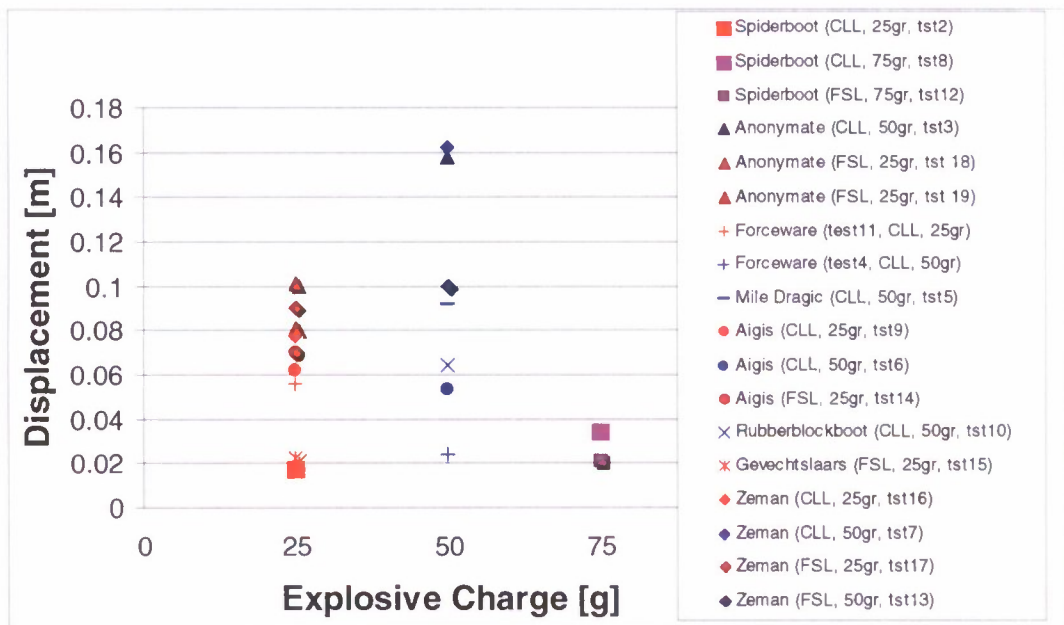


Figure 7 Displacement of piston versus explosive charge.

## Discussion

The boot damage differs significantly. However, the tests show that the boot damage can not be used as a predictor of the foot/leg injuries. For example test 4 shows significant boot damage, while for test 3 only the outer sole of the heel of the boot is partly destroyed (see Figure 8). But both legs show an identical injury pattern (i.e. resulting in the same treatment).

Test 3: (50 g C4),  
treatment: Below Knee Amputation

Test 4: (50 g C4),  
treatment: Below Knee Amputation



Figure 8 Boot damage versus injury.

Anderson [2] also concluded that examination of the boot alone is not sufficient to predict injury to the leg. Bass [4] suggested a two stage procedure, using mechanical test legs. In the first phase the boot should be analyzed for damage. If the boot damage is too high (e.g. test 4 Figure 8) the boot fails the procedure. If the boot shows only minor damage (i.e. portion of the sole blown off; insole destruction, e.g. test 3 Figure 8) than the boot should proceed to the second stage. In that stage the compression forces should be evaluated using an injury risk curve. The risk curve however was developed for post mortem human subjects and a transfer function for the surrogate legs used was not available. However, the current test set-up has the advantage of using surrogate legs, which can be used to study the injury itself.

In general it can be seen that FSSL and CLL results in similar injury, with the only difference in closed versus open contaminated wounds. The main difference between the two surrogate legs focus on the bony structures. When studying the injury response in more detail (see Table 3) it is seen that the injuries (also on bony structures) are similar.

Table 3 Injury assessment of different tests for comparison CLL and FSLL (see Tables 1 and 2 for MTS scores).

Test	CLL	FSLL
25 g Zeman	Comminuted distal tibia fracture	Tibia fracture and fibula fracture above the upper ankle joint.
50 g Zeman	Distal tibia multiframegment fractures. Comminuted fractures distal tibia complex.	Tibia fracture and amputation just below the knee probably caused by the test-configuration. Amputation of lower leg at the upper ankle joint. Fibula shows only small fracture.
75 g Spiderboot	Damage of the soft tissue near the Achilles tendon and medial and lateral ligaments torn. Vertical fracture in calcar bone. Surface defect in lower ankle joint. Insufficient ligamental complex between talar and calcar bone. Multiple soft tissue injuries near ligaments.	Upper ankle joint and midtarsal joint complex (Chopart) too loose. Circular soft injuries. Ligamentous injury of medial and lateral side of ankle joint. Medial ligament disconnected from tibia. Lateral ligaments $\frac{3}{4}$ torn. Probably also rupture of achilles tendon.

The Spiderboot tests show the lowest forces and lowest displacements, as well as the lowest injury scores. This was expected based on previous tests [8]. The measured forces are in the same order of magnitude as the ones measured with mechanical legs [4], but are two to three times higher than the ones measured in post mortem human subject (PMHS) legs [4, 6]. The forces measured using the FSLL were significantly higher than the forces measured with the CLL. However the expected required medical treatments based on the test results with the CLL and FSLL were comparable.

It should be noted that for the Forceware and Aigis boots the displacement for the smaller charge size (25 g) are higher than for the higher charge size test (50 g) (see Figure 8). Additionally, the forces measured on the Zeman and Anonymate boots using the FSLL show higher values for the smaller charges (Figure 7). These differences could not be found in previous publications. However, the displacement and force measurements are not always published. A possible explanation could be that the response mode changes above a certain level, resulting in different forces and displacements. Another explanation could be that the current test set-up is not reproducible enough.

The injury results for the 25 g tests are compared to tests performed by other laboratory and presented in Figure 10. The test results with the combat boot show correspondence with earlier publications [2, 7]. However, when looking the results for the Aigis boot, it is clearly seen that the injury level ranges from 1 to 2b, and that there is much difference in the injury severity itself. Whether the problem lies with the surrogate limbs, the different test rigs used, the exact mine position or the way the sand was pressed on top of the mine, or something else in the test methodology is not known. It can be seen that within one laboratory the test results differ as well.

Because of this, and because of the unexpected outcome of the displacement measurements as mentioned above, one should question the reproducibility of the current test method. Therefore it is recommended for future research to include more results from other laboratories and focus on the details of the test set-up and its reproducibility. Bass [4] already recommended to perform at least five tests per test condition for a boot to pass.

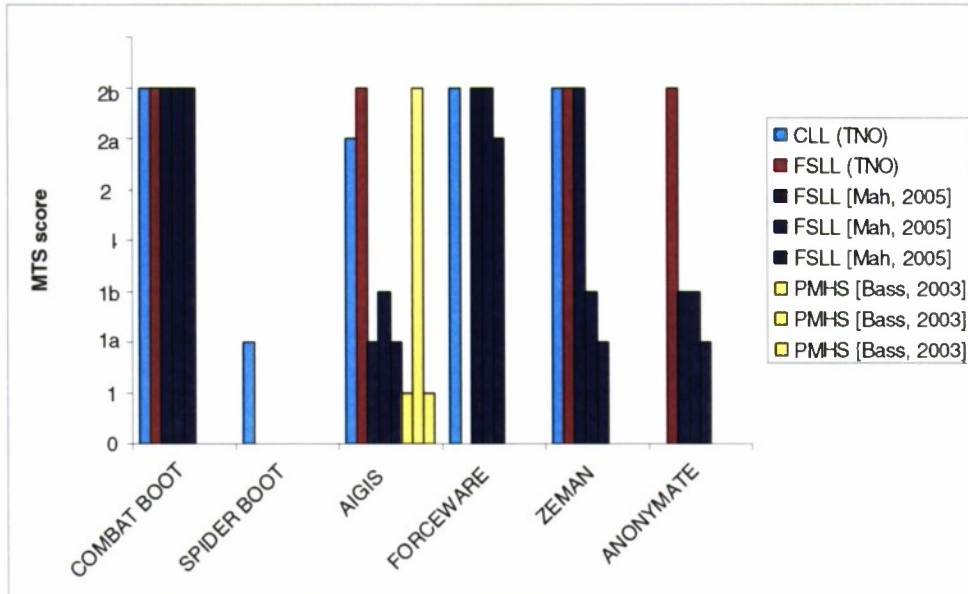


Figure 10 Comparison AP mine boot results for 25 g C4 tests.

From a practical point of view it was easier to work with the CLL than with the FSL. The mould of the CLL was simpler and also the 10% gelatine poured without any trouble. The original FSL gelatine recipe was not reproducible; therefore the 10% gelatine recipe was also used for the FSL. The mine boots that were used in the FSL tests had to be cut open near the tongue of the boot, because the ankle joint with foot was not flexible enough to pass the high shaft of the boot. Since the explosion is in such a short time, and the damage to the boot was on the upper part, it was assumed that this did not influence the test results. However in some cases, in particular the first experiments with the FSL, damage to the soft tissue of the foot due to putting on the mine boot was detected. However, these minor injuries were also considered not to influence the injury mechanism.

## Conclusion

The current study subjected commercially available protective footwear to explosive tests with charges from 25-75 grams of C4 that simulated anti-personnel land mines. The tests were performed in accordance with an objective test methodology that was agreed upon within NATO [8]. Both FSL and CLL were used as the surrogate of the human leg.

Examination of the boot alone is not sufficient to predict the injury to the leg. Several boots displayed little damage but were not able to mitigate the blast that was transferred to the leg, resulting in many fractures of the foot and ankle structure.

It was found that none of the footwear tested, except the platform boot could prevent amputation of the lower leg for charge sizes of either 25, 50 or 75 grams. It should be noted that although the platform boot tests resulted in salvageable limbs, there were still significant injuries to the leg, including soft tissue injuries and fractures.

Both legs, CLL and FSL give similar results focussing on the treatment needed. The results as presented in literature are somewhat contradictory, but it is not clear whether this was caused by the different legs, the test conditions or the test set-up. From a practical point of view, the authors preferred the use of the CLL.

Comparison with other publications showed differences in the injury severity results. Also the force and displacement measurements of the current tests resulted in some questions about the reproducibility of the AP mine boot tests. Therefore it is recommended to continue the comparison of the results of different test facilities, and study the reproducibility of the test set-up in more detail.

The current study focussed only on the prevention of injuries by wearing protective boots. However, the protection level should be combined with the comfort in using the systems. With that respect the platform boot that was tested has the worst score compared to the other boots from the current study [NATO]. This expresses the need to the development of new AP mine boots, which combine the different criteria which the boot need to fulfil.

### Acknowledgements

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### References

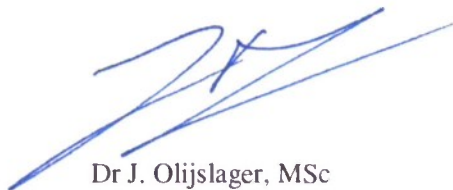
- [1] AIS (2005), The Abbreviated Injury Scale. Association for the Advancement of Automotive Medicine, Des Plaines, IL 60018, USA.
- [2] Anderson, I.B., et al. (2004), Test method for lower limb protective equipment against anti-personnel mines. In Proceedings of Personal Armour Systems Symposium, September 2004, The Netherlands.
- [3] Bass, C.R., et al. (2003), Final Report of the Lower Extremity Assessment Program (LEAP) , MD 21005-5059, ATC-8682, US Army, Aberdeen Test Centre, Aberdeen Proving Ground, MA, USA.
- [4] Bass, C.D. et al. (2004), Development of a test methodology to evaluate mine protective footwear. In Proceedings of Personal Armour Systems Symposium, September 2004, The Netherlands.
- [5] Brown, R., et al. (2001), 10-year experience of injuries sustained during clearance of anti-personnel mines, *The Lancet*, vol. 358, pp2048-2049.
- [6] Griffin, et al. (1999), Effects of anti-personnel blast mines on the lower extremity. In Proceedings of the International Research Council on the Biomechanics of Impact (IRCOBI).
- [7] Mah, J.M.L.; Braid, M.P.; Fall, R.W. and Anderson, I.B. (2005), Blast performance of commercially available demining footwear: a summary of experimental trials with FSLLs. DRDC Suffield TM 2005-009. Defence Research and Development Canada – Suffield.
- [8] NATO HFM – 089 / TG – 024 – Final Technical Report, Test methodologies for personal protective equipment against antipersonnel mine blast, NATO Research and Technology Organization, Neuilly-Sur\_Sein, 2004.



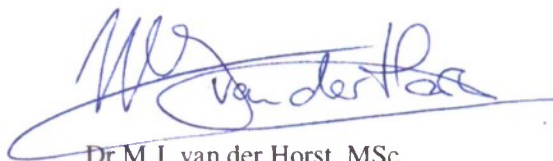
### 3 Signature

Rijswijk, October 2008

TNO Defence, Security and Safety

A handwritten signature in blue ink, consisting of a stylized 'J' followed by a horizontal line and a diagonal stroke.

Dr J. Olijslager, MSc  
Head of department

A handwritten signature in blue ink, featuring a large 'M' and 'J' followed by a horizontal line and a diagonal stroke.

Dr M.J. van der Horst, MSc  
Author



## A Test set-up

Figure A.1 gives an overview of the large calibre range at the Laboratory for Ballistics Research of TNO is shown together with the test set-up for the demining boot tests.

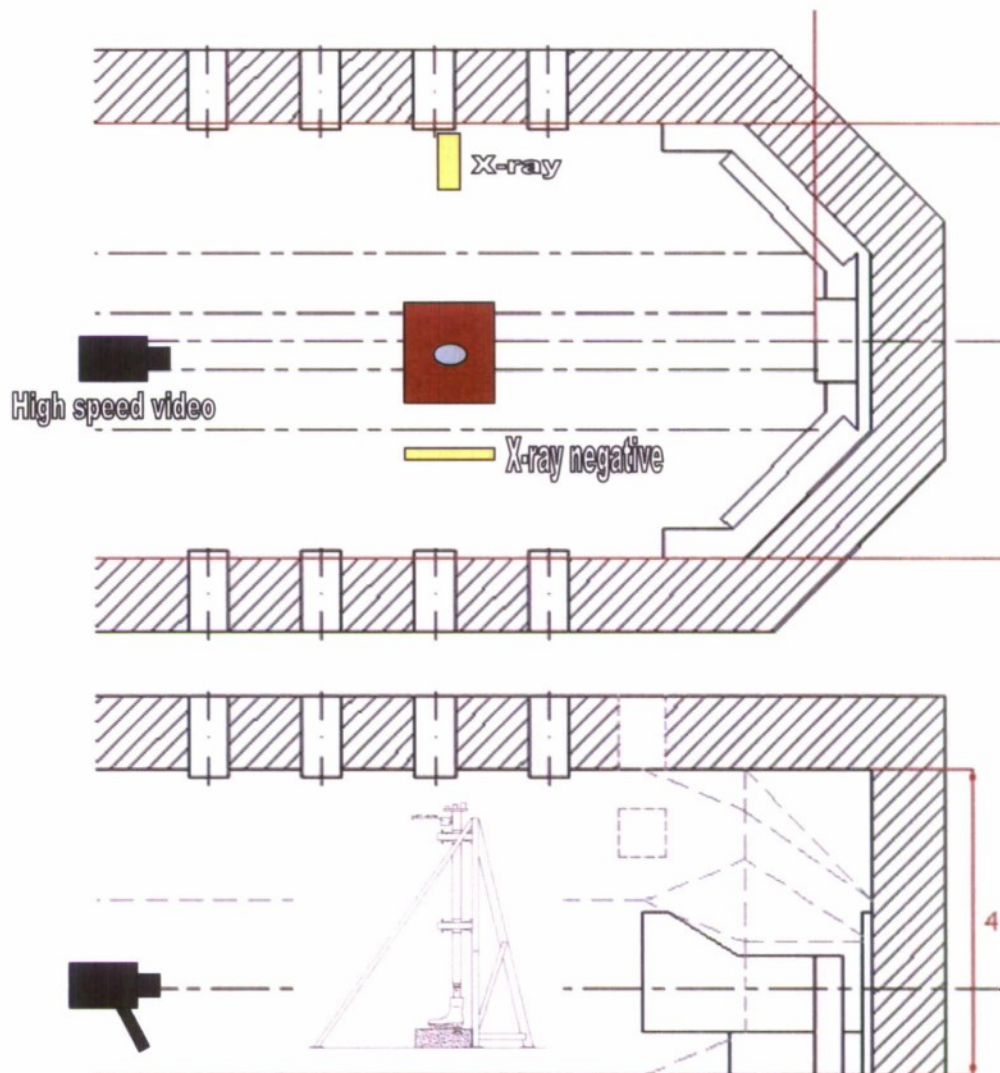


Figure A.1 Test set-up.

### Explosive threat properties

Explosive mass	25, 50 and 75 g
Explosive type	C-4
Charge geometry	A height-to-diameter ratio of 35%
Detonation point	From the bottom in the centre
Container characteristics	None
Placement of charge	Centered under heel (for spiderboot under outer rear pod)
Depth of burial	20 mm overburden (= 20 mm under the sand)

For the trials Composition 4 (C4) was used, each having a height-to-diameter ratio of 35% based on a review of AP mine geometries (see Figure A.2). The charges were bottom-initiated with DM42 detonators. The detonator was positioned in the centre of the mine using a plastic cylinder for fixation.

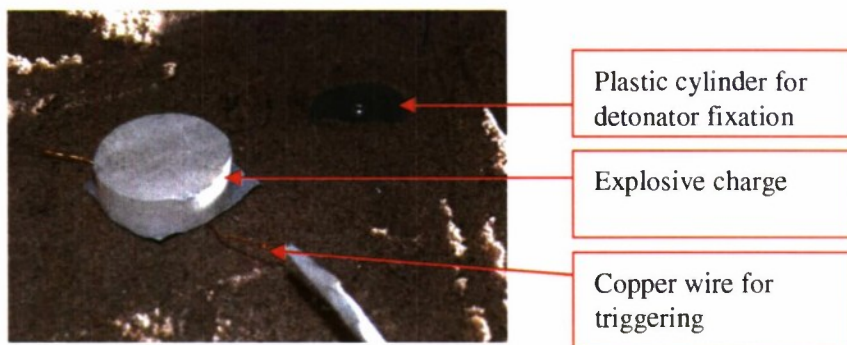


Figure A.2 Explosive charge.

### Soil properties

Soil container dimensions	700 x 630 x 310 mm
Soil type	Sand (0.1 - 0.7 mm)
Compaction	$\pm 1600 \text{ kg/m}^3$
Humidity	$\pm 50\%$

### Surrogate Leg models

Leg type	12 CLLs and 7 FSLLs
Position of test model (leg surrogate)	90° with the sand, in line with the AP mine
Orientation of leg	vertical
Reaction mass	25 kg
Pre-load on the charge	25 kg

#### *Canadian Lower Leg (CLL)*

The Canadian Lower Leg (CLL) was developed by a team including Defence R&D and the university of Waterloo [NATO]. The CLL is presented in Figure A.3. In a mine blast event the worst case is when the mine detonates under the heel. Damage to the calcar bone is therefore key indicator in performance. To avoid unnecessary anatomical details the CLL was designed to focus on the main injuries to the calcar bone, the talus and the tibia. Therefore the CLL is designed simpler than the human skeleton, and it does not have a foot at all, but consists of a double calcar bone.

The soft tissue is represented by gelatin. To preserve the ballistic gelatin, all CLL were maintained at 4 °C in a cooling unit until just prior to the test.

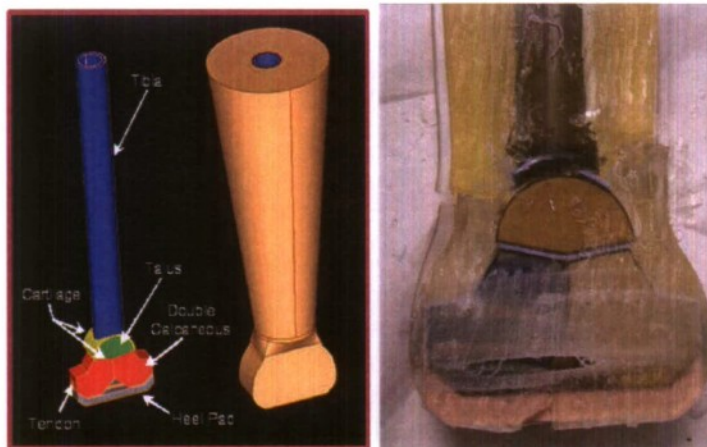


Figure A.3 Schematic of the Canadian Lower Leg (CLL) and right a picture of the CLL cast in gelatin (part of the gelatin was removed to see the inner skeleton).

#### *Frangible Surrogate Lower Leg (FSL)*

The Frangible surrogate lower legs (FSLs) were developed by the Australian Defence Science and Technology Organization (DSTO) [NATO]. The FSL is presented in Figure A.4. The leg consists of a skeleton which mimics the human bony structure, includes the most important ligaments in foot and ankle. The soft tissues are represented by ballistic gelatin. To preserve the ballistic gelatin, all legs were maintained at 4 °C in a cooling unit until just prior to the test.



Figure A.4 Left picture shows the FSL cast in gelatin and right picture shows the inner skeleton of the FSL.

From a practical point of view it was easier to work with the CLL than with the FSL. The mould of the CLL was simpler and also the 10% gelatine poured without any trouble. The original FSL gelatine recipe was not reproducible; therefore the 10% gelatine recipe was also used for the FSL. The mine boots that were used in the FSL tests had to be cut open near the tongue of the boot, because the ankle joint was not flexible enough to pass the high shaft of the boot. Since the explosion is in such a short time, and the damage to the boot was on the upper part, it was assumed that this did not influence the test results. However in some cases, in particular the first experiments with the FSL, damage to the soft tissue of the foot due to putting on the mine boot was detected. Considering the treatment, in most cases amputating the leg below the knee, this was considered to be no problem.

## Measurements

The displacement of the leg has been monitored by means of a displacement transducer (AE sensors, type WS10-1000-R1K-L10-HG) and high speed video recordings (1000 fps). Furthermore a load cell (Denton type 3115) was placed directly above the connection of the surrogate leg and the beam, which measured the shear ( $F_x$ ) and compression ( $F_z$ ) forces and the bending moments ( $M_x$ ,  $M_y$ ) (see Figure A.5).

Additionally, strain gauges were placed on the CLL's (strain gauges 250 BG). One strain gauge was located at 190 mm from the foot sole and four strain gauges were divided over the tibia at a height of 290 mm (see Figure A.5)

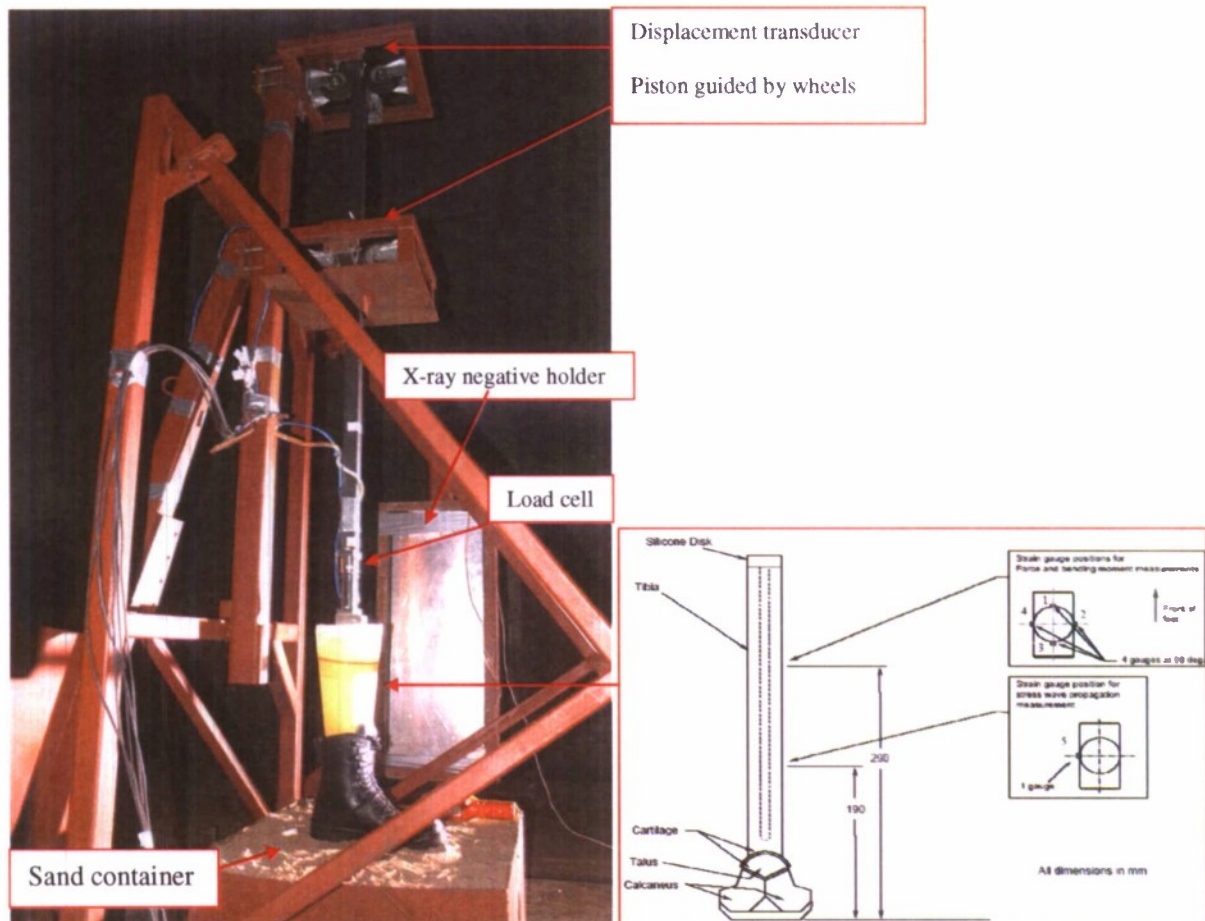


Figure A.5 Test set-up of AP mine shoe tests (left) and schematic view of CLL (right).

Each test was carefully documented with before and after digital photography. Lateral X-ray recording was performed during the test, trying to record the deformation of the boot/leg. Pre X-rays were taken of FSSL's only. Post X-rays were taken of all legs.



## B General results

The test results are summarized in Table B.1 and in Figures B1-B3. The measurement results and medical reports are presented in Appendices C and D.

Table B.1 Test results summarized.

No.	Boot	Leg	Explosive <sup>#</sup> mass	MTS	AIS	Treatment
1	Combat Boot Dutch army	CLL	25 g	2b	3	Below knee amputation (BKA)
2	Spiderboot (combined with CB*)	CLL	25 g	1a	2	Be aware of possible arterial lesions
3	Anonymate	CLL	50 g	2b	3	BKA <sup>§</sup>
4	Forceware	CLL	50 g	2b	3	BKA
5	Mile Dragic	CLL	50 g	2b	3	BKA <sup>§</sup>
6	Aigis	CLL	50 g	2b-3	3	BKA <sup>§</sup>
7	ZEMAN	CLL	50 g	2b	3	BKA <sup>§</sup>
8	Spiderboot (combined with CB)	CLL	75 g	1	2	Conservative; probably temporarily external fixation
9	Aigis	CLL	25 g	2a	3	BKA
10	Rubber block (SA) (combined with CB)	CLL	50 g	2a	2	BKA**
11	Forceware	CLL	25 g	2b	3	BKA
12	Spiderboot (combined with CB)	FSSL	75 g	1b	2	Debridement and external fixation of ankle
13	ZEMAN	FSSL	50 g	2b	4	BKA
14	Aigis	FSSL	25 g	2b	3	BKA
15	Combat Boot Dutch army	FSSL	25 g	2b	3	BKA
16	ZEMAN	CLL	25 g	2b	3	BKA
17	ZEMAN	FSSL	25 g	2b	3	BKA
18	Anonymate	FSSL	25 g	2b	3	BKA
19	Anonymate	FSSL	25 g	2b	3	BKA

<sup>#</sup> Explosive material C4.

\* CB = Combat Boot (Dutch Army).

<sup>§</sup> If degloving is the real mechanism, than above knee amputation would be needed. However it is assumed that the degloving (loosening of the soft tissue) can be seen as a result of the test set-up (gelatine just for lower leg part, whereas in reality the human skin and muscles of the entire leg are holding together). Therefore the degloving as seen in a few tests is assumed not to be a realistic injury mechanism.

The measurement data of test 1 was not captured due to technical problems.

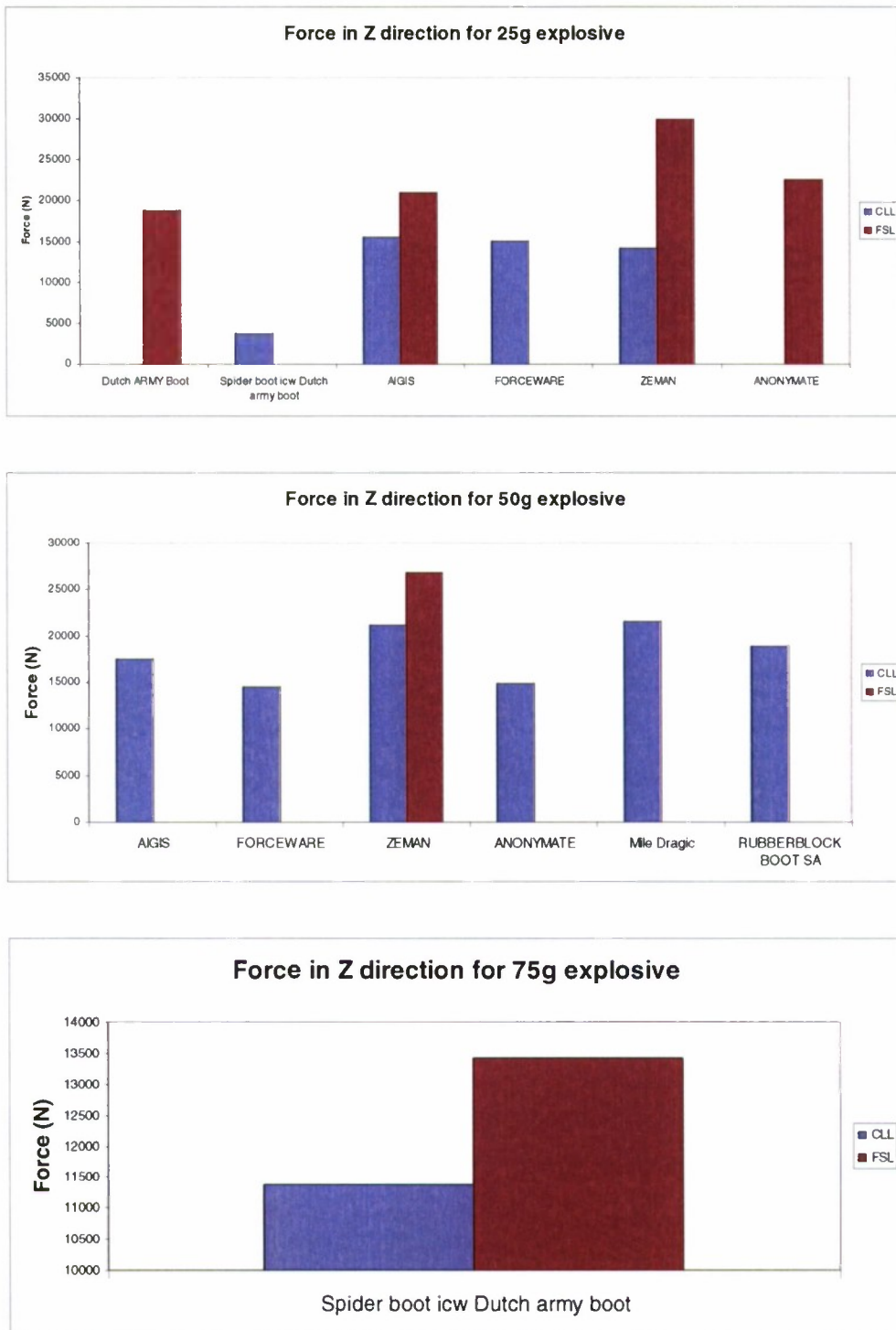


Figure B.1 Axial forces measured in the load cell.

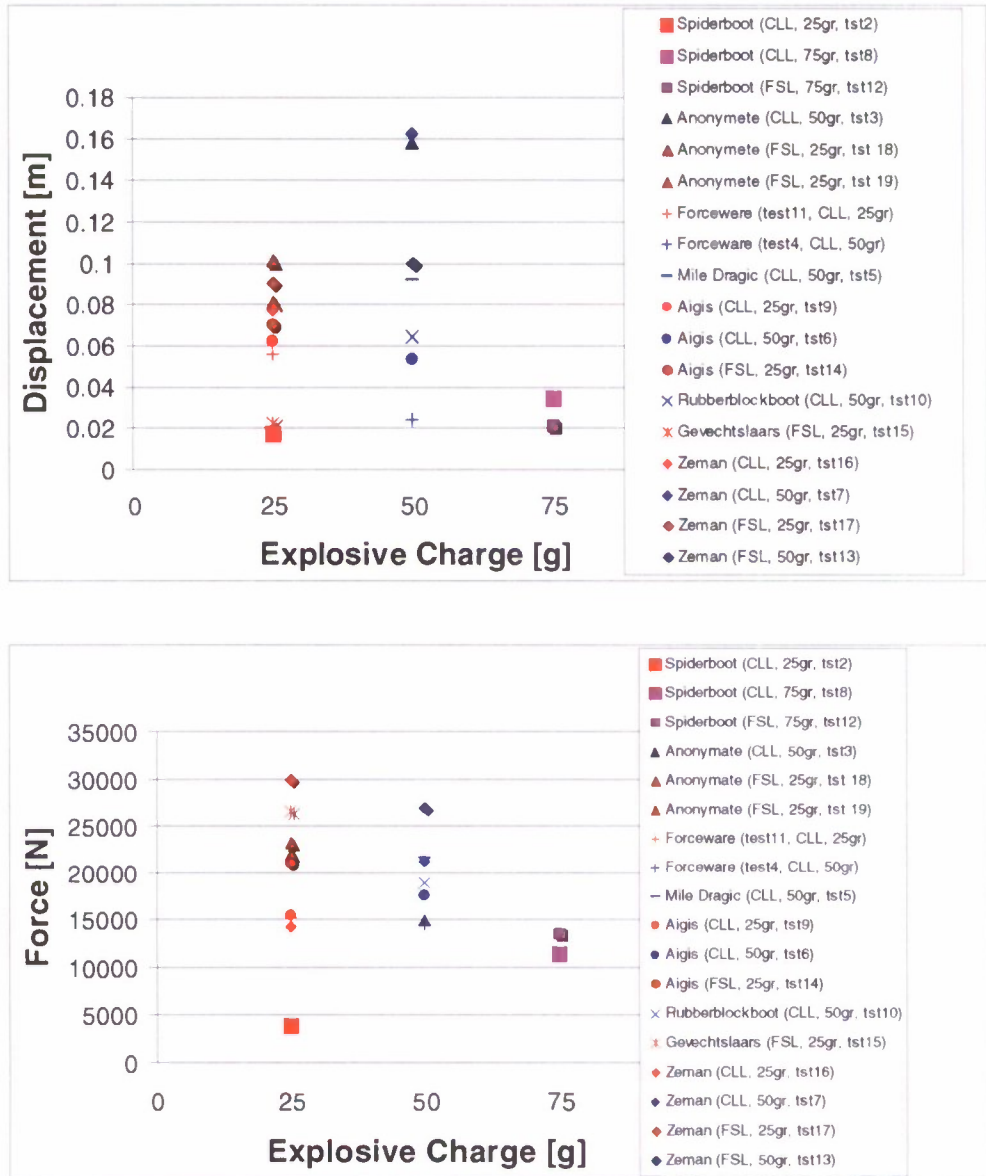


Figure B.2 Forces and displacement for the different tests.

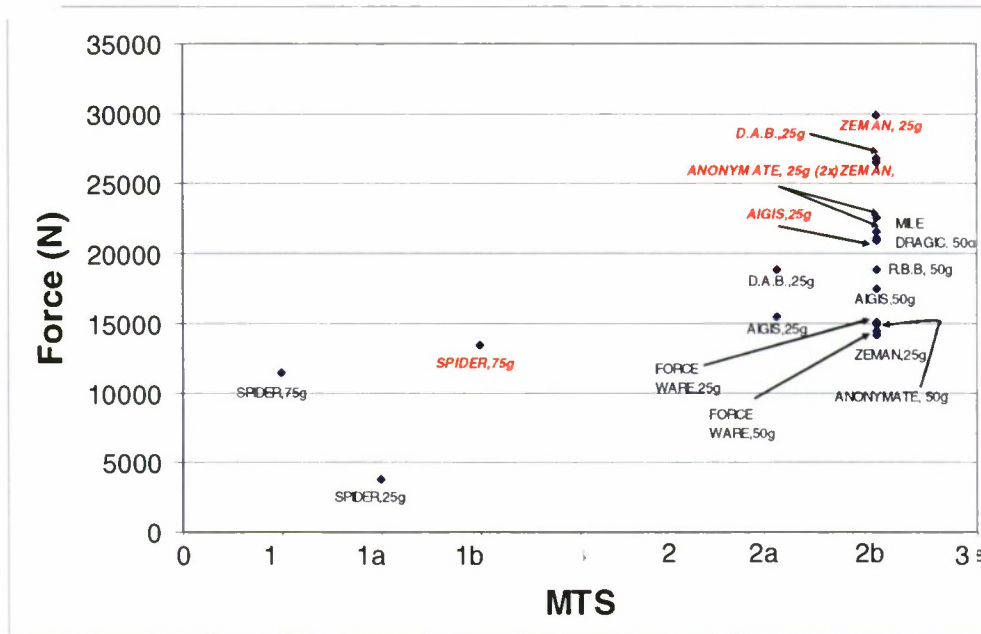


Figure B.3 Forces versus MTS scores for the different tests.

## C Measurement results

For each test the following parameters are presented:

- VI: the displacement of the leg;
- TLU Fx: Tibia shear force;
- TLU Fz: Tibia compression force;
- TLU Mx: Tibia bending moment (side);
- TLU My: Tibia bending moment (flexion/extension).


These results are discussed in the main text of this report.

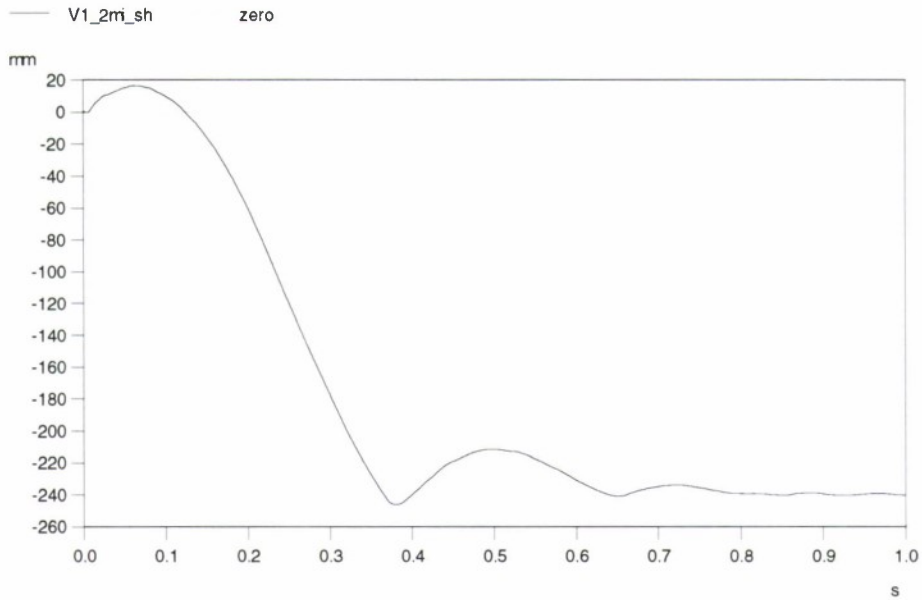
Additionally, the strain gauge measurements, R1-R5 are presented here.

A quick analysis of the measured strain gauge signals shows that;

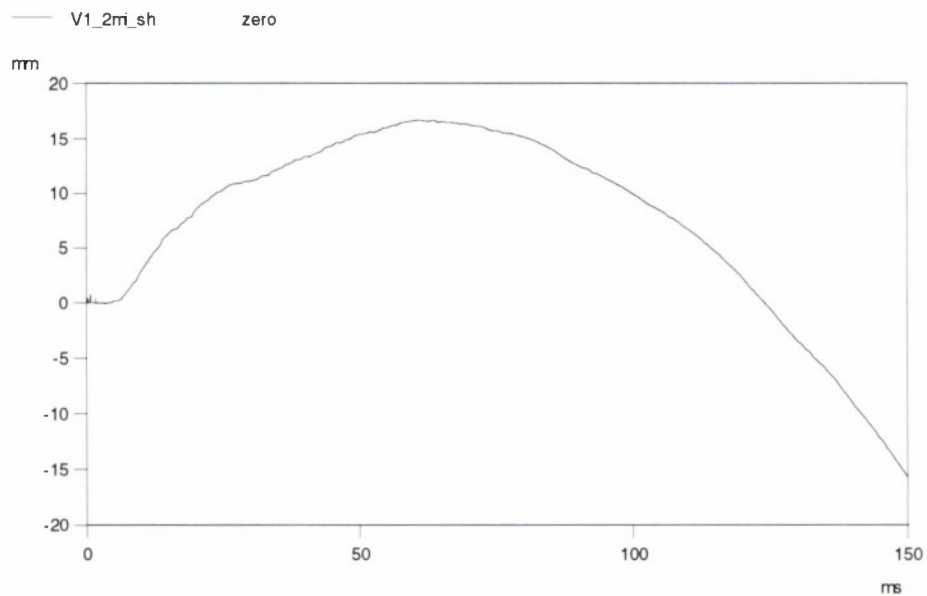
- The shockwave velocity in the CLLs, measured with R4 and R5, cannot be determined. Probably due to the resolution of the sample speed (set to 200 kHz) in combination with the anti analyzing filter the strain signals were too smooth.
- In all test with exception of the rubber block boot test maximum strain values were measured between 25000 and 50000 micro strain. In the rubber block boot test the maximum levels the shapes are different and a maximum level of 5200 micro strain was measured.
- Each shoe type gives a different signal pattern.
- Only in a few tests a relation can be seen between the front and rear and left and right side of the leg. In most other tests a large deviation in the strain results are seen.


It can be concluded that the measured strain signals are difficult to analyze. There is a large variety in the maximum strain values and the relation between the different strain measurements are hard to see. Therefore, these results are not further used.

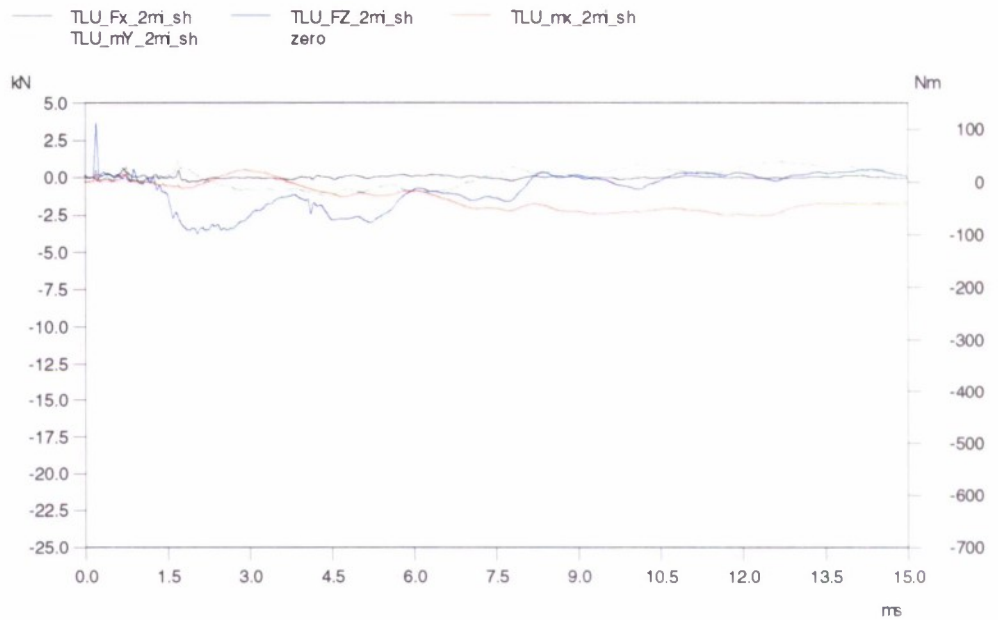
27-11-07	Test_2, 'Spiderboot' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_2mi_sh.drb		



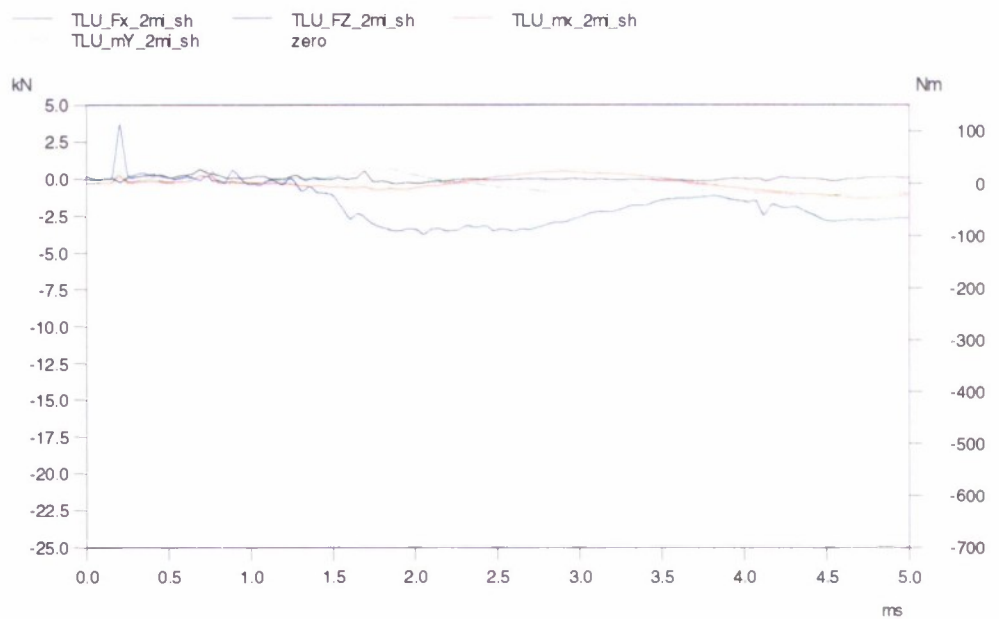
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V1_2mi_sh	0.017	m	60.89	ms	-0.246	m	379.4	ms




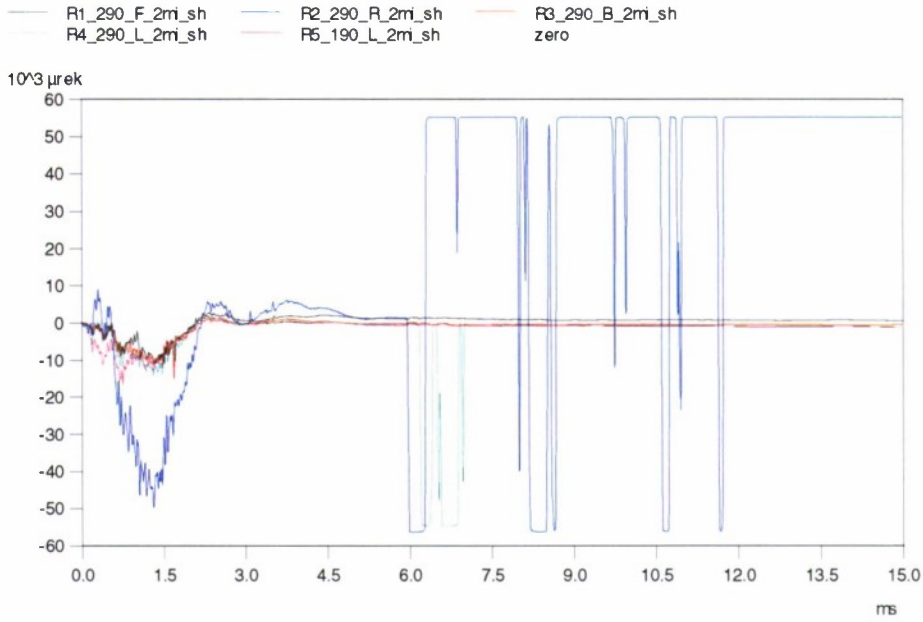
27-11-07	Test_2, 'Spiderboot' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_2mi_sh_TLU.drb		



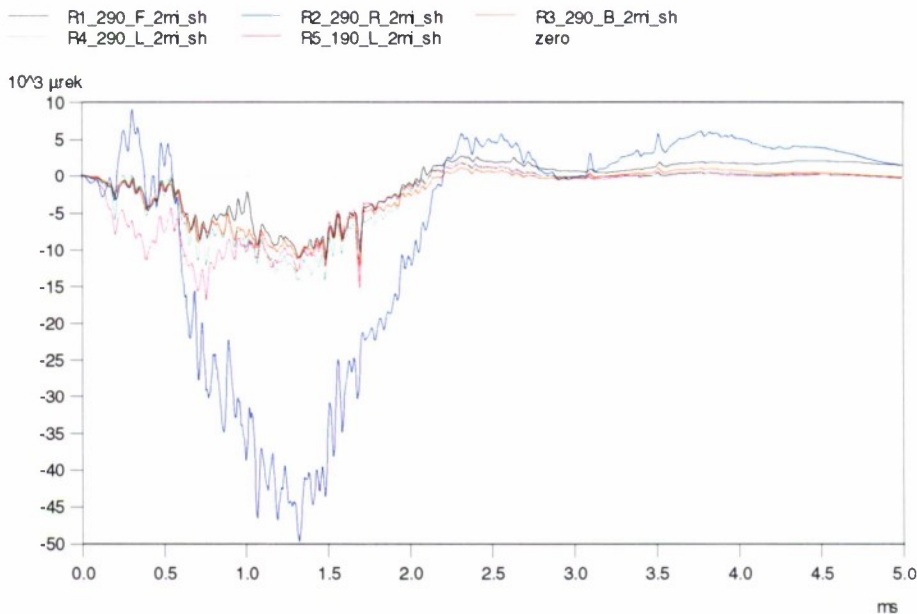
	Max.		at time		Mn.		at time	
<b>TLU_FX</b>	609.91	N	0.7	ms	-291.88	N	1.9	ms
<b>TLU_FZ</b>	3668.79	N	0.2	ms	-3763.27	N	2.1	ms
<b>TLU_MX</b>	23.22	Nm	2.9	ms	-61.52	Nm	9.3	ms
<b>TLU_MY</b>	38.76	Nm	1.7	ms	-26.86	Nm	4.4	ms



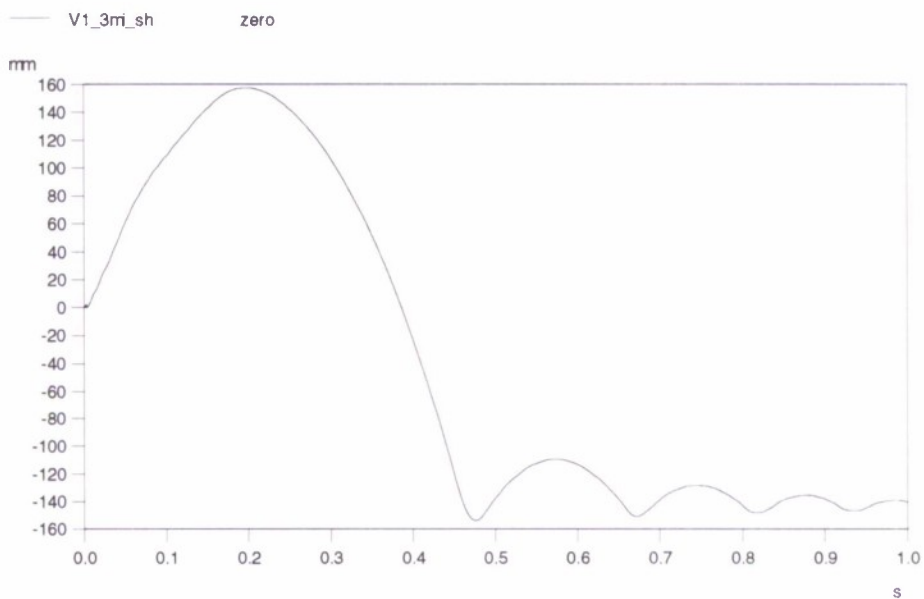
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RvdK		
10784		
_2mi_sh_R.drb		



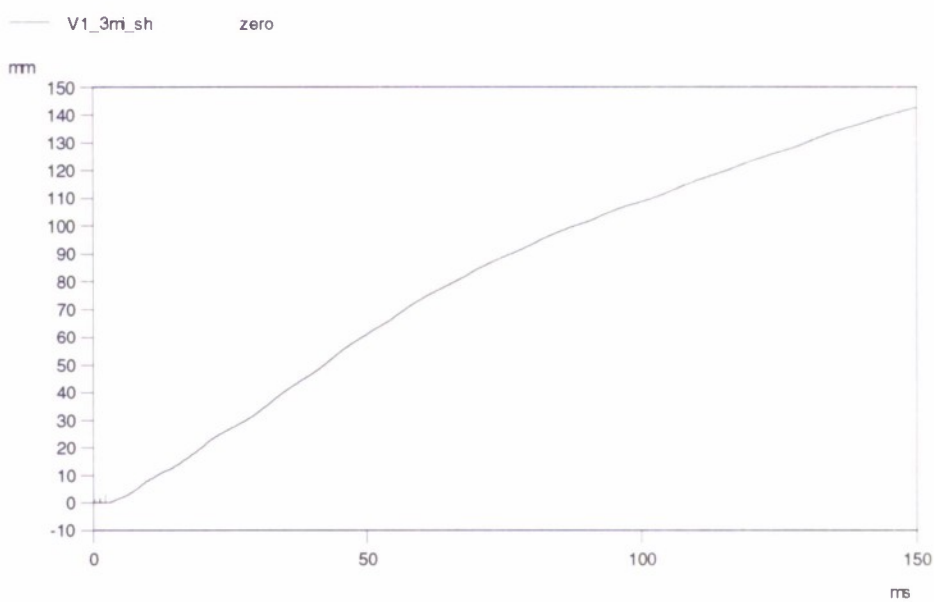
	Max.		at time		Mn.		at time	
<i>R1_290_F_2mi_sh</i>	2814.75	µrek	2.3	ms	-11085.59	µrek	1.5	ms
<i>R2_290_R_2mi_sh</i>	9043.09	µrek	0.3	ms	-49721.26	µrek	1.3	ms
<i>R3_290_B_2mi_sh</i>	1107.65	µrek	2.3	ms	-12175.99	µrek	1.7	ms
<i>R4_290_L_2mi_sh</i>	2006.87	µrek	2.3	ms	-14089.06	µrek	1.5	ms
<i>R5_190_L_2mi_sh</i>	1719.36	µrek	2.3	ms	-16798.80	µrek	0.8	ms




27-11-07	Test _3, 'Anonymate' CLL legg, TNO-LBO, September 2007	
RvdK		
10784		
V1_3mi_sh.drb		



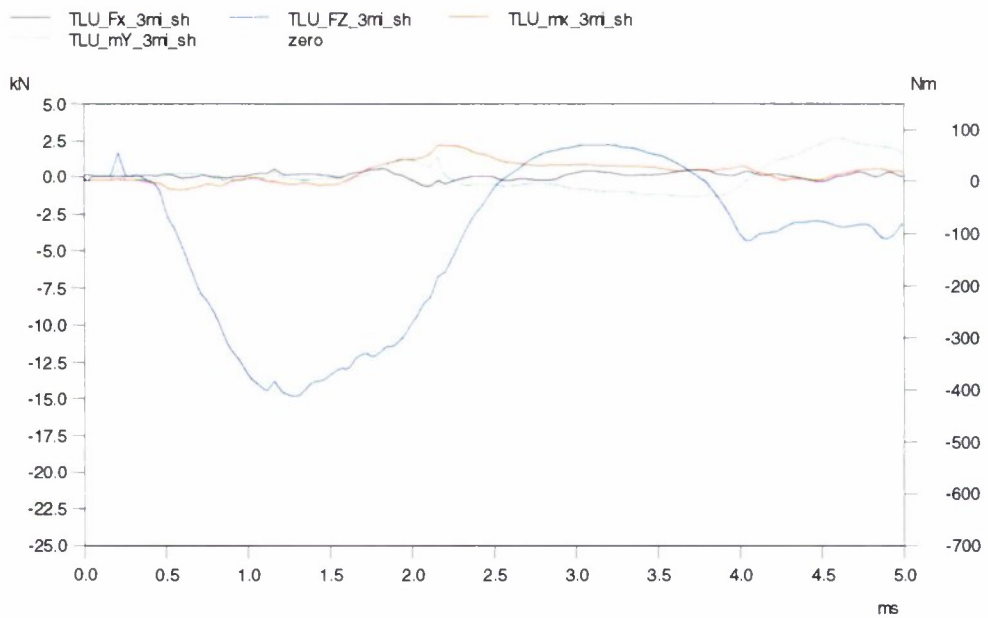
	Max.		at time		Min.		at time	
<b>V1_3mi_sh</b>	0.158	m	198.69	ms	-0.154	m	475.7	ms




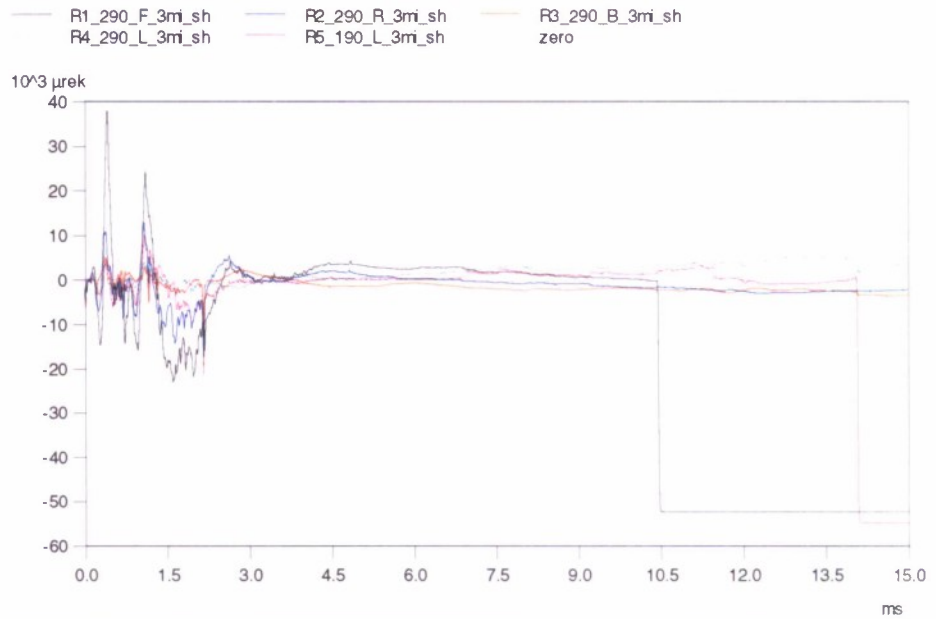
27-11-07	Test_3, 'Anonymate' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_3mi_sh_TLU.drb		



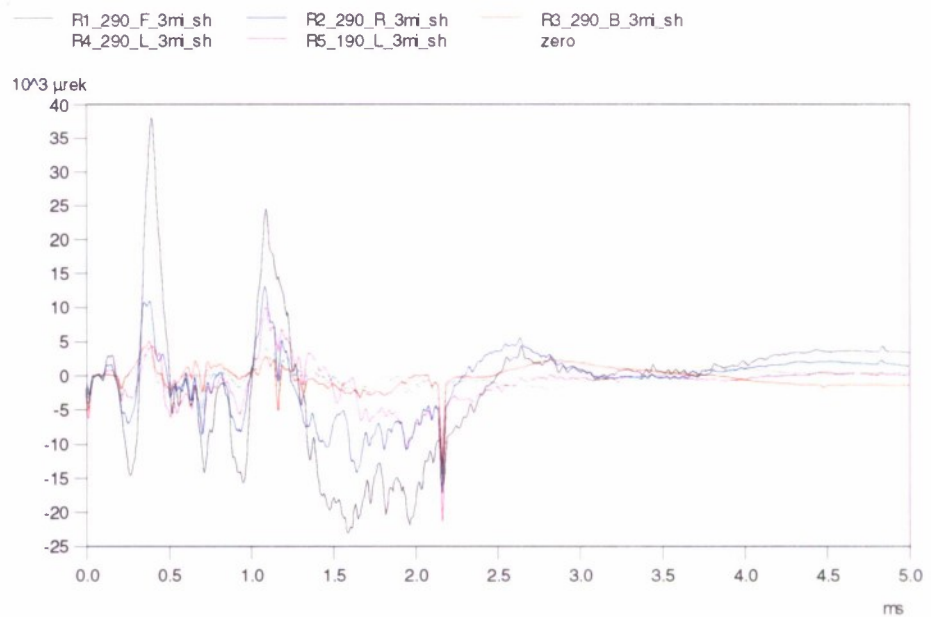
	Max.		at time		Mn.		at time	
<b>TLU_FX</b>	561.30	N	1.8	ms	-889.99	N	6.8	ms
<b>TLU_FZ</b>	2227.34	N	3.2	ms	-14899.12	N	1.3	ms
<b>TLU_MX</b>	69.52	Nm	2.2	ms	-73.34	Nm	10.0	ms
<b>TLU_MY</b>	123.69	Nm	7.3	ms	-31.38	Nm	3.7	ms




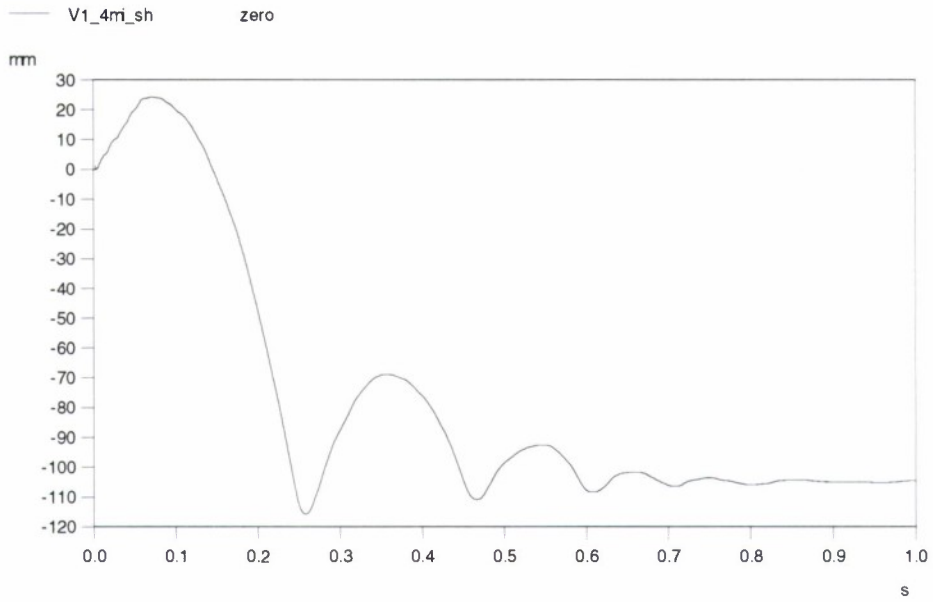
27-11-07	Test_3, 'Anonymate' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_3mi_sh_R.drb		



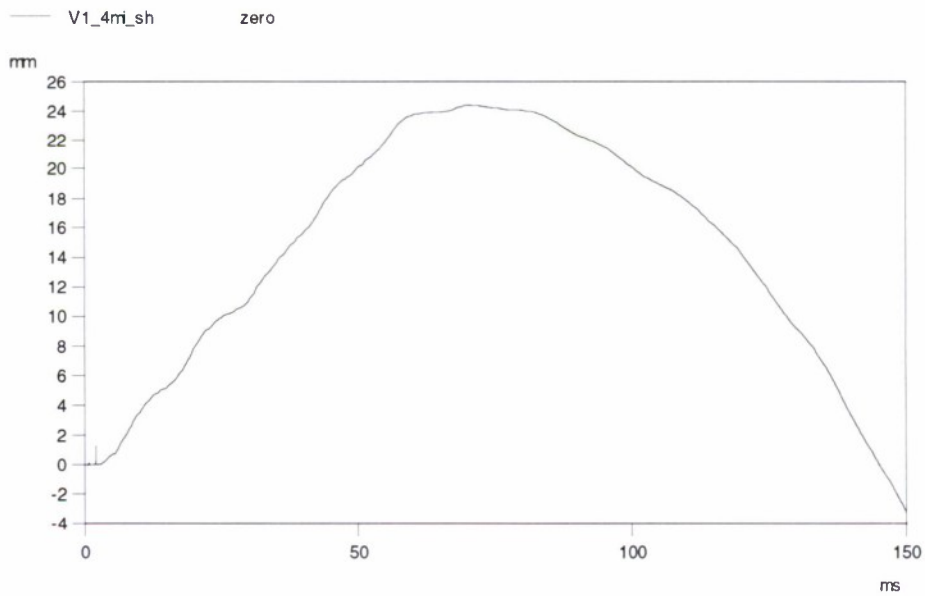
	Max.		at time		Min.		at time	
<i>R1_290_F_3mi_sh</i>	38024.80	µrek	0.4	ms	-23105.94	µrek	1.6	ms
<i>R2_290_R_3mi_sh</i>	12927.59	µrek	1.1	ms	-17181.54	µrek	2.2	ms
<i>R3_290_B_3mi_sh</i>	4954.83	µrek	0.4	ms	-13287.35	µrek	2.2	ms
<i>R4_290_L_3mi_sh</i>	3990.12	µrek	1.1	ms	-14479.87	µrek	2.2	ms
<i>R5_190_L_3mi_sh</i>	10002.67	µrek	1.1	ms	-21469.68	µrek	2.2	ms




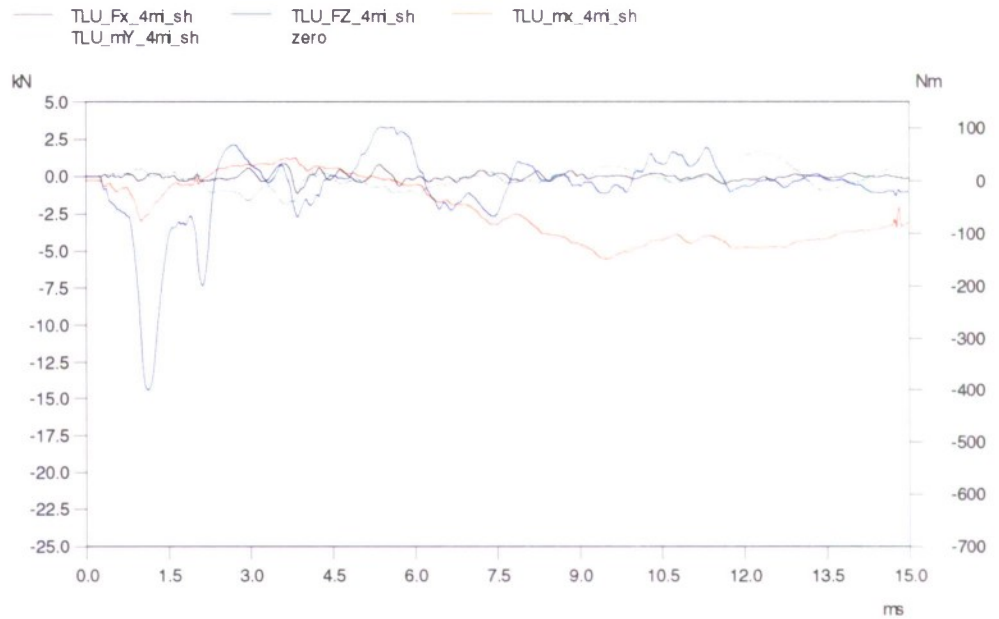
27-11-07	Test_4, 'Foreware' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_4mi_sh.drb		



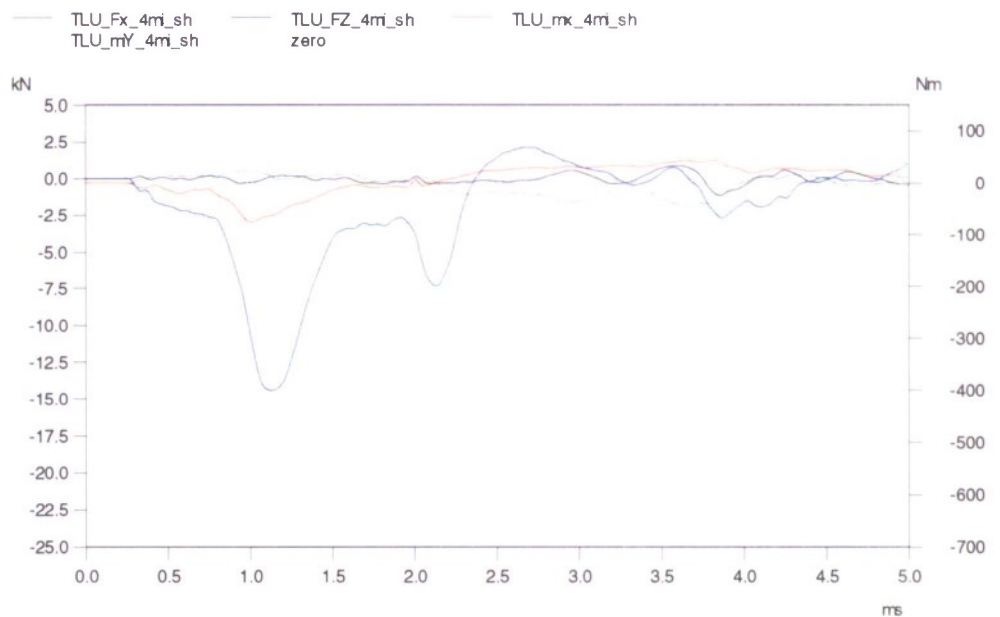
	Max.		at time		Mn.		at time	
<b>V1_4mi_sh</b>	0.024	m	70.12	ms	-0.116	m	257.2	ms




27-11-07 RvdK 10784 _4mi_sh_TLU.drb	<b>Test_4, 'Forceware' CLL legg, TNO-LBO</b> , September 2007	
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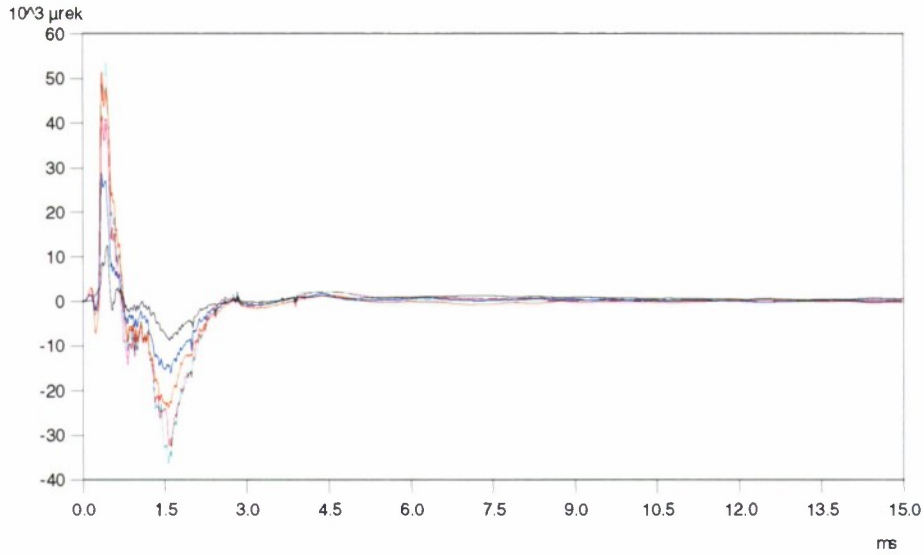


	Max.		at time		Min.		at time	
<b>TLU_FX</b>	915.31	N	3.6	ms	-1122.86	N	3.9	ms
<b>TLU_FZ</b>	3315.60	N	5.4	ms	-14454.45	N	1.1	ms
<b>TLU_MX</b>	43.84	Nm	3.8	ms	-149.78	Nm	9.5	ms
<b>TLU_MY</b>	31.25	Nm	2.0	ms	-45.18	Nm	3.7	ms



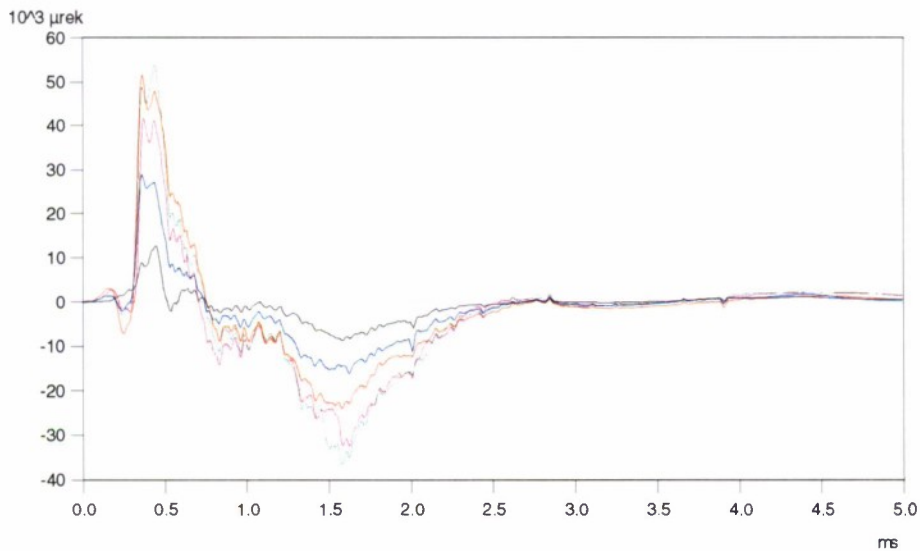
27-11-07	Test_4, 'Forceware' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_4mi_sh_R.drb		


— R1\_290\_F\_4mi\_sh    — R2\_290\_R\_4mi\_sh    — R3\_290\_B\_4mi\_sh  
— R4\_290\_L\_4mi\_sh    — R5\_190\_L\_4mi\_sh    zero

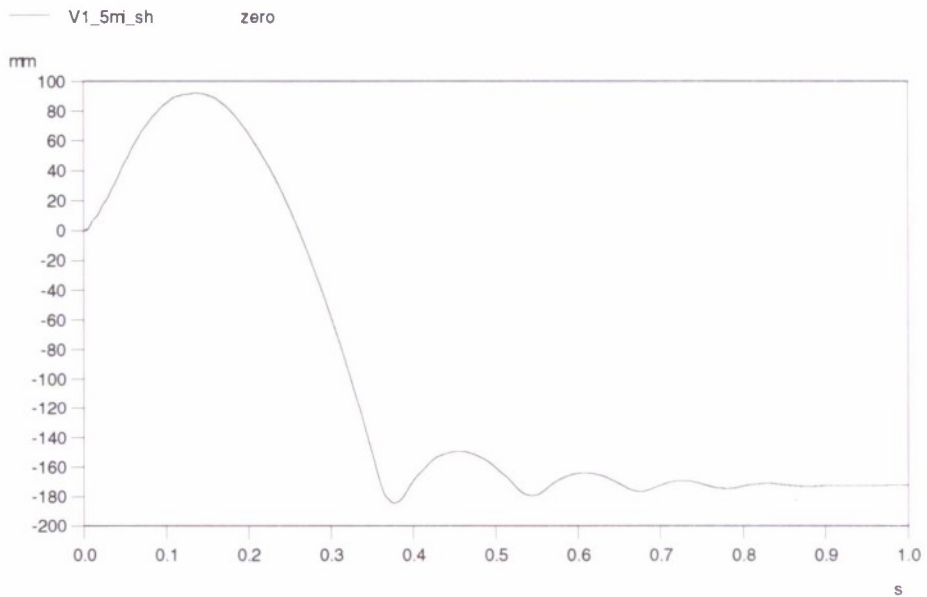


	Max.		at time		Min.		at time	
<i>R1_290_F_4mi_sh</i>	12661.25	µrek	0.4	ms	-8754.12	µrek	1.6	ms
<i>R2_290_R_4mi_sh</i>	28862.41	µrek	0.4	ms	-16161.70	µrek	1.6	ms
<i>R3_290_B_4mi_sh</i>	51541.25	µrek	0.4	ms	-23946.02	µrek	1.6	ms
<i>R4_290_L_4mi_sh</i>	53761.18	µrek	0.4	ms	-36382.38	µrek	1.6	ms
<i>R5_190_L_4mi_sh</i>	41652.32	µrek	0.4	ms	-32597.17	µrek	1.6	ms

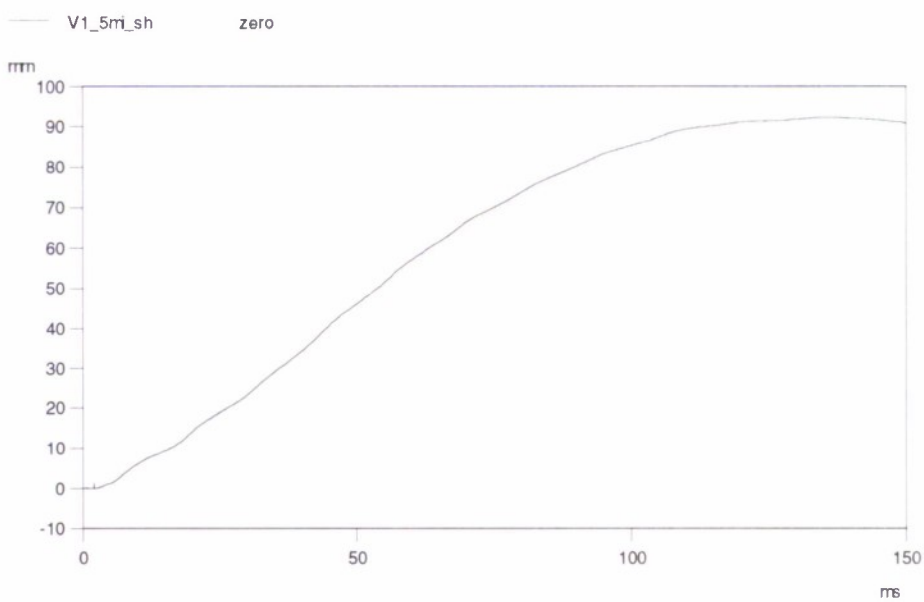
— R1\_290\_F\_4mi\_sh    — R2\_290\_R\_4mi\_sh    — R3\_290\_B\_4mi\_sh  
— R4\_290\_L\_4mi\_sh    — R5\_190\_L\_4mi\_sh    zero




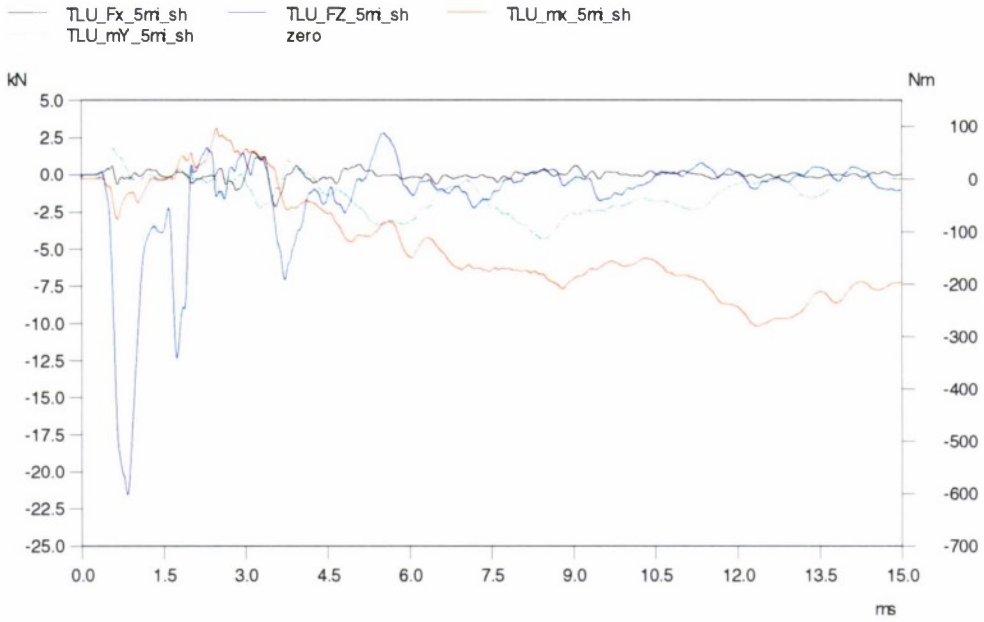
27-11-07	Test _5, 'Mile dragic' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_5mi_sh.drb		



	Max.		at time		Min.		at time	
V1_5mi_sh	0.092	m	137.09	ms	-0.185	m	377.3	ms




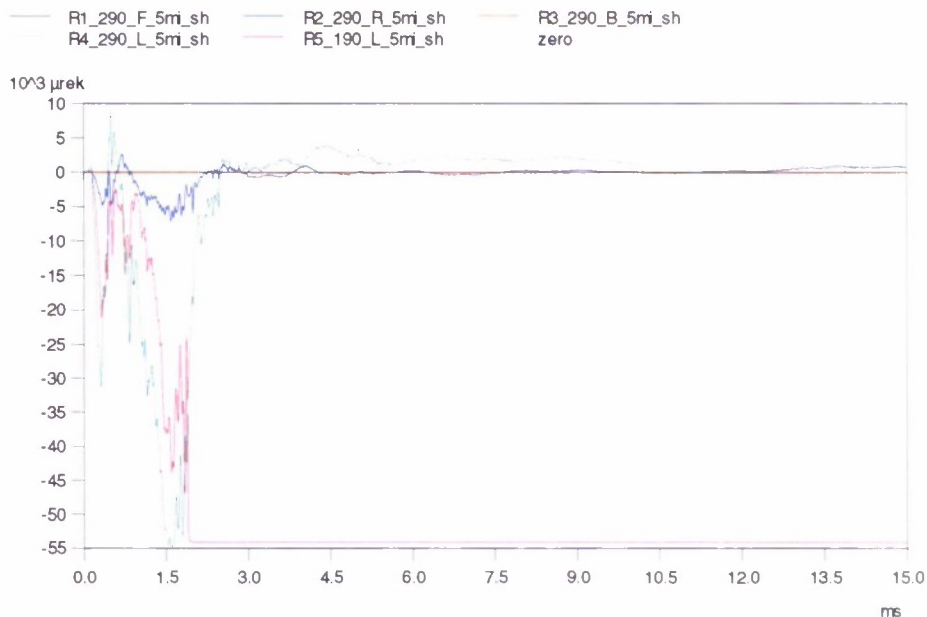
27-11-07	Test_5, 'Mile dragic' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_5mi_sh_TLU.drb		



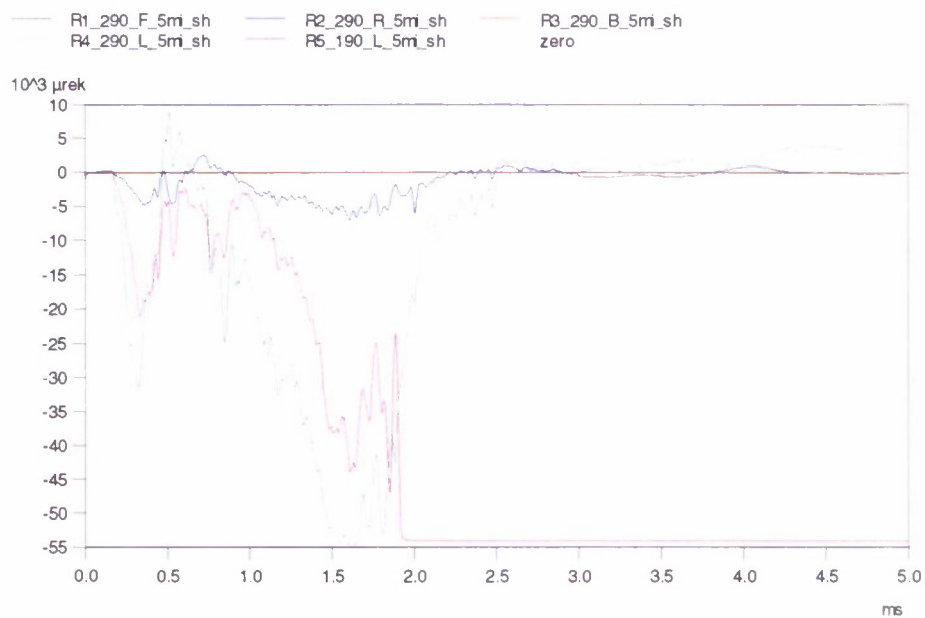
	Max.		at time		Min.		at time	
<b>TLU_FX</b>	1540.91	N	3.1	ms	-2125.77	N	3.5	ms
<b>TLU_FZ</b>	2778.37	N	5.5	ms	-21588.45	N	0.8	ms
<b>TLU_MX</b>	95.73	Nm	2.5	ms	-209.56	Nm	8.8	ms
<b>TLU_MY</b>	58.02	Nm	0.6	ms	-113.56	Nm	8.5	ms




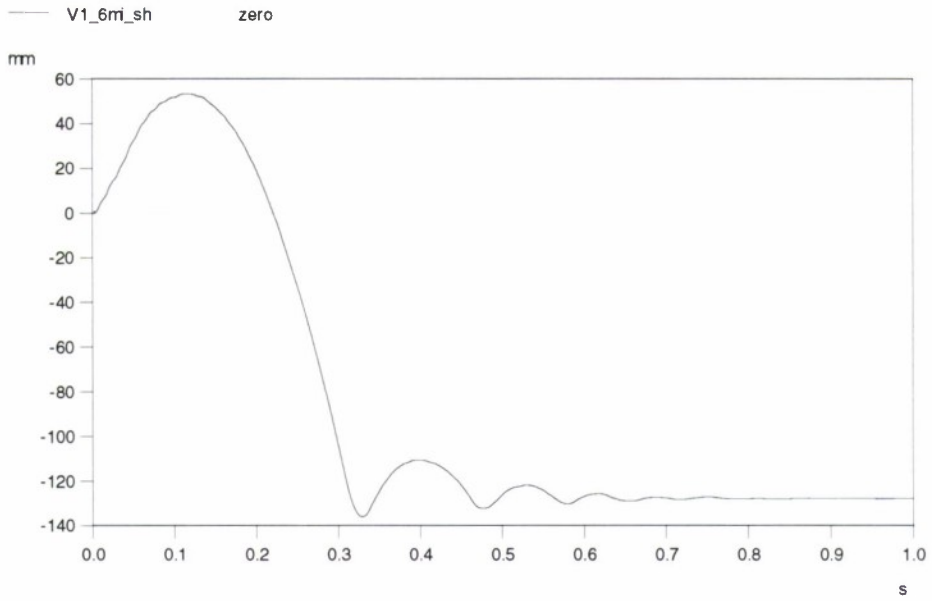
27-11-07	Test_5, 'Mile dragic' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_5mi_sh_R.drb		



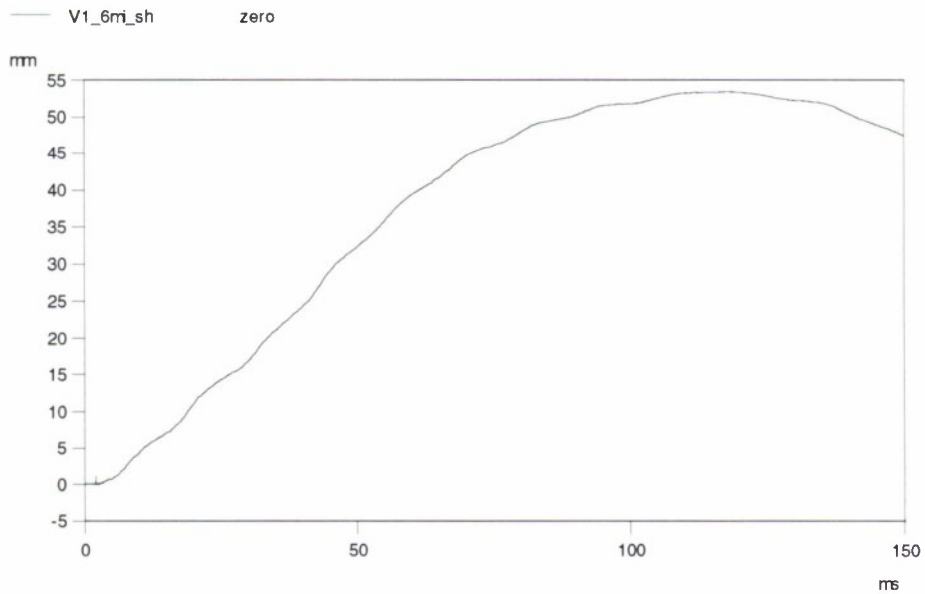
	Max.		at time		Mn.		at time	
R1_290_F_5mi_sh	0.01	µrek	1.2	ms	-0.01	µrek	-10.0	ms
R2_290_R_5mi_sh	2684.15	µrek	0.7	ms	-7110.60	µrek	1.6	ms
R3_290_B_5mi_sh	0.03	µrek	1.8	ms	-0.02	µrek	1.6	ms
R4_290_L_5mi_sh	8823.03	µrek	0.5	ms	-54748.22	µrek	1.6	ms
R5_190_L_5mi_sh	244.18	µrek	0.2	ms	-54243.05	µrek	2.1	ms



27-11-07	Test_6, 'Aigis' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_6mi_sh.drb		

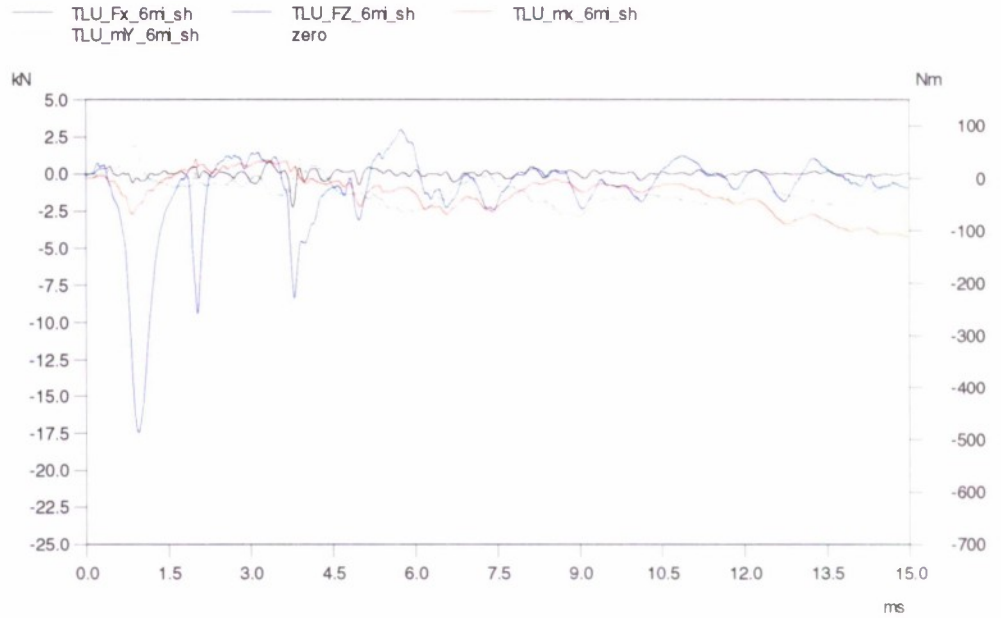


	Max.		at time		Mn.		at time	
<b>V1_6mi_sh</b>	0.053	m	118.17	ms	-0.136	m	328.4	ms

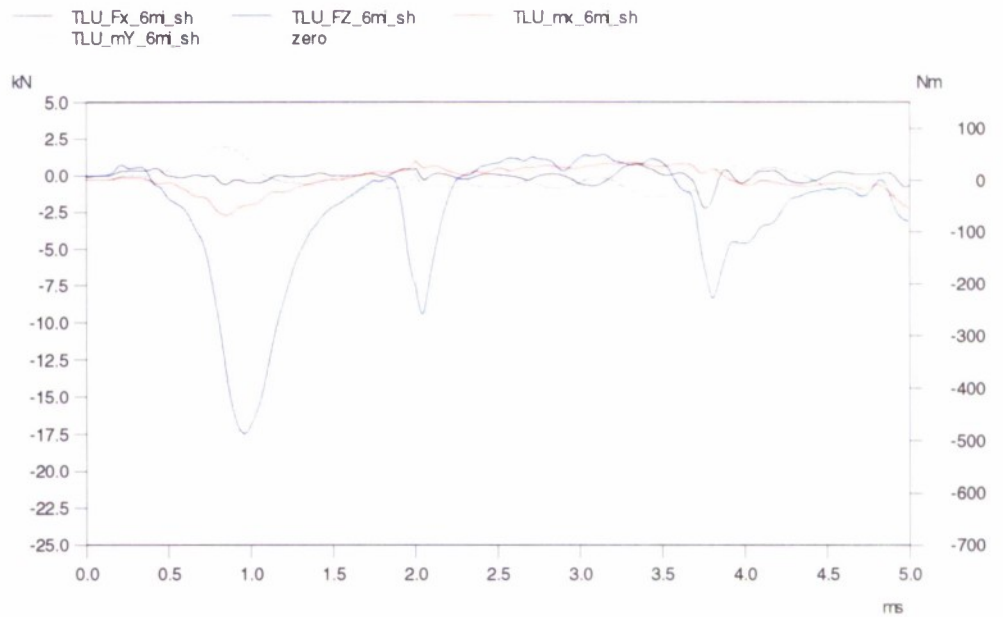



27-11-07
RvdK
10784
_6mi_sh_TLU.drb

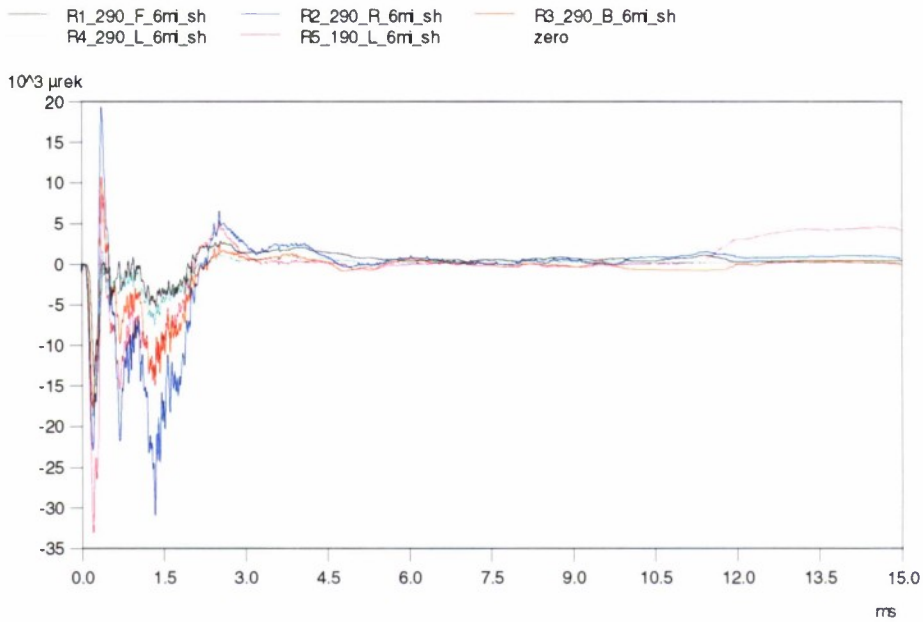
Test\_6, 'Aegis' CLL legg, TNO-LBO ,  
September 2007



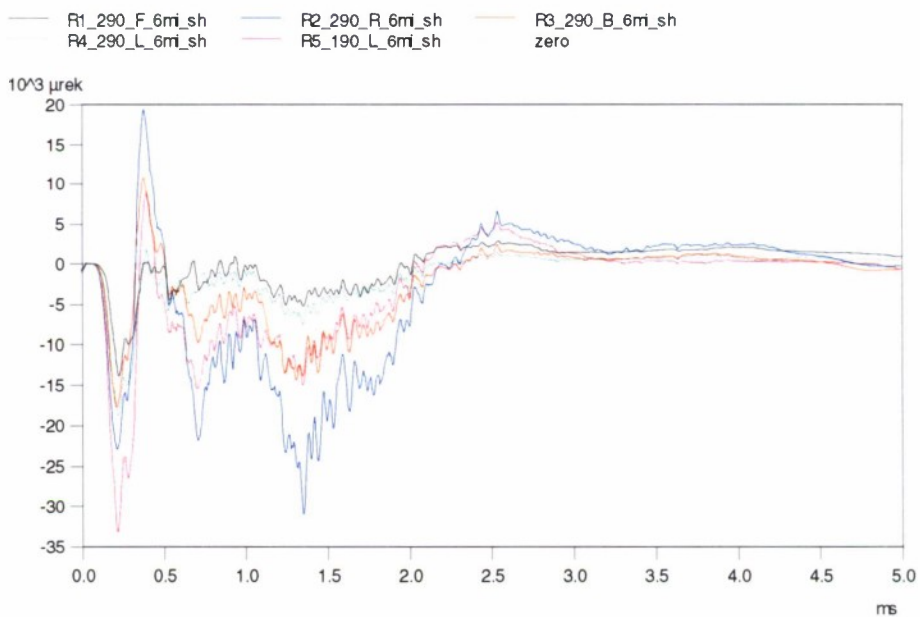
	Max.		at time		Mn.		at time	
<b>TLU_FX</b>	842.16	N	3.3	ms	-2209.11	N	3.8	ms
<b>TLU_FZ</b>	2984.61	N	5.8	ms	-17477.27	N	1.0	ms
<b>TLU_MX</b>	36.41	Nm	2.0	ms	-69.06	Nm	6.6	ms
<b>TLU_MY</b>	64.26	Nm	0.8	ms	-73.20	Nm	9.0	ms



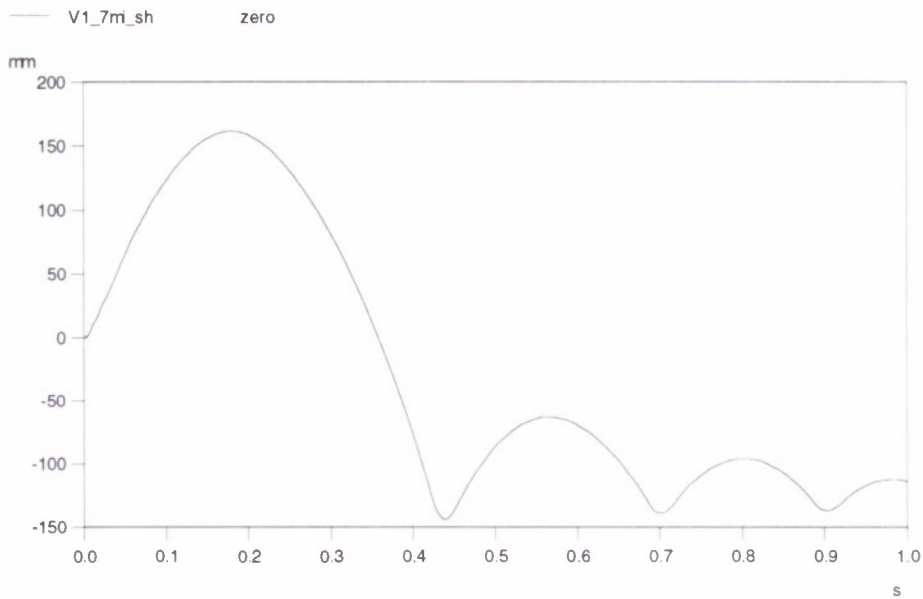
27-11-07	Test_6, 'Aigis' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_6mi_sh_R.dtb		



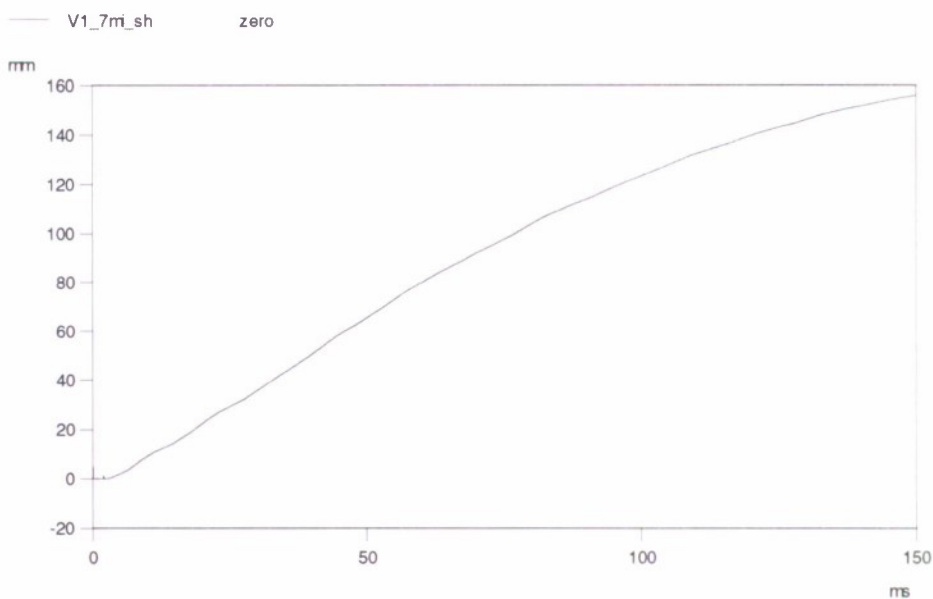
	Max.		at time		Min.		at time	
<i>R1_290_F_6mi_sh</i>	2908.94	µrek	2.5	ms	-13862.27	µrek	0.2	ms
<i>R2_290_R_6mi_sh</i>	19368.46	µrek	0.4	ms	-31015.24	µrek	1.4	ms
<i>R3_290_B_6mi_sh</i>	10716.65	µrek	0.4	ms	-17732.09	µrek	0.2	ms
<i>R4_290_L_6mi_sh</i>	1664.44	µrek	0.4	ms	-18762.38	µrek	0.2	ms
<i>R5_190_L_6mi_sh</i>	8975.04	µrek	0.4	ms	-33197.78	µrek	0.2	ms



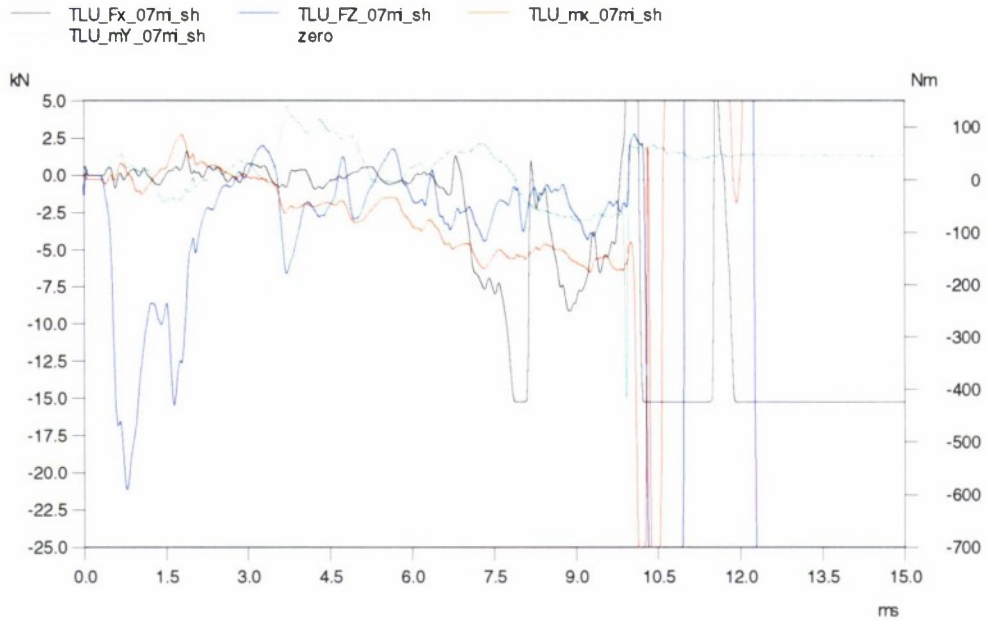
27-11-07	Test_7, 'Zeman' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_7mi_sh.drb		



	Max.		at time		Min.		at time	
<b>V1_7mi_sh</b>	0.162	m	175.58	ms	-0.144	m	438.7	ms



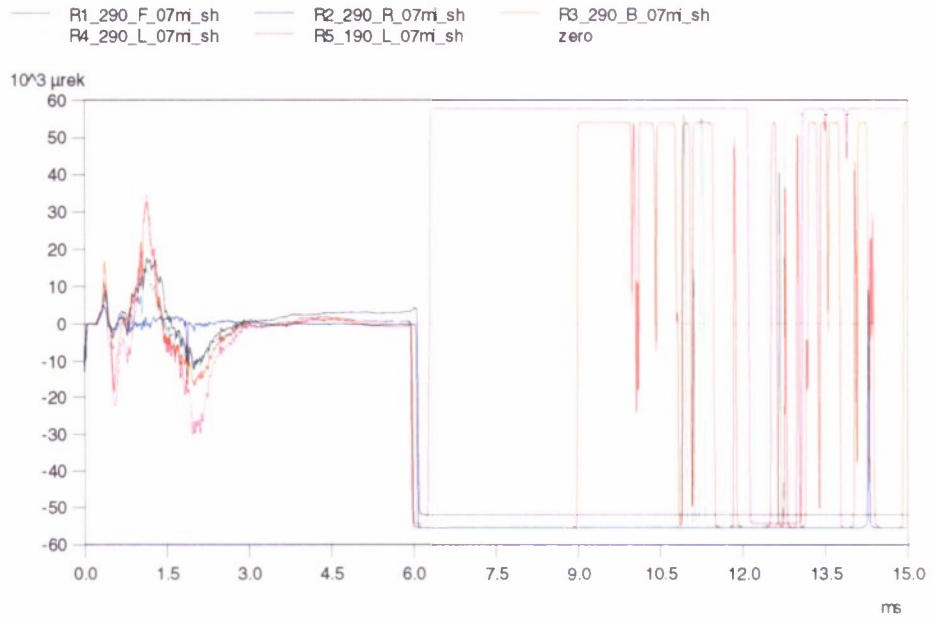
26-11-07	Test_07, 'Zeman' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_07mi_sh_TLU.drb		



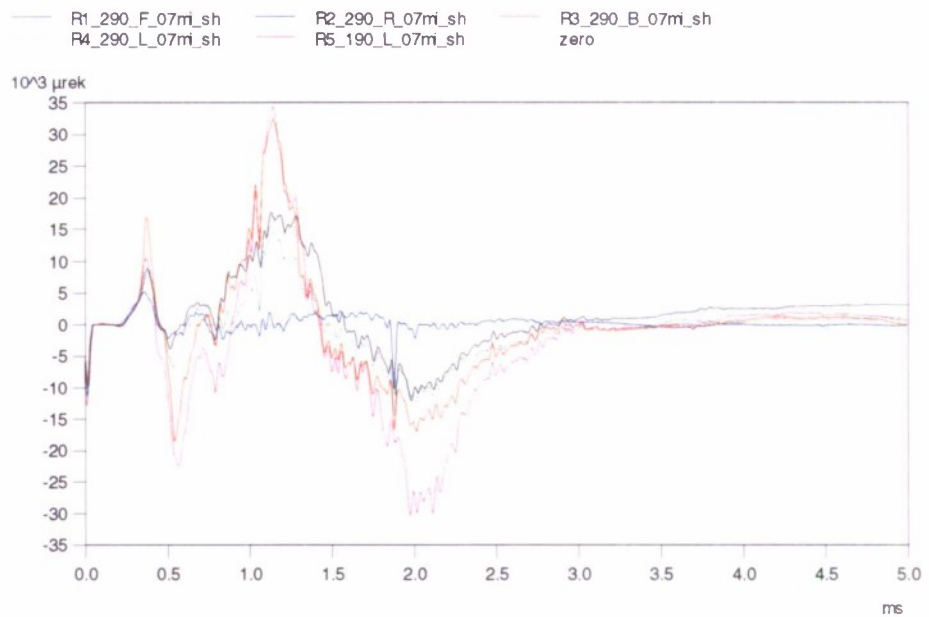
	Max.		at time		Mn.		at time	
<b>TLU_FX</b>	15190.64	N	10.0	ms	-15261.42	N	7.9	ms
<b>TLU_FZ</b>	1998.23	N	3.3	ms	-21150.99	N	0.8	ms
<b>TLU_MX</b>	84.82	Nm	1.8	ms	-177.39	Nm	9.3	ms
<b>TLU_MY</b>	138.75	Nm	3.7	ms	-418.69	Nm	9.9	ms



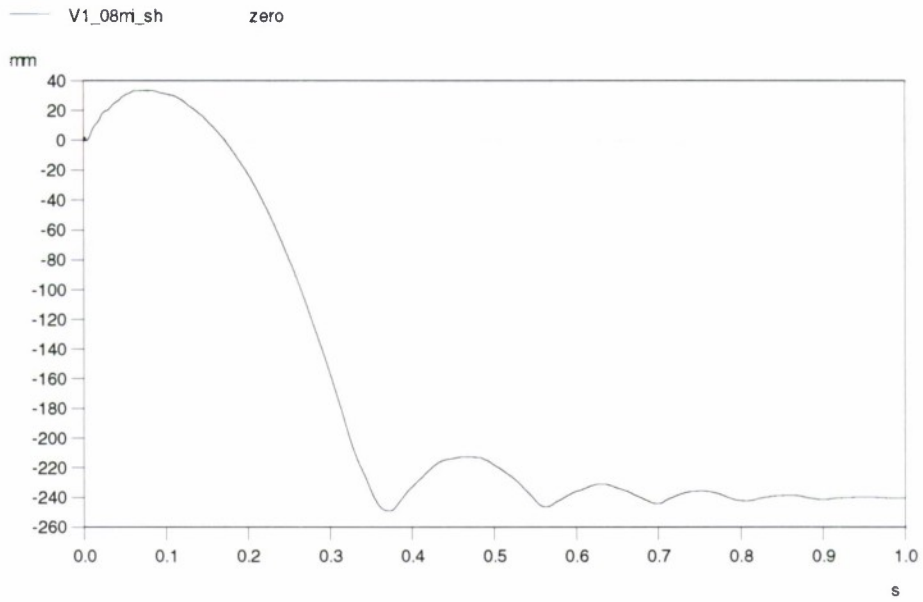
27-11-07	Test_07, 'Zeman' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_07mi_sh_R.drb		



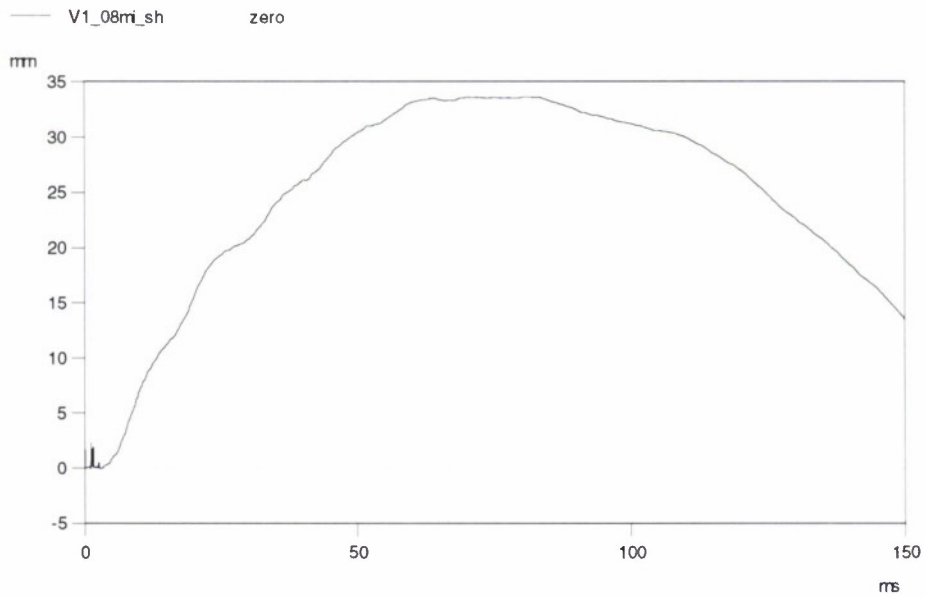
	Max.		at time		Min.		at time	
<i>R1_290_F_07mi_sh</i>	17826.99	µrek	1.1	ms	-12096.35	µrek	2.0	ms
<i>R2_290_R_07mi_sh</i>	5119.72	µrek	0.4	ms	-11236.91	µrek	0.0	ms
<i>R3_290_B_07mi_sh</i>	32523.97	µrek	1.1	ms	-18571.59	µrek	0.5	ms
<i>R4_290_L_07mi_sh</i>	15308.84	µrek	1.1	ms	-14520.57	µrek	1.9	ms
<i>R5_190_L_07mi_sh</i>	34374.38	µrek	1.1	ms	-30394.79	µrek	2.0	ms



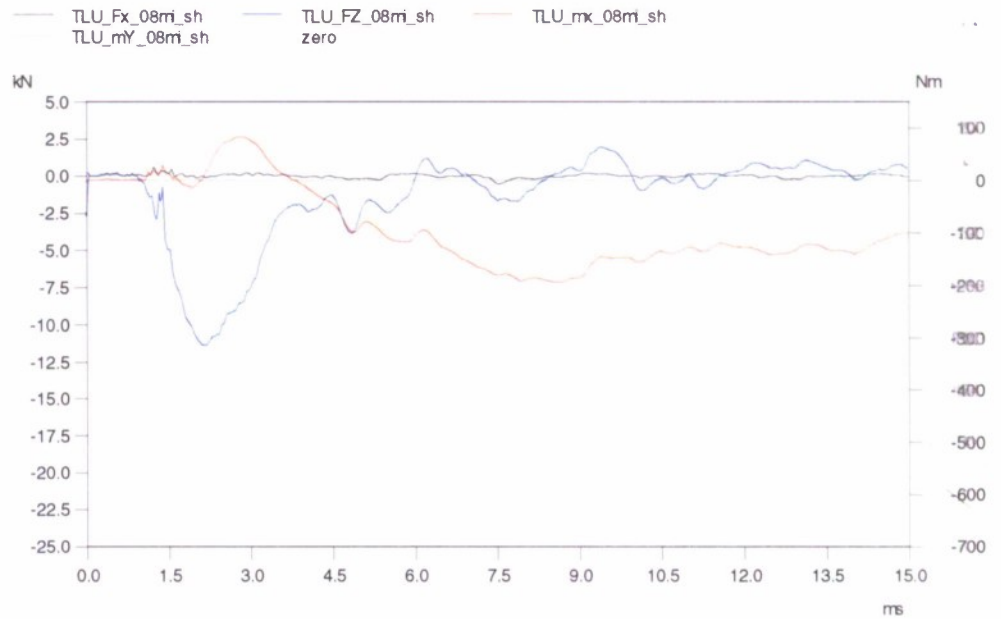
26-11-07	Test_08, 'Spiderboot' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_08mi_sh.drb		



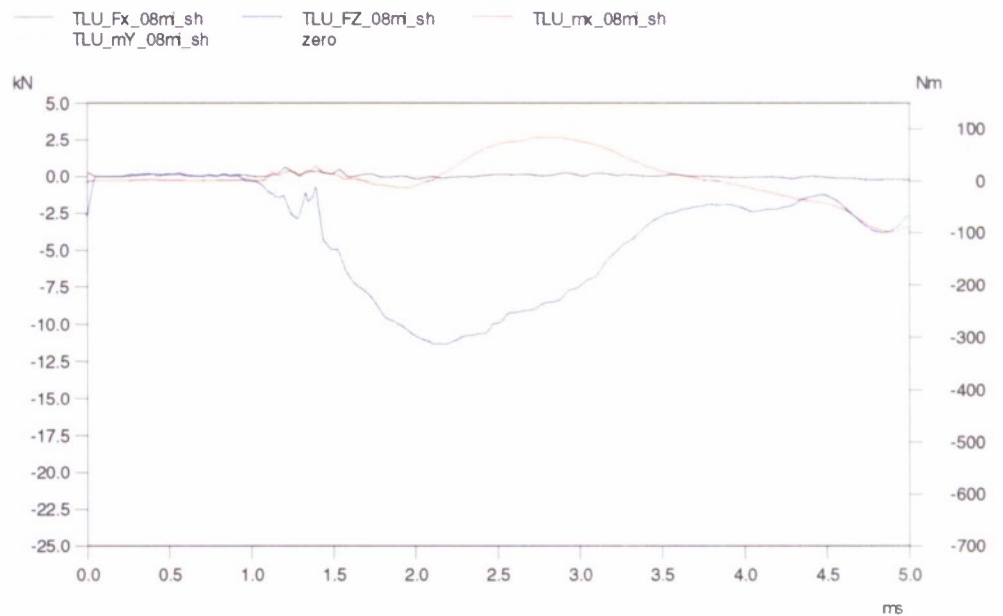
	Max.		at time		Min.		at time	
V1_08mi_sh	0.034	m	80.39	ms	-0.249	m	372.1	ms



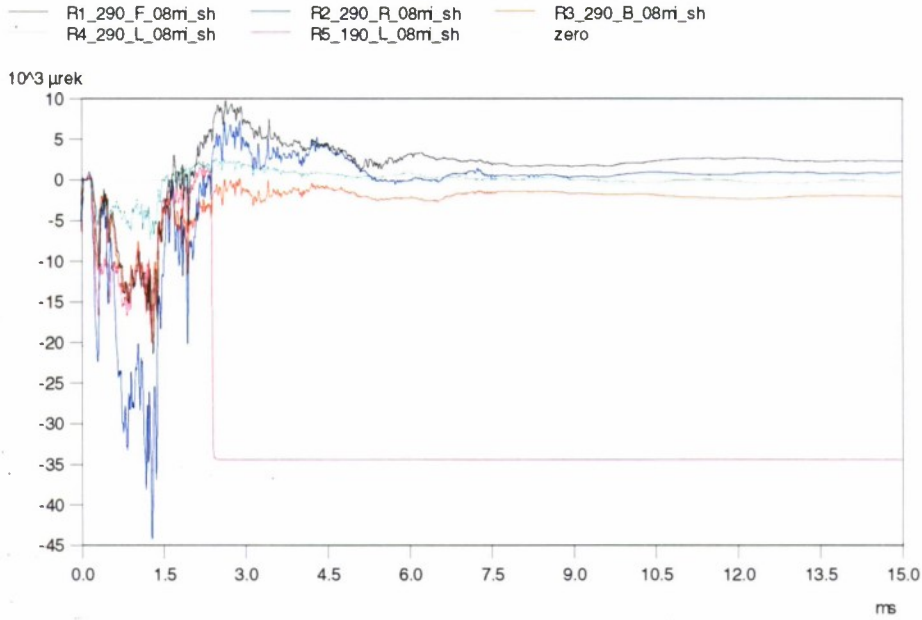
26-11-07	Test_08, 'Spiderboot' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_08mi_sh_TLU.drb		



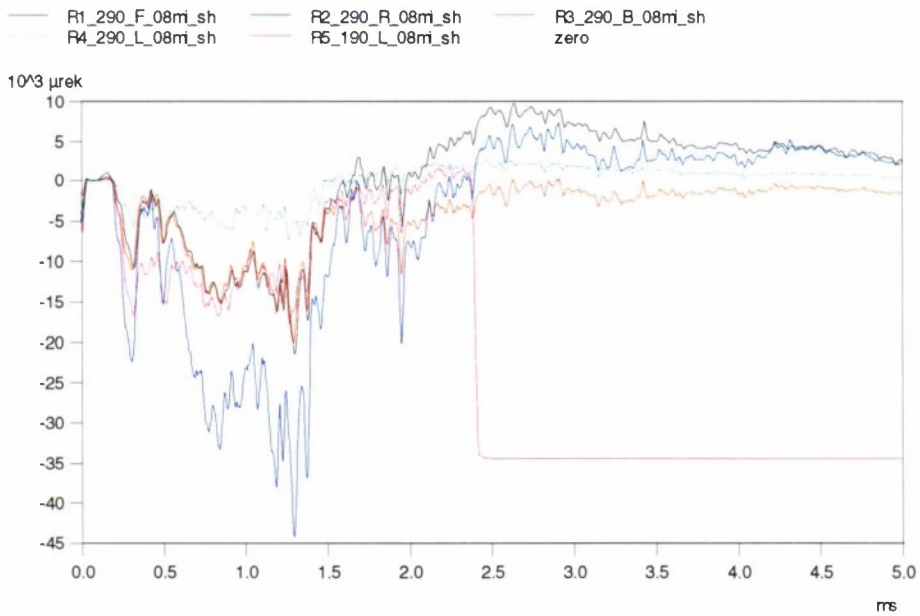
	Max.		at time		Mn.		at time	
<b>TLU_FX</b>	639.46	N	1.2	ms	-511.31	N	7.5	ms
<b>TLU_FZ</b>	1948.63	N	9.4	ms	-11381.37	N	2.2	ms
<b>TLU_MX</b>	83.19	Nm	2.9	ms	-194.79	Nm	8.6	ms
<b>TLU_MY</b>	0.00	Nm	7.1	ms	0.00	Nm	0.0	ms



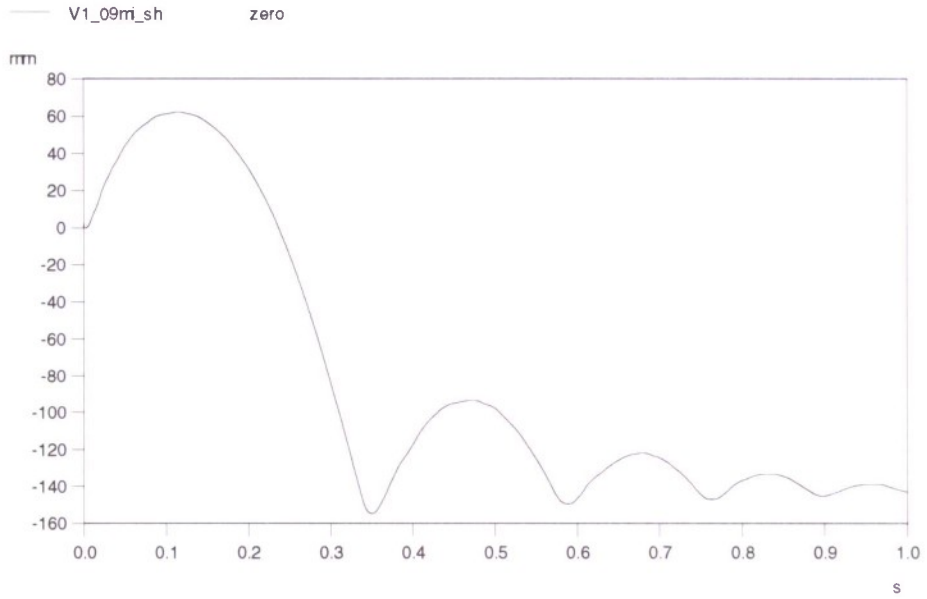
27-11-07	Test_08, 'Spiderboot' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_08mi_sh_R.drb		



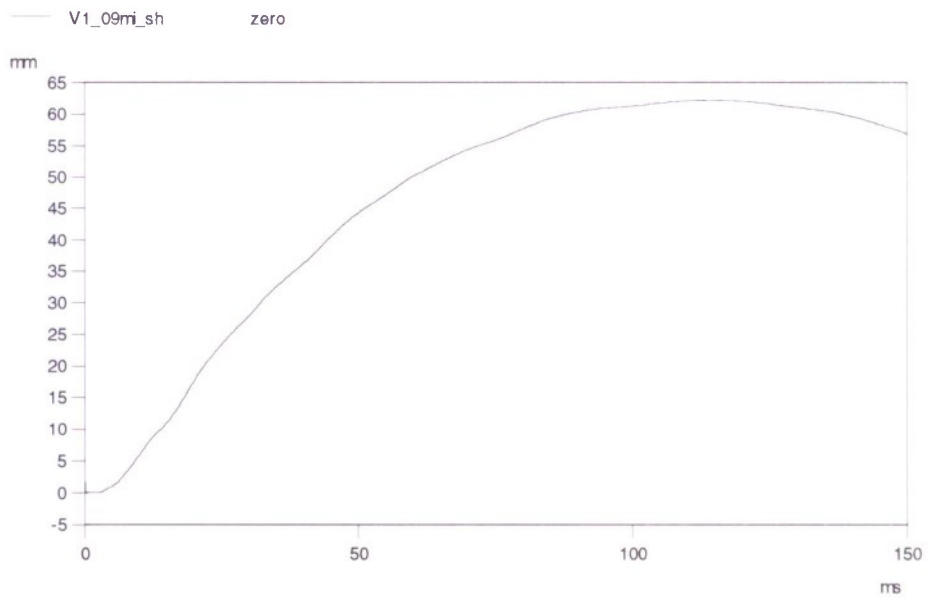
	Max.		at time		Mn.		at time	
<i>R1_290_F_08mi_sh</i>	9770.78	µrek	2.6	ms	-21456.61	µrek	1.3	ms
<i>R2_290_R_08mi_sh</i>	7299.08	µrek	2.9	ms	-44266.14	µrek	1.3	ms
<i>R3_290_B_08mi_sh</i>	490.90	µrek	0.2	ms	-20067.00	µrek	1.3	ms
<i>R4_290_L_08mi_sh</i>	2660.99	µrek	2.5	ms	-7344.83	µrek	1.3	ms
<i>R5_190_L_08mi_sh</i>	1776.26	µrek	2.2	ms	-34443.96	µrek	2.6	ms



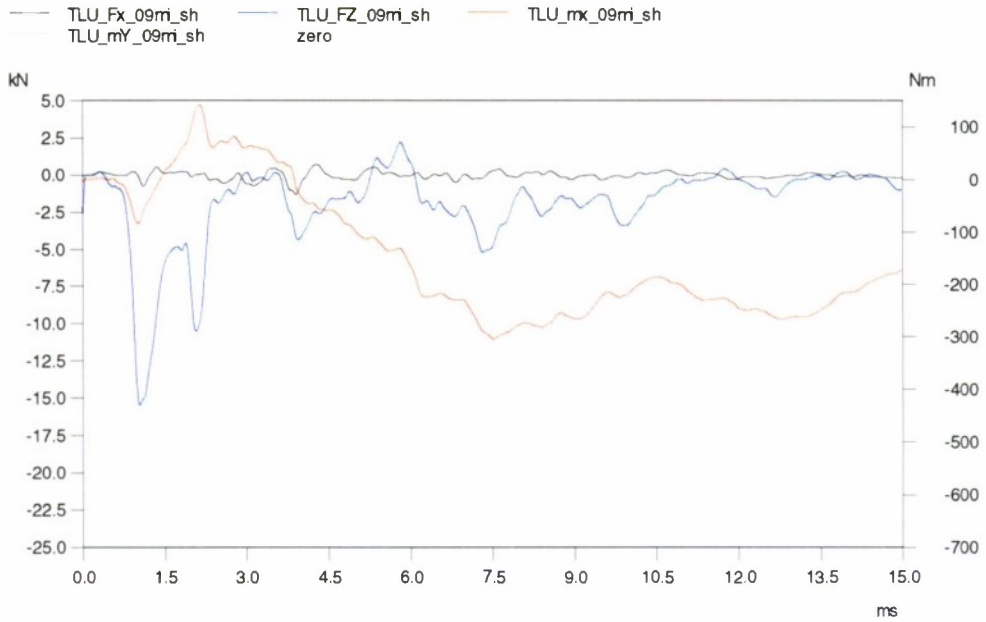
26-11-07	Test_09, 'Aigis' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_09mi_sh.drb		



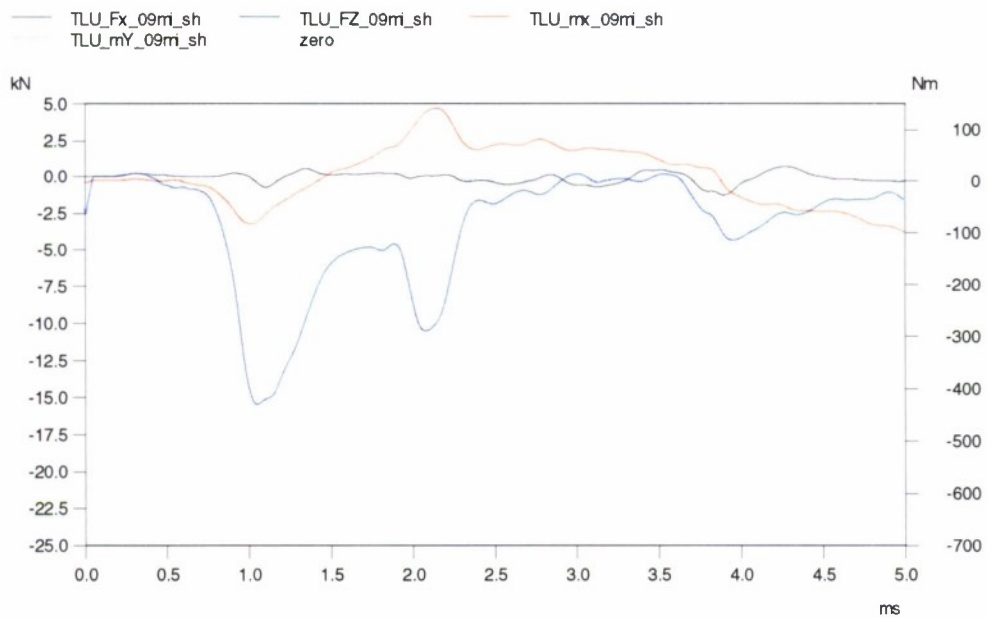
	Max.		at time		Min.		at time	
V1_09mi_sh	0.062	m	111.99	ms	-0.155	m	350.1	ms



26-11-07	Test_09, 'Aigis' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_09mi_sh_TLU.drb		



	Max.		at time		Mn.		at time	
<b>TLU_FX</b>	736.58	N	4.3	ms	-1293.08	N	3.9	ms
<b>TLU_FZ</b>	2200.93	N	5.8	ms	-15464.70	N	1.1	ms
<b>TLU_MX</b>	140.78	Nm	2.2	ms	-305.80	Nm	7.5	ms
<b>TLU_MY</b>	0.00	Nm		ms		Nm		ms

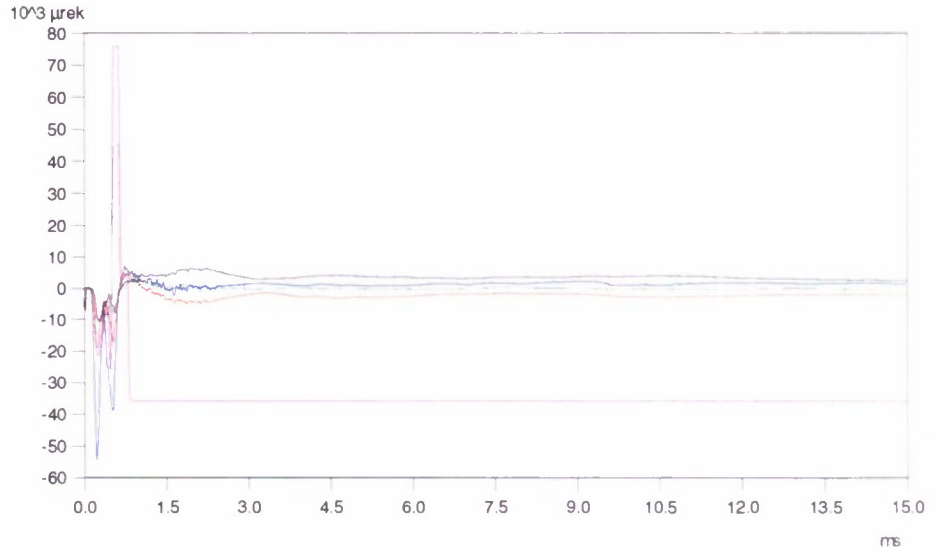


27-11-07
RvdK
10784
_09mi_sh_R.drb

Test\_09, 'Aigis' CLL legg, TNO-LBO ,  
September 2007

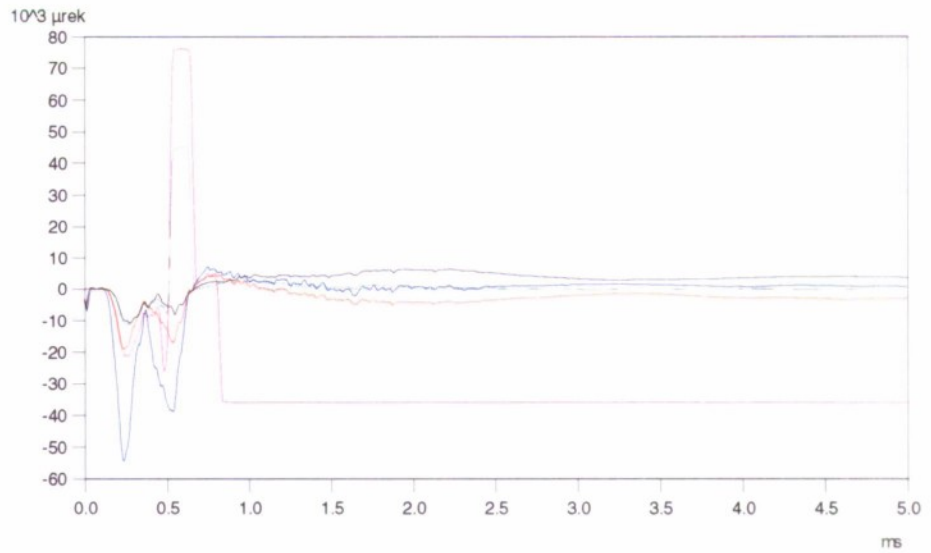



— R1\_290\_F\_09mi\_sh — R2\_290\_R\_09mi\_sh — R3\_290\_B\_09mi\_sh  
 R4\_290\_L\_09mi\_sh — R5\_190\_L\_09mi\_sh zero

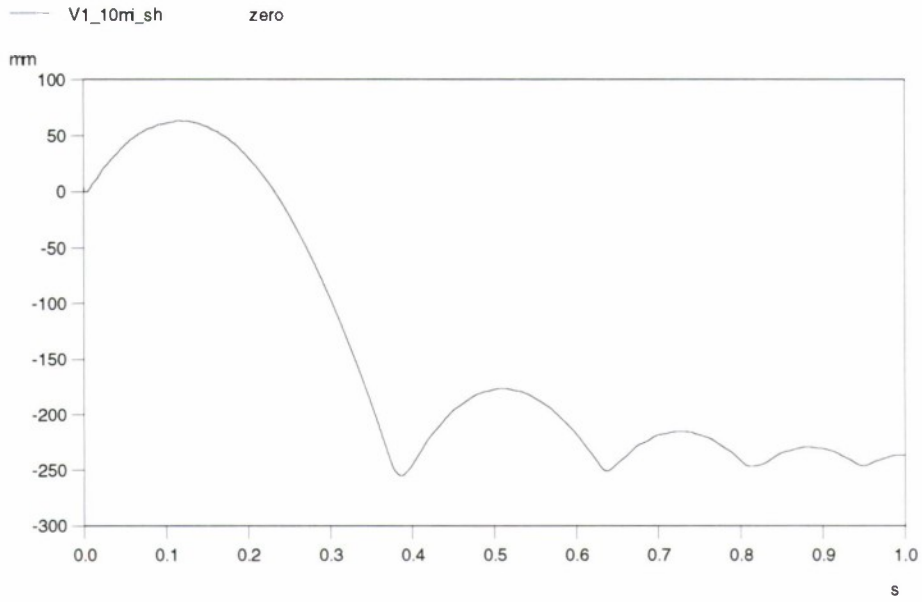


	Max.		at time		Mn.		at time	
R1_290_F_09mi_sh	6515.66	µrek	2.2	ms	-10789.67	µrek	0.3	ms
R2_290_R_09mi_sh	7180.49	µrek	0.8	ms	-54456.73	µrek	0.2	ms
R3_290_B_09mi_sh	4796.43	µrek	0.8	ms	-19198.50	µrek	0.2	ms
R4_290_L_09mi_sh	45134.26	µrek	0.6	ms	-11206.79	µrek	0.3	ms
R5_190_L_09mi_sh	76102.57	µrek	0.6	ms	-35978.82	µrek	1.0	ms

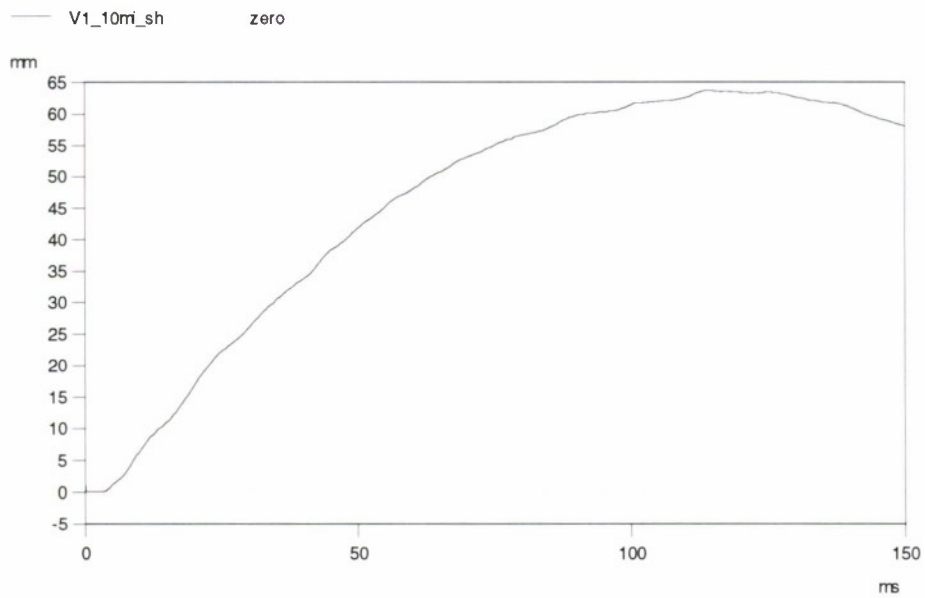
— R1\_290\_F\_09mi\_sh — R2\_290\_R\_09mi\_sh — R3\_290\_B\_09mi\_sh  
 R4\_290\_L\_09mi\_sh — R5\_190\_L\_09mi\_sh zero




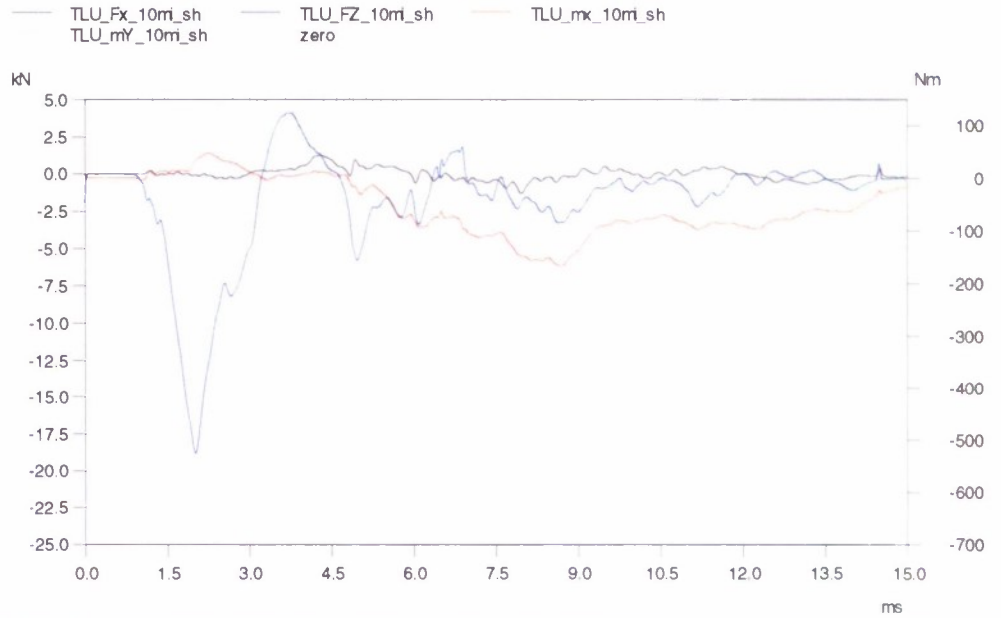
26-11-07	Test_10, 'rubberblock boot' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_10mi_sh.drb		



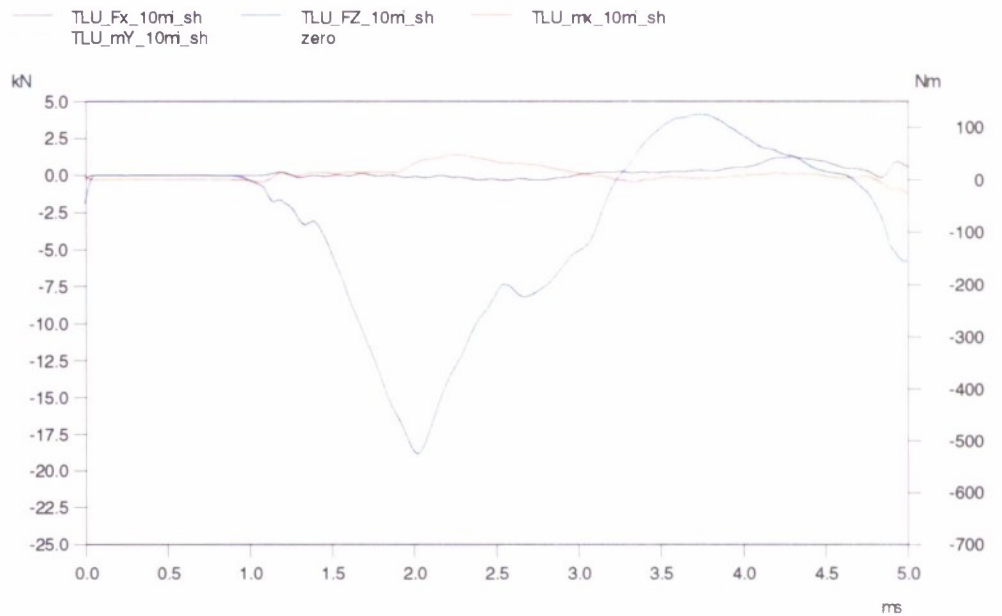
	Max.		at time		Min.		at time	
<b>V1_10mi_sh</b>	0.064	m	114.17	ms	-0.255	m	386.5	ms




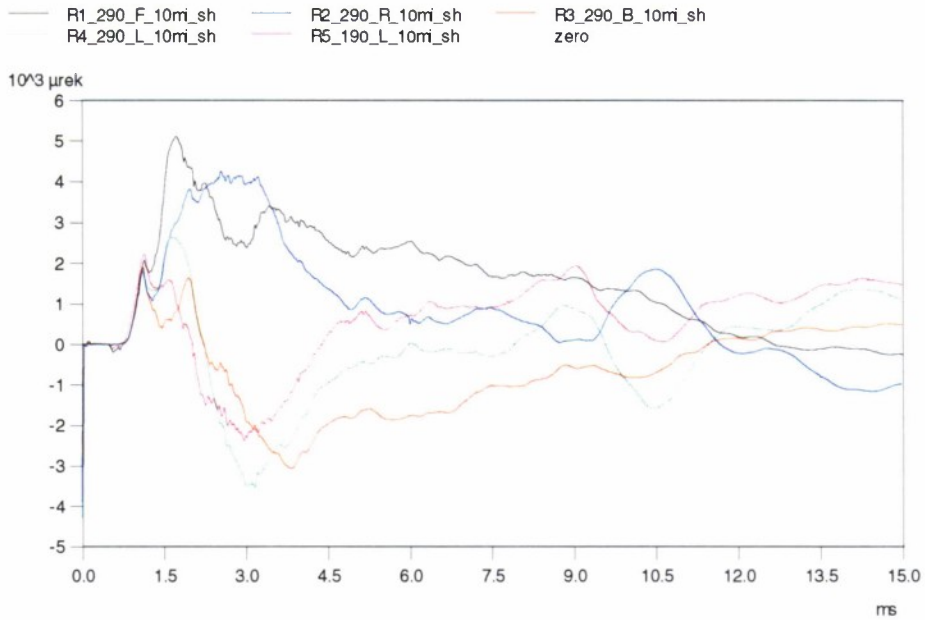
26-11-07	Test_10, 'rubberblock boot' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_10mi_sh_TLU.drb		



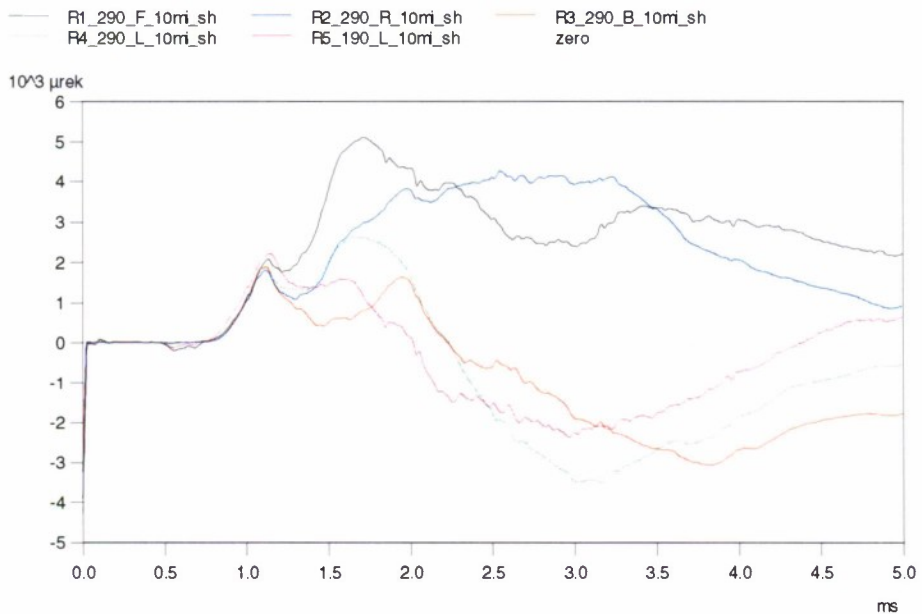
	Max.		at time		Mn.		at time	
<b>TLU_FX</b>	1272.37	N	4.3	ms	-1313.96	N	8.0	ms
<b>TLU_FZ</b>	4134.11	N	3.7	ms	-18852.02	N	2.0	ms
<b>TLU_MX</b>	47.65	Nm	2.3	ms	-167.39	Nm	8.7	ms
<b>TLU_MY</b>	0.00	Nm		ms	0.00	Nm		ms




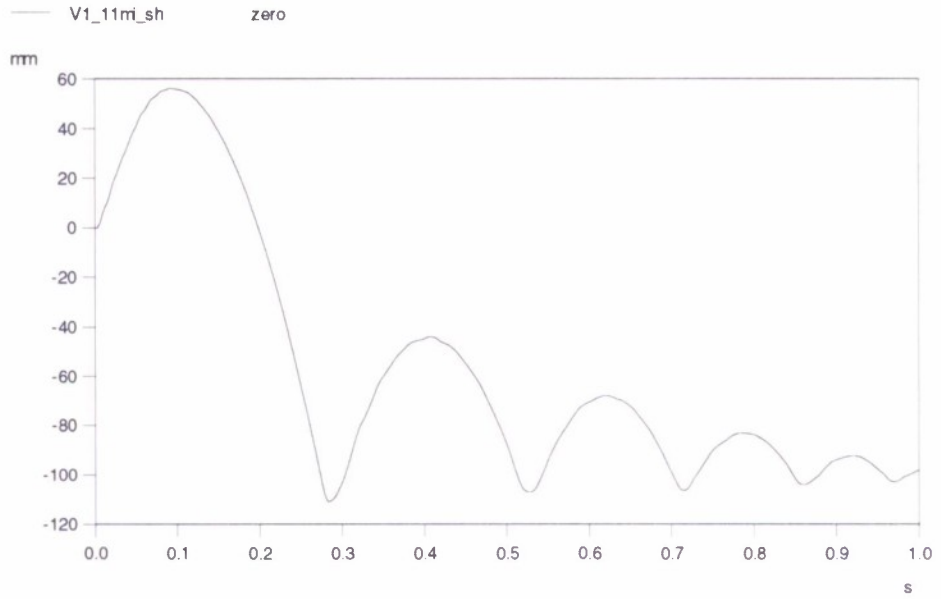
27-11-07	Test_10, 'rubberblock boot' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_10mi_sh_R.drb		



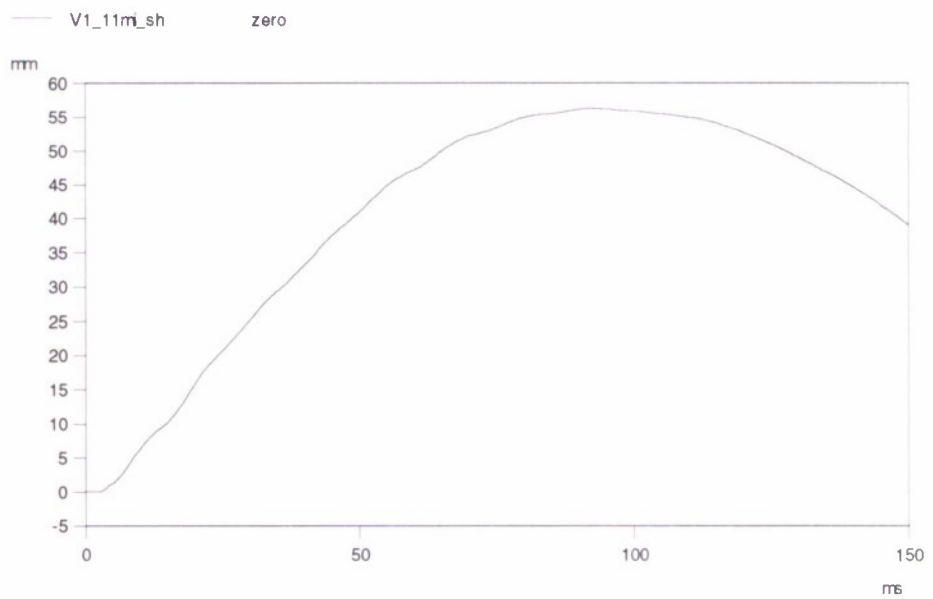
	Max.		at time		Min.		at time	
<i>R1_290_F_10mi_sh</i>	5122.38	µrek	1.7	ms	-2986.73	µrek	-0.0	ms
<i>R2_290_R_10mi_sh</i>	4256.09	µrek	2.6	ms	-3910.16	µrek	-0.0	ms
<i>R3_290_B_10mi_sh</i>	1872.06	µrek	1.1	ms	-3251.06	µrek	-0.0	ms
<i>R4_290_L_10mi_sh</i>	2641.37	µrek	1.7	ms	-4286.91	µrek	0.0	ms
<i>R5_190_L_10mi_sh</i>	2207.93	µrek	1.2	ms	-3236.07	µrek	-0.0	ms



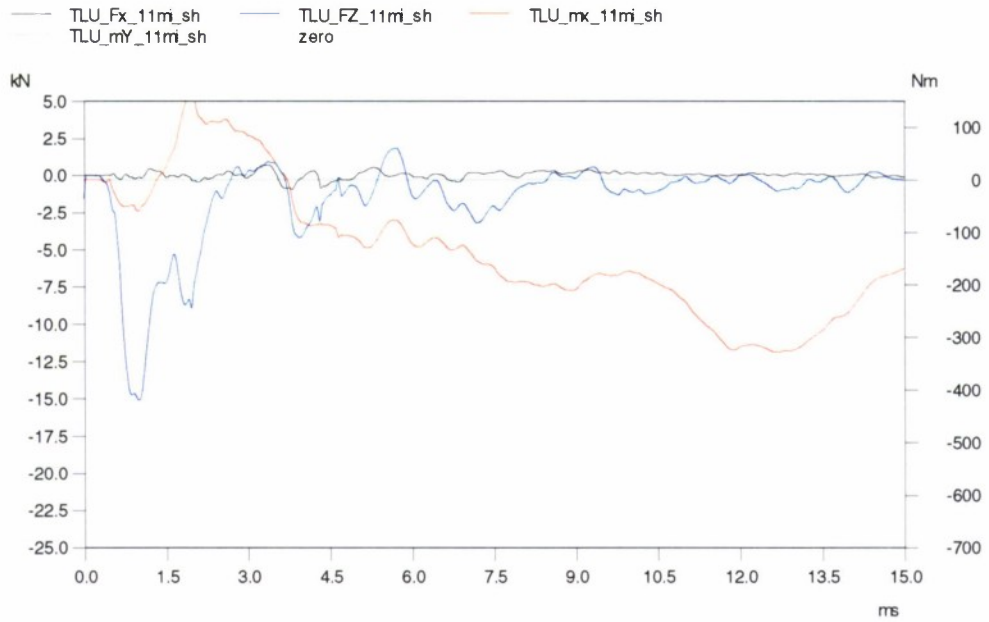
26-11-07	Test_11, 'Forceware' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_11mi_sh.drb		



	Max.		at time		Mn.		at time	
<b>V1_11mi_sh</b>	0.056	m	92.42	ms	-0.111	m	284.0	ms



26-11-07	Test_11, 'Foreware' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_11mi_sb_TLU.drb		

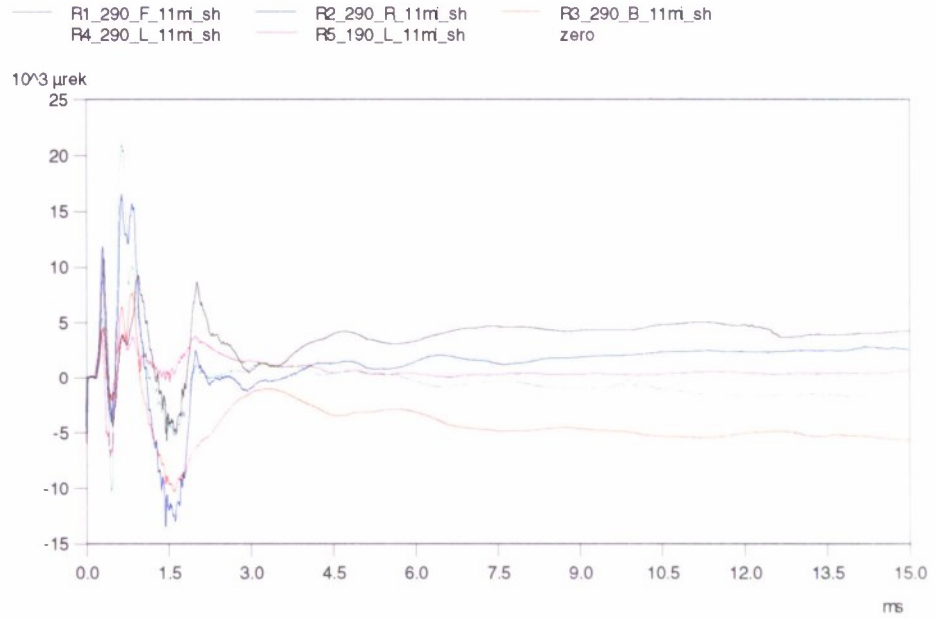


	Max.		at time		Min.		at time	
<b>TLU_FX</b>	734.33	N	3.4	ms	-917.45	N	3.8	ms
<b>TLU_FZ</b>	1860.25	N	5.7	ms	-15117.80	N	1.0	ms
<b>TLU_MX</b>	187.10	Nm	2.0	ms	-211.29	Nm	9.0	ms
<b>TLU_MY</b>	0.00	Nm	-0.0	ms	0.00	Nm	-0.0	ms

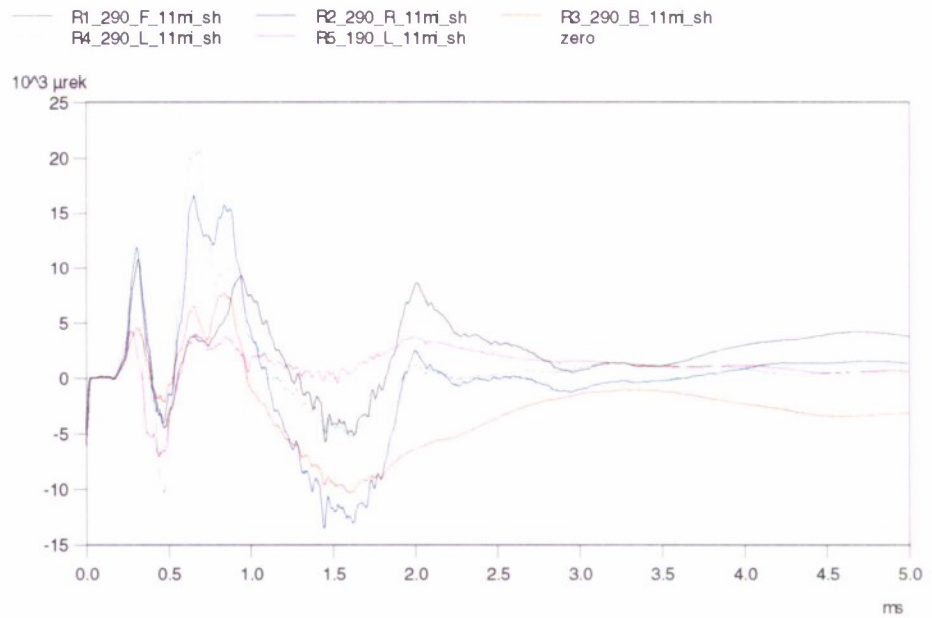


27-11-07
RvdK
10784
_11mi_sh_R.drb

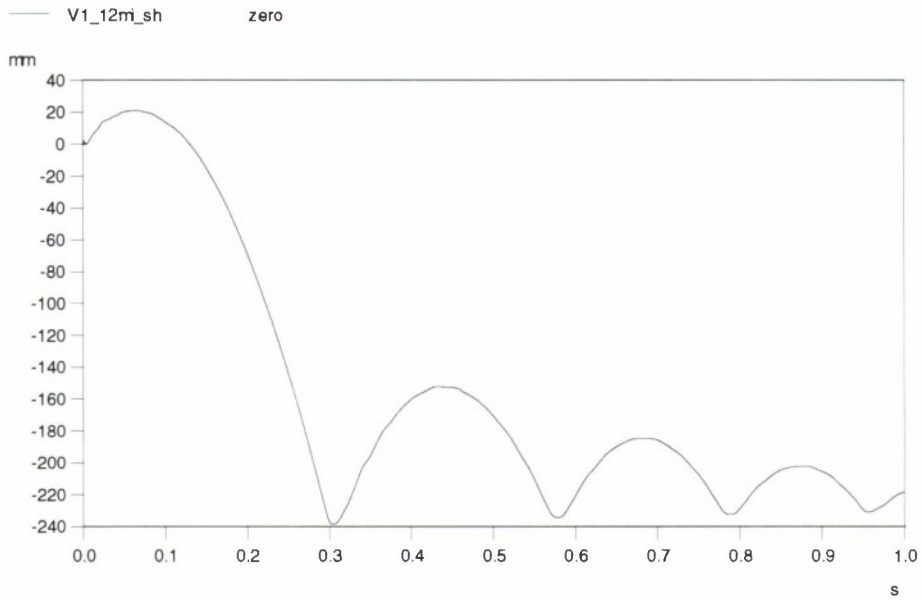
Test\_11, 'Foreware' CLL legg, TNO-LBO, September 2007



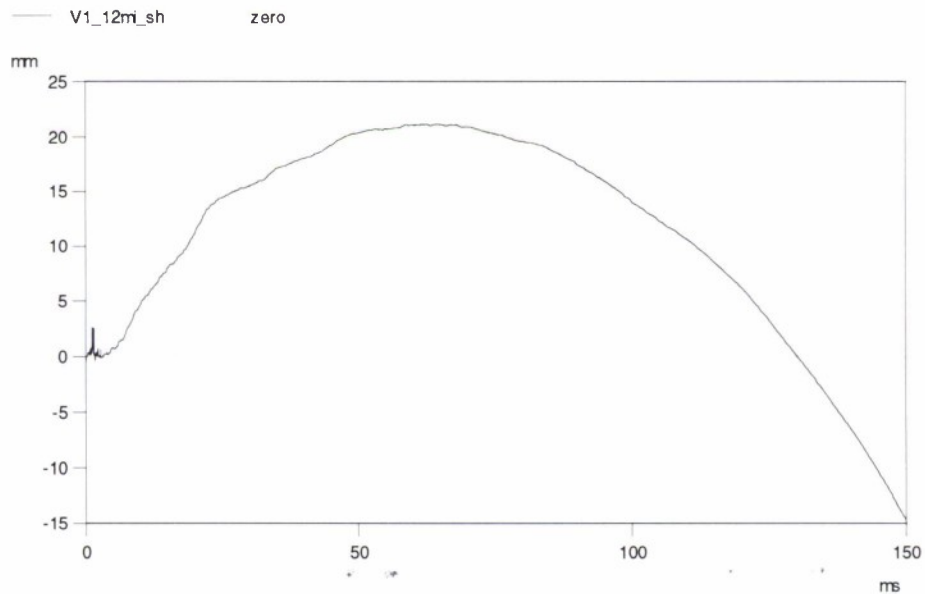
	Max.		at time		Min.		at time	
<i>R1_290_F_11mi_sh</i>	10797.13	µrek	0.3	ms	-5748.63	µrek	1.5	ms
<i>R2_290_R_11mi_sh</i>	16569.79	µrek	0.7	ms	-13504.10	µrek	1.5	ms
<i>R3_290_B_11mi_sh</i>	7621.99	µrek	0.8	ms	-10393.34	µrek	1.6	ms
<i>R4_290_L_11mi_sh</i>	20984.81	µrek	0.7	ms	-10354.25	µrek	0.5	ms
<i>R5_190_L_11mi_sh</i>	4203.43	µrek	0.3	ms	-7135.61	µrek	0.4	ms



26-11-07	Test_12, 'Sipderboot' FSL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_12mi_sh.drb		

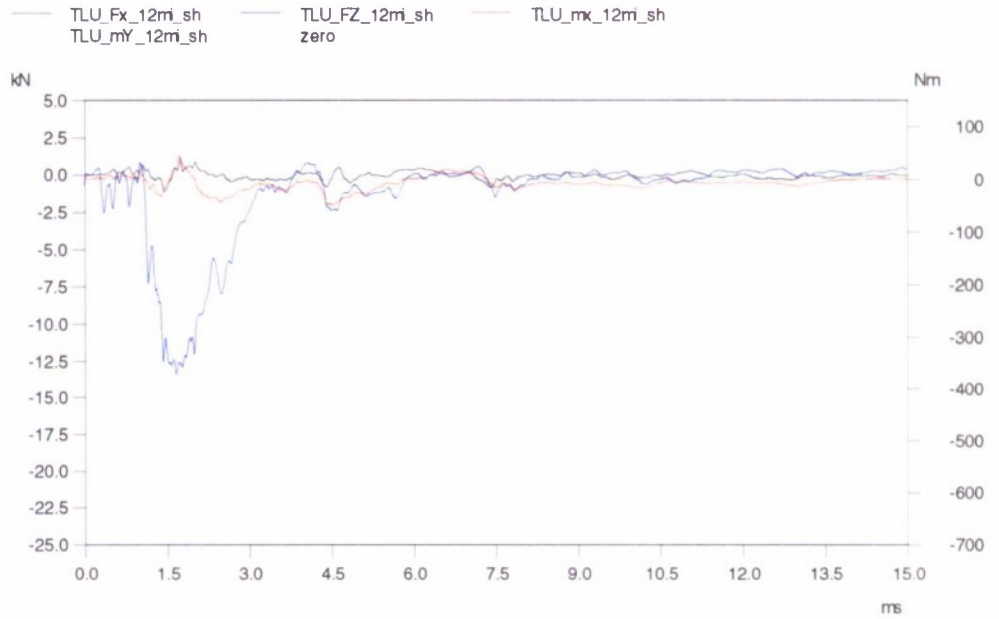


	Max.		at time		Min.		at time	
V1_12mi_sh	0.021	m	64.40	ms	-0.239	m	303.9	ms



26-11-07
RvdK
10784
_12mi_sh_TLU.drb

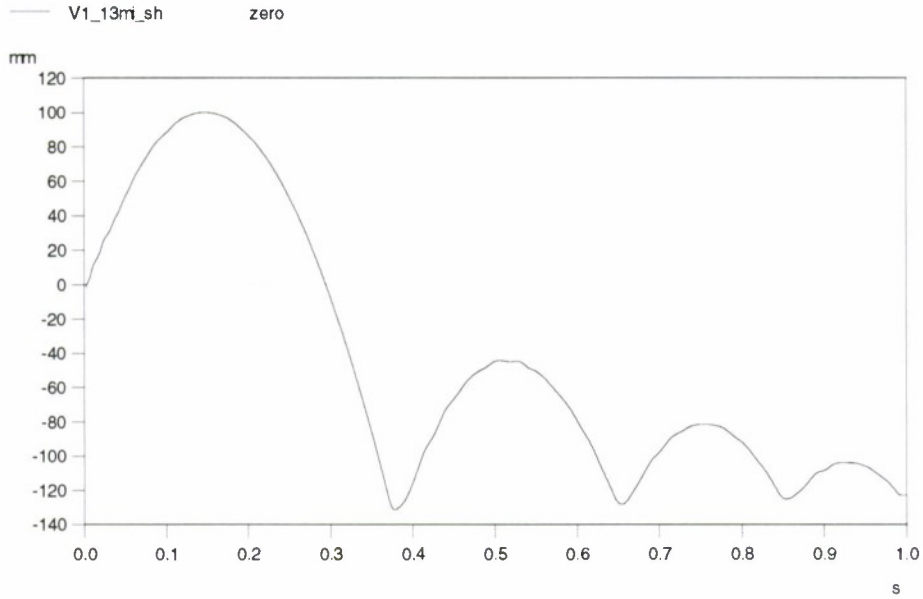
Test\_12, 'Sipderboot' FSL legg, TNO-LBO, September 2007



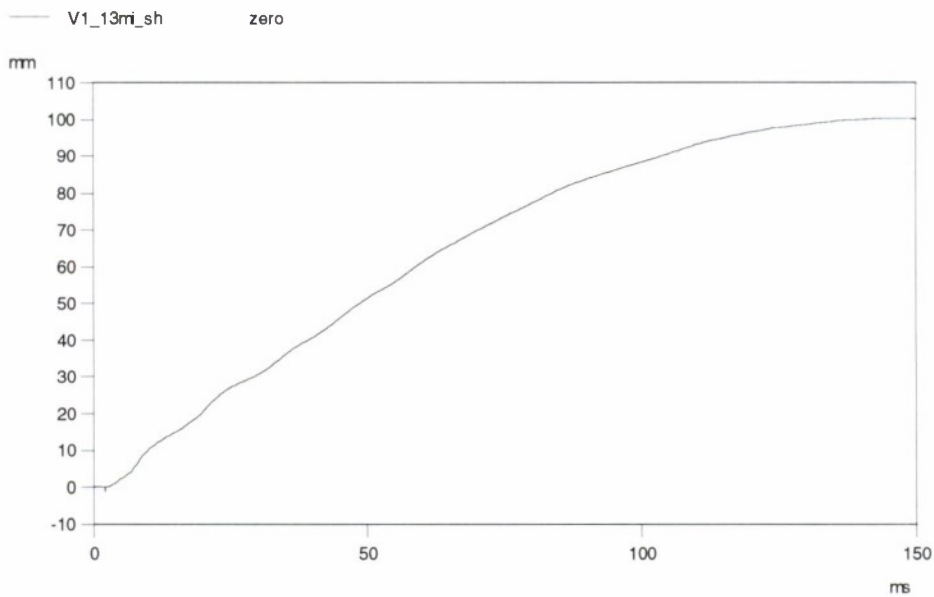
	Max.		at time		Mn.		at time	
<b>TLU_FX</b>	1167.58	N	1.7	ms	-1105.52	N	1.4	ms
<b>TLU_FZ</b>	833.73	N	1.0	ms	-13420.34	N	1.7	ms
<b>TLU_MX</b>	44.43	Nm	1.7	ms	-49.22	Nm	4.5	ms
<b>TLU_MY</b>	0.00	Nm	-0.0	ms	0.00	Nm	-0.0	ms



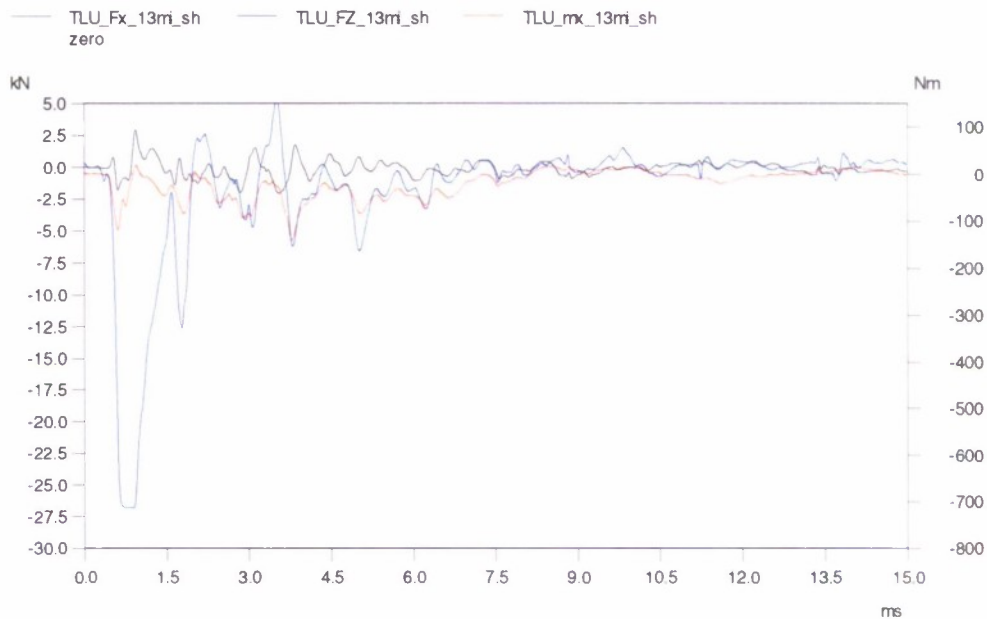
26-11-07	Test_13, 'Zeman' FSL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_13mi_sh.drb		



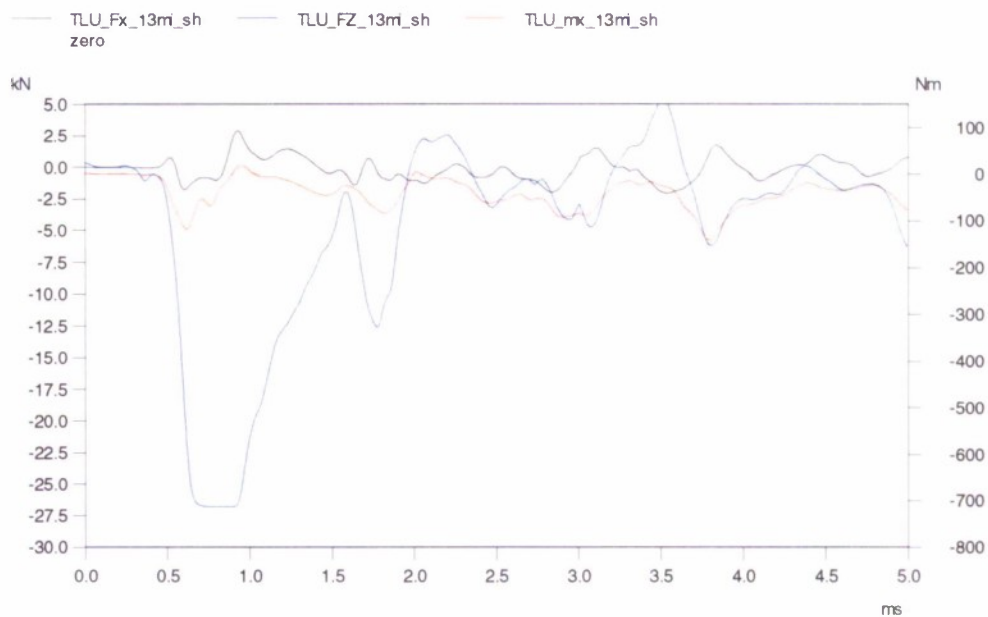
	Max.		at time		Min.		at time	
V1_13mi_sh	0.100	m	148.10	ms	-0.131	m	377.5	ms



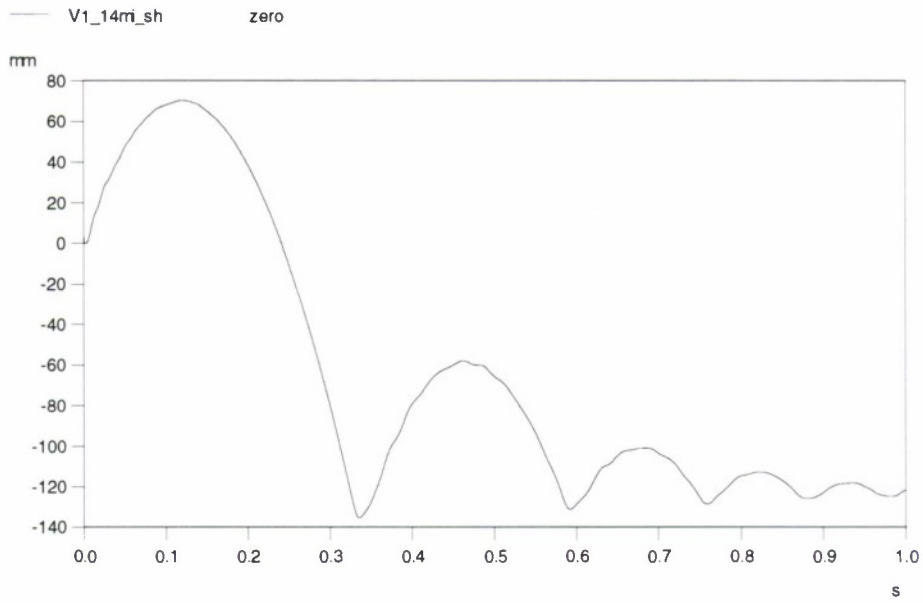
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td style="padding: 2px;">26-11-07</td></tr> <tr><td style="padding: 2px;">RvdK</td></tr> <tr><td style="padding: 2px;">10784</td></tr> <tr><td style="padding: 2px;">_13mi_sh_TLU.drb</td></tr> </table>	26-11-07	RvdK	10784	_13mi_sh_TLU.drb	<h3>Test_13, 'Zeman' FSL legg, TNO-LBO , September 2007</h3>	
26-11-07						
RvdK						
10784						
_13mi_sh_TLU.drb						



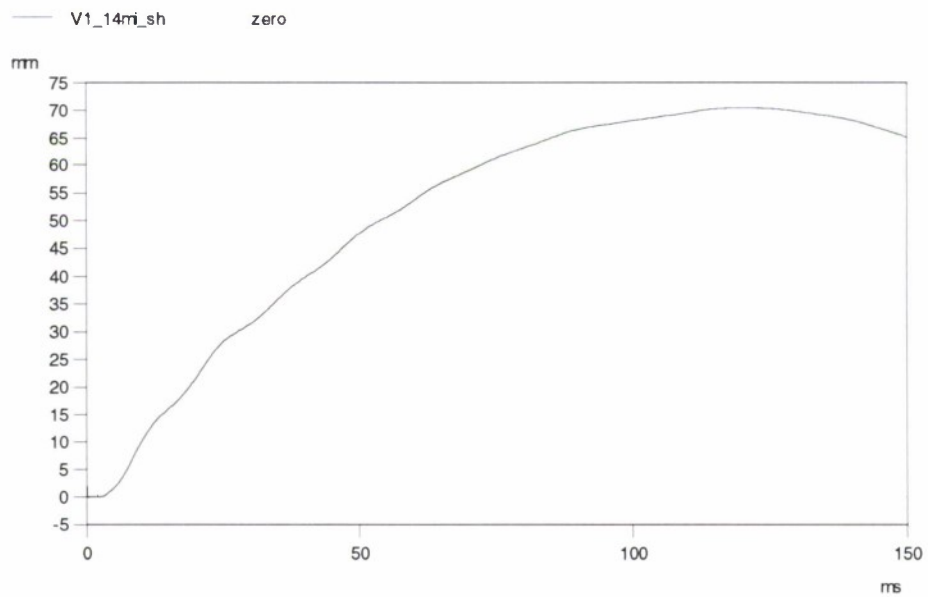
	Max.		at time		Min.		at time	
<b>TLU_FX</b>	2913.44	N	0.9	ms	-2046.47	N	3.5	ms
<b>TLU_FZ</b>	5448.59	N	3.5	ms	-26818.08	N	0.9	ms
<b>TLU_MX</b>	17.81	Nm	1.0	ms	-142.77	Nm	3.8	ms
		Nm		ms		Nm		ms



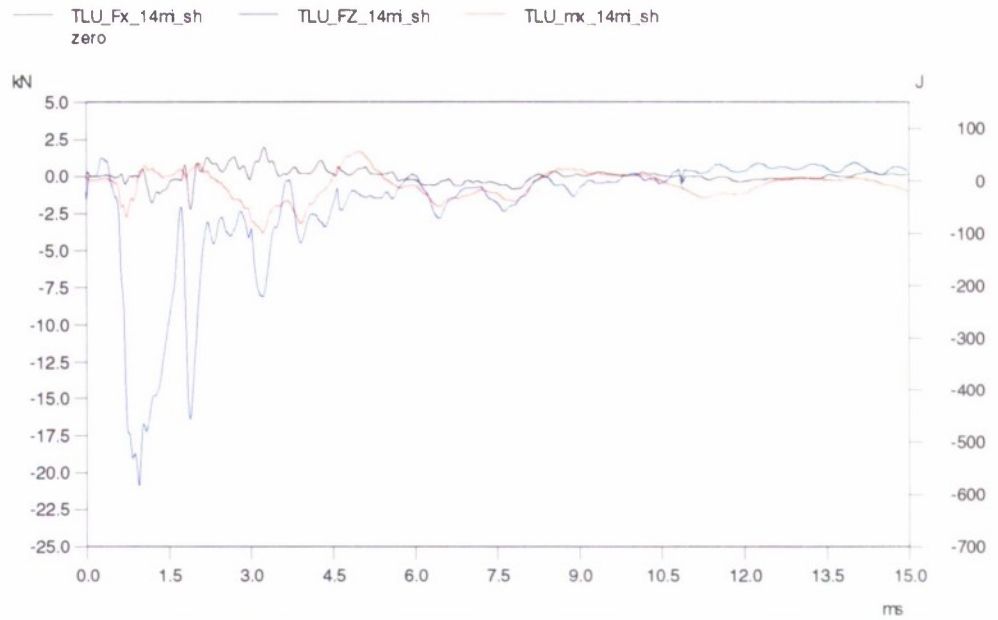
27-11-07	Test_14, 'Aigis', FSL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_14mi_sh.drb		



	Max.		at time		Min.		at time	
V1_14mi_sh	0.070	m	118.95	ms	-0.135	m	335.1	ms




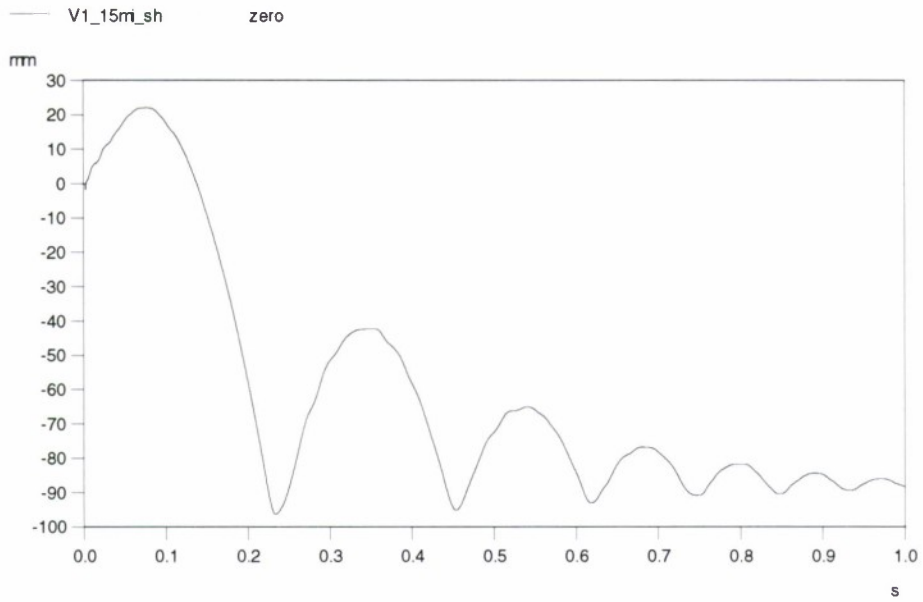
27-11-07	Test_14, 'Aegis', FSL legg, TNO-LBO , September 2007	
RvdK		
10784		
_14mi_sh_TLU.drb		



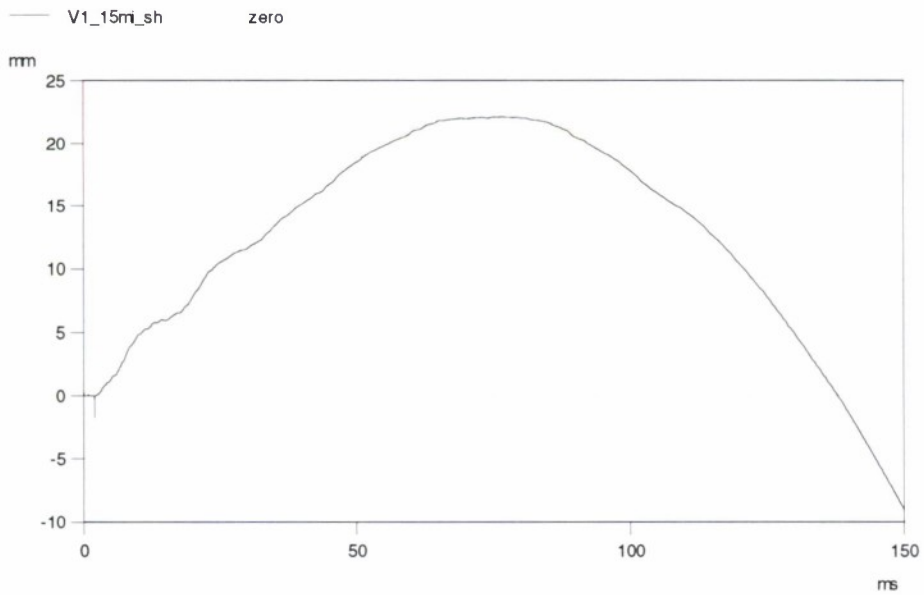
	Max.		at time		Mn.		at time	
<b>TLU_FX</b>	1961.78	N	3.2	ms	-2205.99	N	1.9	ms
<b>TLU_FZ</b>	1238.56	N	0.3	ms	-20902.93	N	1.0	ms
<b>TLU_MX</b>	54.84	Nm	5.0	ms	-99.31	Nm	3.2	ms
		Nm		ms		Nm		ms




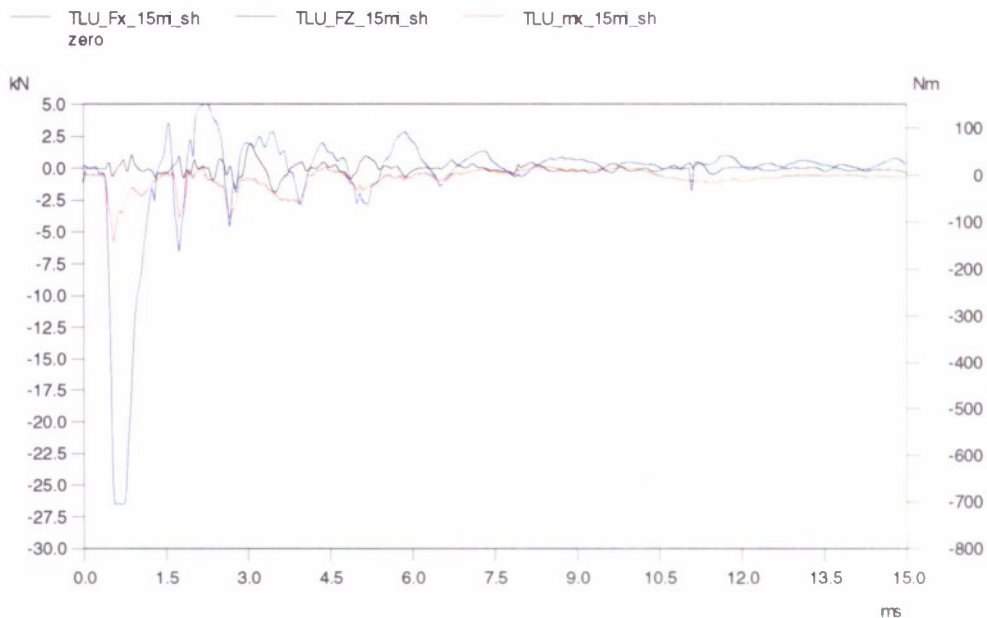
26-11-07	Test_15, 'Dutch army boot' FSL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_15mi_sh.drb		



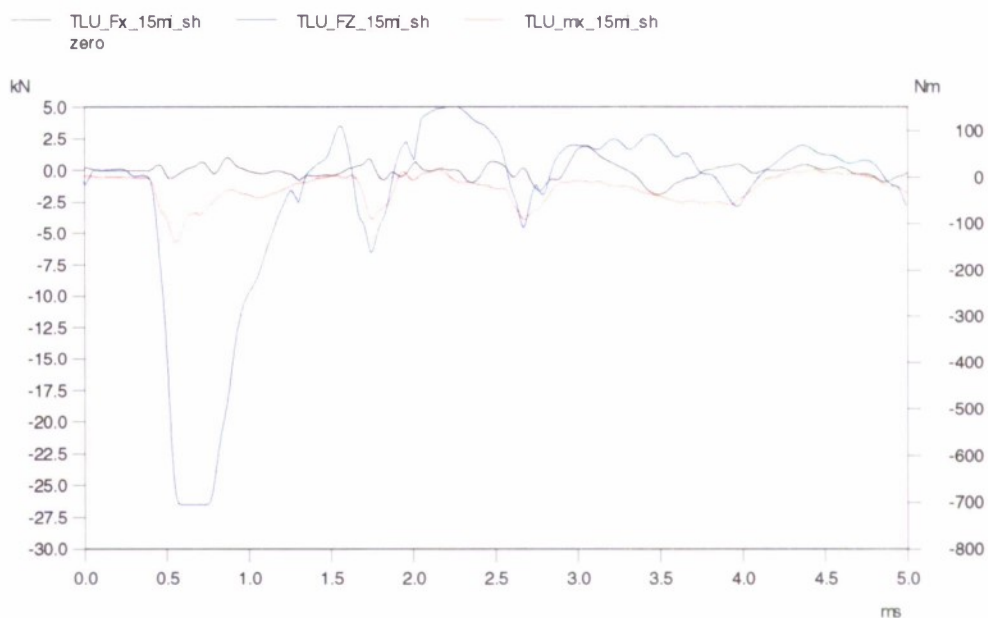
	Max.		at time		Min.		at time	
<b>V1_15mi_sh</b>	0.022	m	76.69	ms	-0.096	m	234.0	ms




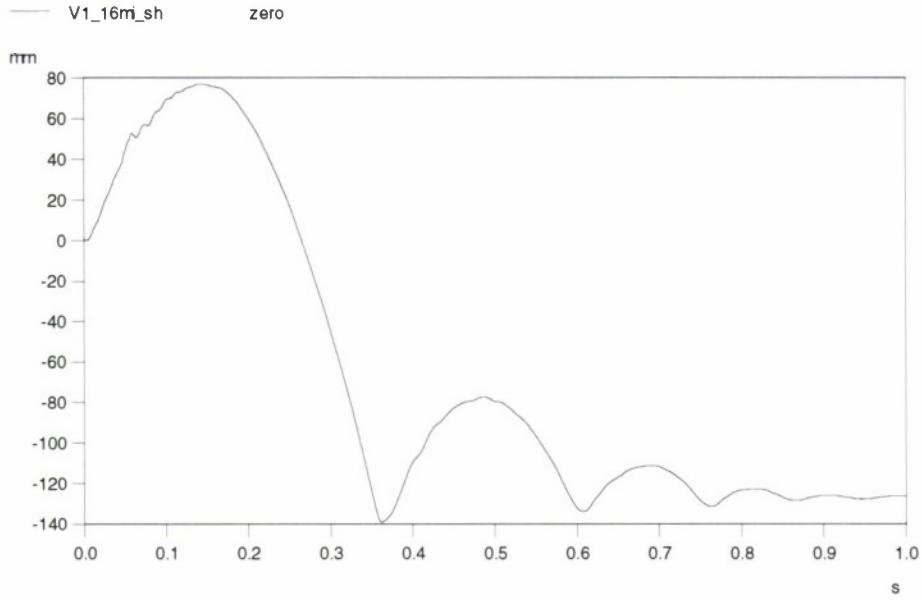
26-11-07 RvdK 10784 _15mi_sb_TLU.drb	<b>Test_15, 'Dutch army boot' FSL legg,                  TNO-LBO, September 2007</b>	
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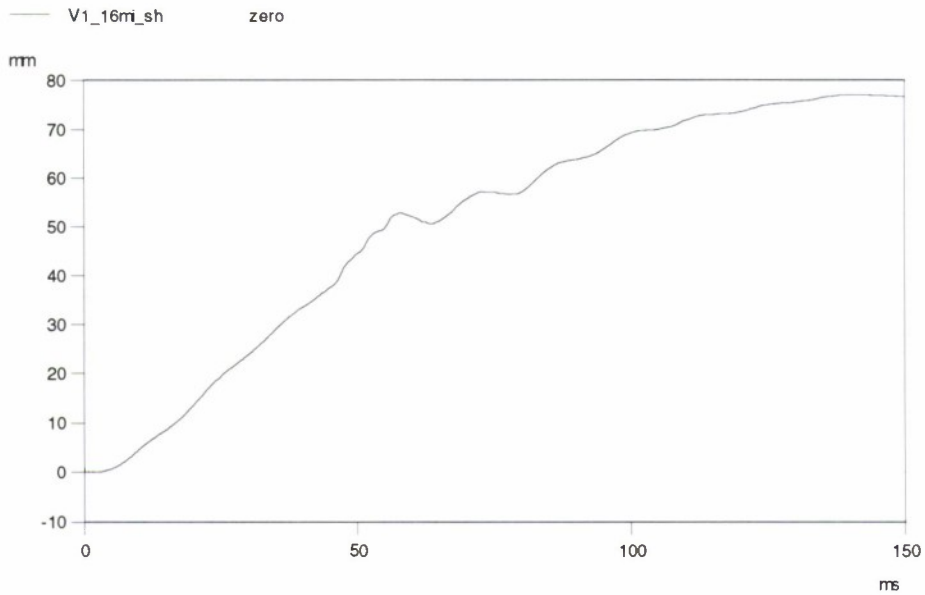
	Max.		at time		Mn.		at time	
<b>TLU_FX</b>	1897.06	N	3.0	ms	-1876.67	N	3.5	ms
<b>TLU_FZ</b>	5099.90	N	2.2	ms	-26543.94	N	0.6	ms
<b>TLU_MX</b>	16.59	Nm	8.3	ms	-141.28	Nm	0.6	ms
		Nm		ms		Nm		ms



26-11-07	Test_16, 'Zeman' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_16mi_sh.drb		

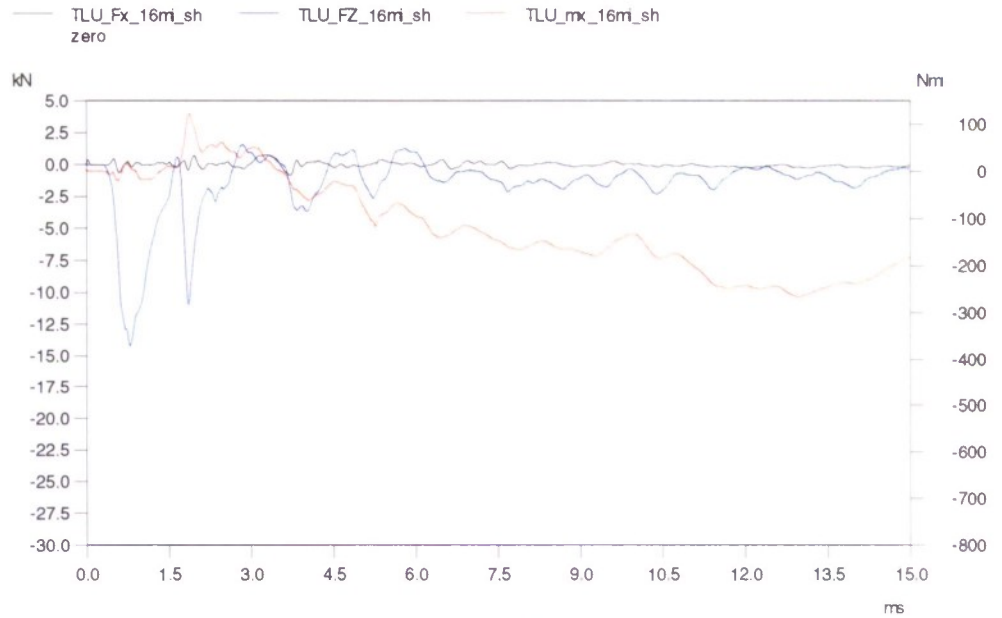


	Max.		at time		Min.		at time	
V1_16mi_sh	0.077	m	141.88	ms	-0.139	m	362.1	ms




26-11-07
RvdK
10784
_16mi_sh_TLU.drb

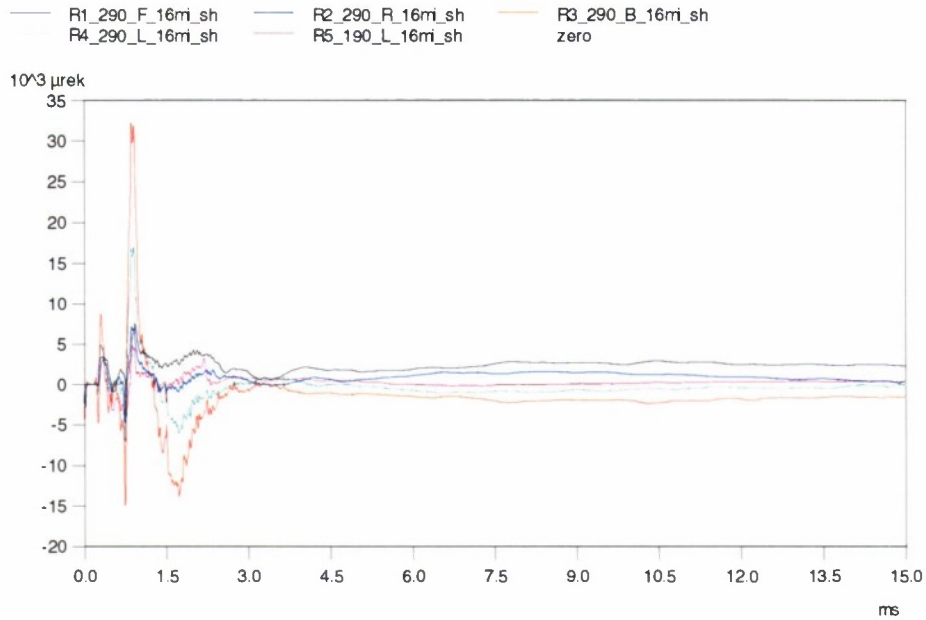
Test\_16, 'Zeman' CLL legg, TNO-LBO ,  
September 2007



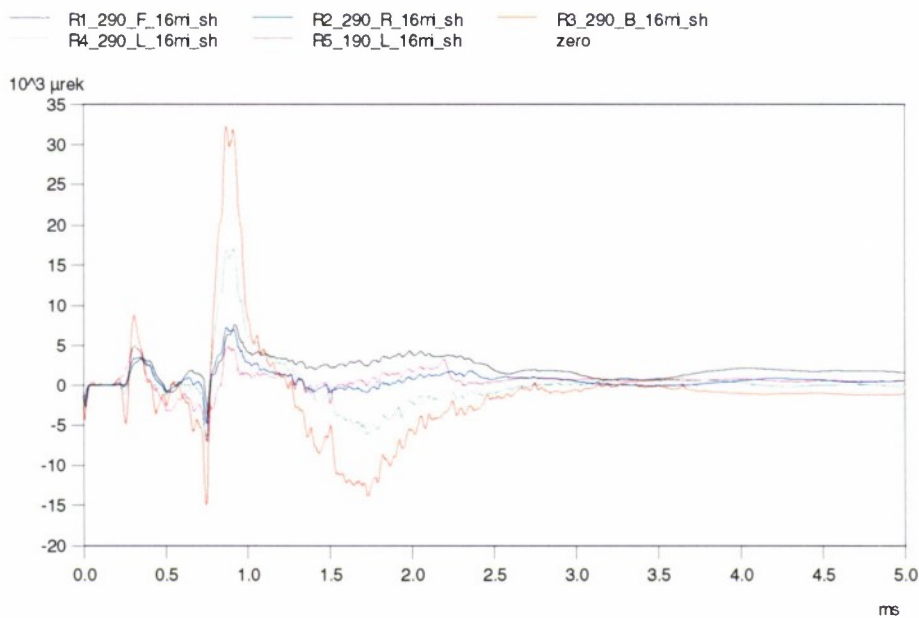
	Max.		at time		Min.		at time	
<b>TLU_FX</b>	772.64	N	3.3	ms	-817.25	N	3.7	ms
<b>TLU_FZ</b>	1541.69	N	2.9	ms	-14204.14	N	0.8	ms
<b>TLU_MX</b>	121.06	Nm	1.9	ms	-180.43	Nm	9.3	ms
		Nm		ms		Nm		ms



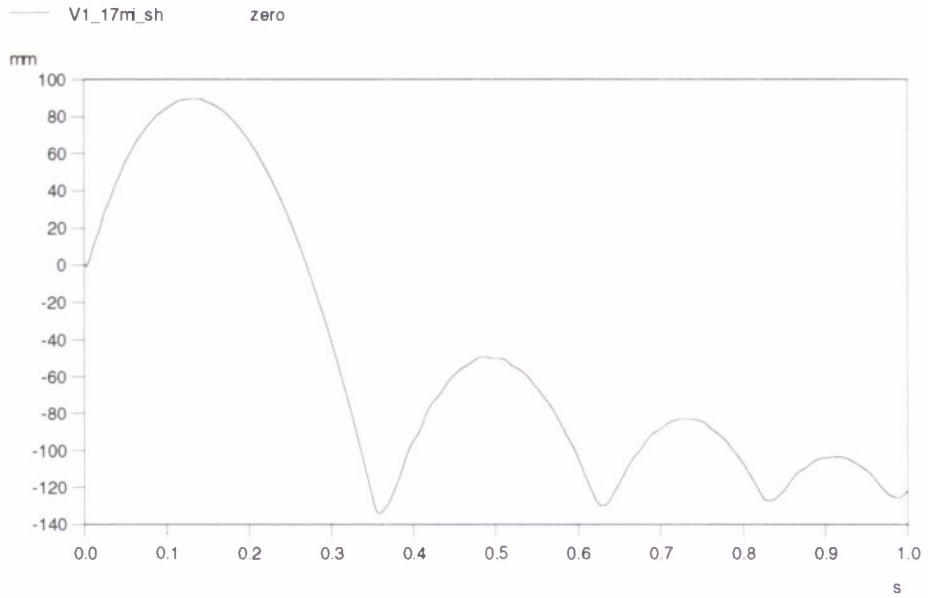
27-11-07	Test_16, 'Zeman' CLL legg, TNO-LBO , September 2007	
RvdK		
10784		
_16mi_sh_R.drb		



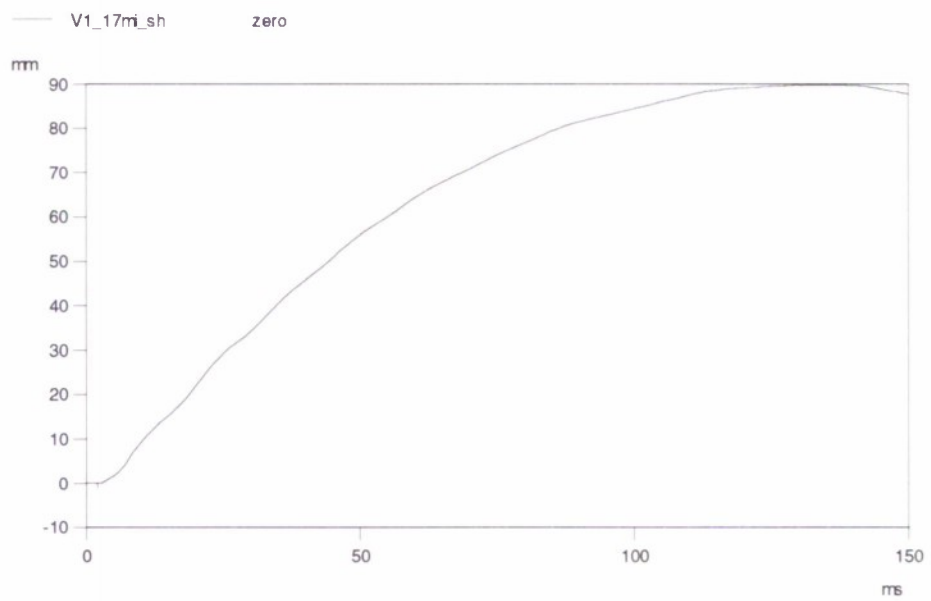
	Max.		at time		Mn.		at time	
<i>R1_290_F_16mi_sh</i>	7581.60	µrek	0.9	ms	-3955.89	µrek	0.8	ms
<i>R2_290_R_16mi_sh</i>	7117.21	µrek	0.9	ms	-4845.59	µrek	0.8	ms
<i>R3_290_B_16mi_sh</i>	32238.85	µrek	0.9	ms	-15002.45	µrek	0.8	ms
<i>R4_290_L_16mi_sh</i>	16927.50	µrek	0.9	ms	-7013.17	µrek	0.8	ms
<i>R5_190_L_16mi_sh</i>	4889.98	µrek	0.3	ms	-7131.34	µrek	0.8	ms



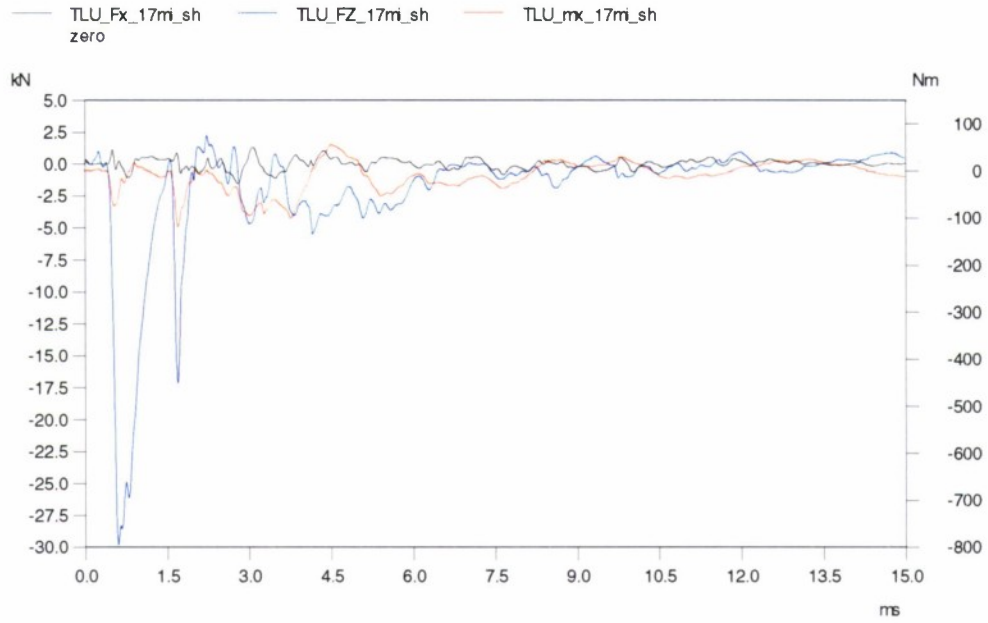
26-11-07	Test_17, 'Zeman', FSL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_17mi_sh.drb		



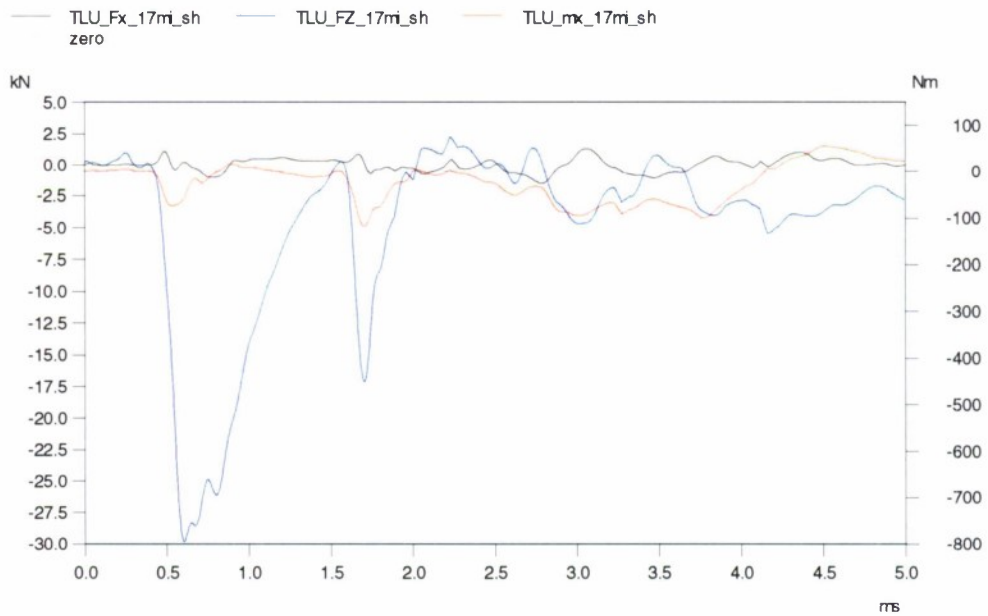
	Max.		at time		Min.		at time	
<b>V1_17mi_sh</b>	0.090	m	136.13	ms	-0.134	m	358.0	ms




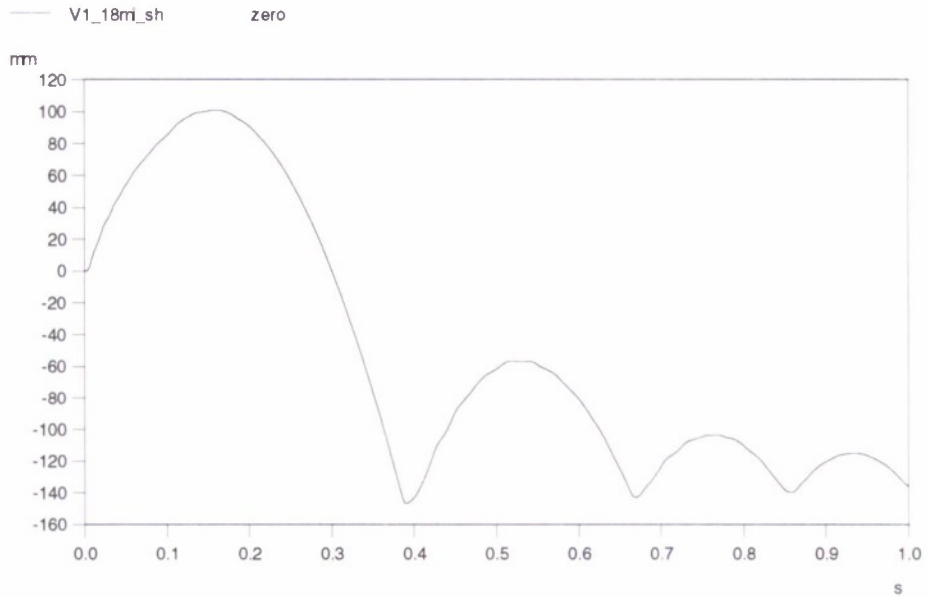
26-11-07	Test_17, 'Zeman', FSL legg, TNO-LBO , September 2007	
RvdK		
10784		
_17mi_sh_TLU.drb		



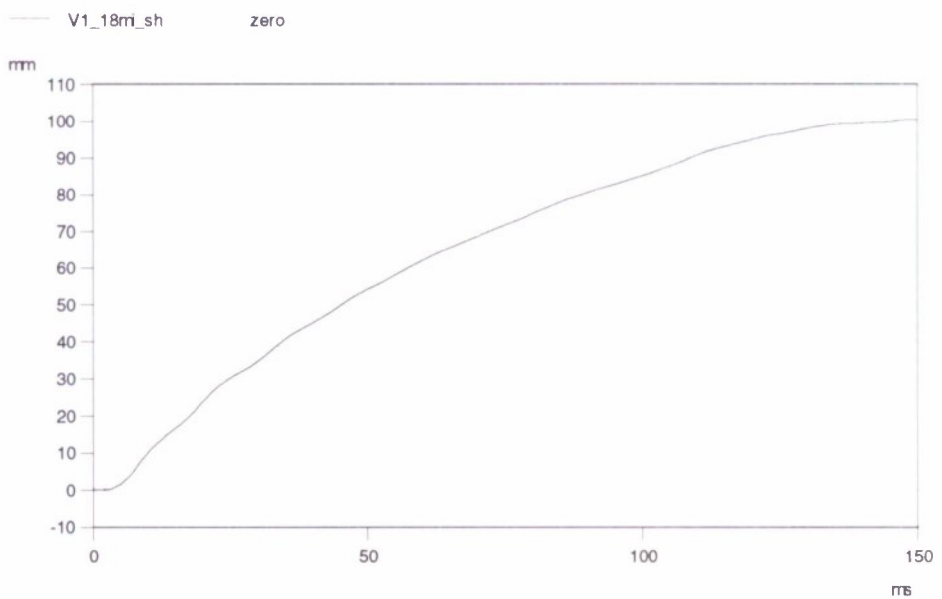
	Max.		at time		Mn.		at time	
<b>TLU_FX</b>	1333.83	N	3.1	ms	-1518.48	N	2.8	ms
<b>TLU_FZ</b>	2245.71	N	2.2	ms	-29846.70	N	0.6	ms
<b>TLU_MX</b>	54.72	Nm	4.5	ms	-119.10	Nm	1.7	ms
		Nm		ms		Nm		ms




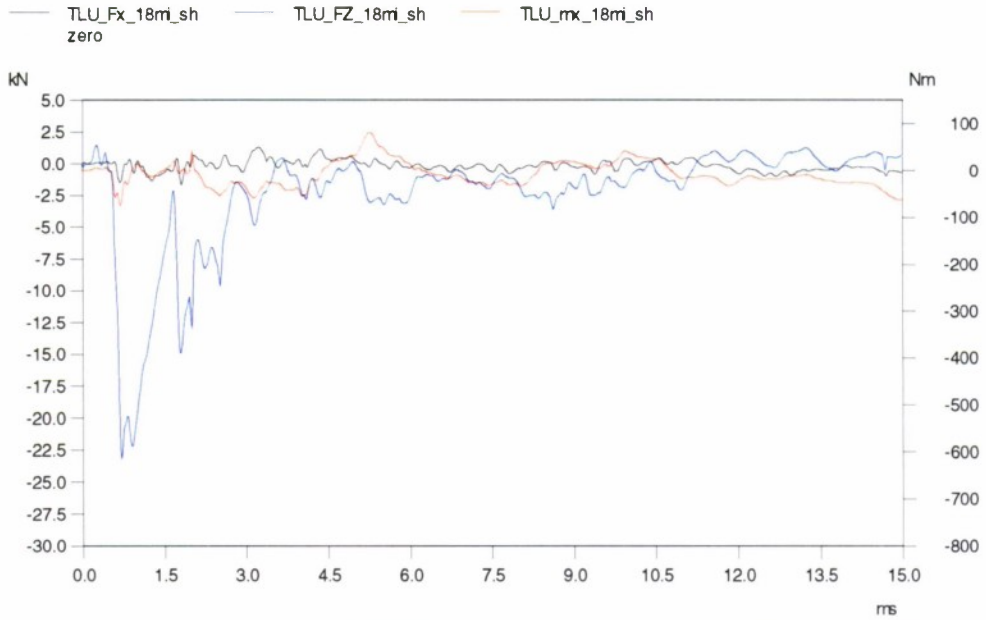
26-11-07	Test_18, 'Anonymate', FSL legg, TNO-LBO , September 2007	
RvdK		
10784		
V1_18mi_sh.drb		



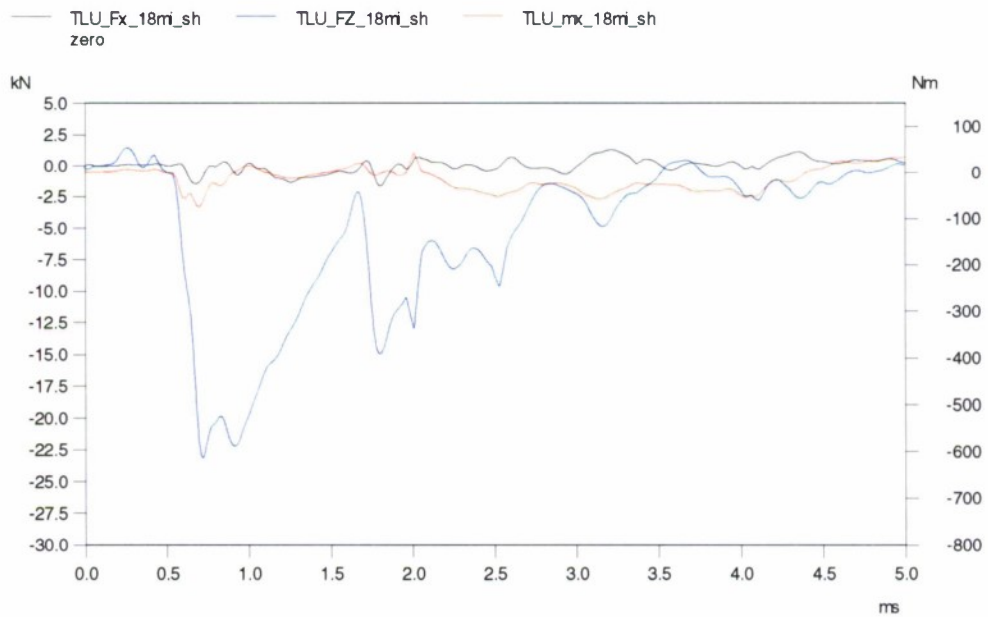
	Max.		at time		Min.		at time	
<b>V1_18mi_sh</b>	0.101	m	158.98	ms	-0.147	m	390.7	ms




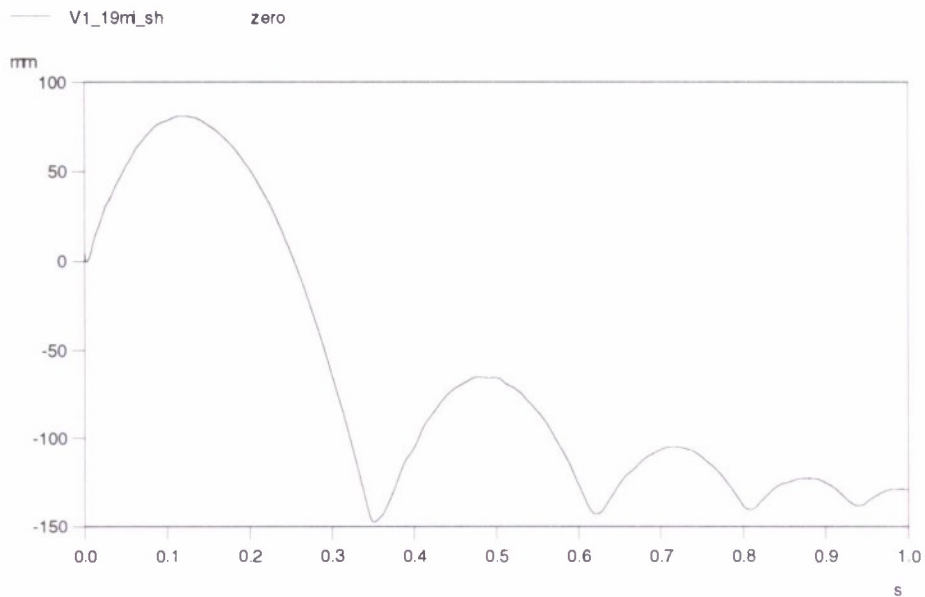
26-11-07	Test_18, 'Anonymate', FSL legg, TNO- LBO , September 2007	
RvdK		
10784		
_18mi_sh_TLU.drb		



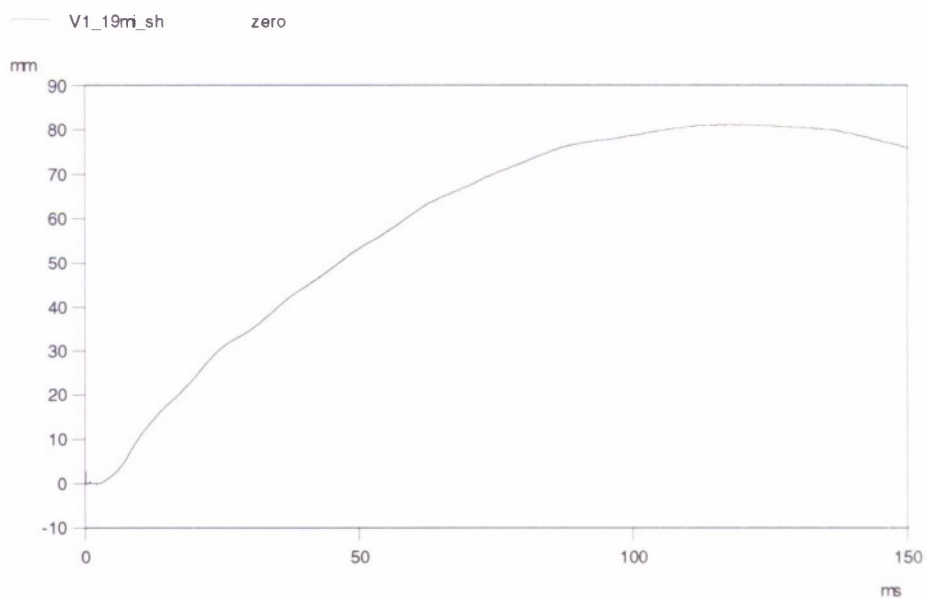
	Max.		at time		Mn.		at time	
<b>TLU_FX</b>	1319.29	N	3.2	ms	-1631.80	N	1.8	ms
<b>TLU_FZ</b>	1429.56	N	0.3	ms	-23165.76	N	0.7	ms
<b>TLU_MX</b>	80.61	Nm	5.3	ms	-76.34	Nm	0.7	ms
		Nm		ms		Nm		ms



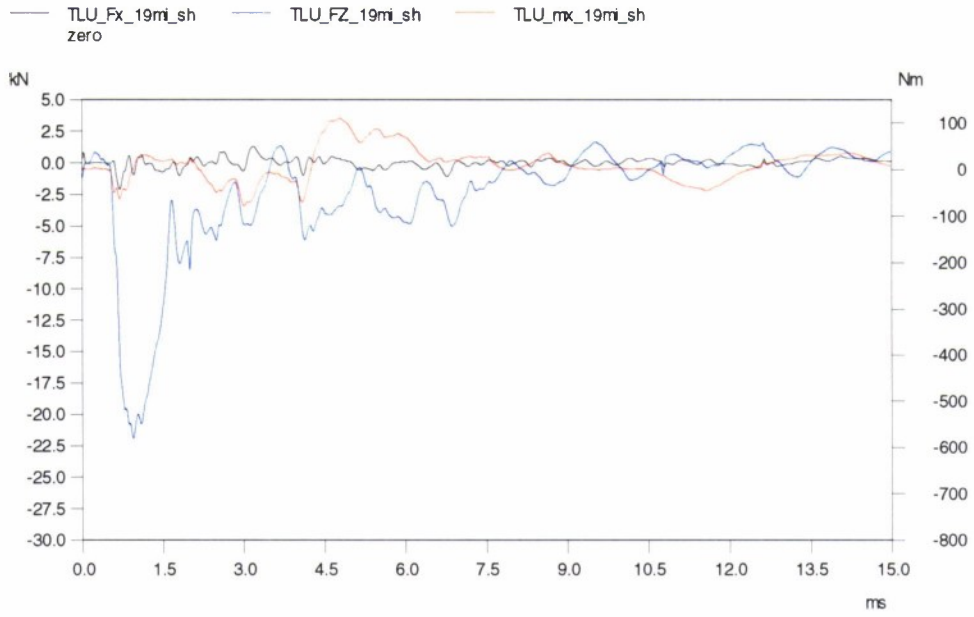
26-11-07	Test_19, 'Anonymate', FSL leg, TNO-LBO , September 2007	
RvdK		
10784		
Vi_19mi_sh.drb		



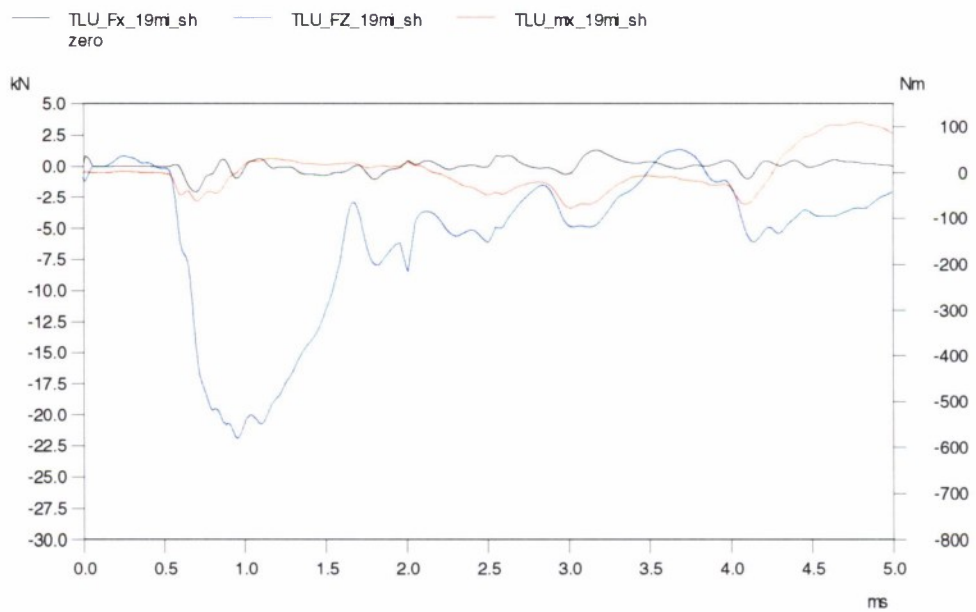
	Max.		at time		Min.		at time	
V1_19mi_sh	0.081	m	117.75	ms	-0.148	m	350.6	ms



26-11-07	Test _19, 'Anonymate', FSL legg, TNO-LBO , September 2007	
RvdK		
10784		
_19mi_sh_TLU.drb		



	Max.		at time		Min.		at time	
<i>TLU_FX</i>	1311.61	N	3.2	ms	-2064.90	N	0.7	ms
<i>TLU_FZ</i>	1646.24	N	9.5	ms	-21899.16	N	1.0	ms
<i>TLU_MX</i>	109.90	Nm	4.8	ms	-78.51	Nm	3.0	ms
		Nm		ms		Nm		ms

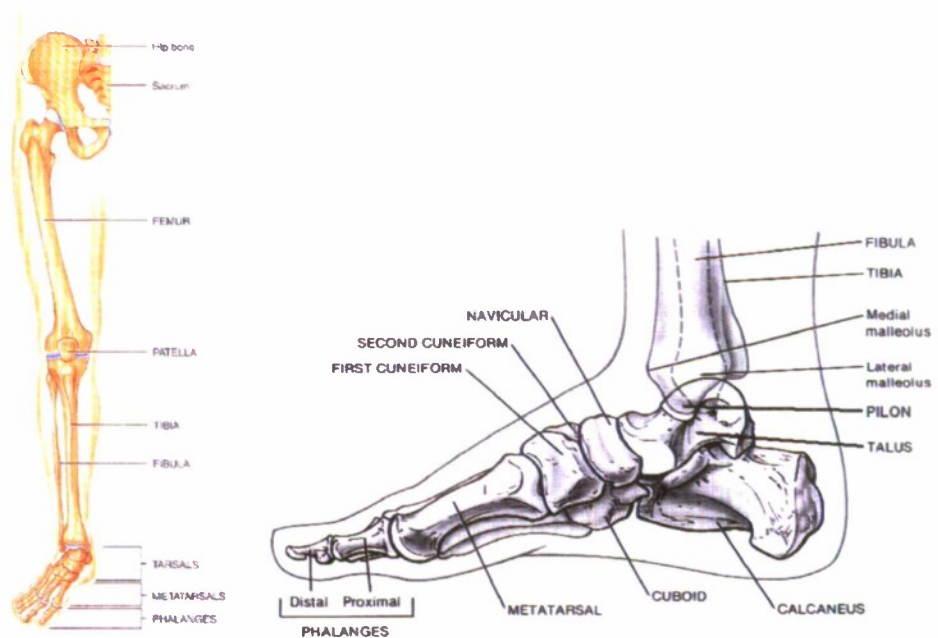


## D Medical results

A medical report of each test is presented below. But first a list with explanation of the medical terms that are used in the report is given.

The most important photos are shown in this report. More photos as well as the high speed movies are gathered on a DVD. Unfortunately, the X-rays taken during the event were not accurate enough to be used for the analysis. The trigger signal was not in time, which means that the X-ray was taken just before the event.

### D.1 Anatomy and list of definitions



The lower limb (left) and the foot/ankle complex anatomy [Tortora, 1984, 2003].

The lower limb (or lower extremity) is divided in four regions: the thigh, the knee, the leg and the foot/ankle complex. The femur is the thigh-bone, the patella is the knee bone, the tibia and the fibula are the leg bones, and the phalanges, the metatarsals and the tarsals are the bones of the foot/ankle complex. The tibia is the larger of the two leg bones and bears most of the body weight. The figure above shows the medial view of the right foot. The tarsal bones (in the ankle) are the calcaneus (= calcar bone), the talus, the cuboid, the navicular and the three cuneiforms. The talus, which is the only bone to articulate with the tibia and the fibula, transmits all the forces from the foot to the leg.

#### References

Tortora, G.; Anagnostakos, N. (1984), Principles of Anatomy and Physiology, Fourth Edition, Harper & Row, Publishers, Inc., New York, NY.

Tortora G.J. and Reynolds Grabowski, S. (2003), Principles of Anatomy & Physiology, 10<sup>th</sup> edition, John Wiley & Sons, Inc., New York.

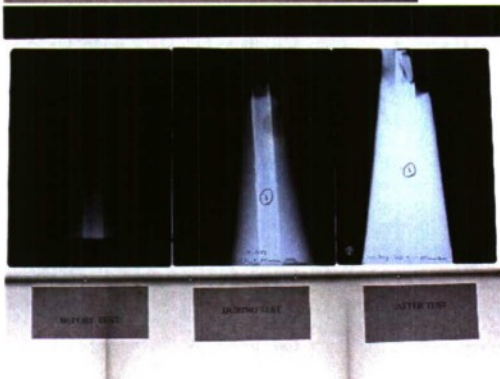
**List of definitions**

Anatomical scales	Described the injury in terms of anatomical location, type of injury and relative severity
Anterior	Front part, to the front
Calcaneus/ calcar bone	Heel bone
Cuboid	Bone in the foot
Cuneiforms	Mid foot bones
Femur	Thigh-bone
Fibula	Calve bone
Injury criterion	Physical parameter or a function of several physical parameters which correlates well with the injury severity of the body region under consideration
Injury criterion level/tolerance level	Magnitude of loading indicated by the threshold of the injury criterion, which produces a specific type of injury severity
Injury mechanism	Mechanism involved with the cause of injury
Injury risk curves	Define the injury risk for a given human body response
Injury scaling	Numerical classification of the type and severity of an injury
Knee clevis	Attachment part at the knee of a dummy leg
Laceration	Tear in skin, muscle or organ.
Laminar fractures	Fractures in longitudinal direction of bone
Lower extremity	Lower limb
Metatarsals	Toe bones
Navicular	Foot bone
Osteoarthritis	Chronic inflammation caused by damage of cartilage
Patella	Knee bone
Pelvis	Hip area
Phalanges	Toe bones
Physiologic scales	Describe the physiological status of the patient based on the functional change due to injury. This status may change over the duration of the injury's treatment period.
Posterior	On the back, backwards
Talus	Foot bone
Tarsals	Foot bones
Tibia	Shin bone
Tolerance level	Magnitude of loading indicated by the threshold of the injury criterion, which produces a specific type of injury severity and risk

## D.2 Medical test reports

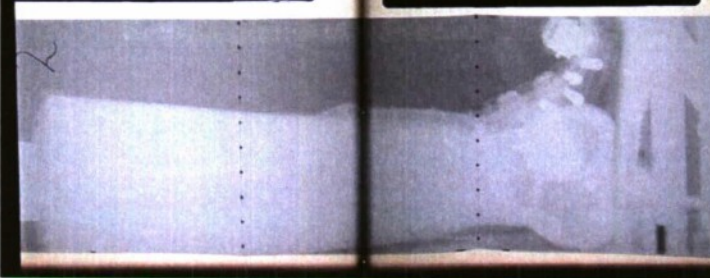
Testnr	1
Date	1-10-2007
charge	25 gram
Type of surrogate	CLL (with nylon stocking)
Shoe type	Dutch army boot (gevechtslaars)
Remarks	Technical problems with x-ray system. Leg was removed again and placed in the fridge. After a large delay the first test was done (with a new leg). However, again technical problems. Therefore the leg was already 45 minutes in the test rig before the test was performed.
Post test remarks	Problems with triggering which resulted in no x-ray photo, no force measurements no strain rate measurements Shoe and foot knocked away by the blast, and pieces found everywhere. Shoe parts more than 8 meters away.
Post test boot damage assessment	Entire shoe damaged. Heel rupture at the mid foot. Leather torn at the seem of the heel of the shoe.
Post test X-ray findings	Amputation of distal fragment of the lower leg (no visualization of ankle/foot because they were amputated)
Post test clinical dissection findings	Comminuted fractures of calcaneous. Talus broken off. Longitudinal fractures in distal (10 cm length) and side part (11 cm length) of tibia starting at talus level.
Treatment	Below knee amputation
MTS score	2b
AIS score	3
AO score tibia	41-; 42-; 43C3; 44C3
AO foot	71C3; 72C3; 73C3
Other medical score	Gustilo 3c



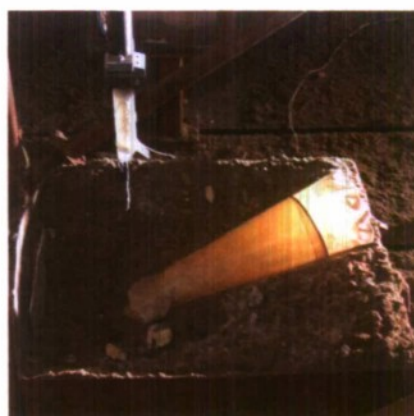


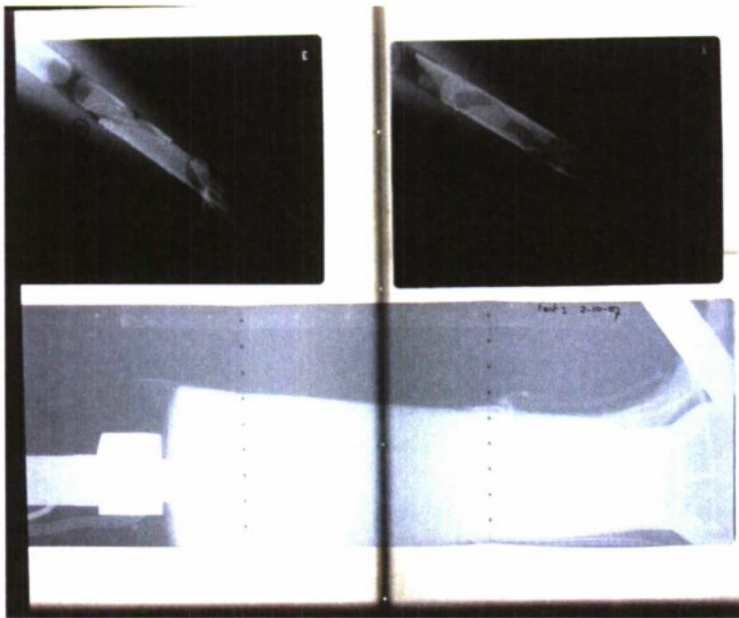
Testnr	2
Date	2-10-2007
charge	25 gram
Type of surrogate	CLL (incl nylon stocking)
Shoe type	Spider Boot in combination with Dutch army boot
Remarks	The x-ray delay was 200 microseconds after detonation Triggering went well Mine under inner rear pod Mine close to rear wall of the steel container.
Post test remarks	Leg broken off just below the fixation point at the test-rig. Leg shows strange orientation of ankle Small pieces of inner rear pod of boot everywhere.
Post test boot damage assessment	Rear inner pod broken off. Mechanism to open spider boot did not function anymore. No further damage. Dutch army boot intact.
Post test X-ray findings	No fractures, cartilagineous lesions in upper ankle joint.
Post test clinical dissection findings	Skin intact and no foreign body contamination. Soft tissue injuries front and medial to the bone. Cartilagineous lesions (tear) in upper ankle joint.
Treatment	Be aware of possible arterial lesions (tibialis posterior and dorsalis pedis). Conservative therapy possible.
MTS score	1a
AIS score	2
AO score tibia	41-; 42-; 43-; 44-
AO foot	71-; 72-; 73-
Other medical score	Gustilo ø





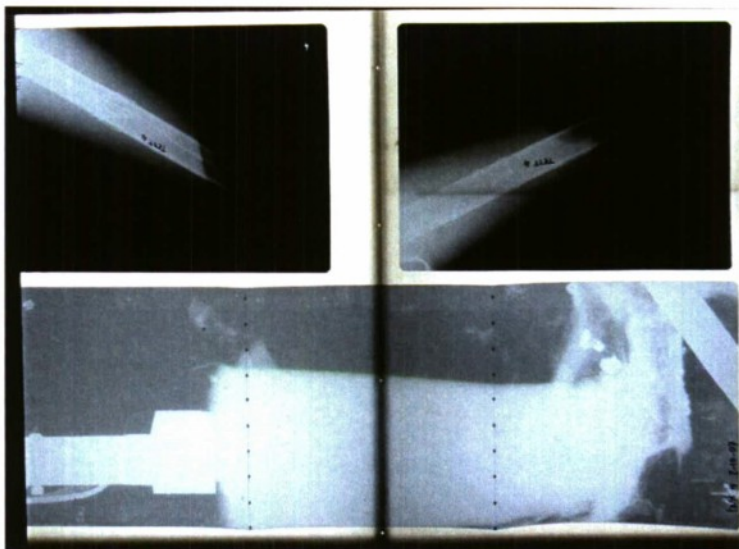
Testnr	3
Date	2-10-2007
charge	50 gram
Type of surrogate	CLL (incl nylon stocking)
Shoe type	Anonymate
Remarks	The x-ray delay was 200 microseconden after detonation Triggering went well
Post test remarks	Shoe torn away from foot. Bone parts found in the shoe. Leg broken off just below the fixation point at the test-rig.
Post test boot damage assessment	Shoe heavily damaged at heel level. Rubber heel gone. Leather seem at rearside of foot entirely torn open. Inner sole damaged
Post test X-ray findings	Destroyed foot/ankle and lower part tibia (knochensalat). Air along tibia. Soft tissue injury foot/ankle.
Post test clinical dissection findings	Soft tissue came loose of bone structure during test: degloving injury over 12 cm (probably caused by test set-up). Comminuted fractures of calcaneus and talus (knochensalat). Fractures in lower part of tibia. Soft tissue injury in lower leg.
Treatment	Below knee amputation. If the degloving is the real injury mechanism, than above knee amputation would be needed.
MTS score	2b
AIS score	3
AO score tibia	41A; 42C, 43C, 44C
AO foot	71C3; 72C3; 73C3.3
Other medical score	Gustilo 3C





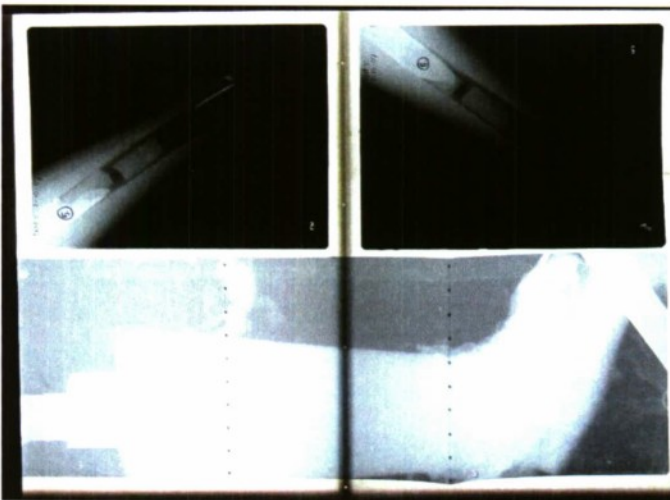
Testnr	4
Date	2-10-2007
charge	50 gram
Type of surrogate	CLL (incl nylon stocking)
Shoe type	Forceware
Remarks	The x-ray delay was 2 milliseconds after detonation (based on information on strain rate measurements of previous tests) Triggering went well
Post test remarks	Shoe and foot knocked away by the blast, and pieces found everywhere
Post test boot damage assessment	Entire shoe damaged. Heel rupture at the mid foot. Heel in many fragments. Leather torn from Kevlar layers, connection with sole gone. Shoe laces intact, but torn at seam of the shoe.
Post test X-ray findings	Amputation of distal fragment of the lower leg (no visualization of ankle/foot) fractures in oblique line of tibia fractures in soft tissue
Post test clinical dissection findings	Foot amputated. Many small bone pieces (knochensalat) foot/ankle. Sole of the foot in different parts. Injuries in upper ankle joint and cartilaginous injury in upper ankle joint. Distal tibia in 4 main fragments. Fracture of 4 cm length in distal tibia. Soft tissues injuries.
Treatment	BKA= Below Knee Amputation
MTS score	2b
AIS score	3
AO score tibia	41-; 42-; 43C; 44C
AO foot	71 C3; 72 C3; 73 C3
Other medical score	Gustilo 3b



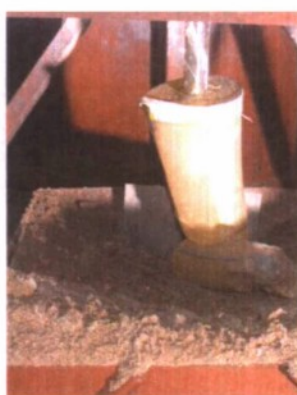


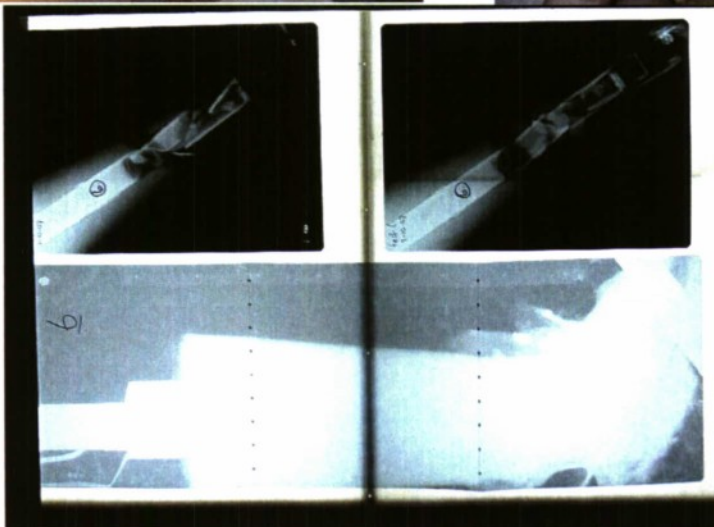
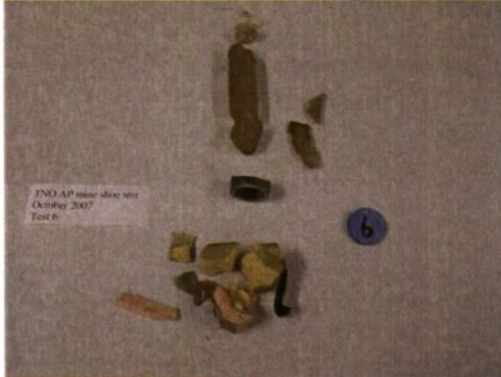
Testnr	5
Date	2-10-2007
charge	50 gram
Type of surrogate	CLL (incl nylon stocking)
Shoe type	Mile dragic
Remarks	
Post test remarks	Shipping of the soft tissues from the bone near the knee joint Shoe thrown away. Extra sole came apart from the shoe and found 3 meters away( intact) Force measurements nearly at its maximum
Post test boot damage assessment	Rear seam open and bone parts of talus and distal tibia found in boot. Heel of the boot pulverized. Sole broken in different parts.
Post test X-ray findings	Compound fracture distal tibia/ankle plus extensive soft tissue injury ankle region
Post test clinical dissection findings	Soft tissue came loose of bone structure during test: degloving injury over 10 cm (probably caused by test set-up). Foot amputated. Soft tissue damage in lower leg part. Just above the ankle. Severely damaged ankle joint. The talus into 2 main fragments. Calcus bone (rear and front) both into 2 main fragments and small pieces. Foot sole damaged.
Assessment	Below knee amputation. If the degloving is the real injury mechanism, than above knee amputation would be needed.
MTS score	2b
AIS score	3
AO score tibia	41-; 42-; 43 C3; 44C3
AO foot	71 C3; 72 C3; 73 C3
AO soft tissue	
Other medical score	Gustilo 3b to 3c



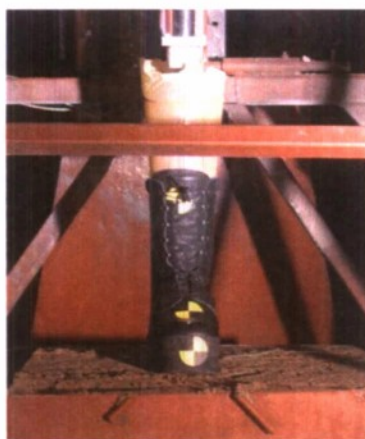


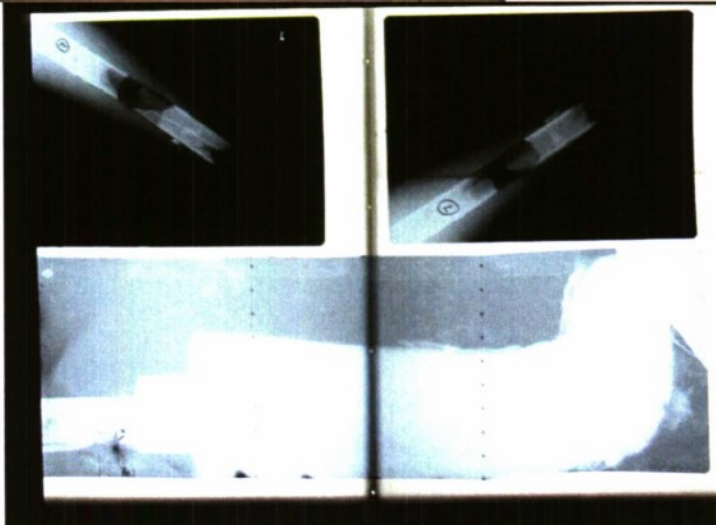
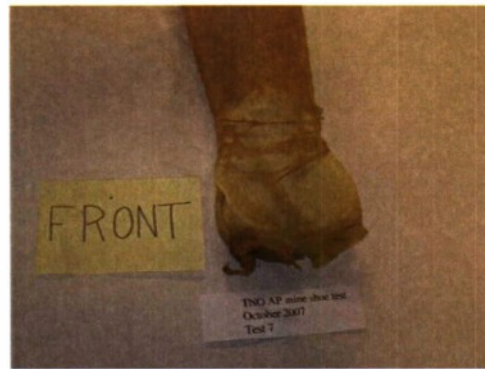
Testnr	6
Date	2-10-2007
charge	50 gram
Type of surrogate	CLL (incl nylon stocking)
Shoe type	Aigis
Remarks	
Post test remarks	Shipping of the soft tissues from the bone near the knee joint Shoe thrown away. Bone parts 2-3 meters away from leg.
Post test boot damage assessment	Shoe sole tore off and in 2 parts: sole & heel. Heel part pulverized. Also depression heelpad inside shoe.
Post test X-ray findings	Compound fracture of distal tibia (à deux étages) with air in soft tissue. Circular “ amputation” of tibia (soft tissue and bone).
Post test clinical dissection findings	Soft tissue came loose of bone structure during test: degloving injury (probably caused by test set-up). Lower leg amputated during the test. Talus fragmented vertically one main fragment and the part in several fragmetns. Rear calcar bone fractured, frontal calcar bone was intact.
Assessment	Below knee amputation. If the degloving is the real injury mechanism, than above knee amputation would be needed.
MTS score	2b to 3, depending on loosening soft tissues
AIS score	3
AO score tibia	41-; 42-; 43 C2; 44C3
AO foot	71 C3; 72 C2;73 C3
Other medical score	Gustilo 3b





Testnr	7
Date	2-10-2007
charge	50
Type of surrogate	CLL (incl nylon stocking)
Shoe type	Zeman
Remarks	
Post test remarks	Shipping of the soft tissues from the bone near the knee joint Shoe thrown away. Broken ankle. Bone fragments found.
Post test boot damage assessment	Heel of shoe torn off. Parts of heel pulverized. Inside covering of heel defect, but still closed.
Post test X-ray findings	Comminuted fractures distal tibia complex plus compound fractures higher up. Air along tibia in soft tissues
Post test clinical dissection findings	Soft tissue came loose of bone structure during test: degloving injury (probably caused by test set-up). Defect skin of sole. Bone fragments gone, were laying around on test scene. talus defects, calcar bone parts comminuted. Distal tibia multifragment fractures. Comminuted fractures distal tibia complex
Treatment	Below knee amputation. If the degloving is the real injury mechanism, than above knee amputation would be needed.
MTS score	2b
AIS score	3
AO score tibia	41-; 42A; 43C3; 44C3
AO foot	71C3; 72 C3; 73 C3
Other medical score	Gustilo 3a

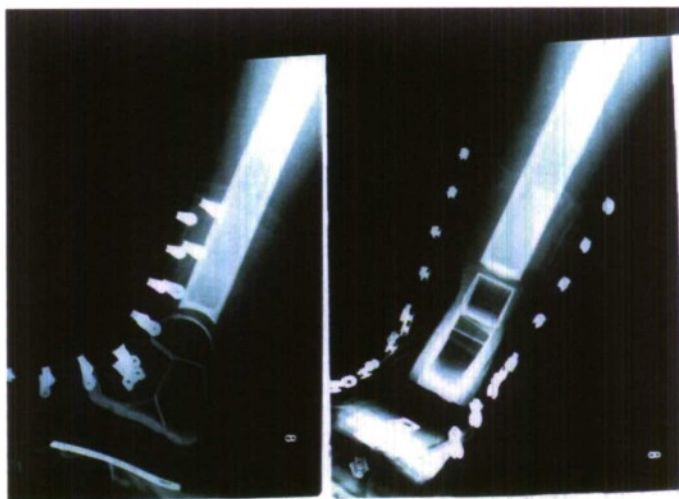




Testnr	8
Date	3-10-2007
charge	75 gram
Type of surrogate	CLL (incl nylon stocking)
Shoe type	Spider Boot with Dutch army boot
Remarks	No x-ray taken during the test mine under inner rear pod box with sand was placed 10 cm backwards, in order to have correct place the spider boot. The pods just fit in the box.
Post test remarks	
Post test boot damage assessment	Both rear pods blown away. One in small fragments, the other in a few larger parts. Fixing sytem of spiderboot still intact
Post test X-ray findings	Upper ankle joint probably damaged, it is too wide. Cartilagineous lesion of calcar bone and vertical fracture.
Post test clinical dissection findings	Damage of the soft tissue near the Achilles tendon and medial and lateral ligaments torn. Vertical fracture in calcar bone. Surface defect in lower ankle joint. Insufficient ligamental complex between talar and calcar bone. Multiple soft tissue injuries near ligaments.
Assessment	Conservative; probably temporarily external fixation
MTS score	1
AIS score	2
AO score tibia	41-, 42-, 43-, 44- (ligamentous injuries)
AO foot	71-; 72 -; 73 C2
Other medical score	Gustilo ø

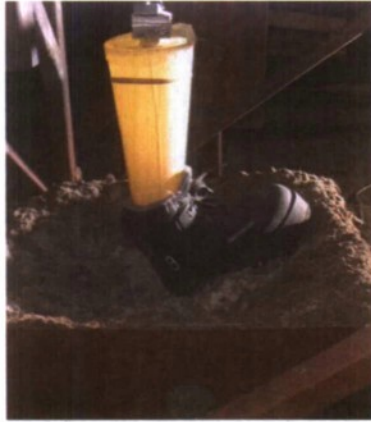


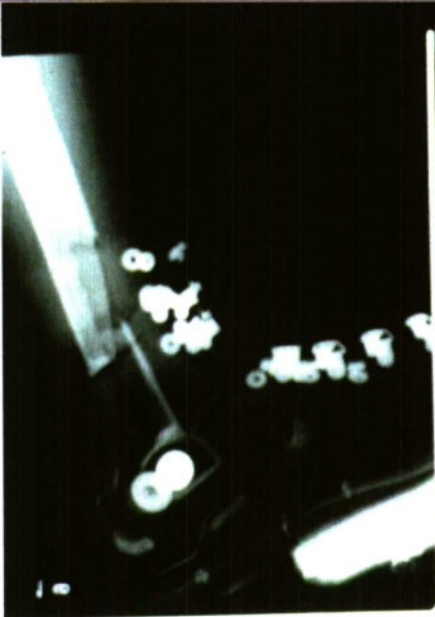




Testnr	9
Date	3-10-2007
charge	25 gram
Type of surrogate	CLL (incl nylon stocking)
Shoe type	Aigis
Remarks	
Post test remarks	
Post test boot damage assessment	Boot intact, but heel of boot disappeared and fragmented. The inside shoe shows a depression of the heel part.
Post test X-ray findings	Distal tibia & talus driven through the calcar bone and adjacent foot. Line fracture in tibia, loose fragments, sole of foot disrupted.
Post test clinical dissection findings	Clearly soft tissue injury ankle region and above at removing leg from boot: part of calcar bone stayed in shoe plus fragment. Soft tissue injury ankle region. At removing soft tissues: clearly talus + part distal tibia driven through connection calcar bone and foot. Several fragments and outer layer of calcar bone was in 2 main fragments. Fractured lower leg. Skin of sole disrupted
Treatment	Below knee amputation
MTS score	2a
AIS score	3
AO score tibia	41-;42C1;43C2, 44C3
AO foot	71-,72-;73C3
Other medical score	Gustilo 3a—3b

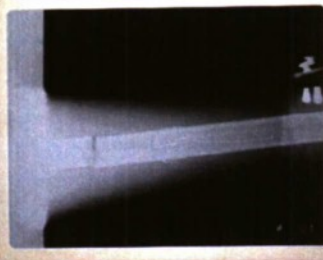
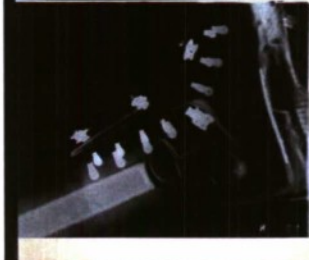
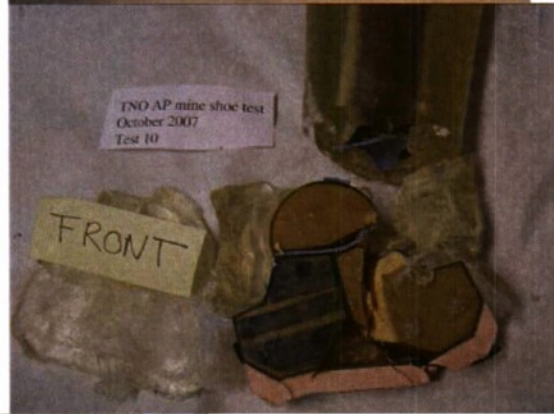
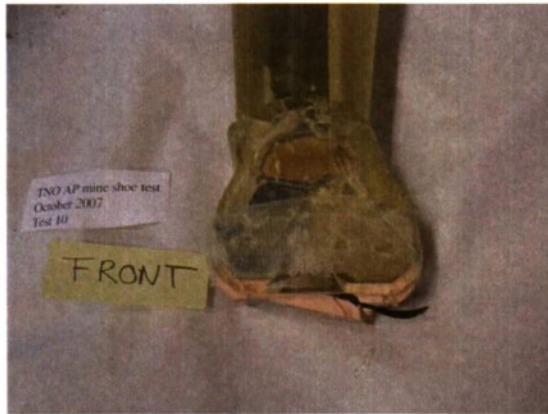




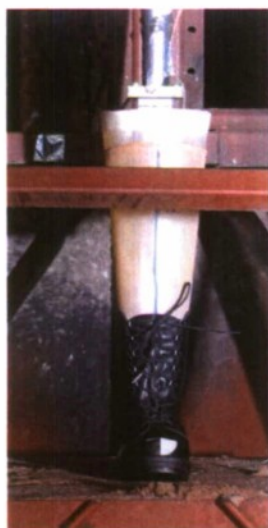


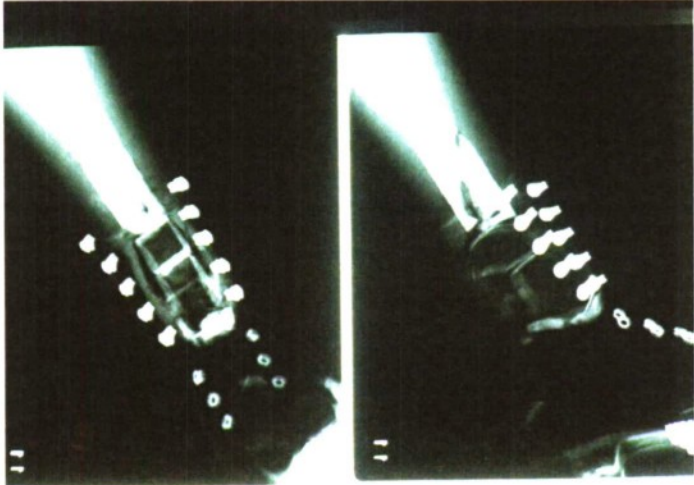
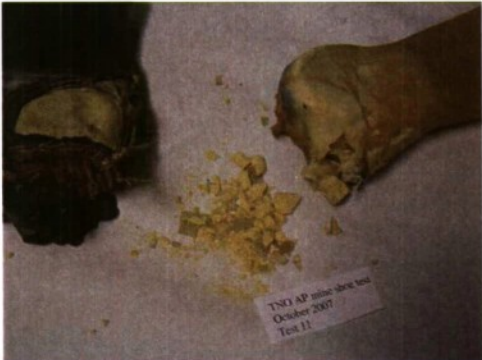
Testnr	10
Date	3-10-2007
charge	50
Type of surrogate	CLL
Shoe type	Rubberblock boot SA (incl Dutch army boot)
Post test boot damage assessment	Dutch army boot intact. Rubber boot itself intact, but the blocksole is broken into several parts. The platform consisted of gelatine/glas/aluminium/cork/polyester. The aluminium triangle container is blown open which resulted into sharp parts.
Post test X-ray findings	Soft tissue injury at ankle level. Extensive fractures talar bone Compound fractures calcar bone, proximal tibial fracture, upper ankle joint too wide, rupture/defect sole of the foot
Post test clinical dissection findings	Soft tissue came loose of bone structure during test including fracture in tibia: degloving injury (probably caused by test set-up). Soft tissues intact above shoe. Cartilaginous lesion ankle joint. Fractures at dorsal side of talus with cartilage lesion. Vertical fractures calcar bone, kind of soft tissues around ankle joint: transected skin of sole: lesions.
Treatment	Below knee amputation The tibia fracture which was probably caused by the test-setup and can be treated by external fixation.
MTS score	2a
AIS score	2
AO score tibia	41A; 42-; 43-; 44-
AO foot	713C;72-;73 3C
Other medical score	Gustilo 3a



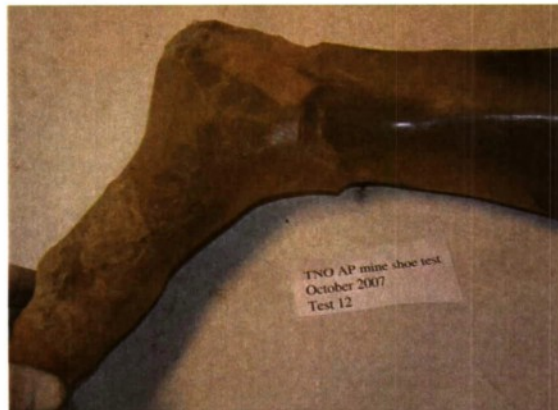


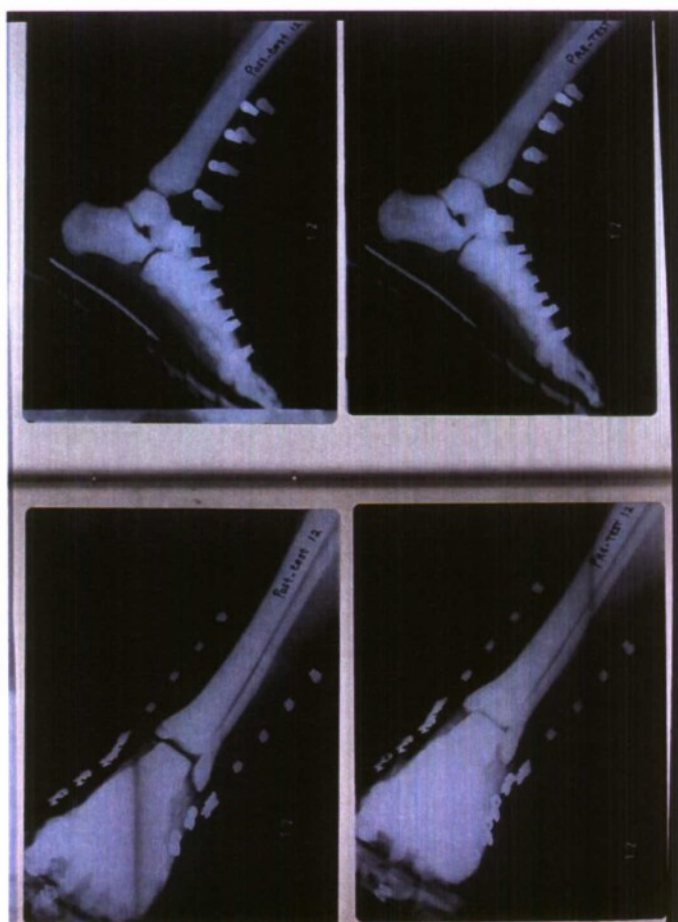
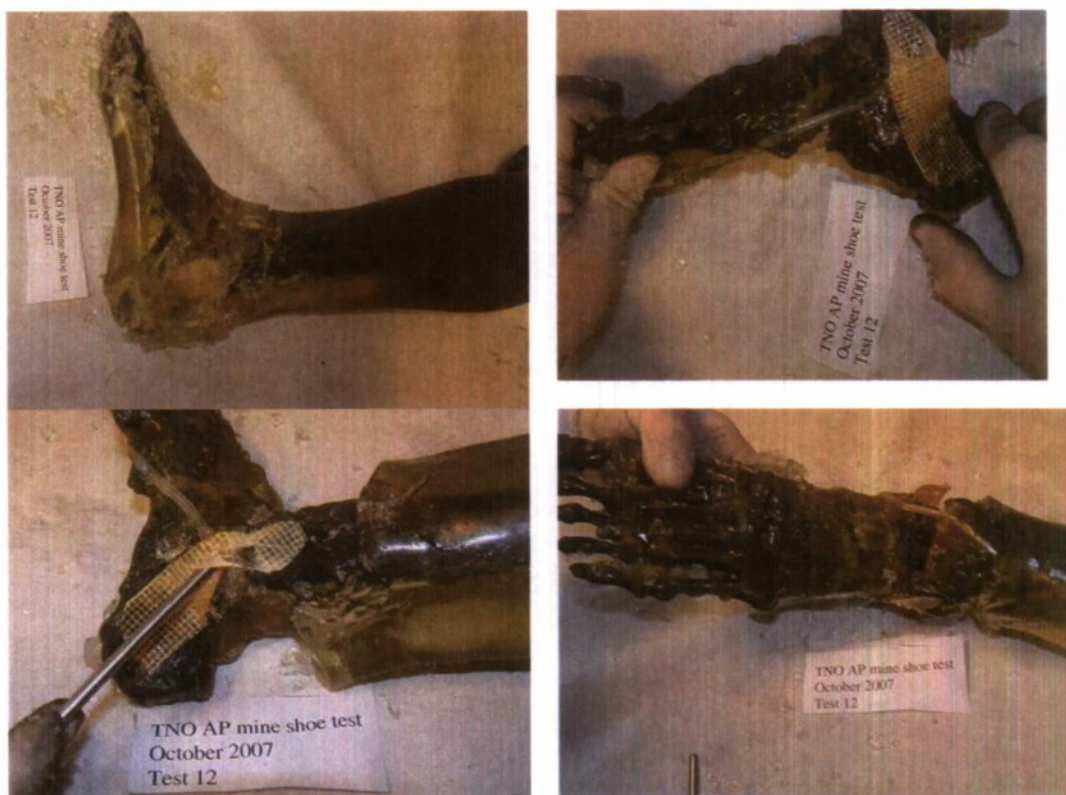
Testnr	11
Date	4-10-07
charge	25
Type of surrogate	CLL
Shoe type	Forceware
Remarks	
Post test remarks	Leg broken just below attachment to rig
Post test boot damage assessment	Heel of shoe disappeared, Kevlar lining disrupted. Inner sole perforated by soft tissues of the sole of the foot. Inside shoe: many little fragments of calcaneous bone
Post test X-ray findings	Distal compound fracture tibia + upper ankle joint fracture, talar fracture, calcaneous fracture, multiple small fragments Soft tissue injury foot and ankle, rupture sole of foot Air along tibia
Post test clinical dissection findings	Crushed calcar bone Fracture talar bone- compound fracture cartilagineous lesion talar bone fracture distal tibia, 3 main fragments and fracture upper ankle joint soft tissue injury foot & ankle region sole of foot disrupted
Assessment	Below knee amputation
MTS score	2b
AIS score	3
AO score tibia	41- ;42- ;43C3; 44 C3
AO foot	71 C2; 72-; 73 C3
Other medical score	Gustilo 3A





Testnr	12
Date	4-10-2007
charge	75 gram
Type of surrogate	FSL (incl nylon stocking)
Shoe type	Spiderboot in combination with Dutch army boot
Remarks	<p>Leg did not fit into the shoe. Ankle too stiff and foot too wide. Shoe was cut open, to better place foot into shoe. But still gelatine prior to test already damaged. Pretest x-ray to show damage prior to test.</p> <p>The positioning of the leg is not so very tight, especially compared to the CLL fixation. However, this is the standard fixation of the FSL.</p>
Pre test x-ray	Small soft tissue damage at heel and small toe.
Post test remarks	Leg came loose from support at knee joint. Fixation was only with 2 small bolts, which came of the bone structure.
Post test boot damage assessment	Rear pods broken off. Mechanism to open boot ok. Dutch army boot not damaged
Post test X-ray findings	Soft tissue injuries. Upper ankle joint too loose → luxation Chopart too loose → luxation Avulsion medial malleolus
Post test clinical dissection findings	Upper ankle joint and chopart too loose. Circular soft injuries. Ligamentous injury of medial and lateral side of ankle joint. Medial disconnected from tibia. Lateral ¾ torn. Probably also rupture of achilles tendon.
Assessment	Debridement and external fixation of ankle. Eventually plaster of paris. Conservative therapy
MTS score	1b
AIS score	2
AO score tibia	41-, 42-, 43-, 44 C1 (because of ligamentous injury and chip fracture)
AO foot	71. 72. 73
Other medical score	Gustilo 2





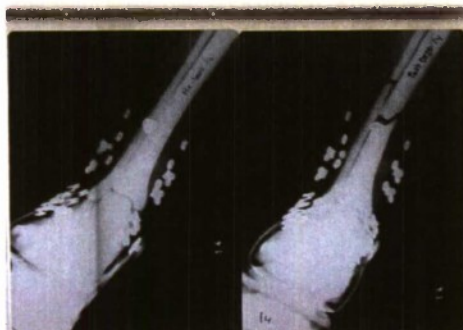
Testnr	13
Date	4-10-07
charge	50 gram
Type of surrogate	FSL
Shoe type	Zeman
Remarks	<p>Leg did not fit into the shoe. Ankle too stiff and foot too wide. Shoe was cut open, to be able to better place foot into shoe. But still damage of gelatine prior to test. Pretest x-ray performed to show damage prior to test.</p> <p>The positioning of the leg is not so tight, especially compared to the CLL fixation. However, this is the standard fixation of the FSL. The nylon stockings were not used anymore with the FSL, since it is more difficult to put the shoe on. A plastic bag was used to put the foot into the shoe.</p>
Pre test x-ray	Ok, no injuries seen
Post test remarks	Leg came loose from support at knee joint. Fixation was only with 2 small bolts, which came off the bone structure. Tibia part was torn out of the soft tissue. Shoe found few meters away. Leg part found even further away.
Post test boot damage assessment	<p>Heel of shoe in many parts, rest of shoe intact.</p> <p>Shoelaces intact, however parts ripped of the leather.</p> <p>Gelatine pushed out the shoe at lateral side of shoe (maybe because shoe was cut open prior to test).</p>
Post test X-ray findings	<p>Tibia not visible and fracture in fibula</p> <p>Foot swollen and multiple bony fragments of hind part (knochensalat).</p>
Post test clinical dissection findings	<p>Tibia fracture and amputation just below the knee probably caused by the test-configuration.</p> <p>Amputation of lower leg at the upper ankle joint. Fibula shows only small fracture. Hind part of the foot destroyed. Frontal part of the foot intact, but soft tissues injury.</p>
Treatment	Below knee amputation
MTS score	2b
AIS score	4
AO score tibia	41 C3, 42 C3, 43 C3, 44 C3
AO foot	71 C3, 72 C3, 73 C3
AO soft tissue	
Other medical score	Gustilo 3b-3c





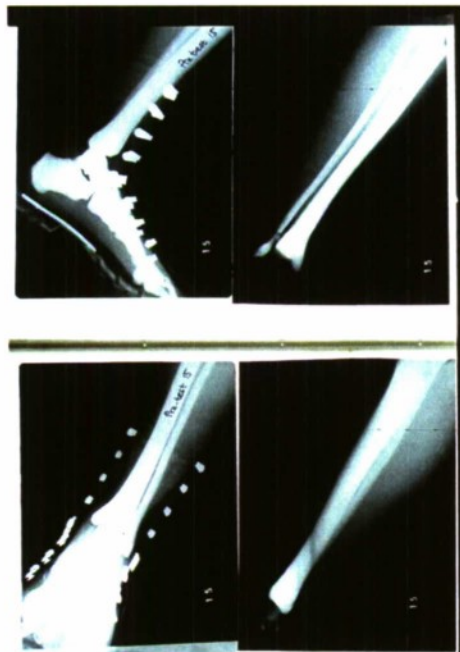
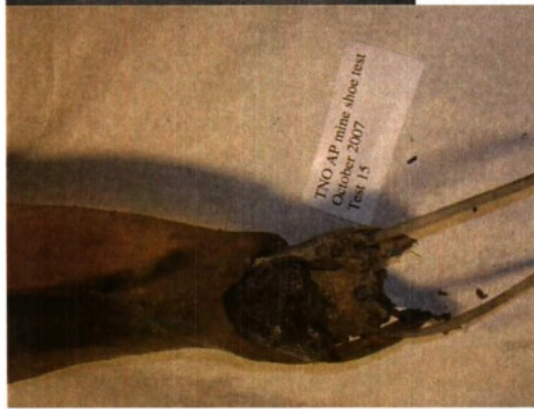
Testnr	14
Date	4-10-07
charge	25 gram
Type of surrogate	FSL
Shoe type	Aigis
Remarks	
pre test x-ray	normal
Post test bevindingen	Leg came loose from support at knee joint. Fixation was only with 2 small bolts, which came of the bone structure. At picking up the leg, it broke just above the shoe level.
Post test boot damage assessment	Heel in fragments. Shoe laces intact and still closed. Innersole shoe and thicker lower layer perforated by bony parts and soft tissue.
Post test X-ray findings	Amputation just below the knee joint probably caused by the test configuration. Fracture lower leg with soft tissue injuries (will be amputation level). Luxation in Chopart en Lisfranc. Multiple fragment calcar bone (Knochensalat)
Post test clinical dissection findings	Fractured lower leg at the level of the shoe shaft. Open calcar fracture. Damaged Lisfranc and Chopart. Separation between 3 <sup>rd</sup> and 4 <sup>th</sup> radius of the mid foot. Ankle ligaments intact
Treatment	Below knee amputation
MTS score	2b
AIS score	3
AO score tibia	41-, 42-, 43 3C, 44-
AO foot	71-, 72 3C; 73 3C
Other medical score	Gustilo 3b





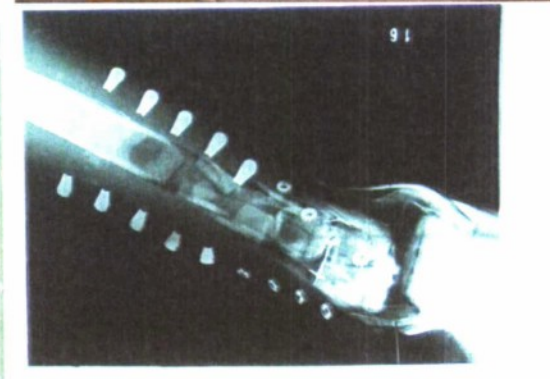
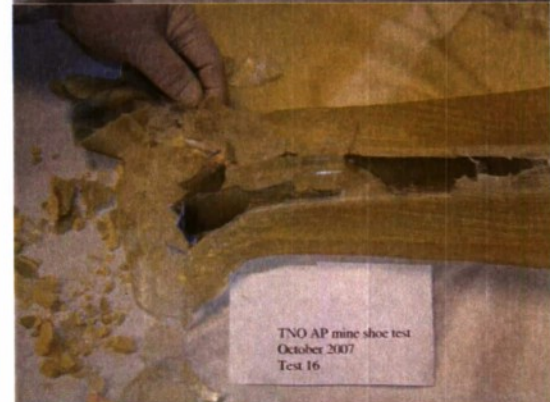
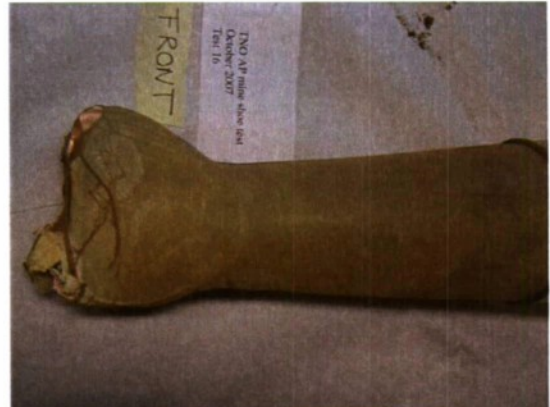
Testnr	15
Date	4-10-07
charge	25 gram
Type of surrogate	FSL
Shoe type	Dutch army boot (same as used in test 2)
Remarks	
Pre test x-ray	normal
Post test remarks	Leg came loose from support at knee joint. Fixation was only with 2 small bolts which came of the bone structure. Shoe in many parts and found everywhere. Foot amputated and thrown away
Post test boot damage assessment	Shoe broken at heel level. Heel in many fragments. Front part of shoe intact. Rest of shoe in many pieces. Shoe laces broken.
Post test X-ray findings	Amputated at ankle joint
Post test clinical dissection findings	Amputation/exarticulation at upper ankle joint. Frontal part of foot intact but separated from rest of foot. Rest of foot and ankle in multiple fragments.
Treatment	BKA
MTS score	2b
AIS score	3
AO score tibia	41-;42-;43 -; 44 C1
AO foot	71 C3; 72C3; 73C3
Other medical score	Gustilo 3b





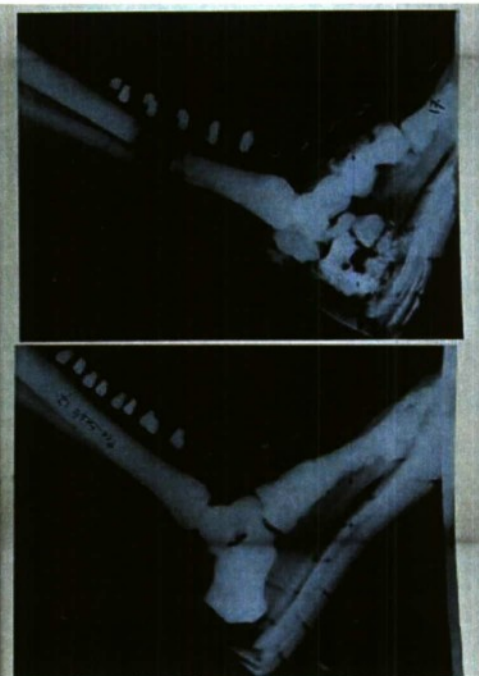
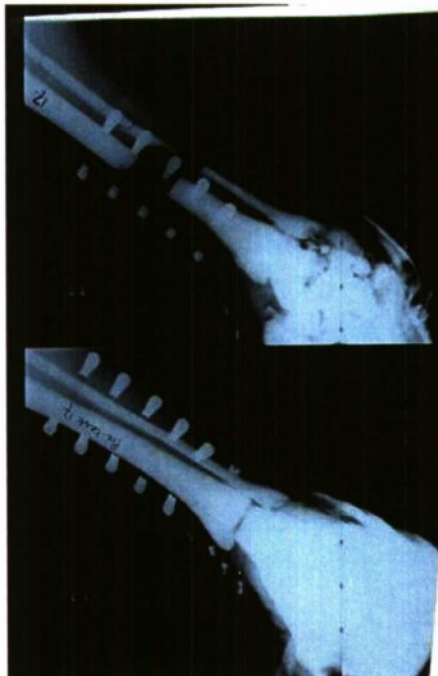
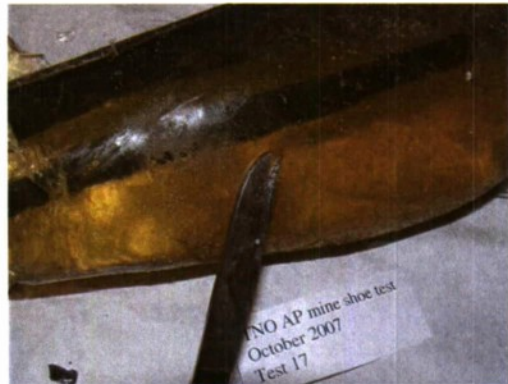
Testnr	16
Date	4-10-07
charge	25 gram
Type of surrogate	CLL
Shoe type	Zeman
Remarks	
Post test remarks	Legposition in x-orientation (valgus)
Post test boot damage assessment	Heel of shoe in many fragments. Heel innersole perforated with bony parts.
Post test X-ray findings	Multiple fragments distal tibia Talar fracture, calcus fractured into multiple fragments (knochensalat) Soft tissue injury of sole of the foot
Post test clinical dissection findings	Too flexible foot/ankle joint with respect to lower leg (mopping). Comminuted distal tibia fracture, talar fracture, calcus fractured into multiple fragments. Soft tissue injury of sole of the foot
Treatment	Below knee amputation
MTS score	2b
AIS score	3
AO score tibia	41-; 42-; 43.3C; 44.3C
AO foot	71 C3, 72-, 73 C3
Other medical score	Gustilo 3b





Testnr	17
Date	5-10-2007
charge	25
Type of surrogate	FSL
Shoe type	Zeman
Remarks	
Pre test x-ray	No injuries
Post test remarks	Leg came loose from support at knee joint. Fixation was only with 2 small bolts, which came of the bone structure.
Post test boot damage assessment	Heel of shoe fragmented Loosening of glue of rubber sole Inner sole perforated with bony parts. Shoe laces intact. Width (both AP and lateral direction) of the foot increased.
Post test X-ray findings	Multiple fracture calcar bone (knochensalat). Damage of Chopart and Lisfranc. Amputation distal cruris (= lower leg amputation) Additional fracture (full fracture) at higher fibula level From x-ray photo during the test the increasement of the enlargement of the midfoot is clearly visible.
Post test clinical dissection findings	Tibia fracture and fibula fracture at 10 à 12 cm above the upper ankle joint. Soft tissue injury: circular (amputation distale cruris) Foot: multiple fragments (knochensalat) Fibula fracture at mid level (weber C) Metatarsus fractured: separation between 2 <sup>nd</sup> and 3 <sup>rd</sup> radius
Treatment	Below knee amputation
MTS score	2B
AIS score	3
AO score tibia	41-;42A3;43C3;44C3
AO foot	71C3;72C3;73C3
Other medical score	Gustilo 3b





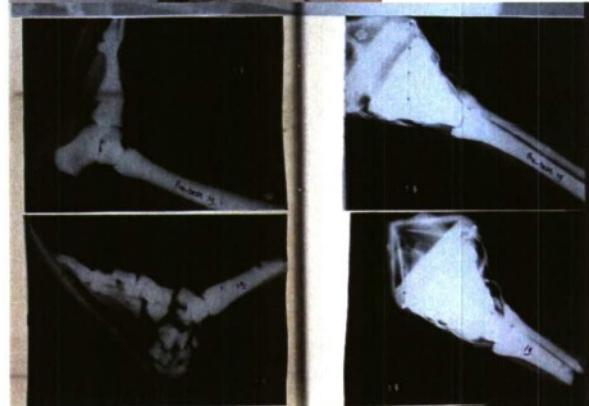
Testnr	18
Date	5-10-07
charge	25 gram
Shoe type	Anonymate
Remarks	
Pre test X ray	No injuries
Post test remarks	Leg broken at fixation point test rig (probably because of test configuration). Leg amputated at shoe level as well.
Post test boot damage assessment	Rubber heel part of shoe extremely stretched and finally turned over the shoe This maybe caused the amputation of the leg. Rear seem partly disrupted. Indent/rupture at heel of inner sole of the shoe.
Post test X-ray findings	Traumatic amputation of lower leg at shoe level. Fractures in upper ankle joint. Damage of Chopart, Lisfranc and middle foot. Soft tissue injuries
Post test clinical dissection findings	Amputation of lower leg distal – 10 cm above the upper ankle joint. Fractures in upper ankle joint. Damage of Chopart, Lisfranc and middle foot. Soft tissue injuries. Metatarsals and toes fractured. Serious soft tissue injuries.
Treatment	Below knee amputation
MTS score	2b
AIS score	3
AO score tibia	41-;42-;43A2;44C3
AO foot	71C3;72 C3;73C3
Other medical score	Gustilo 3b





Testnr	19
Date	5-10-2007
charge	25 gram
Type of surrogate	FSL
Shoe type	Anonymate
Remarks	Same test as test 18, since the results of test 18 were questionable.
Pre test x ray	No injuries
Post test remarks	No breakage of the leg at the fixation point.
Post test boot damage assessment	Heel of the shoe disrupted. Seems at heel level disrupted. Small indent at heel of inner sole of the shoe. Shoe laces intact
Post test X-ray findings	Traumatic amputation of lower leg at shoe level. Fracture in tibia and fibula. Fractures in upper ankle joint. Damage of Chopart, Lisfranc and middle foot. Soft tissue injuries
Post test clinical dissection findings	Amputation of lower leg distal – 13 cm above the upper ankle joint. Fractures in upper ankle joint. Damage of Chopart, Lisfranc and middle foot. Soft tissue injuries. Metatarsals and toes fractured and luxated. Serious soft tissue injuries.
Treatment	Below knee amputation
MTS score	2b
AIS score	3
AO score tibia	41-; 42-; 43A2; 44 C3
AO foot	71 C3; 72 C3 ;73 C3
Other medical score	Gustilo 3a





**ONGERUBRICEERD**  
**REPORT DOCUMENTATION PAGE**  
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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))  This report describes tests of protective footwear (i.e. mine boots) against anti personnel blast mines. The objective of this study is to compare the performance of eight different boots looking at several parameters using two types of surrogate legs, i.e. the Frangible Surrogate Lower Limb (FSLL) and the Canadian Lower Leg (CLL). Analyses of the surrogate legs have been conducted by means of autopsy by a surgeon in the Dutch Armed Forces. Force and displacement measurements were taken for a better understanding of the phenomena. It was found that none of the footwear tested, except one, could prevent amputation of the lower leg for charge sizes of either 25, 50 or 75 grams. The results agree with findings in literature. The CLL and FSLL tests showed similar results, although it should be mentioned that the CLL is more practical in use.		
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- 1 ex. TNO Defensie en Veiligheid, vestiging Rijswijk,  
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