

CHALMERS



Qualities in Öllöv SoftStep

Analysis of Öllöv SoftStep's shock absorbing and vibration damping qualities compared with a steel shoe and unshod hoof, using an accelerometer

Analys av Öllöv SoftStep's stöt- och vibrationsdämpande egenskaper jämfört med en stålsko och oskodd hov med hjälp av en accelerometer

Bachelor's thesis in Mechanical engineering, 15hp

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Cover: Shows a 3D picture of an Öllöv Softstep with the outer layer of rubber peeled of to reveal the inner steel core.

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Abstract

The study is commissioned by AB Halmstad Gummi Fabrik/Öllöv and is in collaboration with Chalmers Sports and Technology. The study concerns the rubber shoe Öllöv Soft-Step, which is a result of a development done on the former shoe, Öllöv Original. Öllöv SoftStep has a forged shoe inside the rubber enclosure and a change in the friction surface to provide a grip similar to the unshod hoof. Former studies have shown that rubber shoes and synthetic shoes have a better impact on the hoof's shock absorbing and expansion qualities.

To measure the shock absorbing and vibration damping qualities, a test including two horses wearing Öllöv SoftStep, steel shoes and unshod hooves was made. The test was designed to be able to measure the qualities on two different grounds, concrete and fibre sand, using an accelerometer attached to the horse's hoof. A logger was attached to the accelerometer with a sampling rate at 7161 points/sec and an associated application connected to an Ipad could process the data during the measurements. The logger provided with raw data which was analyzed in MatLab.

The amplitude values was collected in the five steps in the range of 10 m. Every step had maximum and minimum peak which showed the highest amplitude. Average values for each measurements were calculated in Excel.

To be able to analyze the visible oscillations, every step in the measurements had to be taken into account to be able to find a pattern in every combination of ground and shoe. When the analysis of the vibrations was conducted, the focus was to find characteristics in the oscillations between the steel shoe, Öllöv SoftStep and an unshod hoof in the impact phase of the step.

The analysis of the amplitude showed that Öllöv SoftStep has better shock absorbing qualities than the steel shoe on concrete. Dora's measurements showed a decrease between 12%-28% and for Empe's measurements 69%-76% when comparison with the unshod hoof. On fibre sand there were no significant difference between the shoe types.

The analysis showed that Öllöv SoftStep has better vibration damping qualities than the steel shoe. Öllöv SoftStep has better vibration damping qualities than the unshod hoof, but significance of the differ is not concluded. Öllöv SoftStep has according to the analysis similar vibration damping qualities in fibre sand as an unshod hoof and a hoof wearing steel shoe.

Keywords: Öllöv, vibration, rubber, SoftStep, shock absorbing, damping, horseshoe

Sammanfattning

Denna studien är på uppdrag av AB Halmstad Gummi Fabrik/Öllöv och är ett samarbete med Chalmers Sport och teknologi. Studien handlar om gummiskon Öllöv SoftStep, som är ett resultat av utvecklingen av deras tidigare sko, Öllöv Original. Öllöv SoftStep har en smidd stålsko som omsluts av ett gummihölje med en förändring i friktionsytorna som ska efterlikna greppet på en oskodd hov. Tidigare studier har visat att gummi-och syntetskor har en bättre inverkan på hovens stötdämpning och expansion.

För att mäta de stötdämpande och vibrationsdämpande egenskaperna utfördes ett test med två hästar som var skodda med Öllöv SoftStep, stålskor och då de var oskodda. Testet var designat så att mätningar var utförningsbara på två olika underlag, betong och fibresand, men hjälp av en accelerometer som var fäst på hästens hov. En datalogg var fäst till accelerometern och hade en insamlingshastighet på 7161 punkter/sekund och en tillhörande applikation som var ansluten till en Ipad kunde processa datan direkt. Dataloggen lagrade data som analyserades i Matlab.

Amplitudvärderna var insamlade under de fem stegen hästen tog på den 10 m långa mätningabanan. Varje steg hade ett maximum och minimum värde som visade sig som den högsta amplituden. Medelvärden för alla de olika mätningar räknads ut i Excel för att sedan kunna analysera resultatet.

För att analysera de synliga svängningarna, var varje steg i varje mätning tvungen att tas i beaktning för att kunna urskilja mönster i varje kombination av underlag och sko. När analysen av vibrationerna genomfördes låg fokuset på att se karaktäristiken i svängningarna mellan de två skorna och den oskodda hoven.

Analysen av amplituden visade att Öllöv SoftStep hade bättre stötdämpande egenskaper jämfört med stålskon på betong. Doras mätningar visade en minskning av 12%-28% och för Empes mätningar 69%-76% när Öllöv SoftStep jämfördes med den oskodda hoven. På fibersand var den ingen betydande skillnad mellan de olika skorna.

Analysen av vibrationerna visade att Öllöv SoftStep har en bättre förmåga att dämpa vibrationerna jämfört med stålskon. Öllöv SoftStep hade en något bättre vibrationsdämpning än den oskodda hoven, men exakt hur mycket kunde inte fastslås. Öllöv Softstep har enligt analysen liknande vibrationsdämpande egenskaper på fibersand som en oskodd hov och en stålsko.

Nyckelord: Öllöv, vibration, gummi, SoftStep, stötdämpande, vibrationsdämpande, hästsko

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Contents

Li	List of Tables x List of Figures x							
Li								
1	Intr 1.1 1.2 1.3	oduction Purpose Delimitation Clarification of question	1 1 1 2					
2	Bacl 2.1	kground Hoof-mechanism	3 3					
	2.2	Vibration damage for humans	4					
	2.5 2.4 2.5	Rubber properties	5 5 5					
	2.5	2.5.1 Öllöv SoftStep and differences from Öllöv Original	6					
2	2.0	hod	0					
3	Met	301 Measuring equipment	9					
		3.0.1.1 Accelerometer SEN040F	9					
		3 0 1 2 Data logger HVM200	10					
		3.0.1.3 Metal bracket	10					
		3.0.2 Pre-test at riding cite in Kullavik	10					
		3.0.3 Implementation plan for the test day	11					
		3.0.4 Test site in Vallda	11					
		3.0.5 Horses used during testing day	11					
	3.1	Method for analyzing measurements from testing day	12					
		3.1.1 Approved measurements	12					
		3.1.2 Processing of data	12					
4	Results							
	4.1	Pre-test at riding stable in Kullavik	13					
		4.1.1 Experiences from the pre-test	14					
	4.2	Testing day in Vallda	15					
	4.3	Results and analysis of the testing day	19					
		4.3.1 Approved measurements	19					

		4.3.2 4.3.3 4.3.4	Processing of Amplitude v Vibrations . 4.3.4.1 St	of raw data in Matlab and Excel	19 21 25 25			
			4.3.4.2 O 4.3.4.3 U	Inshod hoof Inshod hoof	28 31			
5	Disc 5.1	ussion Recom	mendations.		35 37			
6	Cone	clusion			39			
Bibliography 39								
A	Docu	ımentat	ion of testing	g day	Ι			
B	Matl	ab code			V			
С	Amp	litude r	esults		VII			
D	Spre	ad of st	eps		XI			
E	Emp	e's vibr	ation measu	irements	XIII			
	E.1	Empe's	measuremen	nts with steel shoe on concrete	XIII			
	E.2	Empe's	measuremen	nts with steel shoe on fibre sand	XIV			
	E.3 E 1	Empe's	measuremen	nts with Ollov Softstep on concrete	XV VVI			
	Е.4 Е.5	Empe's	measuremen	nts on unshod hoof on concrete	XVII			
	E.6	Empe's	measuremen	nts on unshod hoof on fibre sand	XVIII			

List of Tables

4.1	Amplitude for Dora on concrete	21
4.2	Amplitude for Empe on concrete	21
4.3	Comparison between Öllöv SoftStep and steel shoe	22
4.4	Amplitude for Dora on fibre sand	22
4.5	Amplitude for Empe on fibre sand	22

List of Figures

2.1 2.2 2.3	A typical horseshoe made of steel. [1]	3 4 6
3.1	The accelerometer SEN040F which are used during the measurements	10
4.1 4.2	The metal plate attached on the hoof	13
4.3 4.4	The metal bracket attached with two different types of adhesive How the accelerometer is screwed into the metal bracket and how the cord is fixed alongside the leg and into the logger	14 16
4.5	The horse passes through the 10 m track where the measurements take place in the riding hall. Light beam visible on the ground from the high speed camera	17
4.6	Measuring track in stable with concrete as ground and light beam from the high speed camera visible on the ground	18
4.7	The farrier attaches Öllöv SoftStep on the hoof in between the measure-	18
4.8	How measurements differ from concrete to sand	20
4.9	How the middle pulse's amplitude is higher than the rest at concrete for Dora.	23
4.10	How the pulses are more even at sand for Dora	24
4.11	How the middle pulse amplitude is higher than the rest at concrete for Empe	24
4.12	How the pulses are more even at sand for Empe	24
4.13	The characteristics of the oscillations in x-direction of the hoof wearing a steel shoe on concrete.	26
4.14	The left show the character of the oscillation in y-direction and the right	27
4.15	The oscillations in x-direction of the hoof wearing a steel shoe on fibre sand.	27
4.16	The left show the character of the oscillation in y-direction and the right in z-direction, in combination of steel and fibre sand.	28
4.17	The characteristics of the oscillations in x-direction of the hoof wearing a Öllöv SoftStep on concrete.	29

The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of Öllöv SoftStep and concrete.	30
The oscillations in x-direction of the hoof wearing Öllöv SoftStep on fibre sand.	30
The left shows the character of the oscillations in y-direction and the right in z-direction, in combination of Öllöv SoftStep and fibre sand.	31
The characteristics of the oscillations in x-direction of the unshod hoof on concrete.	32
The left shows the character of the oscialltion in y-direction and the right in z-direction, in combination of unshod hoof and concrete	33
The oscillations in x-direction of the unshod hoof on fibre sand The left shows the character of the oscillation in y-direction and the right	33
in z-direction, in combination of rubber and fibre sand.	34
both on concrete.	37
The oscillations in x-direction of the steel shoe hoof on concrete	XIII
in z-direction, in combination of steel and concrete.	XIV
The left shows the character of the oscillation in y-direction and the right	
The oscillations in x-direction of Öllöv SoftStep on concrete.	XV XV
The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of Öllöv SoftStep and concrete	XVI
<i>The oscillations in x-direction of Öllöv SoftStep on fibre sand.</i>	XVI
in z-direction, in combination of Öllöv SoftStep and fibre sand	XVII XVII
The left shows the character of the oscillation in y-direction and the right	VVIII
<i>In z-airection, in combination of the unshod hoof and concrete. The oscillations in x-direction of the unshod hoof on fibre sand.</i>	XVIII XVIII
The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of the unshod hoof and fibre sand.	XIX
	The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of Öllöv SoftStep and concrete. The oscillations in x-direction of the hoof wearing Öllöv SoftStep on fibre sand. The left shows the character of the oscillations in y-direction and the right in z-direction, in combination of Öllöv SoftStep and fibre sand. The left shows the character of the oscillations in x-direction of the unshol hoof on concrete. The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of unshol hoof and concrete. The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of the unshol hoof on fibre sand. The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of rubber and fibre sand. The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of the steel shoe hoof on concrete. The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of steel and concrete. The oscillations in x-direction of the steel shoe hoof on concrete. The oscillations in x-direction of the scillation in y-direction and the right in z-direction, in combination of steel and concrete. The oscillations in x-direction of the steel shoe nof fibre sand. The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of steel and fibre sand. The left shows the chara

1

Introduction

For several thousands of years horses have played an important part in the history of everything from agriculture to warfare, but the more the society developed, the horses part changed. Nowadays the horses are mostly used for equestrian sport and in some cases forestry. The use of the horses exposes them to more strain than they were initially build for. For centuries the horses have been shod with different types of steel shoes, but newer shoes with more developed materials and functions are trying to enter the market against the more established steel shoe.

1.1 Purpose

The purpose of this task is to analyze and evaluate how Öllöv SoftStep behaves during use. The importance of the task lies on the shock absorbing and the vibration damping qualities in Öllöv SoftStep and if it's a better option compared with the classic steel shoe or the unshod hoof based on the analyze.

This study is the first one made on Öllöv SoftStep, therefore the study is going to be the foundation of the future measurements done by AB Halmstad Gummifabrik.

1.2 Delimitation

The assignment will not include working with the development of the shoes construction or any re-design.

The measurement will compare a steel shoe, Öllöv SoftStep and a unshod hoof on the ground of concrete and fibre sand.

The measurement will be taken on two different horses using the steel shoe, Öllöv Soft-Step and an unshod hoof. In this study two horses are used in the measurement and the results from the measurements will be what the conclusions are being based on. Due to time- and logistics limitations there will be no more tests done during this study. During the measurement the horses will be tested in trot. The measurements will be done in the course of one day.

Long term impact on the horses health, particularly the long term well-being of their hooves and in consequence of wearing the different types of shoes is not going to be included in this project due to that is a long-term study, and therefore out of the time range.

1.3 Clarification of question

Questions that will be answered within the end of the project are:

- How good is Öllöv SoftStep shock absorbing qualities?
- How well can Öllöv SoftStep attenuate vibration?
- Is Öllöv SoftStep a better option than the steel shoe according to the analysis?

The results will be compared with the results of a steel shoe and an unshod hoof.

2

Background

To minimize the wear on the hoof, the horse is provided with shoes. The majority of these shoes are made out of steel. Öllöv has developed a shoe with a core of steel and a enclosure of rubber. Rubber is known for its shock absorbing and vibration damping qualities. Horses in all kinds of disciplines is subjected to strain on hooves, joints and back. A shock absorbing shoe can contribute to that the horse is subjected to less strain, which can have positive effects during the horses entire life span.

Figure 2.1 shows a typical horse shoe made out of steel. In the slit are four square holes are placed, this is where the farrier attaches the seams. The seams attached the shoe on the horse's hoof. On both ends of the shoe, two round threads are drilled. These holes are used to screw in studs that give the shoes attachment on slippery grounds.



Figure 2.1: A typical horseshoe made of steel. [1]

2.1 Hoof-mechanism

The hooves carry the horses weight and is therefore constantly exposed to strain. The part that embraces the core of the hoof is called horn and consists of dead tissue. The horse shoe is attached with seams around the hoof in the horn because there isn't any nerve fibres in the horn and therefore no unpleasant pain for the horse.

The bottom of the hoof is divided in such way as figure 2.2 shows. The hoof works as a natural shock absorbing system and provides the horses blood circulation. When the hoof is pressed against the ground it gives a pressure against the frog, which press against the digital cushion inside the frog and it starts the pumping of the blood. The digital cushion gives a pressure on the cartilage which make the hoof expand [2].



Figure 2.2: The division of the main parts of the hooves bottom [3].

2.2 Vibration damage for humans

The damage of vibrations for humans is a common issue in jobs including vibration tools. These damages are separated in hand-and arm vibrations (HAV), which includes tools that's been used by the hands and body vibrations (HKV) which includes working with vehicles such as trucks, buses, excavator etc. The vibrations damage the capillaries and is hurting the nervous system.

Vibration damages doesn't appear immediately, but occurs several years later. These injuries may occur for example as pain in hands and fingers, muscles weakness and numbness in body parts exposed to the vibration[4].

To avoid these types of vibration damages the work environment authority in Sweden have identified the requirements which has to be met by the machines in use. Requirements are stated as limit values and input values. The limit value for HAV of 5 m/s^2 if it's

exceeded it implies immediate action by the employer. The input values for HAV of 2.5 m/s^2 , if this value is to be exceeded it implies a demand of medical controls and a demand that action is taken to reduce the vibration in the tool or vehicle. These values are seen as the maximum daily exposure to vibration [5].

2.3 Problems with current solution

The problem with a steel shoe is that it's impairs the hooves natural shock absorbing system by assisting the hoof with the stiffer material. If it's to thick it also impairs the blood circulation from the hoof, due to that the frog do not get in touched with the ground. Research has been made to produce shock absorbing ground for riding halls and paddocks, but it still remains that the natural shock absorbing quality in the hoof is still reduced due to wearing shoes [6].

Today, infrastructure is built around a society which is depending on vehicles, and therefore roads are intended for vehicles. This means that the roads are hard and stiff. The natural habitat of the horses does not include asphalt or concrete, which contributes to more strain on the horses joints and ligaments than they are made for. The classic steel shoe protects the hoof from unnatural wear, but does not contribute to any shock absorption against these harder grounds.

2.4 Rubber properties

Rubber is a viscoelastic material [7] with many desirable properties. Before the synthetic rubber materials could be fabricated, rubber was synonymous with natural rubber which is usually made from latex, the gum tree's milk juice. The latex is treated and then mixed with a variety of additives to achieve the desired properties, when added together they have formed a rubber material. [8]. Rubber is a very elastic material that has many uses. Rubber is commonly known for use as vibration-and shock absorbers.

2.5 Öllöv and Halmstad Gummifabrik

This study is in collaboration with Öllöv which are a part of AB Halmstad Gummifabrik, from now on is going to be recalled as HGF. HGF are a company that specializes in production in rubber and thermoplastics. They have their head office and production facility in Halmstad, Sweden and another production facility in Riga.

Öllöv is a brand belonging to HGF. The brand was founded around the same time as the first shoe was launched, Öllöv Original. Before this, there had been some studies that were based on the patent [9] that were bought 1993 of its owner Lone Pedersen.

2.5.1 Öllöv SoftStep and differences from Öllöv Original

Öllöv SoftStep is a horseshoe with a steel core with a rubber enclosure as can be seen in figure 2.3. The idea of the shoe is that it will optimize shock absorbing, minimize vibrations and mimic the movement pattern of an unshod hoof and therefore be a better option than the steel shoe.



Figure 2.3: Öllöv SoftStep i partly section view.

Öllöv SoftStep has been developed after several years of studying the previous one, Öllöv Original. The friction surface has been changed to provide a grip more similar to an unshod hoof. In Öllöv Orginal the core was cut out from steel, therefore it was harder to shape and process the shoe for farriers, to do this they needed special tools. This is changed in Öllöv SoftStep to be a forged shoe inside a rubber enclosure. To shape and progress SoftStep is the same as to shape and progress a traditional steel shoe.

2.6 Former studies

In a study from 2006 [10], measurement were made on unshod hooves, steel shoes and synthetic shoes made by polyurethane. The study contained 12 horses, two geldings and two mares in ages between 5-20 years old. The horses were Dutch warm-blood horses with a height between 160-171 cm.

A hypothesis was established that synthetic materials can have a positive impact on the horses joints and prevent lameness and then too chronic articular. According to the author, there is not enough research to ensure this hypothesis. They explain that when the hoof is in direct contact with the ground, the speed is reduced and the distal phalanx, the lower part of the legs bone, is almost zero. This is known for the most critical part of the horse movement when it comes to injuries of the musculoskeletal system of the horse and is called the impact phase.

The group who preformed the measurements chose to convey the horses in trot. They considered that it would minimize the risk of interference in the vibration. The length of the track that preformed the measurements on were 10 m and in a successful test the horse held a mean speed of 3.5 m/s. They calculated the time by the length of the track by the time it took for the horse to get between start and finish. A minimum of six successful trials was collected for each horse wearing each shoe and unshod, so it was 72 trials altogether.

They used a triaxial piezoelectric accelerometer which they attach on the lateral side of the hoof on the horses left feet. To attached the accelerometer they first cleaned the area on the hoof with ethanol an than fixed an aluminum bracket with fast-drying adhesive. To be able to attach the bracket in a similar position on all horses, they attached the brackets lowest part 7-8 mm to the hooves bottom in a perpendicular position towards the ground. The total mass of the equipment was 19.9 g.

The result of the measurements showed that the different in an unshod hoof and the steel shoe were not significant, but the mean relative frequency in the steel shoe was significant higher. The synthetic shoe had a significant lowering of the deceleration amplitudes in the mean maximum values.

During a two year period, 1996-1998, Swedish Agricultural University in Uppsala and HGF made a research about the Öllöv original [11]. These studies included a total of measurements on 32 different horses spread over three different test occasions. Measurements have been made on steel shoes, rubber shoes and unshod hooves. A lot of focus was on measuring the sliding-phase between hoof and ground in the different combinations of shoes and surfaces.

The study reported on how the hoof is given the opportunity to expand, which in itself is a shock-absorbing function in the horse's anatomy. In general, it can be said that the unshod hoof always has a lager expansion than a shod hoof. It is because of the fact that when a hoof is shod, the walls of the hoof will be fixed in the shoe to some extent. The study showed that a hoof shod with Öllöv original increases expansion compared with the traditional steel shoe. In walk, expansion increases by 44 percent and at trot by 19 percent. Expansion of the hoof is important to keep the hoof in a good condition due to blood circulation among other things.

In U. Yxklintens report from 1996 [12] he summarizes measurements done by S. Drevemo and C. Jonhston 1992 [13]. The study was done on three horses shod with steel shoes,

without any shoes and rubber shoes -Öllöv original. The horses was led by hand forward with a velocity of 3 m/s. In the study the acceleration in vertical direction was measured in contact with concrete and also on an dirt track. The results of the study shows that the rubber shoe completely attenuated the shock and the vibrations that occurs in contact with hard ground while the steel shoe and the unshod hoof does not, and therefore the vibrations will spread up to the horses leg and tissues.

3

Method

The tests will be held at a riding cite with two different horses and each will be tested with Öllöv SoftStep, steel shoes and unshod hooves on concrete and fibre sand. To measure shock absorbing and vibrations during the test, an accelerometer will be used. The accelerometer will be attached on the lateral side of the hoof by a metal bracket and a cord will connect the accelerometer to the logger.

3.0.1 Measuring equipment

To be able to measure the acceleration, there will be a need of certain equipment. To sample the acceleration values and to store the data that is sampled there will be a need of an accelerometer, a logger and a metal bracket to attach the accelerometer on the hoof.

The testing day is going to be conducted in collaboration with an other project group, which task is to measure and analyze the sliding phase in the same combinations. Due to this they are going to use a high speed camera which is going to be placed in the middle of the 10 m measuring range.

3.0.1.1 Accelerometer SEN040F

The accelerometer is called SEN040F and has the ability to measure accelerations in three directions, x, y and z. Dimensions of the accelerometer is $10,2 \times 19,6 \times 10,2$ mm and weight 5.3 g, see figure 3.1. The dimensions are small and the weight is low compared to the hoof so the perception is that it will not affect the horse and the measurements noticeably [14].



Figure 3.1: The accelerometer SEN040F which are used during the measurements.

3.0.1.2 Data logger HVM200

To be able to view and store the results from the accelerometer, the logger HVM200 [15] is used. It can be used to measure hand-arm, whole body and general vibration. In this study it is going to be used to store vibration and shock absorbing values on the hoof. To be able to see the measurements directly there is an application to HVM200. The logger supports a removable micro SD memory, so it's possible to store received data into 24-bit format and files can be read with tools as Matlab [16]. The sampling rate in the combination of accelerometer and logger is 7161 points/sec.

3.0.1.3 Metal bracket

The metal bracket will be constructed with measurements similar to the accelerometer. The accelerometer has the dimensions 10×10 mm, and therefore the metal plate will be 15×15 mm. The metal bracket dimension is limited due to the hooves shape. A hoof is arched all the way around and the larger the dimensions are, the bigger risk there is that the space between the metal bracket and the hoof creates vibration which can interfere will the actual vibration the group is interested in.

3.0.2 Pre-test at riding cite in Kullavik

Before the actual test the student group will preform a pre-test on the accelerometer and logger that will be used during the test day, as a preparatory measure. The metal bracket that is constructed to be attached to the horses hooves and concatenate the accelerometer will also be tested. The metal bracket will be fixed on the horses hoof using adhesive. The pre-test will be done on one horse and the purpose of this is to understand the accelerometers function, the best way to attach the metal bracket and to see how the logger stores the data.

3.0.3 Implementation plan for the test day

The test day is estimated to take a whole workday, approximately eight hours. The farrier and the horses have a travelling time in over two hours, therefore the preparations of the tests will start at 9:00 AM. The preparations include measure out a track of exactly 10 m. There is of highest importance that the horses keep similar speed during this length range, else the data from the accelerometer will not be comparable between the different shoes and grounds.

The horses will arrive wearing steel shoes, therefore the first tests will be done on the steel shoe. When the first measurements are done on both steel shoe and unshod hoof, the farrier will attach Öllöv SoftStep. If the day goes according to the implementation plan there will always be a horse available for measurements.

During the whole day there will be five people which monitors the tests. The first one is in charge of the timing, this is carried out by a stopwatch which will start when the equestrians passes the first mark and stops when the equestrians passes the finish line of 10 m. The second one monitors the application, so the data is transmitted correctly to the logger. The third one stores the time range and the accelerometers start time. The fourth monitors the assembly of the equipment between the different horses. The fifth monitors the high speed camera, the data from the high speed camera will not be presented in this study.

3.0.4 Test site in Vallda

The facility is located in Vallda, south of Gothenburg. The facility is a horse farm equipped with a riding hall and stable where the floors are made of concrete. These boxes will be used as store a desk with a computer which controls high speed camera. They will also be used as protection towards the horse who will trot along the corridor.

The riding hall is 30 x 60 m where the long side of the hall will be used for the 10 m track. The riding hall is equipped with cones, which will be used to mark the length of the tracks. Fibre sand is an underlay used in riding halls and paddocks. It is a micro-fibre reinforced, sand based underlay with shock absorbing properties [17]. The fibre sand that were being used had 21 kg fibres/ton mixed sand and consisted of 1.8 % water.

3.0.5 Horses used during testing day

The horses which will be used during the test were brought to the location by its owner on the testing day. The owner is also the farrier which will be in charge of the ferrule. During the test an equestrian will control the horses gaits, direction and speed. The horses will be equipped with saddle and trans. Due to the fact that the tests will take a full day and that living animals are involved, the horses welfare will always come first and how the horses react to the environment can not be controlled.

Both horses are of the breed P.R.E. P.R.E. derived from Spain and is imported to Sweden. The breed is trained in a variable of disciplines and is a very benevolence horse. The

P.R.E. has tactile motion patterns with energetic and forward moving movements. [18]

The horses involved in the test are Emperador and Emparadora. Emperador, from now on is going to be referred to as Empe, is a gelding, 14 years old, weighs around 600 kg and is 1.66 m high. Emparadora, from now on going to be referred to as Dora is a 14 year old mare, weighs around 500 kg and is 1.52 m high. The height of the horse is measured from the ground up to the withers.

3.1 Method for analyzing measurements from testing day

This section describes which tools that are going to be used when analyzing the sampled data from the testing day.

3.1.1 Approved measurements

For the measurements to result in a correct analyze, it is important that the speed during the tests are similar to each other on both of the grounds. The time it takes for the horse get from one side to the other in trot is being measured by a stopwatch and stored into a document. Five measurements for each horse will be analyzed and those which differ the most are not included in the analyze.

3.1.2 Processing of data

When all measurements are done the raw data is going to be stored and be analyzed in Matlab and Excel.

There is accompanied program to the logger that can be used for analyzing the measurements, but accuracy in that program is only 1 point/sec and when using Matlab there can be 7161 points/sec and therefore that is preferred. To the logger a Matlab code is accompanied for creating graphs over the measurements. This code is in need of some modification to reach this analysis purpose.

The measurements that are inside the 10 m track, are the ones that are going to be analyzed, but the total measurement length is longer and includes values before and after the 10 m track. Due to this it is important to be able to choose which interval that is going to be analyzed. The measurements are going to be presented as graphs with impulses, one impulse for each step of the horse. Maximum value of these impulses are what's going to be analyzed in deciding how well the shock absorbing is. The comparison between the different horses wearing the different shoes will result in the analysis of the best shock absorbing choice.

The vibrations damping will be analyzed by observing the different graphs for the diverse combination of horse, shoe and ground. The comparison between the different horses wearing the different shoes will result in the analysis of the best vibration damping choice.

4

Results

In this section, the results are presented. In how the the pre-test resulted in and the experience that were needed to the testing day. Results from the measurements and the analyze of these.

4.1 Pre-test at riding stable in Kullavik

The group arrived to the stable in Kullavik to do the pre-test on the accelerometer, the logger and how well the adhesive attached on the hoof. Sofie Sandhagen from HGF participated in the test and brought all the equipment as needed to the pre-test. The horse Carpe Vita and his equestrian Emma Sjölin participated during the whole time.

The hoof's lateral side was cleaned with water and a cloth to make sure that the adhesive attached properly. The first adhesive which was tested was a quick drying adhesive, which was produced to fit rubber and plastic. This adhesive turned out not to meet the requirements, thus the metal bracket fell of quite easy. The same surface was once again cleaned to remove residual adhesive before the second adhesive was applied. The second adhesive which was used was a partly flexible with a slightly longer curing time. This adhesive was stronger and easily removed by acetone after the test. The position of the metal bracket is shown in figure 4.1. Dimensions of the metal bracket were 15 x 15 mm and had a threading that went all through its width.



Figure 4.1: The metal plate attached on the hoof.

The accelerometer was screwed into the metallic brackets threading and the cord was attached. The cord is 1.5 m long and the idea is that it's long enough to attach the logger somewhere on the horses body. During this pre-test the cord was fixed along the horses leg with two velcro straps. The logger was put in a accompanied arm pocket that was attached around the rider's calf. The cord could be led trough the stirrup and finally be attached to the logger as can be seen i figure 4.2.



Figure 4.2: The cord's attachment along the horse's leg from the accelerometer to the logger.

After a couple of runs the equipment was up running together with the application and in real time showed how the shocks varied in the different directions. Due to a slightly loose fixed cord only walking was tested to avoid the horse getting tangled up.

4.1.1 Experiences from the pre-test

The group quickly notice that the horse lost patience, so the first learning was to bring some snacks for the horses. Water and a cloth for cleaning the hoof worked for the short time of the pre-test but for the testing day there will be needed some more accurate cleaning method.

The horse that were involved was 1,63 m high and to that the cord's length was long enough to be attached to the equestrian's boot, but that can be changed due to the horses size on the testing day.

To prevent that the horses will be affected or to get tangled up in the cord it is important that the cord socket on the accelerometer is pointed upwards, in contrast to this time when it was pointed forward. Due to this it is important how the metallic bracket is fixed on the hoof in the start of the tests. For the cord to be held in place alongside the leg of the horses we will be in need of a flexible sling. While the horses are moving it's important that the cord never gets completely stretched to protect the accelerometer, the logger and to retain the horses natural movement pattern. The attachment of the logger can differ on different horses and from this method used in the pre-test.

After dismantling the equipment from the horse and the analyze of the sampled values in the accompanied computer program we realized that it was problematic to understand in which direction the sampled valued belonged to. The most accurate would be a function in the accelerometer, to reset the directions to zero, but it seems like there is no such function. Therefore the attachment of the metallic bracket is of highest importance, the accelerometer has to be perpendicular to the ground. Consequently the aim is that the cord socket of the accelerometer is pointed straight up so that shocks and vibrations will be sampled in an optional way.

4.2 Testing day in Vallda

The two students groups which will preform the tests met with Sofie Sandhagen and Beate Sofie Fredriksson at the horse cite in Vallda. One student group started with the assembling of the high speed camera and the other group started preparing the accelerometer and the attachments of the accelerometer. The 10 m track were also measured and marked by cones in both the riding hall and the stable hall. The equipment was first installed in the riding hall were the first measurement took place.

Unlike from the pre-test, metal brackets were used which were a bit thicker. The reason for this was to not risk to get glue in the threading and the accelerometer to get stuck. The dimensions of the metal brackets are $15 \times 15 \times 8$ mm and had a weight of 13.5 g and the threading does not go all way through.

The group made a decision to use a another adhesive than the one at the pre-test, which was an adhesive constructed for metal, plastic and rubber. The problem with this adhesive was that the surface on the hoof was to slippery, which made the metal bracket to fall of when the accelerometer was attached. The group decided to use the initially adhesive and to strengthen the attachment with a special hoof glue around the edges of the bracket, see figure 4.3. The lateral side of the hoof was grinded to get a flatter surface to make sure the metal bracket would stay in place.



Figure 4.3: The metal bracket attached with two different types of adhesive.

The cord between the accelerometer and the logger was attached in three places along the horses leg with elastic bandage. The bandage was attached to the horses during the whole day. When changing horse between the measurements, the cord could easily be pulled through. The logger was attached in another way than during the pre-test. The accompanying arm socket were still being used, but it was attached onto the webbing, as can be seen in figure 4.4, where also the way the accelerometer was screwed into the metal bracket can be seen.



Figure 4.4: How the accelerometer is screwed into the metal bracket and how the cord is fixed alongside the leg and into the logger.

Figure 4.5 shows when the horse passes through the measuring track in the riding hall with fibre sand as ground. In figure 4.6 there can be seen what the measuring site looked like in the stables when measurements were done on concrete as ground. In the both pictures it can be seen a light beam that hits the ground. The light beam is part of the high speed cameras equipment.



Figure 4.5: The horse passes through the 10 m track where the measurements take place in the riding hall. Light beam visible on the ground from the high speed camera.



Figure 4.6: Measuring track in stable with concrete as ground and light beam from the high speed camera visible on the ground.

When the steel shoe had been tested on fibre sand and concrete, the farrier removed the shoes so the tests could be made on an unshod hoof and later on the farrier attached Öllöv SoftStep, see figure 4.7



Figure 4.7: The farrier attaches Öllöv SoftStep on the hoof in between the measurements.

During the first measurements in the riding hall, the high speed camera processed the images slowly and the memory on the computer was soon filled, so the files from the camera had to be transferred to other computers. This was unfortunately very time consuming. The original plan was to measure on three horses but this were where the decision was made to only proceed the rest of the measurements with two horses. The following measurement went as planned and a total of 103 measurements were sampled with the accelerometer.

4.3 Results and analysis of the testing day

The approved measurements were calculated and processed in MatLab and Excel. The results of the measurements will be presented in the analysis of the amplitude and the analysis of the vibration damping.

4.3.1 Approved measurements

With a stopwatch the time for each measurement was stored in a document alongside with measuring number, the type of ground, which horse and shoe type. Number of measurements sampled for each ground, horse and shoe type varied between 6-13, depended on there had been a successfully photo taken by the high speed camera or not. The sampled values of the times it took to trot the 10 m long track were converted to a average time and speed for each horse. Dora had a average time om 3.4 s and Empe 3.6 s, that is equivalent to a speed of 2.9 m/s for Dora and 2.8 m/s for Empe. Average time for both horses were 3.5 sec and speed were 2.8 m/s.

Five measurements that differed the least from the average time for each horse was selected for each ground. horse and shoe type. The documentation of the measurements can be seen in appendix A. The measurements that were approved are marked with green colour and the measurements there were not approved are marked with red colour and the letter 'd' i the second column. This screening of the measurements resulted in that the maximum deviation for all the measurements was 0.31 and the average deviation was 0.10 sec on the 10 m track. These measurements proceeded into the analysis, a total of 60 measurements.

4.3.2 Processing of raw data in Matlab and Excel

Maximum and minimum of the impulses in the graphs can be seen quite clearly in the Matlab code accompanying the logger. To choose and be able to store the values for further analysis, a self-composed code was added to the initial code.

Since every measurement started the sampling before the 10 m interval, there was important to be able to choose interval in the graphs. Sampling time for the measurements were around 30 sec and in this graph the interval of 3.5 s were interesting for the analysis. The 3.5 s of the measurement represent approximately $25x10^3$ number of points on the graphs x-axis. When the measurements were taken place on the fibre sand the right interval occurred around 20 seconds into the measurement, which on the x-axis in the figure

is approximately $14.3x10^4$ number of points. On concrete the time into the right interval is around 5 s, which is around $3.5x10^4$ number of points at the x-axis of the graphs. Example of how the different measurement looks like without having zoomed in is shown in figure 4.8 with a graph from a concrete measurement on the left side and a graph from a fibre sand measurement on the right side. The scaling on the y-axis of the both graph differ a lot between the measurements.



Figure 4.8: How measurements differ from concrete to sand.

During the 10 m track and the average time of 3.5 s the horses take 5 steps with each leg, that is five impulses on the graph.

Maximum and minimum values was collected from the graph using 'ginput' in Matlab and to be able to zoom and choose the right interval, the Matlab function 'waitforbuttonpress' were used. The modified Matlab code can be found in appendix B. Maximum and minimum values for each impulse were stored in vectors that later got transferred to Excel to better clarity over the results and to a continuously analysis.

In Matlab, a Z-vector of five maximum and five minimum values was created and transferred to Excel, they were converted to absolute values and stored in a S-vector. Of these an average and a median were calculated for every measurement.

In an F-vector, the highest absolute values for each impulse were stored in Matlab and transferred to Excel, five values for each measurement. In the same way as for the Z-vector an average and an median were calculated to be compared with the other measurements.

For each measurement, a maximum value was stored, that is the highest absolute value for all five impulses for each measurement. This was compared with the same values for the other measurements. The entire document of all the sampled values can be found in appendix C.
4.3.3 Amplitude values to analyze shock absorption

From the analysis that can be seen in appendix C, it had been summarized into four tables, one for each horse and ground. The average values of the measurements can be viewed in the tables. Last row is the maximum amplitude over all the measurements. In the columns for steel shoe and Öllöv SoftStep there is also a percentage within brackets and is the difference from the unshod hoof. Calculated according to:

$$\frac{unshod - (steel/rubber)}{unshod} = (\%)$$

I table 4.1 and 4.2 the the concluded results from concrete as ground for both Dora and Empe.

Do	ora on concrete [#	m/s^2]	
	Steel	Unshod	Öllöv SoftStep
Average max and min values	4286 (+71%)	2500	2194 (-12%)
Average absolute values	6219 (+88%)	3307	2643 (-20%)
Average maximal values	8066 (+46%)	5531	4039(-27%)
Max of maximal values	11046 (+52%)	7290	5238 (-28%)

Table 4.1: Amplitude for Dora on concrete

 Table 4.2: Amplitude for Empe on concrete

En	npe on concrete	$[m/s^2]$	
	Steel	Unshod	Öllöv SoftStep
Average max and min values	4110 (+28%)	3215	1005(-69%)
Average absolute values	4963 (+9%)	4562	1371 (-70%)
Average maximal values	6451 (-4%)	6741	1649 (-76%)
Max of maximal values	7636 (+7%)	7165	2125 (-70%)

The values show that Empe has a more powerful downturn than Dora. Despite this, Dora has the highest sampled maximum values from all the 600 sampled values of 11 046 m/s².

On concrete it's quite clear that the amplitude values is lower in every aspect wearing Öllöv SoftStep compared to the two other options, steel shoe and unshod hoof. For Dora the decrease is between 12% to 28% and for Empe the decrease is considerably higher, between 69% to 76%.

The increase from unshod to steel shoe in almost the opposite. The increase for Dora is big, it lies between the percentage of 46% to 88% while Empe has a smaller increase from 7% till 28% and on the average of maximum values he has a decrease of 4 percent from the unshod hoof.

Due to that the percentage is quite different for the two horses there is a comparison just between steel shoe and Öllöv SoftStep. This was done in a simple way just to see how large part the Öllöv SoftStep values is of the steel shoe values according to:

$$\frac{rubber}{steel} = (\%)$$

The results can be seen in table 4.3 where the percentage is presented in the right column.

Concret	$te [m/s^2]$		
De	ora		
	Steel	Öllöv SoftStep	%
Average max and min values	4286	2194	51
Average absolute values	6219	2643	42
Average maximal values	8066	4039	50
Max of maximal values	11046	5238	49
En	npe		
Average max and min values	4110	1005	24
Average absolute values	4963	1371	28
Average maximal values	6451	1649	26
Max of maximal values	7636	2125	28

Table 4.3: Comparison between Öllöv SoftStep and steel shoe

In comparison just between Öllöv SoftStep and the steel shoe there is more similarities between the two horses results. For Dora the results lie between 42% to 51% and for Empe it's more even and lies between 24% to 28%.

In table 4.4 and 4.5 the results from fibre sand as ground can be seen.

Table 4.4: Amplitude for Dora on fibre sand

Do	ra on fibre sand	[m / s ²]	
	Steel	Unshod	Öllöv SoftStep
Average max and min values	191 (+1%)	189	184 (-3%)
Average absolute values	260 (+11%)	235	265 (+13%)
Average maximal values	293 (+6%)	277	288 (+4%)
Max of maximal values	327 (-13%)	375	347 (-7%)

Table 4.5: Amplitude for Empe on fibre sand

Em	pe on fibre sand	[m/s ²]	
	Steel	Unshod	Öllöv SoftStep
Average max and min values	112(+5%)	107	92 (-14%)
Average absolute values	156 (+13%)	138	120 (-13%)
Average maximal values	177 (+11%)	160	141 (-12%)
Max of maximal values	209 (+8%)	194	162 (-16%)

In the measurements done on fibre sand as ground is it a big difference in amplitudes from the measurements being done on concrete as ground. On fibre sand the highest average maximum value from all the measurements is 293 m/s^2 , which only is 4% of the highest average maximum value for concrete at 8066 m/s². This proofs that the fibre sand as ground is absorbing shocks. The differences between steel, unshod and Öllöv SoftStep is not distinct as it was on concrete for the fibre sand measurements.

For Dora the results is unclear thus they vary between -7% to +13% from the unshod to Öllöv SoftStep and from unshod to steel shoe it varies from -13% to +11%. For Empe the differences between the shoe type is clearer thus the amplitude is lower in all aspects for Öllöv SoftStep and higher in all aspects for steel shoe. It is a small variation and the decrease lies between -12% to -16% and the increase lies between +5% to +13%.

The differences between the shoe types on the fibre sand as ground are to small and follow no clear pattern so therefore there is no comparison just between Öllöv SoftStep and steel shoe as in table 4.3 for concrete as ground.

In the measurements done in the stables, on the concrete, there is a pattern that there is increase in amplitude in the middle of the interval, in the measurements done at the fibre sand there is not the same pattern. In figure 4.9 measurements on Dora on concrete can be seen and the increase of amplitude in the middle of the interval. The maximum value is printed in the figure where it occurs. In figure 4.10 measurements for Dora on fibre sand can be seen and the increase of amplitude in the middle can't be seen.



Figure 4.9: How the middle pulse's amplitude is higher than the rest at concrete for Dora.



Figure 4.10: How the pulses are more even at sand for Dora.

In the same way as the figures above can be seen for Empe, on concrete with the increase in amplitude in the middle in figure 4.11 and on fibre sand in figure 4.12.



Figure 4.11: How the middle pulse amplitude is higher than the rest at concrete for Empe.



Figure 4.12: How the pulses are more even at sand for Empe.

At a more accurate analysis of the sampled values the results weren't the same. Each absolute value of the impulses was compared with that measurements average to see how much higher or lower it was. In that way that spread of the more powerful steps could be seen. It resulted in that there was no significant difference in were the most powerful step were in the interval between measurements done on concrete compared with fibre sand. What the comparison did show was that the steps were more even on fibre sand than on concrete. On concrete the average maximum value was 148% higher than the average step for Dora, on fibre sand the same value were 113%. For Empe the same results was 134% and 115%. All the results can be seen in appendix D. That is that both the horses take more irregular steps in the stables on concrete than in the riding site on fibre sand.

4.3.4 Vibrations

According to the Nyquist sampling theorem the maximum frequency is half of the sampling rate [19]. In this logger the sampling rate is 7161 points/sec and therefore the highest frequency the measurements can read is 3581 hertz. This leads to the fact that the frequencies above this can not be presented in a representative way.

To be able to analyze the visible oscillations, every step in the measurements had to be taken into account to be able to see a pattern in every combination of ground and shoe. Every approved measurement on the 10 m track included five steps with the hoof wearing the accelerometer, every step was analyzed with the same value on the graphs axes to give a result that was as representative as possible.

When the analysis of the vibrations was conducted, the focus was to find characteristics patterns in the oscillations between the steel shoe, Öllöv Original and an unshod hoof in the impact phase of the step. The hoof impact is the phase where the hoof interacts with the ground. In the impact phase is where the largest amplitude was collected and where the most intense oscillations during the step occurred.

4.3.4.1 Steel shoe

In the analysis of the steel shoes oscillations for Dora there had a characteristic pattern in the most intensive oscillations in the hoof impact. The interval of the vibrations starts off with intense oscillations and then decreases gradually during the interval, see figure 4.13.

The oscillations in the x-direction for the steel shoe on the measurements done on the horse Empe shows the similar characteristic pattern as the oscillations in Dora's measurements. The oscillations intense part gradually decreases from the highest collected amplitude, see appendix E.1



Figure 4.13: The characteristics of the oscillations in x-direction of the hoof wearing a steel shoe on concrete.

It was a decrease of oscillations in the y-and x-direction for Dora's measurements, and the y-direction follows the same characteristic pattern as the x-direction. The z-direction had a different pattern compared to the other directions, where the oscillations did not decrease in the same way and kept more intense oscillations during the whole interval. In figure 4.14 you can see the different between the y-direction and the z-direction.

The appearance of the oscillations in Empe's measurement has the same intense characteristic pattern as the y-direction and the z-direction in Dora's measurements. Where the highest amplitude occurred, so did the most intense oscillations occurred, see appendix E.1.



Figure 4.14: The left show the character of the oscillation in y-direction and the right in z-direction, in combination of steel and concrete.

In the combination of steel and fibre sand there was considerably less oscillations where the highest amplitude was collected. There was difficulties to find a characteristic pattern for the steel shoe. This shows that the fibre sand has a large impact on the oscillations in the hoof while wearing a steel shoe. In figure 4.15 the oscillations for Dora's measurements of the x-direction in the combination of steel and fibre sand is shown. The same oscillation pattern was shown when analyzing Empe's measurements, see appendix E.2.



Figure 4.15: The oscillations in x-direction of the hoof wearing a steel shoe on fibre sand.

The analysis in the combination of steel and fibre sand shows that fibre sand also reduces the oscillations in the y-direction and the z-direction in Dora's measurements, see figure 4.16. Appendix E.2 shows how the fibre sand also attenuate the oscillations in Empe's measurements.



Figure 4.16: The left show the character of the oscillation in y-direction and the right in z-direction, in combination of steel and fibre sand.

4.3.4.2 Öllöv SoftStep

The most significant difference between Öllöv SoftStep and the steel shoe was that Öllöv SoftStep showed a different pattern, where the part with the intense oscillations decreased radically until total attenuation. The qualities in Öllöv SoftStep was able to attenuate the oscillations in the same time range, but less intense oscillations occurred, see figure 4.17. Just like the analysis of the steel the intense oscillations appeared where the highest amplitude is collected, but the oscillations is sparser.

Empe's measurements the same characteristics oscillations pattern as Dora's measurements, see appendix E.3



Figure 4.17: The characteristics of the oscillations in x-direction of the hoof wearing a Öllöv SoftStep on concrete.

The same applies in the y-direction and the z-direction in Doras's measurements, where the oscillations were significantly less during the hoof impact and the highest amplitude. As the analysis of the x-direction, the oscillations attenuation more in Öllöv SoftStep than in the steel shoe, see figure 4.18.

Empe's measurements in the y-direction followed the same pattern as Dora, although you could see a slightly intense oscillation which decreased radically in the z-direction, see appendix E.3



Figure 4.18: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of Öllöv SoftStep and concrete.

In the same way as with steel shoe on fibre sand, it was difficult to see a clear pattern in the combination of Öllöv SoftStep and fibre sand in Dora's measurements. The oscillations kept the same characteristic pattern as the steel shoe during the hoof impact, but there were a certain differences in the number of oscillation, see figure 4.19. The oscillation in the combination of Öllöv SoftStep and fibre sand is still less than steel, but the differences are not as significant as on concrete. The same similarities occurred in Empe's measurements for Öllöv SoftStep on fibre sand, see appendix E.4.



Figure 4.19: The oscillations in x-direction of the hoof wearing Öllöv SoftStep on fibre sand.

In y-direction and z-direction, Öllöv SoftStep has the same characteristic as the steel shoe in Dora's measurements, it's the fibre sand that contributes to the most of the damping qualities, see figure 4.20. Empe's measurements follows the same pattern, see appendix E.4



Figure 4.20: The left shows the character of the oscillations in y-direction and the right in z-direction, in combination of Öllöv SoftStep and fibre sand.

4.3.4.3 Unshod hoof

The unshod hoof's most intense oscillations also occurred during the hoof impact in Dora's measurements, where the largest amplitude occurred. The unshod hoof had a similar characteristic pattern as Öllöv SoftStep on concrete, where the part with intense oscillations decreased radically until total attenuation, see figure 4.21.

In Empe's measurements the x-directions was more similar to the steel shoe, than to Öllöv SoftStep. This was the characteristic pattern typical for the analysis of the oscillations in the combination of the unshod hoof and concrete for Empe, see appendix E.5 The intense of the oscillation was still lower than the oscillations in the combination of steel shoe and concrete.



Figure 4.21: The characteristics of the oscillations in x-direction of the unshod hoof on concrete.

As shown in figure 4.22, the oscillations occurred more in the y-direction and the zdirection in the unshod hoof than the hoof wearing Öllöv SoftStep on the concrete. The unshod hoof had a poorer ability to attenuate the oscillations on concrete in these directions. The same pattern with a slightly increase of oscillations occurred in Empe's measurements, see appendix E.5.



Figure 4.22: The left shows the character of the oscialltion in y-direction and the right in *z*-direction, in combination of unshod hoof and concrete.

The analysis of the unshod hoof on fibre sand showed a similar pattern as both the steel shoe and Öllöv SoftStep did for Dora's measurements. The fibre sand attenuate the oscillation in the unshod hoof, and only sparse oscillation occurred. Figure 4.23 shows the unshod hooves oscillations on fibre sand in x-direction for Dora's measurements and has the same characteristics as well as the hoof wearing steel shoe and Öllöv SoftStep. The same pattern is shown in appendix E.6 for Empe's measurements



Figure 4.23: The oscillations in x-direction of the unshod hoof on fibre sand.

Figure 4.24 shows the unshod hoof's oscillations on fibre sand in y-direction and zdirection in Dora's measurements. The left picture in the figure is over a larger range to show that the most intense oscillations occurred by -30 m/s^2 . It still has the same characteristics as the steel shoe and Öllöv SoftStep, but a displacement by the most intense oscillations position. The displacement did not occurred in Empe's measurements, see appendix E.6.



Figure 4.24: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of rubber and fibre sand.

Discussion

The result shows that Öllöv SoftStep is a clearly better option than the steel shoe in shock absorbing on hard grounds. On hard grounds it absorbs shocks better than an unshod hoof as well. On the soft ground, fibre sand, there is no significant difference between the steel shoe, unshod and Öllöv SoftStep. In this study there has only been measurements done on concrete and fibre sand as grounds, which can be seen as two extremes. Concrete is a very hard ground and is mainly used in stables for shorter transports, and then only while the horse is walking. Fibre sand is developed to be an absorbing ground for the horses, so the results show that there are no significant differences between the different shoes on fibre sand. It confirms that it is a shock absorbing ground. How Öllöv SoftStep works on concrete can be compared how it would be to trotting on asphalt, which is a more common ground for horses. Although, measurements on asphalt must be done to determine it.

The measurements have only been done in trotting and with an average speed of 2.8 m/s. The movement pattern for the horses differ between the different gaits, therefore can this study only determine the qualities in trot. In future testing walking and gallop should be tested to realize how they differ from each other in shock and vibrations that occur in different shoes.

The results from the amplitude measurements shows that the steel shoe has higher values than the unshod hoof on concrete, and that Öllöv SoftStep has lower values than the unshod hoof. It is hard to see some clearly similar percentage in table 4.1 and table 4.2, that is very likely because it is two different horses with their own movement pattern. When in table 4.3 not to compare Öllöv SoftStep and the steel shoe with the unshod hoof but to each other instead gives a more aggregated value. In this comparison the highest amplitude value for Dora wearing Öllöv SoftStep is 50% of the highest value wearing the steel shoe. The same comparison for Empe is at 26%.

Due to time limitations there has only been comparison i x-direction for the shock absorbing analysis, that is the vertical direction and there the highest and most decisive amplitude values can be found.

The fact that both the horses had more uneven steps during measurements on concrete than on the fibre sand can have some different factors. A simple explanation is that the horses felt more at ease at the much bigger riding cite than in the stable and therefore had more even steps. On the fibre sand they had quite a long reach to get into the right speed. At the concrete it was a more abrupt start. Due to that is no difference between the shoeing types in the spread of steps, it is not likely that the grip of the shoes has affected the horses to more or less even steps at the grounds. Another possible reason to the irregularly of the horses steps is the light beam was from the high speed camera. In the stables the light beam were clearer than in the riding cite. It is possible that the horses reacted to the light and therefore had irregular steps, and more irregular on the concrete than on the fibre sand.

In the analyze of the vibration, the mainly difficulty was that the logger had a sampling rate at 7161 points/s, so the highest frequency we would be able to calculate would be 3581 hertz according to the Nyquist sampling theorem. The new method we had to apply was a time consuming analytic method, where every five steps in every measurement had to be analyzed. There is always a human factor that has to be taken in to account, this means that there is always a certain percentage risk of making mistakes. To ensure that this human factor won't have any significant impact on the final result, we saved over 400 pictures of graphs from the different combinations of shoe and ground. This to be able to compare as many of the oscillations as possible to give a representative result. The human error is still a factor that has to be taken in to account, when not using a numerical method. A logger with a higher sampling rate would provide the test a more accurate frequency analysis.

The two grounds the measurements were preformed on have two different characteristics. It was easier to see a characteristic pattern of the oscillations on the hoof when they were performed on concrete. The concrete is a hard, tightly packed ground, and after every measurement the ground surface was unchanged. The fibre sand on the other hand, has an airier top layer. This allows the surface of the ground to change between each measurement and depending on where the horse places it's hoof the accelerometer may have an interference between the different directions. This may be a reason why it is easier to find the pattern on the measurements made on concrete.

In Dora's measurements with an unshod hoof on fibre sand, the most intense oscillations occurred by -30 m/s^2 . This was not similar to Empe's measurements with the same combination. This may be a consequence of the accelerometers position on the hoof. The possibility that the accelerometer had been dislocated between the test was not taken in to account.

Dora's and Empe's oscillations with unshod hoof on concrete, was the largest differential in the characteristic oscillation pattern analysis. Empe's measurements showed characteristic similar to the steel shoe, while Dora showed characteristic similar to Öllöv SoftStep. As mentioned earlier in the study, the hoof works as a part of a shock absorbing-system. The hooves quality differs from one to another and Dora may have a better attenuate quality in the hooves.

In figure 5.1 we placed the graph from a measurement with steel shoe on concrete, beside a measurement with Öllöv SoftStep on concrete in the x-direction. This was the characteristics of the oscillations in the analyze that showed how Öllöv SoftStep was able to attenuate the oscillations in a much more effective way than the steel shoe could. The steel shoe has what is called a typical decreasing sinusoidal curve, where the intense oscillations gradually decreases. As a former study had showed, the quality in synthetics have a vibration damping properties and a lower frequency during the hoof impact. According



to this analysis Öllöv SoftStep has similar properties.

Figure 5.1: The left show oscillations with steel and the right with Öllöv SoftStep, both on concrete.

The horses used in the tests was used to wearing steel shoes, this could have an impact on the result. It all comes down to that the horses are living animals. If a horse is used to wearing steel shoe, they adjust to their ability to their movements. If the horses affected their movements while wearing the rubber shoe is hard to say. Therefore would also measurements on horses used to Öllöv SoftStep be interesting to analyze.

5.1 Recommendations

In this study we made a good foundation for testing and analyze measurements with an accelerometer but our belief is that there is still much to examine. Our recommendations for future testing is following:

To do measurements on more horses and on different kind of breeds for a more precise value how the qualities of Öllöv SoftStep are. This study was only done on concrete and fibre sand and more commonly used grounds for horses should be tested on, such as grass, gravel and soil.

For future measurements it should be more prioritized to have similar terms for the different measuring cites and that there are no disturbances on the measuring track that can affect the horses, such as the light from the high speed camera.

A recommendation for future test, is to verify the accelerometers location on the hoof between every measurement to get as similar initial value as possible in every graph.

If the horses affected their movements while wearing the rubber shoe is hard to say. Therefore would also measurements on horses used to Öllöv SoftStep be of a recommendation.

Conclusion

As previous measurements have shown that the rubber shoe is a better option than steel shoe for hard grounds. On soft grounds as fibre sand there is no significant difference. In this study it is proven that Öllöv SoftStep is a better than both unshod hoof and a steel shoe at absorbing shocks that occur when trotting on a hard ground such as concrete.

By the analysis of the vibration damping, significant differences were shown between Öllöv SoftStep and the steel shoe on concrete. Öllöv SoftStep was able to attenuate the resulting oscillations significantly better than the steel shoe during the same interval. It occurred more oscillation in the steel shoe during the impact phase, than in Öllöv Soft-Step during the same interval. Öllöv SoftStep has better vibration damping qualities than the steel shoe.

The analysis between the unshod hoof och Öllöv SoftStep showed two different patterns. Öllöv SoftStep had in both cases better vibration damping, but in one case significantly better and in the other case slightly better. Öllöv SoftStep has better vibration damping qualities than the unshod hoof, but the significance of the differ is not concluded.

The analysis between steel shoe, Öllöv SoftStep and the unshod hoof on fibre sand showed that the characteristics was similar and the vibration damping qualities in Öllöv SoftStep had a lower impact on the vibrations in the fibre sand. Öllöv SoftStep has according to the analysis similar vibration damping qualities in fibre sand as an unshod hoof and a hoof wearing steel shoe.

This study has given results on two different grounds, on two different horses. A more extensive study, which includes different grounds and more different horses, needs to be done to evaluate Öllöv SoftStep full quality.

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Α

Documentation of testing day

Häst	Underlag	Skotyp	Hastighet	Tid	Tidsnr i logger	kamera
Cameron	Sand	Stål				
1				5,4	1218	ja
2				4,13	1226	
3				4,1	1226	ja
4				4,48	122913	
5				4,4	123119	
6				4,3	123514	
7				4,1	123712	ja
8				4,36	124017	
9				4,05	124329	ja
Empe	Sand	Stål				
1						
2						
3						
4						ja
5						
6						ja
7						
8						
9					135213	ja
10		0,021	-0,021	3,59	135615	ja
11		0,109	0,109	3,72	135820	
12		0,159	0,159	3,77	140006	ja
13	d	0,389	0,389	4	140110	
14		0,051	-0,051	3,56	140206	
15		0,309	0,309	3,92	140506	ja
Dora	Sand	Stål				
1	d	0.326	0.326	3.76	142213	ia
2	d	0.406	0,406	3.84	142339	,_
3	d	0.186	0,186	3.62	142456	
4		0,166	0,166	3,6	142548	
5		0,116	0,116	3,55	142648	
6		0,096	0,096	3,53	142923	ja
7	d	0,196	0,196	3,63	143054	
8		0,116	0,116	3,55	143337	
9		0,176	0,176	3,61	143617	
10	d	0,216	0,216	3,65	143717	ja
Dora	Betong	Stål				
1		0.044	-0.044	3.39	150527	ia
2	d	0,206	0,206	3,64	ingen	
3	d	0.156	0,156	3.59	ingen	
4		0,014	-0.014	3,42	150925	ja
5		0,104	-0,104	3,33	151030	
6		0,016	0,016	3,45	151120	
7		0,116	0,116	3,55	151505	
8	d	0,126	0,126	3,56	151605	ja
Empe	Betong	Stål				
1	d	0 121	-0.121	2 /0	1526	
2	d	0,151	-0,151	3,40	152722	ia

	3 d	0,321	-0,321	3,29	152843
	1 d	0,181	-0,181	3,43	1529
	5	0,081	-0,081	3,53	153100 ja
1	5 d	0,231	-0,231	3,38	153240
	7	0,071	-0,071	3,54	153647
	3 d	0,191	-0,191	3,42	1538
	9	0,091	-0,091	3,52	153914
1	ו	0,111	-0,111	3,5	154012
1	1	0,011	-0,011	3,6	1541
1	2 d	0,221	-0,221	3,39	154230
1	3 d	0,361	-0,361	3,25	154342 ja
Dora	Betong	oskodd			
		0.084	-0.084	2 25	160210 ia
		0.254	-0,254	3 18	160437
	2	0.244	-0,234	3 19	160616 ia
	1 d	0 294	-0 294	3 14	160714
	5	0 204	-0 204	3 23	160827 ia
	5 d	0 346	0 346	3 78	160917
	7	0,134	-0.134	3.3	161050 ja, bakhov
		0,101	0,101	3,5	
-					
Empe	Betong	Oskodd			
	L	0,111	-0,111	3,5	162259 ja
	2	0,089	0,089	3,7	162406
	3 d	0,151	-0,151	3,46	162451 ja, bakhov
	1 d	0,351	-0,351	3,26	162615
	5	0,089	0,089	3,7	162718 ja
I	5	0,009	0,009	3,62	162802
	/	0,101	-0,101	3,51	162917 Ja
_		0,101	-0,101	3,51	162917 Ja
Empe	Sand	Oskodd	-0,101	3,51	162917 ja
Empe	Sand	Oskodd 0,161	-0,101	3,51	162917 ja 164144
Empe	Sand L d 2 d	0,101 0,101 0,161 0,109	-0,101 -0,161 0,109	3,31 3,45 3,72	162917 ja 164144 164315 ja
Empe	Sand L d 2 d	0,101 0,101 0,161 0,109 0,051	-0,101 -0,161 0,109 -0,051	3,45 3,45 3,72 3,56	162917 ja 164144 164315 ja 164433
Empe	Sand 1 d 2 d 3	0,101 0,101 0,101 0,101 0,109 0,051 0,021	-0,101 -0,161 0,109 -0,051 -0,021	3,51 3,45 3,72 3,56 3,59	162917 ja 164144 164315 ja 164433 164553
Empe	Sand L d 2 d 3 4 5 d	0,101 0,101 0,101 0,101 0,010 0,051 0,021 0,0119	-0,101 -0,161 0,109 -0,051 -0,021 0,119	3,51 3,45 3,72 3,56 3,59 3,73	162917 ja 164144 164315 ja 164433 164553 164741
Empe	Sand 1 d 2 d 3 4 5 d 5	0,101 0,101 0,101 0,109 0,051 0,021 0,119 0,029	-0,101 -0,161 0,109 -0,051 -0,021 0,119 0,029	3,45 3,72 3,56 3,59 3,73 3,64	162917 ja 164144 164315 ja 164433 164553 164741 164830 ja
Empe	Sand d d d d d d d d d d d d d	0,101 Oskodd 0,161 0,051 0,021 0,119 0,021 0,021 0,029 0,161	-0,101 -0,161 -0,051 -0,051 -0,021 0,119 0,029 -0,161	3,45 3,45 3,72 3,56 3,59 3,73 3,64 3,45	162917 ja 164144 164315 ja 164433 164553 164741 164830 ja 164925
Empe	Sand 1 d 2 d 3 4 5 d 7 d 3 d	0,101 Oskodd 0,161 0,051 0,051 0,021 0,029 0,161 0,029 0,161 0,169	-0,101 -0,161 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,169	3,31 3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,45 3,78	162917 ja 164144 164315 ja 164433 164553 164553 164741 164830 ja 164925 1652203
Empe	Sand L d 2 d 3 4 5 d 7 d 3 d	0,101 Oskodd 0,161 0,161 0,051 0,021 0,029 0,161 0,029 0,161 0,029 0,161 0,169 0,019	-0,101 -0,161 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 0,019	3,31 3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,78 3,63	162917 ja 164144 164315 ja 164433 164553 164553 164741 164830 ja 164925 1652203 1652203 165223
Empe	Sand d d d d d d d d d d d d d	0,101 0,101 0,161 0,161 0,051 0,021 0,021 0,029 0,161 0,029 0,161 0,029 0,161 0,029 0,161 0,029 0,161 0,019 0,019 0,019 0,019 0,019 0,019 0,011	-0,101 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 -0,011	3,31 3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,78 3,63 3,63 3,6	162917 ja 164144 164315 ja 164433 164553 164741 164830 ja 164925 1652203 1652203 165223 165344 ja + bak
Empe	Sand L d 2 d 3 4 5 d 5 7 d 3 d 9 0 0 0 0 0 0 0 0 0 0 0 0 0	0,101 Oskodd 0,161 0,051 0,021 0,029 0,161 0,029 0,161 0,029 0,161 0,019 0,011	-0,101 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 -0,011	3,31 3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,78 3,63 3,63 3,6	162917 ja 164144 164315 ja 164433 164553 164741 164830 ja 164925 1652203 1652203 165223 165344 ja + bak
Empe	Sand	0,101 0 0,161 0,161 0,051 0,001 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,011 0,021 0,011 0,011 0,011 0,011 0,011	-0,101 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 -0,011	3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,78 3,63 3,63 3,63	162917 ja 164915 ja 164433 164553 164741 164830 ja 164925 1652203 165223 165344 ja + bak
Empe	Sand d d d d d d d d d d d d d d d d d d	0,101 0,161 0,161 0,161 0,051 0,051 0,021 0,021 0,029 0,161 0,029 0,161 0,029 0,161 0,0161 0,019 0,019 0,011 0,011 0,011 0,011 0,001 0,001	-0,101 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 -0,011 -0,011	3,31 3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,78 3,63 3,63 3,63 3,63 3,63 3,63 3,63	162917 ja 164915 ja 164433 164433 164553 164741 164830 ja 164925 1652203 1652203 165253 165344 ja + bak
Empe	Sand Sand d d d d d d d d d d d d	0,101 0,161 0,161 0,161 0,0051 0,0021 0,022 0,029 0,161 0,029 0,161 0,029 0,0161 0,0161 0,0161 0,0161 0,0111 0,0111 0,0111 0,0111 0,0111 0,0111 0,0011 0,0011 0,086 0,0004	-0,101 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 -0,011 -0,011 -0,011 -0,011	3,31 3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,63 3,63 3,63 3,63 3,63 3,63 3,63 3,6	162917 ja 164915 ja 164433 164553 164433 164553 164741 164830 ja 164925 1652203 1652203 1655253 1655344 ja + bak 171356 171510 ja
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Empe	Sand Sand d d d d d d d d d d d d	0,101 0,101 0,161 0,109 0,010 0,021 0,021 0,029 0,161 0,029 0,161 0,019 0,019 0,019 0,019 0,019 0,019 0,0114 0,114	-0,101 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 -0,011 0,086 -0,004 -0,114 -0,154	3,51 3,45 3,72 3,56 3,59 3,73 3,64 3,78 3,63 3,63 3,63 3,63 3,63 3,63 3,63 3,6	162917 ja 164914 164315 ja 164433 164553 164741 164830 ja 164925 1652203 165253 165253 165344 ja + bak 171356 171510 ja 171558 171726 ja
Empe	Sand d d d d d d d d d d d d d d d d d d	0,101 0 0,161 0,161 0,051 0,051 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,029 0,0161 0,019 0,011 0,011 0,004 0,004 0,114 0,154 0,144	-0,101 -0,161 -0,051 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 -0,011 -0,011 -0,086 -0,004 -0,114 -0,154 -0,144	3,51 3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,64 3,63 3,63 3,6 3,6 3,6 3,6 3,52 3,43 3,32 3,28 3,29	162917 ja 164917 ja 164915 ja 164333 164333 164553 164741 164830 ja 164925 1652203 1652203 165253 165344 ja + bak 171356 171510 ja 171558 171726 ja 171816
Empe	Sand D Sand D Sand D C Sand D C Sand D Sand C Sand C	0,101 0,101 0,161 0,161 0,051 0,051 0,021 0,011 0,011 0,011 0,004 0,004 0,014 0,154 0,144 0,174	-0,101 -0,161 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 -0,011 -0,011 -0,014 -0,154 -0,144 -0,174	3,31 3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,64 3,45 3,63 3,63 3,63 3,63 3,63 3,63 3,63 3,6	162917 ja 164917 ja 164915 ja 164433 164553 164741 164830 ja 164925 1652203 1652203 165253 165344 ja + bak 171356 171510 ja 171558 171726 ja 171816 172006 ja
Empe	Sand Sand d d d d d d d d d d d d	0,101 0,101 0,161 0,109 0,051 0,051 0,021 0,021 0,021 0,021 0,029 0,161 0,029 0,161 0,029 0,019 0,019 0,019 0,019 0,011 0,014 0,004 0,114 0,154 0,144 0,174	-0,101 -0,161 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 -0,011 -0,011 -0,014 -0,154 -0,174	3,31 3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,64 3,45 3,63 3,63 3,63 3,63 3,63 3,63 3,63 3,6	162917 ja 164917 ja 164915 ja 164433 164553 164741 164830 ja 164925 1652203 1652203 165253 165344 ja + bak 171356 171510 ja 171558 171558 171558 171756 ja 171558
Empe	Sand	O,101 0,161 0,161 0,109 0,051 0,051 0,021 0,021 0,029 0,161 0,029 0,161 0,029 0,161 0,019 0,019 0,011 0,051 0,014 0,114 0,174 0,174 0,174	-0,101 -0,161 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 -0,011 -0,011 -0,014 -0,114 -0,174	3,51 3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,78 3,63 3,63 3,63 3,63 3,63 3,63 3,63 3,6	162917 ja 164917 ja 164915 ja 164433 164553 164741 164830 ja 164925 1652203 1652203 1652203 165253 165344 ja + bak 171356 1711510 ja 171558 171726 ja 171816 172006 ja
Empe	Sand d d d d d d d d d d d d d d d d d d	O,101 0,101 0,101 0,101 0,102 0,051 0,051 0,021 0,011 0,011 0,0386 0,004 0,114 0,174 0,174 0,049	-0,101 -0,161 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 -0,011 -0,011 -0,014 -0,114 -0,154 -0,174	3,51 3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,78 3,63 3,63 3,63 3,63 3,63 3,63 3,63 3,52 3,43 3,52 3,43 3,32 3,28 3,29 3,26	162917 ja 164917 ja 164915 ja 164433 164553 164741 164830 ja 164925 1652203 1652203 1652203 1652203 165253 165344 ja + bak 171356 171510 ja 171558 171726 ja 171816 172006 ja
Empe	Sand	O,101 0,161 0,161 0,051 0,051 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,029 0,0161 0,019 0,011 0,011 0,011 0,011 0,011 0,011 0,011 0,011 0,011 0,011 0,011 0,011 0,011 0,011 0,014 0,114 0,114 0,114 0,114 0,114 0,114 0,114 0,014 0,049 0,019	-0,101 -0,161 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 -0,011 -0,011 -0,004 -0,154 -0,174 -0,174 -0,174	3,51 3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,78 3,63 3,64 3,63 3,66 3,52 3,43 3,32 3,28 3,28 3,29 3,26 3,66 3,66 3,63	162917 ja 164917 ja 164915 ja 164433 ja 164553 164741 1 164830 ja 164925 1 1652203 1 165220 1 171356 1 1717156 1 171726 1 171726 1 171726 1 172006 1 173854 1 173946 1 173946 1 173946 1 173946 1 17400 1 1740
Empe	Sand d d d d d d d d d d d d d d d d d d	0,101 0,161 0,161 0,051 0,051 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,021 0,019 0,011 0,011 0,011 0,011 0,011 0,011 0,011 0,011 0,011 0,011 0,011 0,014 0,114 0,114 0,114 0,114 0,114 0,114 0,014 0,014 0,014 0,014 0,014 0,014 </td <td>-0,101 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 -0,011 -0,014 -0,154 -0,144 -0,154 -0,144 -0,174</td> <td>3,51 3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,78 3,63 3,64 3,63 3,66 3,66 3,66 3,66 3,66</td> <td>162917 ja 164917 ja 164915 ja 164433 164433 ja 164553 164741 164830 ja 164925 1652203 1652203 1652203 165223 165344 ja + bak 171356 171510 ja 171578 171726 ja 171816 172006 ja 173854 ja 173946 174050</td>	-0,101 0,109 -0,051 -0,021 0,119 0,029 -0,161 0,169 0,019 -0,011 -0,014 -0,154 -0,144 -0,154 -0,144 -0,174	3,51 3,45 3,72 3,56 3,59 3,73 3,64 3,45 3,78 3,63 3,64 3,63 3,66 3,66 3,66 3,66 3,66	162917 ja 164917 ja 164915 ja 164433 164433 ja 164553 164741 164830 ja 164925 1652203 1652203 1652203 165223 165344 ja + bak 171356 171510 ja 171578 171726 ja 171816 172006 ja 173854 ja 173946 174050

4	l .	0,169	0,169	3,78	175025	ja
5	5	0,119	0,119	3,73	175202	
6	i d	0,309	0,309	3,92	175332	ja
Dora	Sand	Gummi				
1		0,226	0,226	3,66	181208	ia
2	! d	0,266	0,266	3,7	181326	
3	1	0,134	-0,134	3,3	181440	ja
4	L .	0,234	-0,234	3,2	181554	
5	;	0,074	-0,074	3,36	181648	
e	5	0,044	-0,044	3,39	182500	ja
Dora	Betong	Gummi				
1		0.064	-0.064	3.37	184918	ia
2	2	0.054	-0.054	3.38	185021	,-
3	- }	0,114	-0.114	3.32	185121	
4	l d	0,254	-0,254	3,18	185226	ia
5	i d	0,164	-0.164	3.27	185322	-
6	i d	0,304	-0,304	3,13	185556	ja
7	,	0,054	-0,054	3,38	185641	
8	3	0,064	-0,064	3,37	185718	
Empe	Betong	Gummi				
1	Detong	0.019	0.019	3 63	190536	
	I	0,019	0,019	3.68	190639	ia
	- 	0,169	0,169	3,78	190745	<u> </u>
4	1	0,109	0,109	3.72	190904	ia
5	i d	0.259	0.259	3.87	190951	-
6	;	0,059	0,059	3,67	191037	
7	/ d	0,269	0,269	3,88	191127	ja
8	d d	0,269	0,269	3,88	191219	
Medeltid Empe	3,6	m.hastighet	2,8	m/s		
Medeltid Dora	3,4	m.hastighet	2,9	m/s		
Medeltia		3,5	Sek			
Medelhastigh	iet	2,8	m/s			
Medelavikelse nå	DORA	0.12				
MAX avikelse nå D	ORA	0,12				
the state of the s		0,23				
Medelavikelse på	EMPE	80.0	sek			
MAX avikelse pa	å EMPE	0 31	sek			
BAAN AVINCISE P		0,51	sek			
IVIAX AVIKELS		0,31	sek			
Medelavikelse	9	0,10				

V

В

Matlab code

```
%% Example Matlab / GNU Octave code for parsing HVM200 raw data format
close all; clear all; cl;
    % Number of Samples to read
Sample_Time = 60;    % second
num_samples_to_read = Sample_Rate*Sample_Time;
    % Open file, Read, Close
    % filename = 'HVM_SERIAL_NUMER_BASENAME_DATESTAMP.00.raw';
    filename = 'HVM_SERIAL_NUMER_BASENAME_DATESTAMP.00.raw';
    filename = 'HVM_SUBAIAL_NUMER_BASENAME_DATESTAMP.00.raw';
    filename = 'HVM_SUBAIAL_NUMER_BASENAME_DATESTAMP.00.raw';
    filename = 'HVM_0000056';
    fileredsavename = 'HVM_SIL_0000056';
    FID = fopen(filename,'r');
    A = fread(FID),(num_samples_to_read*3],'float'); % varför *3??
    fclose(FID);
    % Build Axis data
    axis_counter = 1;
    x_axis = zeros(1,floor(num_samples_to_read));
    y_axis = zeros(1,floor(num_samples_to_read));
    y_axis = zeros(1,floor(num_samples_to_read));
    x_axis = A(1:3:end);
    y_axis = A(3:3:end);
    % Remove DC bias from data (optional)
    x_axis = y_axis - mean(y_axis);
    %y_axis = y_axis - mean(x_axis);
    %y_axis = y_axis - mean(x_axis);
    %y_axis = y_axis - mean(x_axis);
    %y_axis = y_axis - mean(y_axis);
    %y_axis = 
      %2_axis - Z_axis - mean(2_axis);
figure(1);
plot(x_axis,'-b');
ylabel('m/s^2')
xlabel('Time * measurements/second')
     title('Empe-Steel-Sand: 140506') %ÄNDRA DENNA TILL VARJE MÄTNING
   grid on;
     for i= 1:200
    w= waitforbuttonpress;
    if w==1
                                                       w==1
[x,y,button] = ginput(7);
break
                                 end
if w==0
                              i;
clearvars w
end
      end
      [a,b]= sort(abs(x_axis(x(1):x(6))),'descend');
C = [a,b];
     str1 = sprintf('%0.5g',(C(1)));
text(x(7),y(7),str1,'Color','red','Fontsize',15)
     Z = zeros(10,1);
F = zeros(5,1);
   21 = max((x_axis(x(1):x(2))));
22 = min((x_axis(x(1):x(2))));
23 = max((x_axis(x(2):x(3))));
25 = max((x_axis(x(2):x(3))));
25 = max((x_axis(x(3):x(4))));
26 = min((x_axis(x(3):x(4))));
27 = max((x_axis(x(4):x(5))));
28 = min((x_axis(x(4):x(5))));
29 = max((x_axis(x(5):x(6))));
210 = min((x_axis(x(5):x(6))));
    \begin{array}{l} \mathbb{Z}(1,1) = \mathbb{Z}1; \\ \mathbb{Z}(2,1) = \mathbb{Z}2; \\ \mathbb{Z}(3,1) = \mathbb{Z}3; \\ \mathbb{Z}(4,1) = \mathbb{Z}4; \\ \mathbb{Z}(5,1) = \mathbb{Z}5; \\ \mathbb{Z}(6,1) = \mathbb{Z}6; \\ \mathbb{Z}(7,1) = \mathbb{Z}7; \\ \mathbb{Z}(8,1) = \mathbb{Z}8; \\ \mathbb{Z}(9,1) = \mathbb{Z}9; \\ \mathbb{Z}(10,1) = \mathbb{Z}10; \end{array} 
     f1 = max(abs((x_axis(x(1):x(2)))));
f2 = max(abs((x_axis(x(2):x(3))))));
f3 = max(abs((x_axis(x(3):x(4)))));
f4 = max(abs((x_axis(x(4):x(5)))));
f5 = max(abs((x_axis(x(5):x(5)))));
   F(1,1) = f1;
F(2,1) = f2;
F(3,1) = f3;
F(4,1) = f4;
F(5,1) = f5;
```

% Max och min som absolut värden

S = abs(Z)

С

Amplitude results

| Dora | | | |
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| Concrete | | | |
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 | | |
 | |
| <u>Mätningsnr :</u> | | 151505 | 151120 | <u>151030</u>
 | 150925

 | 150527
 | | | 161050 | 160827 | 160616
 | 160437
 | 160310 | | | 185718 | 185641
 | 185121 | <u>185021</u> | <u>184918</u>
 | |
| Z-vector | | 2732,9222 | 2708,2815 | 1896,3166
 | 1642,804

 | 1560,8842
 | | | 605,94193 | 1968,0845 | 2300,993
 | 888,10786
 | 1667,7036 | | | 2418,7923 | 1348,8532
 | 677,19123 | 354,54316 | 670,39859
 | |
| Max & min values | | -7742,734 | -6628,8948 | -5358,554
 | -5448,2834

 | -6883,5113
 | | | -1602,3354 | -4307,8725 | -5166,9211
 | -2124,2525
 | -1603,7114 | | | -2402,6852 | -3096,2005
 | -1076,8576 | -1655,8299 | -1956,8387
 | |
| | | -5301.8952 | -7266.2395 | -7032.3436
 | -5673.4328

 | -6211.4576
 | | | -2238.895 | -7124.7729 | -7069.3801
 | -3412.7291
 | -2547.5268 | | | -5209.3923 | -2337.47
 | -3976.9533 | -1718.4578 | -1429.537
 | |
| | | 1594,2259 | 2572,0549 | 3136,4016
 | 2728,7298

 | 2417,5297
 | | | 997,12064 | 2252,9683 | 946,97635
 | 2079,7309
 | 2848,7368 | | | 1129,3568 | 2736,6794
 | 3367,6951 | 2108,6096 | 1009,9201
 | |
| | | -1497,279 | -4585,7908 | -7390,5926
 | -11045,916

 | -6854,5904
 | | | -1918,6372 | -5426,3466 | -1316,4914
 | -1888,2183
 | -7289,8779 | | | -1810,8561 | -3586,7278
 | -5237,6237 | -3486,5955 | -1050,0038
 | |
| | | 3586,2083 | 2768,8879 | 1621,549
 | 2059,5784

 | 2311,7972
 | | | 255,08744 | 1330,5152 | 2090,2947
 | 1338,1733
 | 1958,522 | | | 2366,9017 | 1317,2282
 | 3146,5535 | 2302,8771 | 849,69644
 | |
| | | -6970,8903 | -6102,198 | -5743,3055
 | -5616,8864

 | -5251,1256
 | | | -1129,9057 | -2559,6547 | -4698,3132
 | -2036,7027
 | -2318,8188 | | ö | -4214,1784 | -1394,7073
 | -2813,5256 | -2351,907 | -749,6141
 | |
| | | 1883,7396 | 1690,9612 | 1131,34
 | 4153,4583

 | 1918,3988
 | | | 837,66557 | 2212,8521 | 1358,6629
 | 2120,9877
 | 752,96438 | | U | 1782,3978 | 2762,7331
 | 2024,2703 | 1281,4797 | 985,56851
 | |
| | | -0010,0002 | -0007,0044 | -1067.06706
 | -0720,1200

 | -40400010
 | | II | -2/3//3// | -3737,7387 | -1074040
 | -31.77,6477
 | -2000,0071 | | T | -004,777 | -1270/0402
 | -2200,0014 | -67 10,0040 | -1709,7094
 | |
| S-vector | | 2732,9222 | 2708,2815 | 1896,3166
 | 1642,804

 | 1560,8842
 | | U | 605,94193 | 1968,0845 | 2300,993
 | 888,10786
 | 1667,7036 | | - | 2418,7923 | 1348,8532
 | 677,19123 | 354,54316 | 670,39859
 | |
| abs. values | | 7742,734 | 6628,8948 | 5358,554
 | 5448,2834

 | 6883,5113
 | | Ν | 1602,3354 | 4307,8725 | 5164,9211
 | 2124,2525
 | 1603,7114 | | L | 2402,6852 | 3096,2005
 | 1076,8576 | 1655,8299 | 1956,8387
 | |
| | S | 2820,6273 | 2582,2395 | 3444,5227
 | 2394,3304

 | 1536,3685
 | | | 1772,8863 | 3190,4263 | 3089,6902
 | 2001,9252
 | 1713,6509 | | | 3169,7923 | 1681,8268
 | 3498,4881 | 503,38203 | 590,35562
 | |
| | - | 5301,8952 | 7266,2395 | 7032,3436
 | 5673,4328

 | 6211,4576
 | | S | 2238,895 | 7124,7729 | 7069,3801
 | 3412,7291
 | 2547,5268 | | 0 | 5209,3923 | 2337,47
 | 3976,9533 | 1718,4578 | 1429,537
 | |
| | 1 | 1094,2209 | 4585 2908 | 7390 5926
 | 2/28,/298

 | 6854 5904
 | | TT | 997,12064 | 2252,9683 | 946,97635
 | 1888 2183
 | 2595,7305 | | 17 | 1810 8561 | 2/30,0/94
 | 5237 6237 | 2108,6096 | 1050,0038
 | |
| | F | 3586,2083 | 2768,8879 | 1621,549
 | 2059,5784

 | 2311,7972
 | | н | 255,08744 | 1330,5152 | 2090,2947
 | 1338,1733
 | 1958,522 | | V | 2366,9017 | 1317,2282
 | 3146,5535 | 2302,8771 | 849,69644
 | |
| | - | 6970,8903 | 6102,198 | 5743,3055
 | 5616,8864

 | 5251,1256
 | | 0 | 1129,9057 | 2559,6547 | 4698,3132
 | 2036,7027
 | 2318,8188 | | | 4214,1784 | 1394,7073
 | 2813,5256 | 2351,907 | 749,6141
 | |
| | Ε | 1883,7396 | 1690,9612 | 1131,34
 | 4153,4583

 | 1918,3988
 | | v | 837,66557 | 2212,8521 | 1358,6629
 | 2120,9877
 | 752,96438 | | | 1782,3978 | 2762,7331
 | 2024,2703 | 1281,4797 | 985,56851
 | |
| | Ē | 6315,5602 | 6069,8044 | 4827,2962
 | 8726,1255

 | 4840,0616
 | | D | 2757,9379 | 3959,9809 | 2394,9445
 | 3197,2457
 | 2338,5571 | | S | 2894,777 | 4295,0462
 | 2206,9074 | 2715,3045 | 1964,7342
 | |
| Mean | Ĺ | 4045 | 4298 | 4158
 | 4949

 | 3979
 | Mean
4286 | | 1412 | 3433 | 3043
 | 2109
 | 2504 | Mean
2500 | 0 | 2740 | 2456
 | 2803 | 1848 | 1126
 | Mean
2194 |
| Median | | 3203 | 3677 | 4136
 | 4801

 | 3629
 | 3677 | | 1366 | 2875 | 2348
 | 2058
 | 2139 | 2139 | U | 2411 | 2537
 | 2980 | 1914 | 998
 | 2411 |
| Evector | | 7743 734 | 6479 80.10 | E100 E71
 | E448 787 1

 | 6993 5114
 | | U | 1602.2271 | 1307 9727 | E164.00**
 | 2121252
 | 1467 7024 | | F | 2418 7572 | 2004 2027
 | 1074 6574 | 1622.0000 | 1054 81/1
 | |
| 5 abs values | | 5301,8952 | 7266.2395 | 2028,254
 | 5673,4328

 | 6883,5113
 | | NT | 2238,895 | 4307,8725 | 5169,9211
7069,3801
 | 2124,2525
 | 2547,5268 | | - | 2418,7923
5209,3973 | 2337,47
 | 3976,9533 | 1005,8299 | 1906,8387
 | |
| o no cunto | C | 1594,2259 | 4585,7908 | 7390,5926
 | 11045,916

 | 6854,5904
 | | N | 1918,6372 | 5426,3466 | 1316,4914
 | 2079,7309
 | 7289,8779 | | T | 1810,8561 | 3586,7278
 | 5237,6237 | 3486,5955 | 1050,0038
 | |
| | 5 | 6970,8903 | 6102,198 | 5743,3055
 | 5616,8864

 | 5251,1256
 | | C | 1129,9057 | 2559,6547 | 4698,3132
 | 2036,7027
 | 2318,8188 | | C | 4214,1784 | 1394,7073
 | 3146,5535 | 2351,907 | 849,69644
 | |
| | т | 6315,5602 | 6069,8044 | 4827,2962
 | 8726,1255

 | 4840,0616
 | | 5 | 2757,9379 | 3959,9809 | 2394,9445
 | 3197,2457
 | 2338,5571 | | 3 | 2894,777 | 4295,0462
 | 2206,9074 | 2715,3045 | 1964,7342
 | |
| | | | |
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 |
 | Mean | н | | |
 |
 | | Mean | Т | |
 | | |
 | Mean |
| Median | E | 6316 | 6131 | 5743
 | 7302

 | 6211
 | 6219 | | 1930 | 4676 | 4129
 | 2570
 | 3232 | 23307 | | 2895 | 2942
 | 3129 | 2386 | 1450
 | 2693 |
| | T | 0010 | 0102 | 0,10
 | 5075

 |
 | Max | 0 | | 1000 | 1070
 |
 | 2007 | Max | Ε | 2070 | 0070
 | 010 | 2002 | 100
 | Max |
| MAX | E | 7743 | 7266 | 7391
 | 11046

 | 6884
 | 11046 | D | 2758 | 7125 | 7069
 | 3413
 | 7290 | 7290 | р | 5209 | 4295
 | 5238 | 3487 | 1965
 | 5238 |
| | т | | |
 | medel max

 |
 | 8066 | υ | | |
 | medel max
 | | 5531 | r | |
 | | medel max |
 | 4039 |
| | | | |
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 | | 2010 | | |
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 | |
| | - | | |
 | median max

 |
 | 7391 | | | |
 | median max
 | | 7069 | | |
 | | median max |
 | 4295 |
| Sand | Ĩ | 142617 | 142227 | 142022
 | median max

 | 143549
 | 7391 | | 171016 | 171734 | 171550
 | median max
 | 171256 | 7069 | | 182500 | 101640
 | 101554 | median max | 101200
 | 4295 |
| Sand
Measurement nr: | | 143617 | <u>143337</u> | <u>142923</u>
 | median max
<u>142648</u>

 | <u>142548</u>
 | 7391 | U | 171816 | <u>171726</u> | 171558
 | median max
<u>171510</u>
 | 171356 | 7069 | Ö | 182500 | <u>181648</u>
 | <u>181554</u> | median max
<u>181440</u> | <u>181208</u>
 | 4295 |
| Sand
Measurement nr:
Z-vector | S | 143617
111,4995 | <u>143337</u>
99,349381 | <u>142923</u>
92,877593
 | median max
<u>142648</u>
100,26456

 | 142548
151,367
 | 7391 | UN | 171816
131,83116 | <u>171726</u>
114,99548 | 171558
152,74845
 | median max
<u>171510</u>
154,81435
 | 171356
106,40529 | 7069 | Ö | 182500
91,885474 | 181648
93,904769
 | 181554
101,01455 | median max
<u>181440</u>
99,665583 | 181208
96,481837
 | 4295 |
| Sand
Measurement nr:
Z-vector
Max & min values | S | 143617
111,4995
-301,58644 | <u>143337</u>
99,349381
-225,52953 | <u>142923</u>
92,877593
-222,31772
 | median max
<u>142648</u>
100,26456
-270,34579

 | 142548
151,367
-266,00214
 | 7391 | U
N | 171816
131,83116
-280,787 | 171726
114,99548
-224,16272 | 171558
152,74845
-278,97811
 | median max
<u>171510</u>
154,81435
-267,31553
 | 171356
106,40529
-130,60448 | 7069 | Ö
L | 182500
91,885474
-259,56472 | <u>181648</u>
93,904769
-216,17726
 | <u>181554</u>
101,01455
-278,21689 | median max
<u>181440</u>
99,665583
-305,93012 | 181208
96,481837
-218,61875
 | 4295 |
| Sand
Measurement nr:
Z-vector
Max & min values | S
T | 143617
111,4995
-301,58644
114,85985 | 143337
99,349381
-225,52953
106,74391 | 142923
92,877593
-222,31772
130,31607
 | median max
142648
100,26456
-270,34579
116,94523

 | 142548
151,367
-266,00214
132,65704
 | 7391 | U
N
S | 171816
131,83116
-280,787
127,52941 | 171726
114,99548
-224,16272
135,84899 | 171558
152,74845
-278,97811
161,96525
 | 171510
154,81435
-267,31553
168,58388
 | 171356
106,40529
-130,60448
85,059584 | 7069 | Ö
L
L | 182500
91,885474
-259,56472
81,415747 | 181648
93,904769
-216,17726
109,98973
 | 181554
101,01455
-278,21689
70,780176 | median max
181440
99,665583
-305,93012
105,36676 | 181208
96,481837
-218,61875
104,76602
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| Sand
Measurement nr:
Z-vector
Max & min values | S
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-259,22983
109,5065
 | median max
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116,94523
-279,77938
120,21085

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 | 7391 | U
N
S | 171816
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-265,6786
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L
L | 182500
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| Sand
Measurement nr
Z-vector
Max & min values | S
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N
S
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-265,6786
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-203,318 | 171558
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85,059584
-122,8994
126,25587
-139,90819 | 7069 | Ö
L
L
Ö | 182500
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Measurement nr:
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N
S
H | 171816
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-139,90819
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L
L
Ö | 182500
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-232,43191
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 | 181554
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 | 4295 |
| Sand
Measurement nr.
Z-vector
Max & min values | S
T
E
E | 143617
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-272,81566
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 | 7391 | U
N
S
H
O | 171816
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-265,6786
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-375,12684
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-291,36024 | 171726
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-224,16272
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-171,27894
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-203,318
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-130,60448
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-122,8994
126,25587
-139,90819
123,18068
-158,76561 | 7069 | Ö
L
L
Ö
V | 182500
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-259,56472
81,415747
-232,43191
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-236,57839
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-239,69656 | 181648
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105,85113
-305,86078 | 181208
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 | 4295 |
| Sand
Measurement.nr:
Z-vector
Max & min values | S
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106,74391
-224,9514
119,89137
-272,81566
122,6902
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-259,22983
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-158,46323
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-279,77938
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142,03995

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91,10626
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146,97931
 | 7391 | U
N
S
H
O
D | 171816
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171,98253 | 171726
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-224,16272
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-171,27894
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-203,318
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 | median max
171510
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 | 171356
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-122,8994
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L
Ö
V | 182500
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152,96719
 | 4295 |
| Sand
Measurement nr
Z-voctor
Max & min values | S
T
E
L | 143617
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-224,9514
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-272,81566
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-235,46995 | 142923
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116,25357
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 | median max
142648
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N
S
H
O
D | 171816
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-125,24901 | 7069 | Ö
L
Ö
V | 182500
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| Sand
Measurement nn
Z-vector
Max & min values | S
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E
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118,04166
118,04166
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N
S
H
O
D | 171816
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L
Ö
V
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Measurement nr
Z-vector
Max & min values
S-vector
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L
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122,6902
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-255,56995
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225,52953 | 142923
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 | median max
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270,34579

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H
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D | 171816
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161,13615
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152,74845
278,97811
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 | 171356
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126,25887
-139,90819
123,18068
-158,76581
117,14259
-125,24901
106,40329
130,60448 | 7069 | Ö
L
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V
S | 182500
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99,738013
-234,57839
115,75364
-239,66456
93,691138
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93,691138
-259,56472 | 181648
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278,21689 | median max
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-250,38242
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-221,56504
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 | 4295 |
| Sand
Msawarement nr
Z-vector
Max & min values
S-vector
abs. relues | S
T
E
L
S
T | 143617
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114,8985 | 143337
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Measurement nr:		154106	154012	153914	153647	153100			162917	162802	162718	162406	162259			191037	190904	190745	190639	190536	
Z-vector		3945,3642	2187,3899	4364,2221	2313,8957	2076,6741			1731,1161	1022,1249	891,18075	929,12803	1323,8475			311,03093	878,29245	700,68231	724,00135	447,69737	
Max & min values		-5763,9688	-4944,4621	-5594,464	-3339,9979	-4906,0549			-2797,2716	-1912,1095	-3167,2636	-2799,8427	-4891,1237			-1676,554	-1332,6714	-1533,2767	-1034,8844	-1429,9911	
		3528,2275	3758,6429	4958,4799	3519,8498	4112,9719			3168,8544	2848,3124	2121,3233	2273,7364	3622,8622			210,23015	770,78854	868,2575 -1833 805	697,36073	1484 0155	
		4152,0009	2665,2884	2781,5844	2654,4357	4967,7434			2375,5702	3510,328	2224,4903	2060,7501	1079,5897			463,8864	544,67135	1348,946	568,99452	535,39366	
		-5690,5606	-6079,8156	-5611,0064	-7163,8778	-7635,8289			-4367,1934	-6122,8311	-5833,1576	-3142,1796	-6843,4992			-1280,4613	-1191,4351	-2124,8392	-1292,5406	-1317,8309	
		2200,5663	3016,4974	3997,8529	3862,0412	3483,6946			1345,0517	2512,2812	1058,169	1325,7315	2648,8036			412,92937	724,97116	528,05438	603,9369	1204,2169	
		-3388,8849	-3543,7731	-5567,9791	-4727,4095	-4348,7097			-4602,8907	-7165,2535	-1785,1308	-3065,1259	-6030,736		ö	-1818,3529	-1060,771	-2050,3763	-1371,9088	-1274,2245	
		-4934,7838	-3413,8015	-3772,6998	-5691,6981	-4400,073			-2626,7335	-3062,9434	-2440,8837	-4909,1161	-4761,7902		U	-901,27278	-941,2515	-1367,9739	-1397,7467	-847,59462	
		-						U							L						
S-vector		3945,3642	2187,3899	4364,2221	2313,8957	2076,6741			1731,1161	1022,1249	891,18075	929,12803	1323,8475		-	311,03093	878,29245	700,68231	724,00135	447,69737	
abs. values	c	5763,9688	4944,4621	5594,464	3339,9979	4906,0549		N	2797,2716	1912,1095	3167,2636	2799,8427	4891,1237		L	1676,554	1332,6714	1533,2767	1034,8844	1429,9911	
	5	3311,71	4378,9792	4179,3668	5968,2889	4713,6619		c	7071,5367	6750,8897	4830,9467	6791,2885	6267,9791		ö	895,2513	1342,7525	1833,805	1477,3229	1484,0155	
	Т	4152,0009	2665,2884	2781,5844	2654,4357	4967,7434		0	2375,5702	3510,328	2224,4903	2060,7501	1079,5897		V	463,8864	544,67135	1348,946	568,99452	535,39366	
		5690,5606	6079,8156	5611,0064	7163,8778	7635,8289		H	4367,1934	6122,8311	5833,1576	3142,1796	6843,4992		V	1280,4613	1191,4351	2124,8392	1292,5406	1317,8309	
	E	2200,5663	3016,4974	3997,8529	3862,0412	3483,6946		~	1345,0517	2512,2812	1058,169	1325,7315	2648,8036			412,92937	724,97116	528,05438	603,9369	1204,2169	
	E	2683,7948	2039,2249	2196,5619	3050,2101	3918,9446		0	4602,8907 721,90812	1461,3495	894,73154	2129,8224	1407,4227			824,84831	562,59616	504,26434	336,05827	440,12218	
	C	4934,7838	3413,8015	3772,6998	5691,6981	4400,073		D	2626,7335	3062,9434	2440,8837	4909,1161	4761,7902		S	901,27278	941,2515	1367,9739	1397,7467	847,59462	
	L						Mean	U						Mean	3	_					Mean
Mean Median		3960	3603	4302	4229	4456	4110		3081	3637	2525	2943 2537	3888 4192	3215	0	879	935	1286	950 879	973 1026	100
								II							E						
F-vector		5763,9688	4944,4621	5594,464	3339,9979	4906,0549		U	2797,2716	1912,1095	3167,2636	2799,8427	4891,1237		r	1676,554	1332,6714	1533,2767	1034,8844	1429,9911	
5 abs values		3528,2275	4378,9792	4958,4799	5968,2889	4713,6619		N	7071,5367	6750,8897	4830,9467	6791,2885	6267,9791		Τ	895,2513	1342,7525	1833,805	1477,3229	1484,0155	
	S	3388,8849	6079,8156	5611,0064	7163,8778	7635,8289 4348,7097			4367,1934 4602,8907	6122,8311 7165,2535	5833,1576 1785,1308	3142,1796 3065.1259	6843,4992 6030,736		-	1280,4613 1818,3529	1191,4351	2124,8392 2050.3763	1292,5406	1317,8309	
	T	4934,7838	3413,8015	3772,6998	5691,6981	4400,073		S	2626,7335	3062,9434	2440,8837	4909,1161	4761,7902		S	901,27278	941,2515	1367,9739	1397,7467	847,59462	
	1						Mean	н						Mean	т						Mean
Mean	E	4661	4472	5101	5378	5201	4963		4293	5003	3611	4142	5759	4562	1	1314	1174	1782	1315	1271	137
Median	-	4935	4379	5568	5692	4714	4935	0	4367	6123	3167	3142	6031	4367	Ε	1280	1191	1834	1372	1318	131
MAX	E	5764	6080	5611	7164	7636	Max 7636	n	7072	7165	5833	6791	6843	Max 7165	n	1818	1343	2125	1477	1484	Max 212
	T				medel max		6451	D				medel max		6741	P				medel max		1649
	-				median maa		6080					median max	c .	6843					median max		148
Sand																					
Measurement nr:	c	140506	140205	140006	135820	135615		U	165344	165253	164830	164543	164433		0	173854	173946	174050	175025	175202	
Z-vector	5	55,145093	85,111673	64,218928	77,107524	53,532269		N	49,190138	64,238587	78,814956	93,144373	75,744281		T	79,402712	34,789878	65,47279	47,715343	58,981687	
Max & min values	Т	-119,15959	-134,92446	-146,42658	-205,66005	-151,92183		IN	-129,01885	-145,39618	-161,25243	-114,16715	-125,20884		L	-123,70178	-151,51286	-123,10143	-122,53759	-152,4939	
		70,693921	51,05015	107,15155	59,865336	76,138715		S	58,182326	76,885071	79,713394	98,11117	81,238422		L	102,26795	55,875816	70,380017	60,008312	49,030515	
	E	-120,68792	-174,49673	-160,33478	-151,39443	-169,63082			-138,27861	-104,50262	-104,70653	-193,73453 81,439795	-111,1981		ä	-96,016233	-152,12614	-133,58873	-128,187	-103,92066	
	E	-123,82366	-116,81801	-158,94416	-208,59755	-184,69625		н	-143,47881	-145,18915	-125,23973	-177,96988	-154,19029		0	-98,020139	-116,20817	-100,79772	-99,006336	-101,31128	
	E	51,153882	39,267923	79,88885	72,373149	59,665082		0	55,937209	81,938782	82,31398	76,86117	78,776508		v	81,709353	56,048667	59,650524	59,999523	40,434812	
	L	-129,77581	-193,50942	-129,97931	-179,08877	-183,78023		U	-141,18096	-130,24481	-127,95165	-137,78434	-131,16978		Y	-94,331663	-154,01774	-135,94713	-109,86473	-81,521242	
		53,26228	87,962259	75,647639	81,054789	91,609418		D	75,476271	72,738587	91,591323	81,405115	81,541156			79,609744	56,955894	75,735485	69,268078	71,644773	
		-127/6807%	-100,91079	-110,07 407	-100,09440	-100,73031			-143,404.57	-110,2702	-130,73920	-1/3,182/3	-100,0800		0	-93,247078	*127,27411	-100,04097	-144,7700	-101,7107	
S-vector	C	55,145093	85,111673	64,218928	77,107524	53,532269			49,190138	64,238587	78,814956	93,144373	75,744281		5	79,402712	34,789878	65,47279	47,715343	58,981687	
abs. values	3	119,15959	134,92446	146,42658	205,66005	151,92183		II	129,01885	145,39618	161,25243	114,16715	125,20884		0	123,70178	151,51286	123,10143	122,53759	152,4939	
	Т	70,693921	51,05015	107,15155	59,865336 151,39443	76,138715		č	58,182326	76,885071	79,713394 104,70653	98,11117	81,238422		v	102,26795	55,875816 152,12614	70,380017	60,008312	49,030515	
		54,307202	24,885111	76,70135	87,809672	84,12016		N	68,004591	60,273743	82,011245	81,439295	78,137836		F	109,27381	38,538902	62,388806	50,842296	55,664304	
	E	123,82366	116,81801	158,94416	208,59755	184,69625		c	143,47881	145,18915	125,23973	177,96988	154,19029		т	98,020139	116,20817	100,79772	99,006336	101,31128	
	F	51,153882	39,267923	79,88885	72,373149	59,665082		3	55,937209	81,938782	82,31398	76,86117	78,776508		1	81,709353	56,048667	59,650524	59,999523	40,434812	
	-	53,26228	87,962259	75,647639	81,054789	91,609418		H	75,476271	72,738587	91,591323	81,405115	81,541156		S	79,609744	56,955894	75,735485	69,268078	71,644773	
	T	127,48674	136,91079	170,37287	150,69423	165,73531		-	143,26299	113,2702	130,75926	173,18375	153,5858		-	95,247678	129,25211	103,32897	122,7788	161,7107	
							Mean	U						Mean	Т						Mean
	Ľ.			-							106	123	107	107	-	96	95	0.2	87	88	9
Mean	Ĩ	91	104	117	127	122	112	D	100	99	100	104	01	0.0	H.	01	07	93	64	77	0
Mean Median	Ĩ	91 95	104 102	117 119	127 119	122 122	112 119	D	100	99	98	106	96	98	E	96	87	88	84	77	8
Mean Median F-vector	Ĩ	91 95 119,15959	104 102 134,92446	117 119 146,42658	127 119 205,66015	122 122 151,92183	112 119	D	100 102 129,01885	99 93 145,39618	98 161,25243	106 114,16715	96 125,20884	98	E P	96 123,70178	87 151,51286	93 88 123,10143	84 122,53759	77 152,4939	8
Mean Median F-vector 5 abs values	Ĩ	91 95 119,15959 120,68792	104 102 134,92446 174,49673	117 119 146,42658 160,33478	127 119 205,66015 151,39443	122 122 151,92183 169,63082	112 119	D	100 102 129,01885 138,27861	99 93 145,39618 104,50262	98 161,25243 104,70653	106 114,16715 193,73453	96 125,20884 111,1981	98	E P	96 123,70178 102,26795	87 151,51286 152,12614	93 88 123,10143 133,58873	84 122,53759 128,187	77 152,4939 103,92066	8
Mean Median F-vector 5 abs values	Ĩ	91 95 119,15959 120,68792 123,82366 129,77581	104 102 134,92446 174,49673 116,81801 193,50942	117 119 146,42658 160,33478 158,94416 129,9793	127 119 205,66005 151,39443 208,59755 179,08877	122 122 151,92183 169,63082 184,69625 183,78071	112 119	D	100 102 129,01885 138,27861 143,47881 141,180%	99 93 145,39618 104,50262 145,18915 130,24491	98 161,25243 104,70653 125,23973 127,95145	106 114,16715 193,73453 177,96988 137,78434	96 125,20884 111,1981 154,19029 131,16978	98	E P	96 123,70178 102,26795 109,27381 94,331663	87 151,51286 152,12614 116,20817 154,01774	93 88 123,10143 133,58873 100,79772 135,94773	84 122,53759 128,187 99,006336 109,86473	77 152,4939 103,92066 101,31128 81,521242	8
Mean Median F-vector 5 abs values	Ĩ	91 95 119,15959 120,68792 123,82366 129,77581 127,48674	104 102 134,92446 174,49673 116,81801 193,50942 136,91079	117 119 146,42658 160,33478 158,94416 129,97931 170,37287	127 119 205,66005 151,39443 208,59735 179,08877 150,69423	122 122 151,92183 169,63082 184,69625 183,78023 165,73531	112 119	D	100 102 129,01885 138,27861 143,47881 141,18096 143,26299	99 93 145,39618 104,50262 145,18915 130,24481 113,2702	98 161,25243 104,70653 125,23973 127,95165 130,75926	106 114,16715 193,73453 177,96988 137,78434 173,18375	96 125,20884 111,1981 154,19029 131,16978 153,5858	98	E P	96 123,70178 102,26795 109,27381 94,331663 95,247678	87 151,51286 152,12614 116,20817 154,01774 129,25211	93 88 123,10143 133,58873 100,79772 135,94713 103,32897	84 122,53759 128,187 99,006336 109,86473 122,7788	77 152,4939 103,92066 101,31128 81,521242 161,7107	8
Mean Median F-vector 5 abs values	Ĩ	91 95 119,15959 120,68792 123,82366 129,77581 127,48674	104 102 134,92446 174,49673 116,81801 193,50942 136,91079	117 119 146,42658 160,33478 158,94416 129,97931 170,37287	127 119 205,66005 151,39443 208,59755 179,08877 150,69423	122 122 151,92183 169,63082 184,69625 183,78023 165,73531	112 119 Mean	D	100 102 129,01885 138,27861 143,47881 141,18096 143,26299	99 93 145,39618 104,50242 145,18915 130,24481 113,2702	98 161,25243 104,70653 125,23973 127,95165 130,75926	106 114,16715 193,73453 177,96988 137,78434 173,18375	96 125,20884 111,1981 154,19029 131,16978 153,5858	98 Mean	E P	96 123,70178 102,26795 109,27381 94,331663 95,247678	87 151,51286 152,12614 116,20817 154,01774 129,25211	93 88 123,10143 133,58873 100,79772 135,94713 103,32897	84 122,53759 128,187 99,006336 109,86473 122,7788	77 152,4939 103,92066 101,31128 81,521242 161,7107	8 Mean
Mean Median F-vector 5 abs values Mean	Ĩ	91 95 119,15959 120,68792 123,82366 129,77581 127,48674 124	104 102 134,92446 174,49673 116,81801 193,50942 136,91079 151	117 119 146,42658 160,33478 158,94416 129,97931 170,37287 153	127 119 205,66005 151,39443 208,59755 179,08877 150,69423 179	122 122 151,92183 169,63082 184,69625 183,78023 165,73531 171	112 119 Mean 156	D	100 102 129,01885 138,27861 143,47881 141,18096 143,26299 139	99 93 145,39618 104,50262 145,18915 130,24481 113,2702 128	98 161,25243 104,70653 125,23973 127,95165 130,75926 130	106 114,16715 193,73453 177,96988 137,78434 173,18375 159	96 125,20884 111,1981 154,19029 131,16978 153,5858 153	98 Mean 138	E P	96 123,70178 102,26795 109,27381 94,331663 95,247678 105	87 151,51286 152,12614 116,20817 154,01774 129,25211 141	93 88 123,10143 133,58873 100,79772 135,94713 103,32897 119	84 122,53759 128,187 99,006336 109,86473 122,7788 112	77 152,4939 103,92066 101,31128 81,521242 161,7107 120	8 Mean 12
Mean Median F-vector 5 abs values Mean Median	Ĩ	91 95 119,15959 120,68792 123,82366 129,77581 127,48674 124 124	104 102 134,92446 174,49673 116,81801 193,50942 136,91079 151 137	117 119 146,42658 160,33478 158,94416 129,97931 170,37287 153 159	127 119 205,66005 151,39443 208,59755 179,08877 150,69423 179 179	122 122 151,52183 169,63082 184,69625 183,78023 165,73531 165,73531 1771 1770	112 119 Mean 156 159 Max	D	100 102 129,01885 138,27861 143,47881 141,18096 143,26299 143 141	99 93 145,39618 104,50262 145,18915 130,24481 113,2702 128 130	160 98 161,25243 104,70653 125,23973 127,95165 130,75926 130 128	106 114,16715 193,73453 177,96988 137,78434 173,18375 159 173	96 125,20884 111,1981 154,19029 131,16978 153,5858 153,5858 135 135	98 Mean 138 131 Max	E P	96 123,70178 102,26795 109,27381 94,331663 95,247678 105 105	87 151,51286 152,12614 116,20817 154,01774 129,25211 141 152	93 88 123,10143 133,58873 100,79772 135,94713 103,32897 119 123	84 122,53759 128,187 99,006336 109,86473 122,7788 112,7788 116 123	77 152,4939 103,92066 101,31128 81,521242 161,7107 120 104	8 Mean 12 12 Max
Mean Median F-vector 5 abs values Mean Median MAX	Ĩ	91 95 119,19959 120,68792 123,82366 129,7781 127,48674 124 124 124 124	104 102 134,92446 174,49673 116,81801 193,50942 136,91079 151 137 194	117 119 146,42658 160,33478 158,94416 129,97931 170,37287 153 159 159	127 119 205,66005 151,39443 208,59755 179,08877 150,69423 179 179 179 209	122 122 151,92183 169,63082 184,69625 183,78023 165,73531 171 170 185	112 119 Mean 156 159 Max 209	D	100 102 129,01885 138,27861 143,47881 141,180% 143,26299 139 141 141	99 93 145,39618 104,50262 145,18915 130,24481 113,2702 128 130 130 145	160 98 161,25243 104,70653 125,23973 127,95165 130,75926 130 128 130	106 114,16715 193,73433 177,96988 137,78434 173,18375 159 173 159 173	96 125,20884 111,1981 154,19029 131,16978 133,5858 133 135 131	98 Mean 138 131 Max 194	E P	96 123,70178 102,26795 109,27381 94,331663 95,247678 105 105 102 124	87 151,51286 152,12614 116,20817 154,01774 129,25211 141 152 152	93 88 123,10143 133,58873 100,79772 135,94713 103,32897 119 123 136	84 122,53759 128,187 99,006336 109,86473 122,7788 1116 123 123 128	77 152,4939 103,92066 101,31128 81,521242 161,7107 120 104 104	8 Mean 12 12 Max 16
Mean Median F-vector S abs realises Mean Median MAX	Ī	91 95 119,19959 120,68792 123,82366 129,77581 127,48674 124 124 124 130	104 102 134,92446 174,49673 116,81801 193,50942 136,91079 151 137 194	117 119 146,42698 160,33478 158,94416 129,97931 170,37287 153 159 170	127 119 205,66005 151,39443 208,59755 179,08877 150,69423 179 179 179 209 medel max	122 122 151,52183 169,63082 184,69625 183,78023 165,73531 171 170 185	112 119 Mean 156 159 Max 209 177	D	100 102 129,01885 138,27861 143,47881 141,18096 143,28299 139 141 141	99 93 145,39618 104,50262 145,18915 130,24481 113,2702 128 130 145	98 161,25243 104,70633 125,23973 127,95165 130,75926 130 128 130	106 114,16715 193,73433 177,96988 137,78434 173,18375 159 173 173 194 medel max	96 125,20884 111,1981 154,19029 131,16978 133,5858 135 135 135	98 Mean 138 131 Max 194 160	E P	96 123,70178 102,26795 109,2781 94,331663 95,247678 105 102 124 124	87 151,51286 152,12614 116,20817 154,01774 129,25211 141 152 152 154	93 88 123,10143 133,58873 100,79772 135,94713 103,32897 119 123 136	122,53759 128,187 99,00636 109,86473 122,7788 1116 1223 medel max	77 152,4939 103,92066 101,31128 81,521242 161,7107 120 104 104 162	8 Mean 12 12 Max 16 143

D

													128%	114%												124%	115%											135%	117%	115%	
	51,9218322	69,6308165	84,6962462	83,7802306	65,7353087	71,152887		89%	%66	108%	107%	8/6	108%		25,2088439	11,1981017	54,1902892	53 5857071	* 50 second no.	35,070563	93%	82%	114%	97%	114%	114%		52,4938987	0000026/00	1,52124242	61,7106955	20,191555	%LC1	86%	84%	68%	135%	135%			
	5,6600546 1	51,3944296 1	8,5975546 1	9,0887656 1	50,6942343 1	9,087008 17	_	115%	85%	116%	100%	R to	116%		14,1671505 1	3,7345333 1	1 918869617	1 10302607/1/01	-	9,367932 13	72%	122%	112%	86%	109%	122%		22,5375864 1	1 000/31/32	9,8647348 8	22,7787973 1	6,474891 12	105%	110%	85%	94%	105%	110%		-	
	6,4265798 20	0,3347829 11	8,9441579 20	11 1915679,91	0,3728688 11	3,211541 17		96%	105%	104%	85%	4111	111%		1,2524266 11	M,7065281 19	5,2397312 1	1 7500695 1		9,981919 15	124%	81%	96%	98%	101%	124%		3,1014288 11	0 022/20210	6,9471319 10	3,3289679 11	9,352796 11	103%	112%	84%	114%	87%	114%			114%
	4,9244596 14	4,4967252 16	6,8180143 15	3,5094206 12	6,9107877 17	L,331881 15:	_	89%	115%	77%	128%	808	128%		5,3961787 16	04,502624 10	5,1891474 12	71 CT10M/7/0		7,720593 129	114%	82%	114%	102%	89%	114%		1,5128561 12	4,12015/5 13 6,2081686 10	4,0177389 13	9,2521139 10	0,623403 115	108%	108%	83%	110%	92%	110%			
	9,1595949 13	0,6879152 17	3,8236574 11	9,7758058 19	7,4867433 13	,186743 15:	_	96%	97%	100%	105%	103%	105%		9,0188461 14	8,2786117 1	43,478807 14	11 23000011		044041 12	93%	%66	103%	102%	103%	103%		3,7017799 15	0.2738061 11	33166266 15	24767829 12	,964575 140	11,8%	47%	104%	%06	91%	118%			
	11	12(12	125	12	124							120%	113%	125	13	- :	2 3	:	139						128%	117%	 12	2 2	đ	35	104					+	119%	109%	113%	
	0021387	0070215	(9337793	5,070498	5656152	915811		94%	107%	106%	76%	110%	116%		6044785	8994003	1681806	CT1000/		485338	96%	91%	103%	117%	92%	117%		(6187492	1126262	1646477	9615227	538476	91%	104%	92%	119%	95%	119%			
	3457898 266	7793835 302	8008679 299	7725476 21	1739148 326	574501 281		866	103%	108%	88% %	102%	108%		3155332 130	2032285 122	1387754 139	561 7770110		599127 135	104%	102%	111%	98%	85%	111%		9301198 218	100 1009722	8607838 287	7230885 229	450237 241	101%	104%	92%	101%	101%	104%			
	3177196 270	229829 279,	4632274 294,	9651805 238,	4026805 279,	475727 272,		%66	115%	71%	120%	8406	120%		9781118 267,	6109243 263,	5474478 286,	4138775 217		,36151 257,	98%	%66	113%	98%	92%	113%		2168947 305,	212 4050205 8487306 777	0499025 305	3018556 305,	383887 301,	87%	%66	109%	102%	103%	109%		-	
	5295251 222,	9514001 25%	8156579 158/	3898767 268,	1699548 213,	131283 224,		91%	91%	110%	104%	103%	110%		1627247 278	2789357 280,	3179982 321,	096 1160414		86943 284	109%	83%	98%	93%	117%	117%		1772618 278,	MOS431 346	044103 327)	6655431 328,	246793 319,	200%	104%	101%	107%	89%	107%			
	864376 225,5	092891 224,5	84844 272,8	202266 258,3	577266 255,4	11633 247,4		110%	104%	87%	88%	2111%	111%		787001 224,1	786025 171,2	268447 203,5	CT41 100700		99696 206,5	96%	91%	128%	100%	86%	128%		647214 216,1	7/77 144 177 14	965573 233,0	053464 193,6	95385 218,2	106%	45%	97%	98%	103%	106%			
	301,5	285,0	237,5	240,7	303,1	273,6				_			147%	130%	280	265,6	375,1	24	1	292,7						165%	150%	239,5	2325	239,6	252,2	244,0						138%	120%	134%	
	054937	3,66187	828862	709722	073003	86568		94%	91%	147%	84% erec	\$1.09	147%		123669	979138	499157	200172		02562	85%	109%	119%	105%	83%	119%		901106	25010/6	224504	946212	73134	113%	117%	104%	100%	67%	117%			
	9,9979 4906	288916 471	877783 7635	4348, 4348,	698095 4400	25444 5200,		62%	111%	133%	88%	100%	133%		842674 4891	288475 6267	179588 6843	1927 01001		51055 5759,	68%	164%	76%	74%	119%	164%		884391 1429	54286/ 198	908805 1274	746695 847,5	88068 1270,	79%	112%	98%	104%	106%	112%		-	
	63964 333	79883 5968,	06445 7163,	7274 10160	(1695 10866)	2584 5378,		110%	97%	110%	109%	14%	110%		63582 2799,	46687 6791,	57625 3142,	5007 00903		17647 4141,	88%	134%	162%	49%	68%	162%		76677 1034,	1100 1200	76287 1371,	73943 1397,	5422 1314,	86%	103%	119%	115%	77%	119%			
_	\$2106 5594,4	79196 4958,4	15622 5611,0	73141 5567,5	01462 3772,6	6631 5100,5		11%	98%	136%	79%	/0%	136%		10946 3167,2	89733 4830,5	31139 5833,1	1/00/1 00000		0546 3611,4	38%	I35%	122%	143%	61%	143%		71421 1533,2	2/0/2 2/0/2	71031 2050,3	14994 1367,9	7763 1782,0	11.4%	14%	102%	90%	80%	114%		_	
_	8837 4944,46	7452 4378,95	0633 6079,81	4852 3543,77	3778 3413,8	1211 4472,1		24% 3	76%	22% 3	73%	00%	24% 1		1566 1912,	6703 6750,88	3441 6122,8 ontor 714.0 M	77601 / 102/10		518 5002,8	65%	65% 3	02% 1	07%	61%	65% 3		4031 1332,62	2/2861 1342/2	2859 1060,77	7807 941,251	844 1173,	28%	68%	97%	38%	869%	38%			
	5763,96	3528,22	5690,56	3388,88	4934,78	4661,28		-		-		-	51% 1	29%	27,7972	7071,53	4367,19	10/7/01-		4293,12		1	-	1		26% 1	55%	1676,35	102/0621	1818,35	901,272	1314,37				1		57% 1	20%	48%	
	347	636	619	505	164	34		5%	3%	4%	× .	8	5% 1	1	638	683	905	2 2		86	2%	9%6	6%	2%	2%	6% 2	-	714	40 IS	121	222	02	5%	2%	2%	9%6	5%	5% 1	-	-	
	13 6883,511	27 6211,457	6854,590	44 5251,125	54 4840,06	75 6008,149		% 11	%	% 11	8 8	8	% 11		96 1667,703	38 2547,52	7289,877	71 2210/010		6 3232,496	8	%	% 22	%	*	% 22		82 1956,838	1050,000 1050,000	31 849,644	92 1964,734.	1450,162	13	9	2 %	8	* 13	% 13			
	8 5448,28341	8 5673,4328.	2 11045,9154	3 5616,886	6 8726,1254.	6 7302,1287		8 75	% 78	K 151	44	N71 %	K 151		8 2124,25245	3 3412,7290	2079,7309	070 / 10 L2 9		7 2570,1321	K 83	¥ 133	81	% 79.	% 124	K 133		1655,8298	3 2486 5055	3 2351,90700	M 2715,304	1 2385,6189	205	8 72	146	%	% 114	6 146			
	5358,55400	7032,34355	7390,59258	5743,30547	4827,29619	6070,4183		188	116	122	955	500	122		5164,92110	7069,38009	1316,49142	CICIC/0/01		4128,8100	125	171	325	114	283	171		1076,857	5247 67371	3146,55353	2206,90740	3128,9791	305	127	167	101	715	167			
	6628,894777	7266,23950	4585,790775	6102,198	6069,804445	6130,5855		108%	119%	75%	100%	866	119%		4307,872515	712A,772906	5426,346636	10080 0508	- constants	4675,72554	92%	152%	116%	55%	85%	152%		3096,200495	3686 77784	1394,707334	4295,046203	2942,03038	105%	29%	122%	47%	146%	146%			
	7742,734035	5301,895168	1594,225926	6970,890285	6315,560207	5585,06112		139%	95%	29%	125%	113%	139%		1602,335411	2238,894981	1918,637169	20/20/2211		1929,54225	83%	116%	%66	59%	143%	143%		2418,79232	107766'6070	4214,178383	2894,777016	3309,59922	7952	157%	55%	127%	87%	157%			
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Spread of steps

XII
Empe's vibration measurements

Ε

E.1 Empe's measurements with steel shoe on concrete



Figure E.1.1: The oscillations in x-direction of the steel shoe hoof on concrete.



Figure E.1.2: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of steel and concrete.

E.2 Empe's measurements with steel shoe on fibre sand



Figure E.2.1: The oscillations in x-direction of the steel shoe on fibre sand.



Figure E.2.2: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of steel and fibre sand.

E.3 Empe's measurements with Öllöv Softstep on concrete



Figure E.3.1: The oscillations in x-direction of Öllöv SoftStep on concrete.



Figure E.3.2: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of Öllöv SoftStep and concrete.

E.4 Empe's measurements with Öllöv Softstep on fibre sand



Figure E.4.1: The oscillations in x-direction of Öllöv SoftStep on fibre sand.



Figure E.4.2: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of Öllöv SoftStep and fibre sand.

E.5 Empe's measurements on unshod hoof on concrete



Figure E.5.1: The oscillations in x-direction of the unshod hoof on concrete.



Figure E.5.2: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of the unshod hoof and concrete.

E.6 Empe's measurements on unshod hoof on fibre sand



Figure E.6.1: The oscillations in x-direction of the unshod hoof on fibre sand.



Figure E.6.2: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of the unshod hoof and fibre sand.