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 SoftStep, 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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Frida Jönsson & Amanda Salfjord, Gothenburg, May 2018

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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 SoftStep 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].

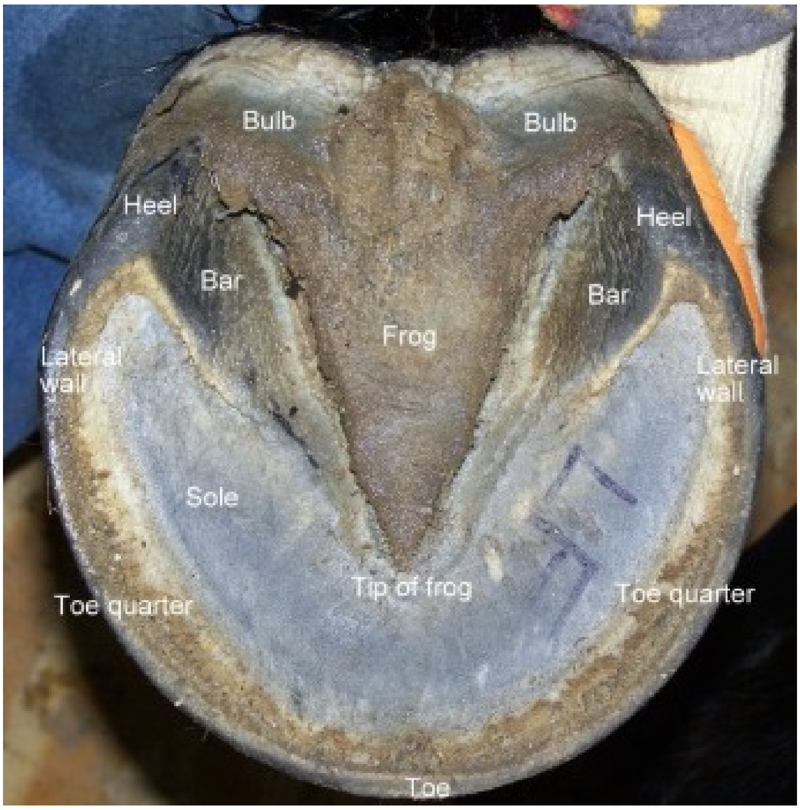

Figure 2.2: The division of the main parts of the hooves bottom [3].

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 *x* 19,6 *x* 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 *x* 10 mm, and therefore the metal plate will be 15 *x* 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 *x* 15 *x* 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.

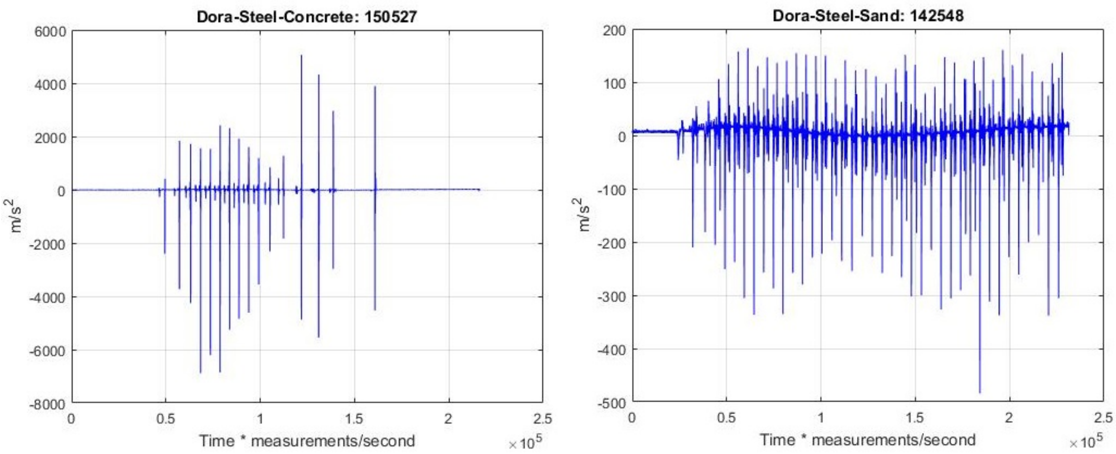

Figure 4.8: How measurements differ from concrete to sand.

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.

Table 4.1: Amplitude for Dora on concrete

Dora 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 4.2: Amplitude for Empe on concrete

Empe 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/s^2.

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.

Table 4.3: Comparison between Öllöv SoftStep and steel shoe

Concrete [m/s^2]			
Dora			
	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*
Empe			
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*

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

Dora 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

Empe 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/s^2. 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.

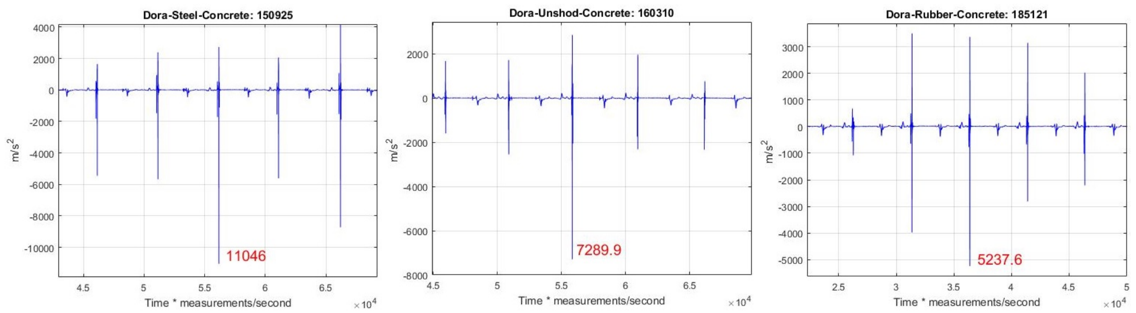

Figure 4.9: How the middle pulse's amplitude is higher than the rest at concrete for Dora.

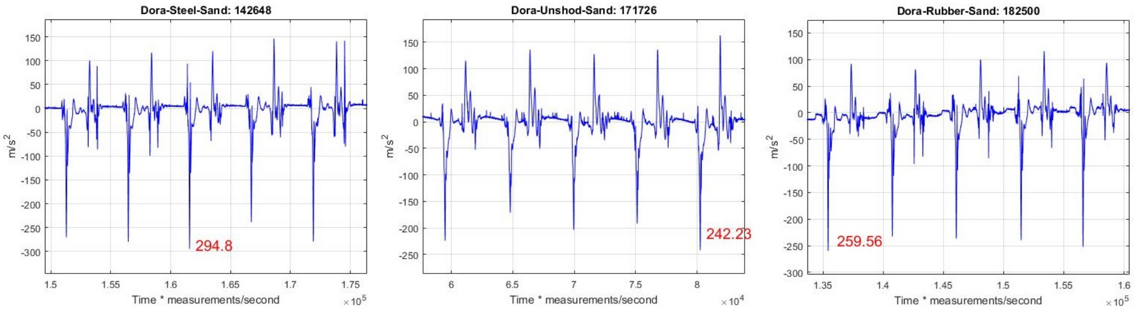

Figure 4.10: How the pulses are more even at sand for Dora.

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.

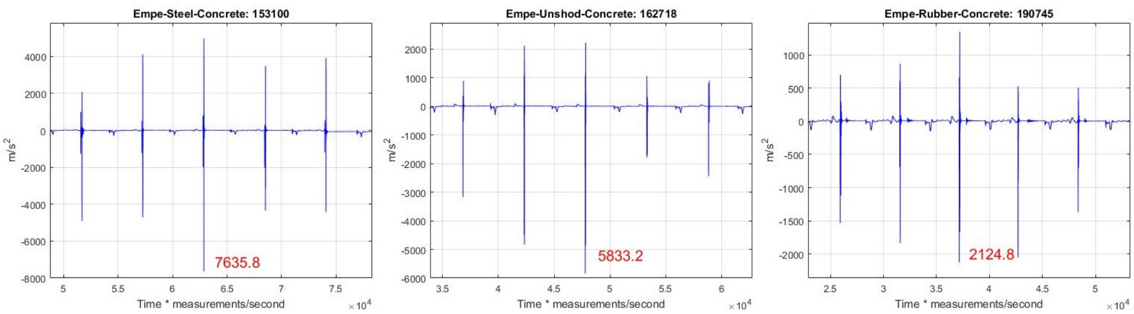

Figure 4.11: How the middle pulse amplitude is higher than the rest at concrete for Empe.

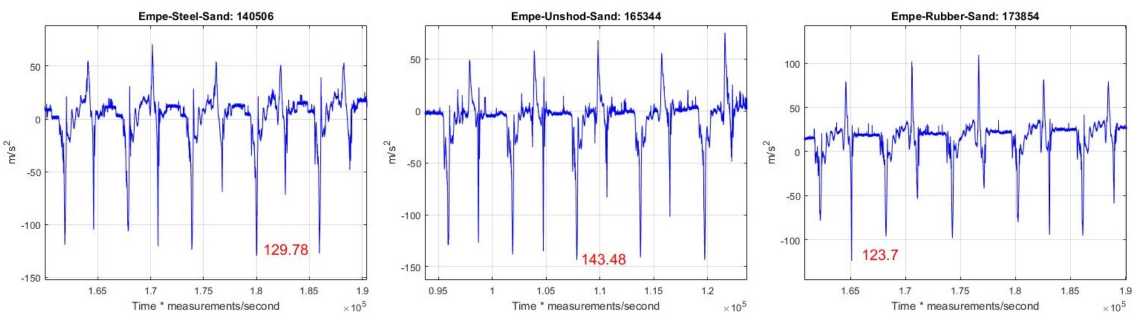

Figure 4.12: How the pulses are more even at sand for Empe.

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

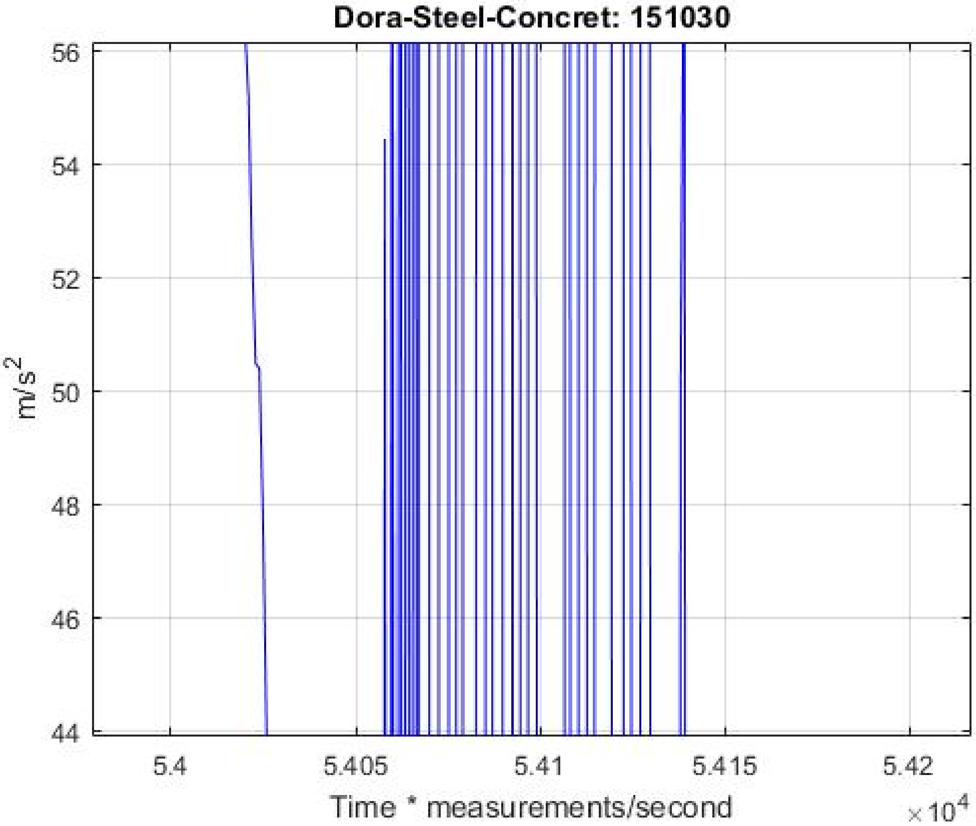

Figure 4.13: The characteristics of the oscillations in x-direction of the hoof wearing a steel shoe on concrete.

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.

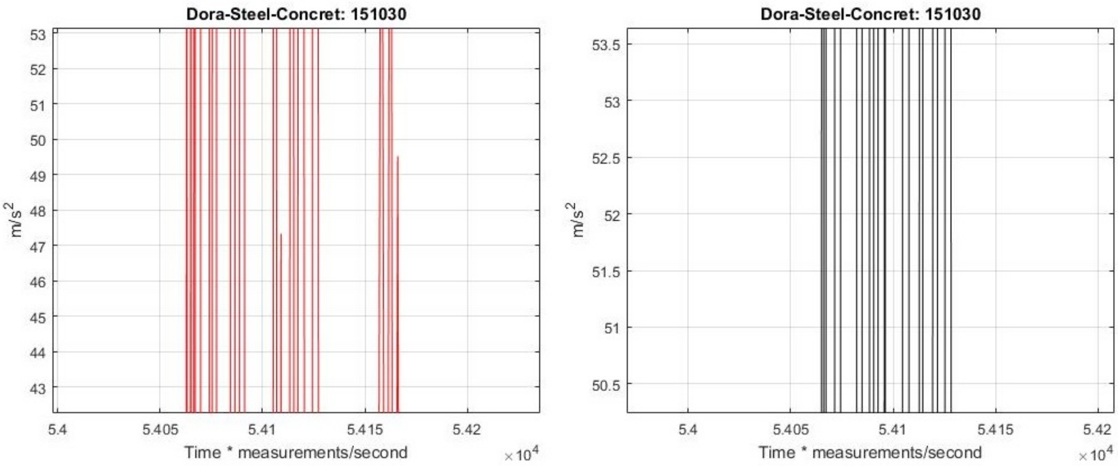

Figure 4.14: The left show the character of the oscillation in y-direction and the right in z-direction, in combination of steel and concrete.

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.

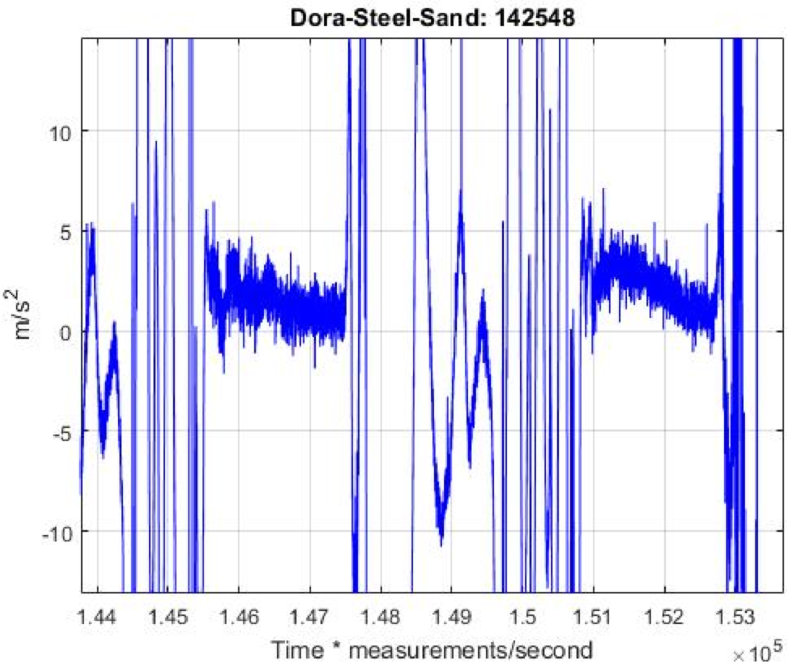

Figure 4.15: The oscillations in x-direction of the hoof wearing a steel shoe on fibre sand.

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.

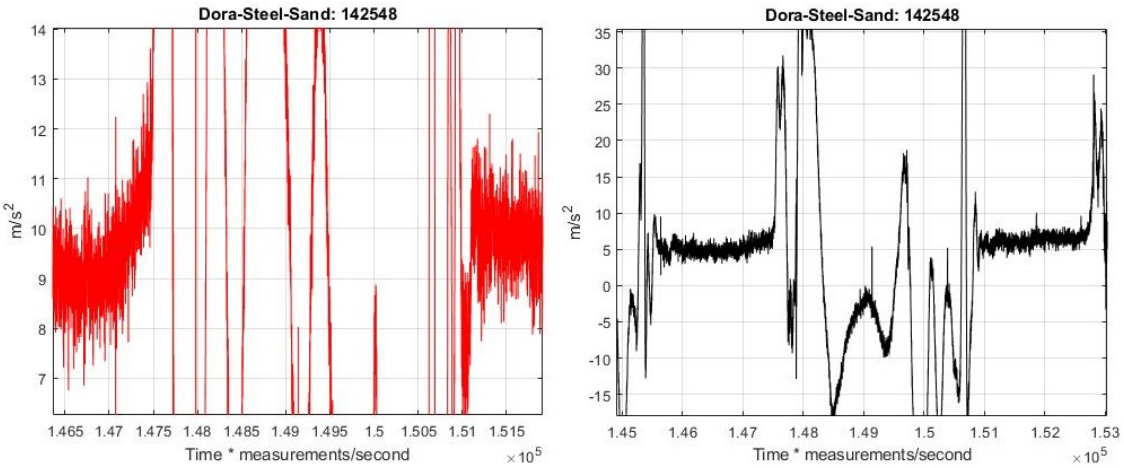

Figure 4.16: The left show the character of the oscillation in y-direction and the right in z-direction, in combination of steel and fibre sand.

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

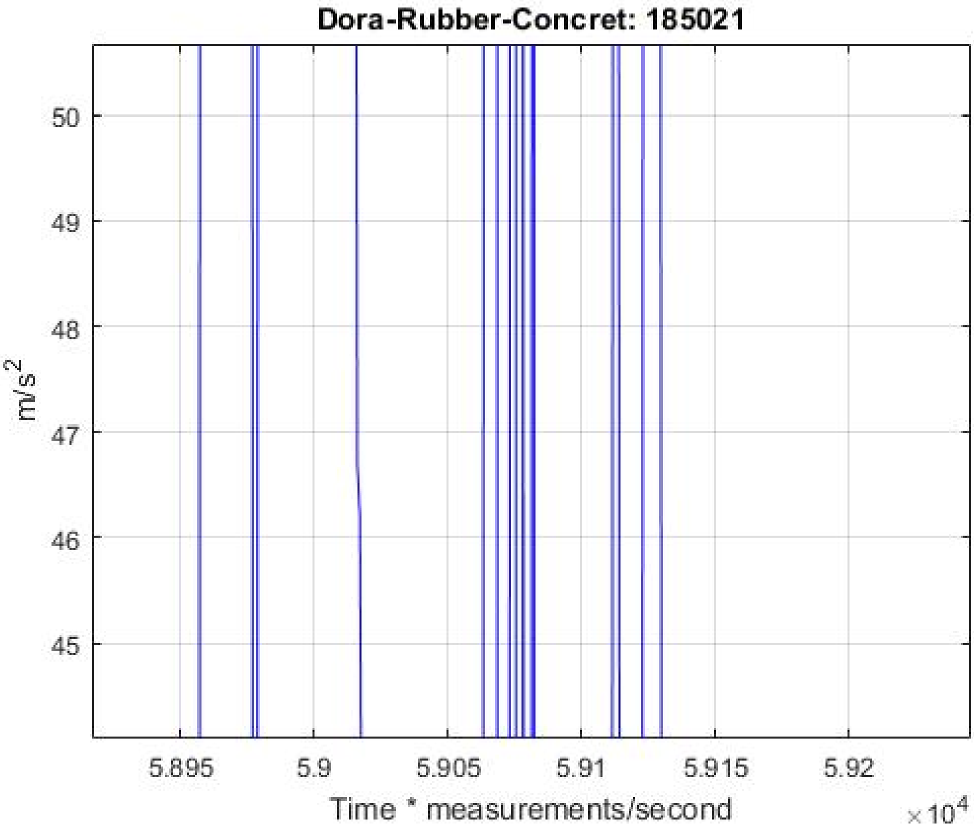

Figure 4.17: The characteristics of the oscillations in x-direction of the hoof wearing a Öllöv SoftStep on concrete.

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

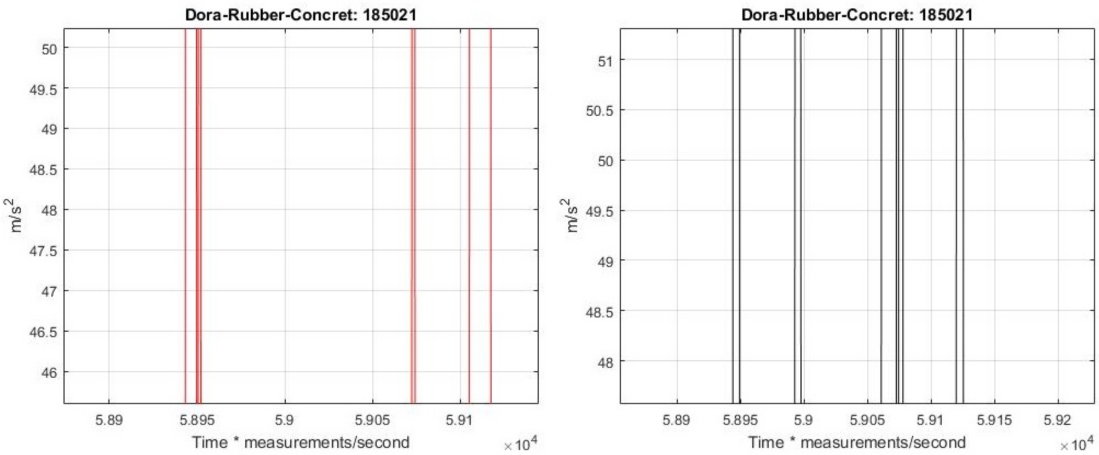

Figure 4.18: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of Öllöv SoftStep and concrete.

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.

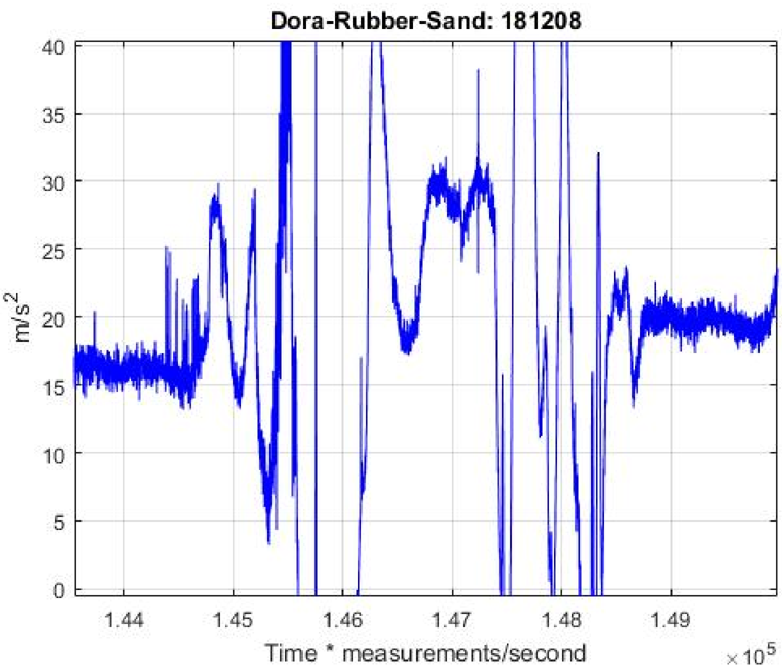

Figure 4.19: The oscillations in x-direction of the hoof wearing Öllöv SoftStep on fibre sand.

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

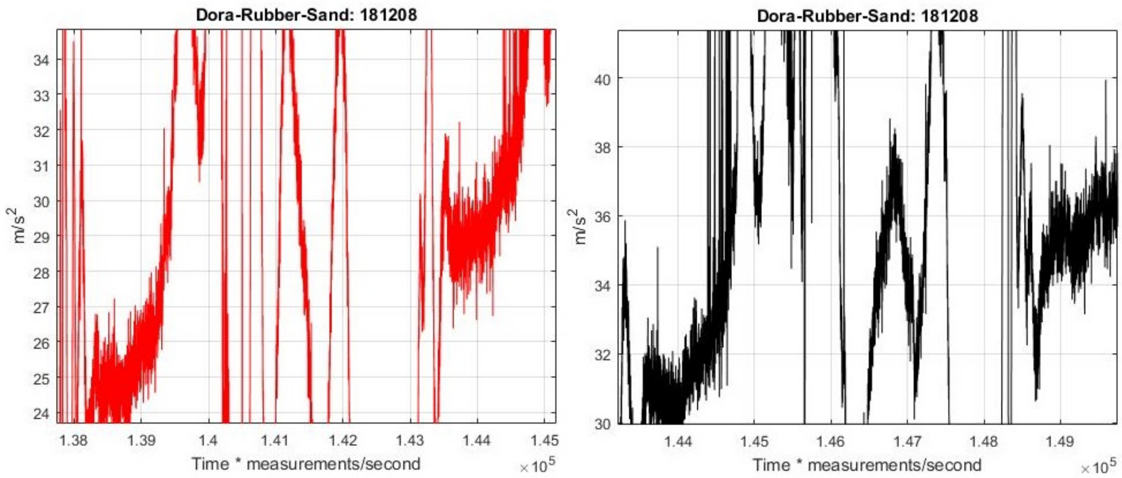

Figure 4.20: The left shows the character of the oscillations in y-direction and the right in z-direction, in combination of Öllöv SoftStep and fibre sand.

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.

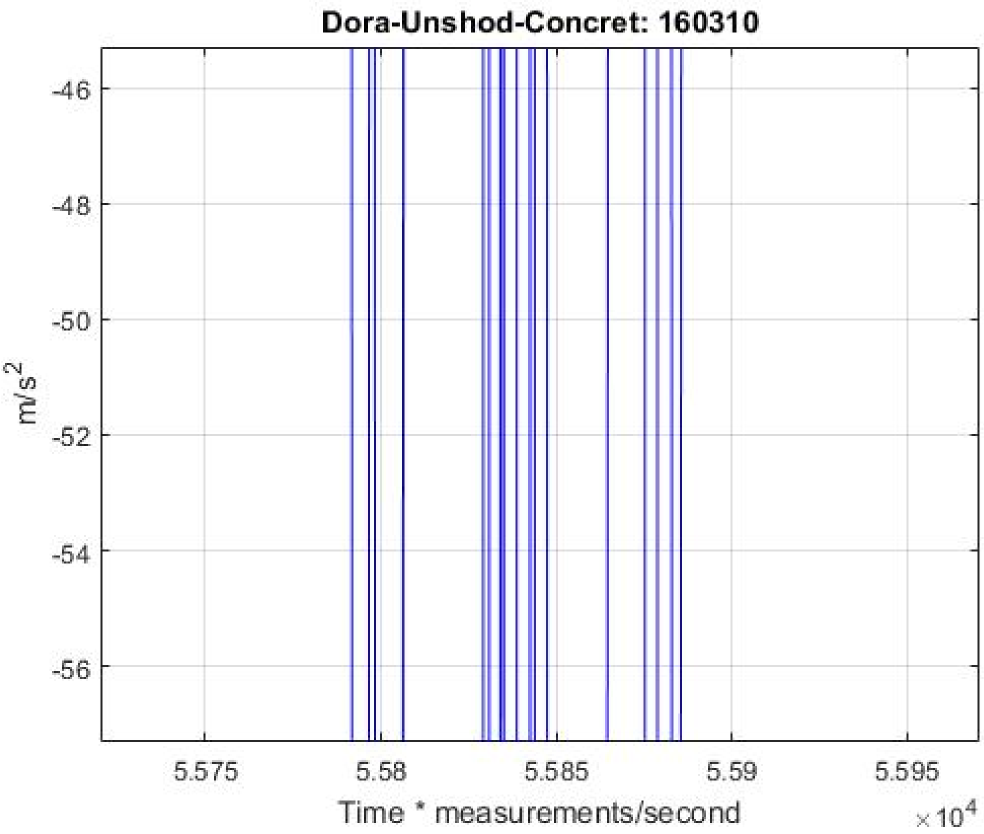

Figure 4.21: The characteristics of the oscillations in x-direction of the unshod hoof on concrete.

As shown in figure 4.22, the oscillations occurred more in the y-direction and the z-direction 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.

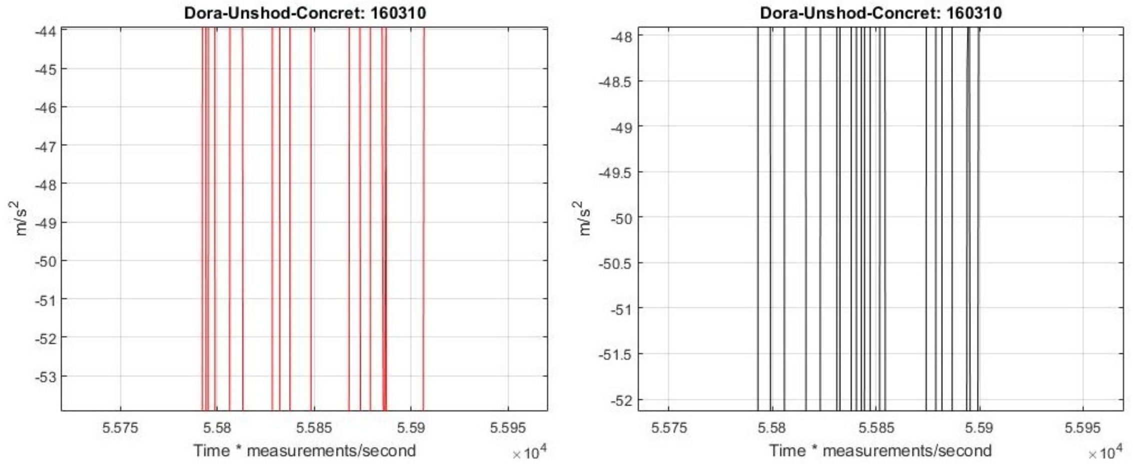

Figure 4.22: The left shows the character of the oscialltion in y-direction and the right in z-direction, in combination of unshod hoof and concrete.

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

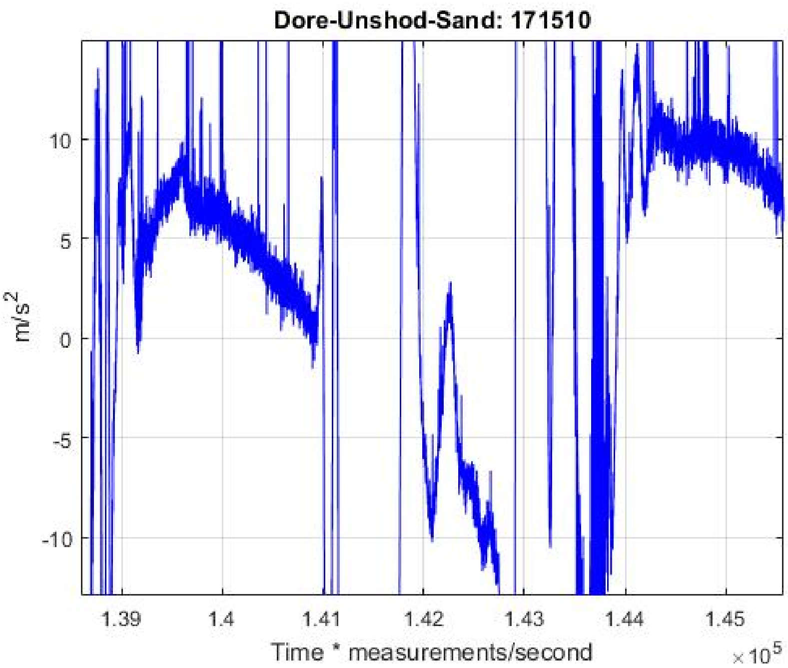

Figure 4.23: The oscillations in x-direction of the unshod hoof on fibre sand.

Figure 4.24 shows the unshod hoof's oscillations on fibre sand in y-direction and z-direction 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.

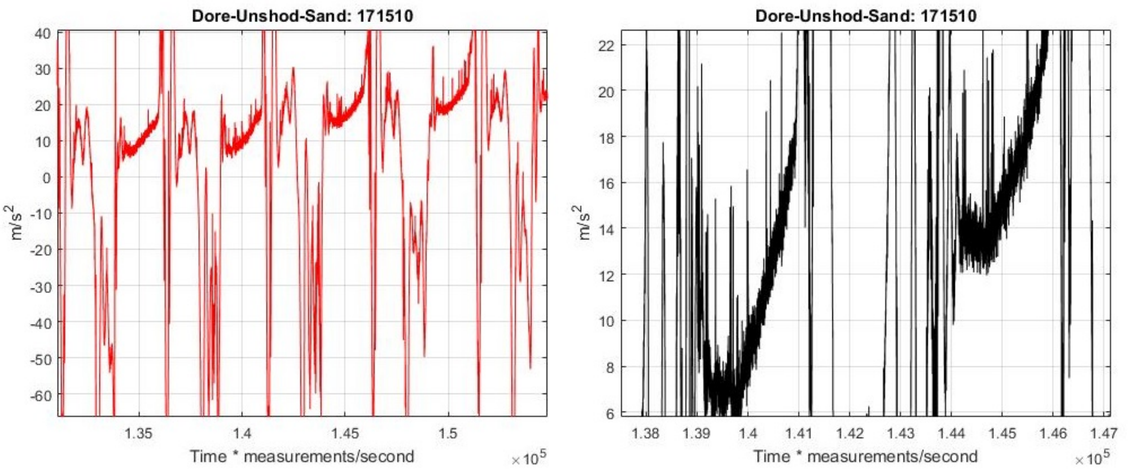

Figure 4.24: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of rubber and fibre sand.

5

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.

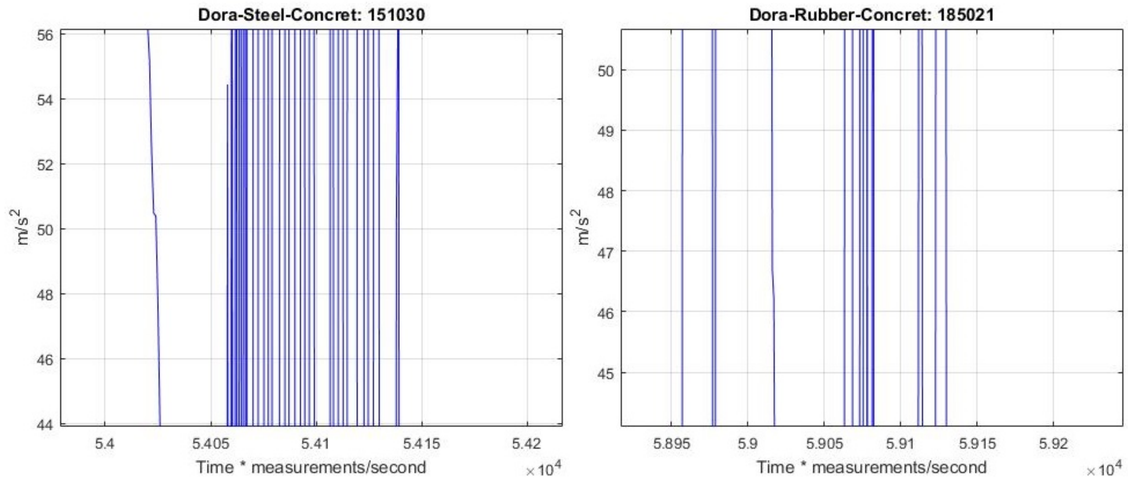

Figure 5.1: The left show oscillations with steel and the right with Öllöv SoftStep, both on concrete.

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.

6

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 SoftStep 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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A
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	ja
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	ja
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	0,131	-0,131	3,48	1526	
2	d	0,361	-0,361	3,25	152722	ja

3	d	0,321	-0,321	3,29	152843	
4	d	0,181	-0,181	3,43	1529	
5		0,081	-0,081	3,53	153100	ja
6	d	0,231	-0,231	3,38	153240	
7		0,071	-0,071	3,54	153647	
8	d	0,191	-0,191	3,42	1538	
9		0,091	-0,091	3,52	153914	
10		0,111	-0,111	3,5	154012	
11		0,011	-0,011	3,6	1541	
12	d	0,221	-0,221	3,39	154230	
13	d	0,361	-0,361	3,25	154342	ja
Dora	**Betong**	**oskodd**				
1		0,084	-0,084	3,35	160310	ja
2		0,254	-0,254	3,18	160437	
3		0,244	-0,244	3,19	160616	ja
4	d	0,294	-0,294	3,14	160714	
5		0,204	-0,204	3,23	160827	ja
6	d	0,346	0,346	3,78	160917	
7		0,134	-0,134	3,3	161050	ja, bakhov
Empe	**Betong**	**Oskodd**				
1		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
4	d	0,351	-0,351	3,26	162615	
5		0,089	0,089	3,7	162718	ja
6		0,009	0,009	3,62	162802	
7		0,101	-0,101	3,51	162917	ja
Empe	**Sand**	**Oskodd**				
1	d	0,161	-0,161	3,45	164144	
2	d	0,109	0,109	3,72	164315	ja
3		0,051	-0,051	3,56	164433	
4		0,021	-0,021	3,59	164553	
5	d	0,119	0,119	3,73	164741	
6		0,029	0,029	3,64	164830	ja
7	d	0,161	-0,161	3,45	164925	
8	d	0,169	0,169	3,78	1652203	
9		0,019	0,019	3,63	165253	
10		0,011	-0,011	3,6	165344	ja + bak
Dora	**Sand**	**oskodd**				
1		0,086	0,086	3,52	171356	
2		0,004	-0,004	3,43	171510	ja
3		0,114	-0,114	3,32	171558	
4		0,154	-0,154	3,28	171726	ja
5		0,144	-0,144	3,29	171816	
6	d	0,174	-0,174	3,26	172006	ja
Empe	**Sand**	**Gummi**				
1		0,049	0,049	3,66	173854	ja
2		0,019	0,019	3,63	173946	
3		0,049	0,049	3,66	174050	

4		0,169	0,169	3,78	175025	ja	
5		0,119	0,119	3,73	175202		
6	d	0,309	0,309	3,92	175332	ja	
Dora	Sand	Gummi					
1		0,226	0,226	3,66	181208	ja	
2	d	0,266	0,266	3,7	181326		
3		0,134	-0,134	3,3	181440	ja	
4		0,234	-0,234	3,2	181554		
5		0,074	-0,074	3,36	181648		
6		0,044	-0,044	3,39	182500	ja	
Dora	Betong	Gummi					
1		0,064	-0,064	3,37	184918	ja	
2		0,054	-0,054	3,38	185021		
3		0,114	-0,114	3,32	185121		
4	d	0,254	-0,254	3,18	185226	ja	
5	d	0,164	-0,164	3,27	185322		
6	d	0,304	-0,304	3,13	185556	ja	
7		0,054	-0,054	3,38	185641		
8		0,064	-0,064	3,37	185718		
Empe	Betong	Gummi					
1		0,019	0,019	3,63	190536		
2		0,069	0,069	3,68	190639	ja	
3		0,169	0,169	3,78	190745		
4		0,109	0,109	3,72	190904	ja	
5	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	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			
Medeltid		3,5	sek				
Medelhastighet		2,8	m/s				
Medelavikelse på DORA		0,12					
MAX avikelse på DORA		0,25					
Medelavikelse på EMPE		0,08	sek				
MAX avikelse på EMPE		0,31	sek				
MAX AVIKELSE		0,31	sek				
Medelavikelse		0,10					

B
Matlab code

```
%% Example Matlab / GNU Octave code for parsing HVM200 raw data format
close all; clear all; clc;
    % Number of Samples to read
Sample_Rate = 7161.45833;       % Hz (Hard wired sample rate)
Sample_Time = 60;               %second
num_samples_to_read = Sample_Rate*Sample_Time;
    % Open file, Read, Close
    % filename = 'HVM_SERIAL_NUMBER_BASENAME_DATESTAMP.00.raw';
filename = 'Z:\EXJ\Användbara\emperador stål sand\Användbara Emparador Stål
Sand\HVM_0001301_horse_180511_140506.00.raw';
rawsavename = 'HVM_0000056';
filteredsavename = 'HVMFilt_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));
z_axis = zeros(1,floor(num_samples_to_read));
x_axis = A(1:3:end);
y_axis = A(2:3:end);
z_axis = A(3:3:end);
% Remove DC bias from data (optional)
x_axis = x_axis - mean(x_axis);
%y_axis = y_axis - mean(y_axis);
%z_axis = z_axis - mean(z_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
        [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);

z1 = max((x_axis(x(1):x(2)))) ;
z2 = min((x_axis(x(1):x(2))));
z3 = max((x_axis(x(2):x(3)))) ;
z4 = min((x_axis(x(2):x(3))));
z5 = max((x_axis(x(3):x(4)))) ;
z6 = min((x_axis(x(3):x(4))));
z7 = max((x_axis(x(4):x(5)))) ;
z8 = min((x_axis(x(4):x(5))));
z9 = max((x_axis(x(5):x(6)))) ;
z10 = min((x_axis(x(5):x(6))));

Z(1,1) = z1;
Z(2,1) = z2;
Z(3,1) = z3;
Z(4,1) = z4;
Z(5,1) = z5;
Z(6,1) = z6;
Z(7,1) = z7;
Z(8,1) = z8;
Z(9,1) = z9;
Z(10,1)= z10;

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(6))))) ;

F(1,1) = f1;
F(2,1) = f2;
F(3,1) = f3;
F(4,1) = f4;
F(5,1) = f5;

S = abs(Z)      % Max och min som absolut värden
```

C
Amplitude results

Dora

Concrete

STEEL | STEEL

Mätningsnr :	151505	151120	151030	150925	150527	
Z-vector	2732,9222	2708,2815	1896,3166	1642,804	1560,8842	
Max & min values	-7742,734	-6628,8948	-5358,554	-5448,2834	-6883,5113	
	2820,6273	2582,2395	3444,5227	2394,3304	1536,3685	
	-5301,8952	-7266,2395	-7032,3436	-5673,4328	-6211,4576	
	1594,2259	2572,0549	3136,4016	2728,7298	2417,5297	
	-1497,279	-4585,7908	-7390,5926	-11045,916	-6854,5904	
	3586,2083	2768,8879	1621,549	2059,5784	2311,7972	
	-6970,8903	-6102,198	-5743,3055	-5616,8864	-5251,1256	
	1883,7396	1690,9612	1131,34	4153,4583	1918,3988	
	-6315,5602	-6069,8044	-4827,2962	-8726,1255	-4840,0616	
S-vector	2732,9222	2708,2815	1896,3166	1642,804	1560,8842	
abs. values	7742,734	6628,8948	5358,554	5448,2834	6883,5113	
	2820,6273	2582,2395	3444,5227	2394,3304	1536,3685	
	5301,8952	7266,2395	7032,3436	5673,4328	6211,4576	
	1594,2259	2572,0549	3136,4016	2728,7298	2417,5297	
	1497,279	4585,7908	7390,5926	11045,916	6854,5904	
	3586,2083	2768,8879	1621,549	2059,5784	2311,7972	
	6970,8903	6102,198	5743,3055	5616,8864	5251,1256	
	1883,7396	1690,9612	1131,34	4153,4583	1918,3988	
	6315,5602	6069,8044	4827,2962	8726,1255	4840,0616	
						Mean
Mean	4045	4298	4158	4949	3979	4286
Median	3203	3677	4136	4801	3629	3677
F-vector	7742,734	6628,8948	5358,554	5448,2834	6883,5113	
5 abs values	5301,8952	7266,2395	7032,3436	5673,4328	6211,4576	
	1594,2259	4585,7908	7390,5926	11045,916	6854,5904	
	6970,8903	6102,198	5743,3055	5616,8864	5251,1256	
	6315,5602	6069,8044	4827,2962	8726,1255	4840,0616	
						Mean
Mean	5585	6131	6070	7302	6008	6219
Median	6316	6102	5743	5673	6211	6102
						Max
MAX	7743	7266	7391	11046	6884	11046
				medel max		*8066*
				median max		*7391*

UNSHOD | UNSHOD

	161050	160827	160616	160437	160310	
Z-vector	605,94193	1968,0845	2300,993	888,10786	1667,7036	
Max & min values	-1602,3354	-4307,8725	-5164,9211	-2124,2525	-1603,7114	
	1772,8863	3190,4263	3089,6902	2001,9252	1713,6509	
	-2238,895	-7124,7729	-7069,3801	-3412,7291	-2547,5268	
	997,12064	2252,9683	946,97635	2079,7309	2848,7368	
	-1918,6372	-5426,3466	-1316,4914	-1888,2183	-7289,8779	
	255,08744	1330,5152	2090,2947	1338,1733	1958,522	
	-1129,9057	-2559,6547	-4698,3132	-2036,7027	-2318,8188	
	837,66557	2212,8521	1358,6629	2120,9877	752,96438	
	-2757,9379	-3959,9809	-2394,9445	-3197,2457	-2338,5571	
S-vector	605,94193	1968,0845	2300,993	888,10786	1667,7036	
abs. values	1602,3354	4307,8725	5164,9211	2124,2525	1603,7114	
	1772,8863	3190,4263	3089,6902	2001,9252	1713,6509	
	2238,895	7124,7729	7069,3801	3412,7291	2547,5268	
	997,12064	2252,9683	946,97635	2079,7309	2848,7368	
	1918,6372	5426,3466	1316,4914	1888,2183	7289,8779	
	255,08744	1330,5152	2090,2947	1338,1733	1958,522	
	1129,9057	2559,6547	4698,3132	2036,7027	2318,8188	
	837,66557	2212,8521	1358,6629	2120,9877	752,96438	
	2757,9379	3959,9809	2394,9445	3197,2457	2338,5571	
						Mean
Mean	1412	3433	3043	2109	2504	2500
Median	1366	2875	2348	2058	2139	2139
F-vector	1602,3354	4307,8725	5164,9211	2124,2525	1667,7036	
5 abs values	2238,895	7124,7729	7069,3801	3412,7291	2547,5268	
	1918,6372	5426,3466	1316,4914	2079,7309	7289,8779	
	1129,9057	2559,6547	4698,3132	2036,7027	2318,8188	
	2757,9379	3959,9809	2394,9445	3197,2457	2338,5571	
						Mean
Mean	1930	4676	4129	2570	3232	3307
Median	1919	4308	4698	2124	2339	2339
						Max
MAX	2758	7125	7069	3413	7290	7290
				medel max		*5531*
				median max		*7069*

ÖLLÖV | SOFTSTEP

	185718	185641	185121	185021	184918	
Z-vector	2418,7923	1348,8532	677,19123	354,54316	670,39859	
Max & min values	-2402,6852	-3096,2005	-1076,8576	-1655,8299	-1956,8387	
	3169,7923	1681,8268	3498,4881	503,38203	590,35562	
	-5209,3923	-2337,47	-3976,9533	-1718,4578	-1429,537	
	1129,3568	2736,6794	3367,6951	2108,6096	1009,9201	
	-1810,8561	-3586,7278	-5237,6237	-3486,5955	-1050,0038	
	2366,9017	1317,2282	3146,5535	2302,8771	849,69644	
	-4214,1784	-1394,7073	-2813,5256	-2351,907	-749,6141	
	1782,3978	2762,7331	2024,2703	1281,4797	985,56851	
	-2894,777	-4295,0462	-2206,9074	-2715,3045	-1964,7342	
S-vector	2418,7923	1348,8532	677,19123	354,54316	670,39859	
abs. values	2402,6852	3096,2005	1076,8576	1655,8299	1956,8387	
	3169,7923	1681,8268	3498,4881	503,38203	590,35562	
	5209,3923	2337,47	3976,9533	1718,4578	1429,537	
	1129,3568	2736,6794	3367,6951	2108,6096	1009,9201	
	1810,8561	3586,7278	5237,6237	3486,5955	1050,0038	
	2366,9017	1317,2282	3146,5535	2302,8771	849,69644	
	4214,1784	1394,7073	2813,5256	2351,907	749,6141	
	1782,3978	2762,7331	2024,2703	1281,4797	985,56851	
	2894,777	4295,0462	2206,9074	2715,3045	1964,7342	
						Mean
Mean	2740	2456	2803	1848	1126	2194
Median	2411	2537	2980	1914	998	2411
F-vector	2418,7923	3096,2005	1076,8576	1655,8299	1956,8387	
5 abs values	5209,3923	2337,47	3976,9533	1718,4578	1429,537	
	1810,8561	3586,7278	5237,6237	3486,5955	1050,0038	
	4214,1784	1394,7073	3146,5535	2351,907	849,69644	
	2894,777	4295,0462	2206,9074	2715,3045	1964,7342	
						Mean
Mean	3310	2942	3129	2386	1450	2643
Median	2895	3096	3147	2352	1430	2895
						Max
MAX	5209	4295	5238	3487	1965	5238
				medel max		*4039*
				median max		*4295*

Sand

STEEL | STEEL

Measurement nr:	143617	143337	142923	142648	142548	
Z-vector	111,4995	99,349381	92,877593	100,26456	151,367	
Max & min values	-301,58644	-225,52953	-222,31772	-270,34579	-266,00214	
	114,85985	106,74391	130,31607	116,94523	132,65704	
	-285,00929	-224,9514	-259,22983	-279,77938	-302,00702	
	134,55516	119,89137	109,5065	120,21085	78,658994	
	-237,58448	-272,81566	-158,46323	-294,80087	-299,93378	
	151,39989	122,6902	118,04166	146,80753	91,10626	
	-240,72023	-258,38988	-268,96518	-238,77255	-215,0705	
	128,71532	146,48903	116,25357	142,03995	146,97931	
	-303,15773	-255,46995	-213,40268	-279,17391	-326,56562	
S-vector	111,4995	99,349381	92,877593	100,26456	151,367	
abs. values	301,58644	225,52953	222,31772	270,34579	266,00214	
	114,85985	106,74391	130,31607	116,94523	132,65704	
	285,00929	224,9514	259,22983	279,77938	302,00702	
	134,55516	119,89137	109,5065	120,21085	78,658994	
	237,58448	272,81566	158,46323	294,80087	299,93378	
	151,39989	122,6902	118,04166	146,80753	91,10626	
	240,72023	258,38988	268,96518	238,77255	215,0705	
	128,71532	146,48903	116,25357	142,03995	146,97931	
	303,15773	255,46995	213,40268	279,17391	326,56562	
						Mean
Mean	201	183	169	199	201	191
Median	194	186	144	193	183	186
F-vector	301,58644	225,52953	222,31772	270,34579	266,00214	
5 abs values	285,00929	224,9514	259,22983	279,77938	302,00702	
	237,58448	272,81566	158,46323	294,80087	299,93378	
	240,72023	258,38988	268,96518	238,77255	215,0705	
	303,15773	255,46995	213,40268	279,17391	326,56562	
						Mean
Mean	274	247	224	273	282	260
Median	285	255	222	279	300	279
						Max
MAX	303	273	269	295	327	327
				medel max		*293*
				median max		*295*

UNSHOD | UNSHOD

	171816	171726	171558	171510	171356	
Z-vector	131,83116	114,99548	152,74845	154,81435	106,40529	
Max & min values	-280,787	-224,16272	-278,97811	-267,31553	-130,60448	
	127,52941	135,84899	161,96525	168,58388	85,059584	
	-265,6786	-171,27894	-280,61092	-263,20323	-122,8994	
	157,8673	127,55603	143,95451	129,7538	126,25587	
	-375,12684	-203,318	-321,54745	-286,13878	-139,90819	
	148,62413	136,0736	180,40861	181,18642	123,18068	
	-291,36024	-191,94983	-280,05819	-253,51182	-158,76561	
	171,98253	162,64489	161,13615	147,14345	117,14259	
	-251,04579	-242,22522	-260,61288	-217,82628	-125,24901	
S-vector	131,83116	114,99548	152,74845	154,81435	106,40529	
abs. values	280,787	224,16272	278,97811	267,31553	130,60448	
	127,52941	135,84899	161,96525	168,58388	85,059584	
	265,6786	171,27894	280,61092	263,20323	122,8994	
	157,8673	127,55603	143,95451	129,7538	126,25587	
	375,12684	203,318	321,54745	286,13878	139,90819	
	148,62413	136,0736	180,40861	181,18642	123,18068	
	291,36024	191,94983	280,05819	253,51182	158,76561	
	171,98253	162,64489	161,13615	147,14345	117,14259	
	251,04579	242,22522	260,61288	217,82628	125,24901	
						Mean
Mean	220	171	222	207	124	189
Median	212	167	221	200	124	200
F-vector	280,787	224,16272	278,97811	267,31553	130,60448	
5 abs values	265,6786	171,27894	280,61092	263,20323	122,8994	
	375,12684	203,318	321,54745	286,13878	139,90819	
	291,36024	191,94983	280,05819	253,51182	158,76561	
	251,04579	242,22522	260,61288	217,82628	125,24901	
						Mean
Mean	293	207	284	258	135	235
Median	281	203	280	263	131	263
						Max
MAX	375	242	322	286	159	375
				medel max		*277*
				median max		*286*

ÖLLÖV | SOFTSTEP

	182500	181648	181554	181440	181208	
Z-vector	91,885474	93,904769	101,01455	99,665583	96,481837	
Max & min values	-259,56472	-216,17726	-278,21689	-305,93012	-218,61875	
	81,415747	109,98973	70,780176	105,36676	104,76602	
	-232,43191	-227,34621	-316,50205	-312,00239	-250,38242	
	99,738013	104,43504	101,29092	83,710505	136,26992	
	-236,57839	-221,04054	-346,84873	-277,73481	-221,56504	
	115,75364	97,152816	102,06826	105,85113	107,94473	
	-239,69656	-233,00441	-327,0499	-305,86078	-287,16465	
	93,691138	119,57762	76,386621	125,66754	152,96719	
	-252,20535	-193,66554	-328,30186	-305,72309	-229,96152	
S-vector	91,885474	93,904769	101,01455	99,665583	96,481837	
abs. values	259,56472	216,17726	278,21689	305,93012	218,61875	
	81,415747	109,98973	70,780176	105,36676	104,76602	
	232,43191	227,34621	316,50205	312,00239	250,38242	
	99,738013	104,43504	101,29092	83,710505	136,26992	
	236,57839	221,04054	346,84873	277,73481	221,56504	
	115,75364	97,152816	102,06826	105,85113	107,94473	
	239,69656	233,00441	327,0499	305,86078	287,16465	
	93,691138	119,57762	76,386621	125,66754	152,96719	
	252,20535	193,66554	328,30186	305,72309	229,96152	
						Mean
Mean	170	162	205	203	181	184
Median	174	157	190	202	186	186
F-vector	259,56472	216,17726	278,21689	305,93012	218,61875	
5 abs values	232,43191	227,34621	316,50205	312,00239	250,38242	
	236,57839	221,04054	346,84873	277,73481	221,56504	
	239,69656	233,00441	327,0499	305,86078	287,16465	
	252,20535	193,66554	328,30186	305,72309	229,96152	
						Mean
Mean	244	218	319	301	242	265
Median	240	221	327	306	230	240
						Max
MAX	260	233	347	312	287	347
				medel max		*288*
				median max		*287*

Empe

Concrete

STEEL – STEEL

Measurement nr:	154106	154012	153914	153647	153100	
Z-vector	3945,3642	2187,3899	4364,2221	2313,8957	2076,6741	
Max & min values	-5763,9688	-4944,4621	-5594,464	-3339,9979	-4906,0549	
	3528,2275	3758,6429	4958,4799	3519,8498	4112,9719	
	-3311,71	-4378,9792	-4179,3668	-5968,2889	-4713,6619	
	4152,0009	2665,2884	2781,5844	2654,4357	4967,7434	
	-5690,5606	-6079,8156	-5611,0064	-7163,8778	-7635,8289	
	2200,5663	3016,4974	3997,8529	3862,0412	3483,6946	
	-3388,8849	-3543,7731	-5567,9791	-4727,4095	-4348,7097	
	2683,7948	2039,2249	2196,5619	3050,2101	3918,9446	
	-4934,7838	-3413,8015	-3772,6998	-5691,6981	-4400,073	
S-vector	3945,3642	2187,3899	4364,2221	2313,8957	2076,6741	
abs. values	5763,9688	4944,4621	5594,464	3339,9979	4906,0549	
	3528,2275	3758,6429	4958,4799	3519,8498	4112,9719	
	3311,71	4378,9792	4179,3668	5968,2889	4713,6619	
	4152,0009	2665,2884	2781,5844	2654,4357	4967,7434	
	5690,5606	6079,8156	5611,0064	7163,8778	7635,8289	
	2200,5663	3016,4974	3997,8529	3862,0412	3483,6946	
	3388,8849	3543,7731	5567,9791	4727,4095	4348,7097	
	2683,7948	2039,2249	2196,5619	3050,2101	3918,9446	
	4934,7838	3413,8015	3772,6998	5691,6981	4400,073	
						Mean
Mean	3960	3603	4302	4229	4456	4110
Median	3737	3479	4272	3691	4374	3737
F-vector	5763,9688	4944,4621	5594,464	3339,9979	4906,0549	
5 abs values	3528,2275	4378,9792	4958,4799	5968,2889	4713,6619	
	5690,5606	6079,8156	5611,0064	7163,8778	7635,8289	
	3388,8849	3543,7731	5567,9791	4727,4095	4348,7097	
	4934,7838	3413,8015	3772,6998	5691,6981	4400,073	
						Mean
Mean	4661	4472	5101	5378	5201	4963
Median	4935	4379	5568	5692	4714	4935
						Max
MAX	5764	6080	5611	7164	7636	7636
				medel max		*6451*
				median max		6080

UNSHOD – UNSHOD

Measurement nr:	162917	162802	162718	162406	162259	
Z-vector	1731,1161	1022,1249	891,18075	929,12803	1323,8475	
Max & min values	-2797,2716	-1912,1095	-3167,2636	-2799,8427	-4891,1237	
	3168,8544	2848,3124	2121,3233	2273,7364	3622,8622	
	-7071,5367	-6750,8897	-4830,9467	-6791,2885	-6267,9791	
	2375,5702	3510,328	2224,4903	2060,7501	1079,5897	
	-4367,1934	-6122,8311	-5833,1576	-3142,1796	-6843,4992	
	1345,0517	2512,2812	1058,169	1325,7315	2648,8036	
	-4602,8907	-7165,2535	-1785,1308	-3065,1259	-6030,736	
	721,90812	1461,3495	894,73154	2129,8224	1407,4227	
	-2626,7335	-3062,9434	-2440,8837	-4909,1161	-4761,7902	
S-vector	1731,1161	1022,1249	891,18075	929,12803	1323,8475	
abs. values	2797,2716	1912,1095	3167,2636	2799,8427	4891,1237	
	3168,8544	2848,3124	2121,3233	2273,7364	3622,8622	
	7071,5367	6750,8897	4830,9467	6791,2885	6267,9791	
	2375,5702	3510,328	2224,4903	2060,7501	1079,5897	
	4367,1934	6122,8311	5833,1576	3142,1796	6843,4992	
	1345,0517	2512,2812	1058,169	1325,7315	2648,8036	
	4602,8907	7165,2535	1785,1308	3065,1259	6030,736	
	721,90812	1461,3495	894,73154	2129,8224	1407,4227	
	2626,7335	3062,9434	2440,8837	4909,1161	4761,7902	
						Mean
Mean	3081	3637	2525	2943	3888	3215
Median	2712	2956	2173	2537	4192	2712
F-vector	2797,2716	1912,1095	3167,2636	2799,8427	4891,1237	
5 abs values	7071,5367	6750,8897	4830,9467	6791,2885	6267,9791	
	4367,1934	6122,8311	5833,1576	3142,1796	6843,4992	
	4602,8907	7165,2535	1785,1308	3065,1259	6030,736	
	2626,7335	3062,9434	2440,8837	4909,1161	4761,7902	
						Mean
Mean	4293	5003	3611	4142	5759	4562
Median	4367	6123	3167	3142	6031	4367
						Max
MAX	7072	7165	5833	6791	6843	7165
				medel max		*6741*
				median max		6843

ÖLLÖV – SOFTSTEP

Measurement nr:	191037	190904	190745	190639	190536	
Z-vector	311,03093	878,29245	700,68231	724,00135	447,69737	
Max & min values	-1676,554	-1332,6714	-1533,2767	-1034,8844	-1429,9911	
	210,23015	770,78854	868,2575	697,36073	750,73057	
	-895,2513	-1342,7525	-1833,805	-1477,3229	-1484,0155	
	463,8864	544,67135	1348,946	568,99452	535,39366	
	-1280,4613	-1191,4351	-2124,8392	-1292,5406	-1317,8309	
	412,92937	724,97116	528,05438	603,9369	1204,2169	
	-1818,3529	-1060,771	-2050,3763	-1371,9088	-1274,2245	
	824,84831	562,59616	504,26434	336,08827	440,12218	
	-901,27278	-941,2515	-1367,9739	-1397,7467	-847,59462	
S-vector	311,03093	878,29245	700,68231	724,00135	447,69737	
abs. values	1676,554	1332,6714	1533,2767	1034,8844	1429,9911	
	210,23015	770,78854	868,2575	697,36073	750,73057	
	895,2513	1342,7525	1833,805	1477,3229	1484,0155	
	463,8864	544,67135	1348,946	568,99452	535,39366	
	1280,4613	1191,4351	2124,8392	1292,5406	1317,8309	
	412,92937	724,97116	528,05438	603,9369	1204,2169	
	1818,3529	1060,771	2050,3763	1371,9088	1274,2245	
	824,84831	562,59616	504,26434	336,08827	440,12218	
	901,27278	941,2515	1367,9739	1397,7467	847,59462	
						Mean
Mean	879	935	1286	950	973	1005
Median	860	910	1358	879	1026	910
F-vector	1676,554	1332,6714	1533,2767	1034,8844	1429,9911	
5 abs values	895,2513	1342,7525	1833,805	1477,3229	1484,0155	
	1280,4613	1191,4351	2124,8392	1292,5406	1317,8309	
	1818,3529	1060,771	2050,3763	1371,9088	1274,2245	
	901,27278	941,2515	1367,9739	1397,7467	847,59462	
						Mean
Mean	1314	1174	1782	1315	1271	1371
Median	1280	1191	1834	1372	1318	1318
						Max
MAX	1818	1343	2125	1477	1484	2125
				medel max		*1649*
				median max		1484

Sand

STEEL – STEEL

Measurement nr:	140506	140206	140006	135820	135615	
Z-vector	55,145093	85,111673	64,218928	77,107524	53,532269	
Max & min values	-119,15959	-134,92446	-146,42658	-205,66005	-151,92183	
	70,693921	51,05015	107,15155	59,865336	76,138715	
	-120,68792	-174,49673	-160,33478	-151,39443	-169,63082	
	54,307202	24,885111	76,70135	87,809672	84,12016	
	-123,82366	-116,81801	-158,94416	-208,59755	-184,69625	
	51,153882	39,267923	79,88885	72,373149	59,665082	
	-129,77581	-193,50942	-129,97931	-179,08877	-183,78023	
	53,26228	87,962259	75,647639	81,054789	91,609418	
	-127,48674	-136,91079	-170,37287	-150,69423	-165,73531	
S-vector	55,145093	85,111673	64,218928	77,107524	53,532269	
abs. values	119,15959	134,92446	146,42658	205,66005	151,92183	
	70,693921	51,05015	107,15155	59,865336	76,138715	
	120,68792	174,49673	160,33478	151,39443	169,63082	
	54,307202	24,885111	76,70135	87,809672	84,12016	
	123,82366	116,81801	158,94416	208,59755	184,69625	
	51,153882	39,267923	79,88885	72,373149	59,665082	
	129,77581	193,50942	129,97931	179,08877	183,78023	
	53,26228	87,962259	75,647639	81,054789	91,609418	
	127,48674	136,91079	170,37287	150,69423	165,73531	
						Mean
Mean	91	104	117	127	122	112
Median	95	102	119	119	122	119
F-vector	119,15959	134,92446	146,42658	205,66005	151,92183	
5 abs values	120,68792	174,49673	160,33478	151,39443	169,63082	
	123,82366	116,81801	158,94416	208,59755	184,69625	
	129,77581	193,50942	129,97931	179,08877	183,78023	
	127,48674	136,91079	170,37287	150,69423	165,73531	
						Mean
Mean	124	151	153	179	171	156
Median	124	137	159	179	170	159
						Max
MAX	130	194	170	209	185	209
				medel max		*177*
				median max		185

UNSHOD – UNSHOD

Measurement nr:	165344	165253	164830	164543	164433	
Z-vector	49,190138	64,238587	78,814956	93,144373	75,744281	
Max & min values	-129,01885	-145,39618	-161,25243	-114,16715	-125,20884	
	58,182326	76,885071	79,713394	98,11117	81,238422	
	-138,27861	-104,50262	-104,70653	-193,73453	-111,1981	
	68,004591	60,273743	82,011245	81,439295	78,137836	
	-143,47881	-145,18915	-125,23973	-177,96988	-154,19029	
	55,937209	81,938782	82,31398	76,86117	78,776508	
	-141,18096	-130,24481	-127,95165	-137,78434	-131,16978	
	75,476271	72,738587	91,591323	81,405115	81,541156	
	-143,26299	-113,2702	-130,75926	-173,18375	-153,5858	
S-vector	49,190138	64,238587	78,814956	93,144373	75,744281	
abs. values	129,01885	145,39618	161,25243	114,16715	125,20884	
	58,182326	76,885071	79,713394	98,11117	81,238422	
	138,27861	104,50262	104,70653	193,73453	111,1981	
	68,004591	60,273743	82,011245	81,439295	78,137836	
	143,47881	145,18915	125,23973	177,96988	154,19029	
	55,937209	81,938782	82,31398	76,86117	78,776508	
	141,18096	130,24481	127,95165	137,78434	131,16978	
	75,476271	72,738587	91,591323	81,405115	81,541156	
	143,26299	113,2702	130,75926	173,18375	153,5858	
						Mean
Mean	100	99	106	123	107	107
Median	102	93	98	106	96	98
F-vector	129,01885	145,39618	161,25243	114,16715	125,20884	
5 abs values	138,27861	104,50262	104,70653	193,73453	111,1981	
	143,47881	145,18915	125,23973	177,96988	154,19029	
	141,18096	130,24481	127,95165	137,78434	131,16978	
	143,26299	113,2702	130,75926	173,18375	153,5858	
						Mean
Mean	139	128	130	159	135	138
Median	141	130	128	173	131	131
						Max
MAX	143	145	161	194	154	194
				medel max		*160*
				median max		154

ÖLLÖV – SOFTSTEP

Measurement nr:	173854	173946	174050	175025	175202	
Z-vector	79,402712	34,789878	65,47279	47,715343	58,981687	
Max & min values	-123,70178	-151,51286	-123,10143	-122,53759	-152,4939	
	102,26795	55,875816	70,380017	60,008312	49,030515	
	-96,016233	-152,12614	-133,58873	-128,187	-103,92066	
	109,27381	38,538902	62,388806	50,842296	55,664304	
	-98,020139	-116,20817	-100,79772	-99,006336	-101,31128	
	81,709353	56,048667	59,650524	59,999523	40,434812	
	-94,331663	-154,01774	-135,94713	-109,86473	-81,521242	
	79,609744	56,955894	75,735485	69,268078	71,644773	
	-95,247678	-129,25211	-103,32897	-122,7788	-161,7107	
S-vector	79,402712	34,789878	65,47279	47,715343	58,981687	
abs. values	123,70178	151,51286	123,10143	122,53759	152,4939	
	102,26795	55,875816	70,380017	60,008312	49,030515	
	96,016233	152,12614	133,58873	128,187	103,92066	
	109,27381	38,538902	62,388806	50,842296	55,664304	
	98,020139	116,20817	100,79772	99,006336	101,31128	
	81,709353	56,048667	59,650524	59,999523	40,434812	
	94,331663	154,01774	135,94713	109,86473	81,521242	
	79,609744	56,955894	75,735485	69,268078	71,644773	
	95,247678	129,25211	103,32897	122,7788	161,7107	
						Mean
Mean	96	95	93	87	88	92
Median	96	87	88	84	77	87
F-vector	123,70178	151,51286	123,10143	122,53759	152,4939	
5 abs values	102,26795	152,12614	133,58873	128,187	103,92066	
	109,27381	116,20817	100,79772	99,006336	101,31128	
	94,331663	154,01774	135,94713	109,86473	81,521242	
	95,247678	129,25211	103,32897	122,7788	161,7107	
						Mean
Mean	105	141	119	116	120	120
Median	102	152	123	123	104	123
						Max
MAX	124	154	136	128	162	162
				medel max		*141*
				median max		136

D
Spread of steps

		DORA	BETONG					EMPE	BETONG					DORA	SAND					EMPE	SAND			
	7742,734035	6628,894777	5358,554008	5448,283413	6883,511347		5763,968837	4944,462106	5594,463964	3339,9979	4906,054937		301,5864376	225,5295251	222,3177196	270,3457898	266,0021387		119,1595949	134,9244596	146,4265798	205,6600546	151,9218322	
	5301,895168	7266,239504	7032,343558	5673,432827	6211,457636		3528,227452	4378,979196	4958,479883	5968,288916	4713,66187		285,0092891	224,9514001	259,229829	279,7793835	302,0070215		120,6879152	174,4967252	160,3347829	151,3944296	169,6308165	
	1594,225926	4585,790773	7390,592582	11045,91561	6854,590449		5690,560633	6079,815622	5611,006445	7163,877783	7635,828862		237,5844844	272,8156579	158,4632274	294,8008679	299,9337793		123,8236574	116,8180143	158,9441579	208,5975546	184,6962462	
	6970,890285	6102,198	5743,305473	5616,88644	5251,125605		3388,884852	3543,773141	5567,979101	4727,409521	4348,709722		240,7202266	258,3898767	268,9651805	238,7725476	215,070498		129,7758058	193,5094206	129,9793141	179,0887656	183,7802306	
	6315,560207	6069,804445	4827,296195	8726,125454	4840,06164		4934,783778	3413,801462	3772,699804	5691,698095	4400,073003		303,1577266	255,4699548	213,4026805	279,1739148	326,5656152		127,4867433	136,9107877	170,3728688	150,6942343	165,7353087	
STÅL																								
	5585,06112	6130,5855	6070,41836	7302,12875	6008,14934		4661,28511	4472,16631	5100,92584	5378,25444	5200,86568		273,611633	247,431283	224,475727	272,574501	281,915811		124,186743	151,331881	153,211541	179,087008	171,152887	
	139%	108%	88%	75%	115%		124%	111%	110%	62%	94%		110%	91%	99%	99%	94%		96%	89%	96%	115%	89%	
	95%	119%	116%	78%	103%		76%	98%	97%	111%	91%		104%	91%	115%	103%	107%		97%	115%	105%	85%	99%	
	29%	75%	122%	151%	114%		122%	136%	110%	133%	147%		87%	110%	71%	108%	106%		100%	77%	104%	116%	108%	
	125%	100%	95%	77%	87%		73%	79%	109%	88%	84%		88%	104%	120%	88%	76%		105%	128%	85%	100%	107%	
	113%	99%	80%	120%	81%		106%	76%	74%	106%	85%		111%	103%	95%	102%	116%		103%	90%	111%	84%	97%	
	139%	119%	122%	151%	115%	151%	124%	136%	110%	133%	147%	147%	111%	110%	120%	108%	116%	120%	105%	128%	111%	116%	108%	128%
						129%						130%						113%						114%
	1602,335411	4307,872515	5164,921108	2124,252496	1667,703638		2797,271566	1912,10946	3167,263582	2799,842674	4891,123669		280,787001	224,1627247	278,9781118	267,3155332	130,6044785		129,0188461	145,3961787	161,2524266	114,1671505	125,2088439	
	2238,894981	7124,772905	7069,380093	3412,729058	2547,52683		7071,536703	6750,889733	4830,946687	6791,288475	6267,979138		265,6786025	171,2789357	280,6109243	263,2032285	122,8994003		138,2786117	104,502624	104,7065281	193,7345333	111,1981017	
	1918,637169	5426,346636	1316,491421	2079,730903	7289,877905		4367,193441	6122,831139	5833,157625	3142,179588	6843,499157		375,1268447	203,3179982	321,5474478	286,1387754	139,9081894		143,478807	145,1891474	125,2397312	177,9698849	154,1902892	
	1129,905723	2559,654741	4698,313198	2036,702691	2318,818823		4602,890707	7165,253503	1785,130769	3065,125877	6030,735974		291,3602431	191,9498341	280,05819	253,5118222	158,7656113		141,1809554	130,2448115	127,9516453	137,784338	131,1697814	
	2757,93795	3959,980913	2394,944546	3197,24566	2338,557104		2626,733481	3062,943444	2440,883699	4909,116112	4761,790173		251,04579	242,2252247	260,6128775	217,8262754	125,2490097		143,2629867	113,2702021	130,7592625	173,1837521	153,5857971	
	1929,54225	4675,72554	4128,81007	2570,13216	3232,49686		4293,12518	5002,80546	3611,47647	4141,51055	5759,02562		292,799696	206,586943	284,36151	257,599127	135,485338		139,044041	127,720593	129,981919	159,367932	135,070563	
OSKODD																								
	83%	92%	125%	83%	52%		65%	38%	88%	68%	85%		96%	109%	98%	104%	96%		93%	114%	124%	72%	93%	
	116%	152%	171%	133%	79%		165%	135%	134%	164%	109%		91%	83%	99%	102%	91%		99%	82%	81%	122%	82%	
	99%	116%	32%	81%	226%		102%	122%	162%	76%	119%		128%	98%	113%	111%	103%		103%	114%	96%	112%	114%	
	59%	55%	114%	79%	72%		107%	143%	49%	74%	105%		100%	93%	98%	98%	117%		102%	102%	98%	86%	97%	
	143%	85%	58%	124%	72%		61%	61%	68%	119%	83%		86%	117%	92%	85%	92%		103%	89%	101%	109%	114%	
	143%	152%	171%	133%	226%	226%	165%	143%	162%	164%	119%	165%	128%	117%	113%	111%	117%	128%	103%	114%	124%	122%	114%	124%
						165%						150%						117%						115%
	2418,79232	3096,200499	1076,8576	1655,829882	1956,838714		1676,554031	1332,671421	1533,276677	1034,884391	1429,991106		259,5647214	216,1772618	278,2168947	305,9301198	218,6187492		123,7017799	151,5128561	123,1014288	122,5375864	152,4938987	
	5209,392251	2337,47003	3976,953303	1718,457812	1429,536956		895,2512963	1342,752476	1833,804998	1477,322867	1484,01552		232,4319089	227,3462072	316,5020509	312,0023854	250,3824211		102,2679467	152,1261373	133,5887335	128,1870004	103,9206565	
	1810,856118	3586,727842	5237,623713	3486,595507	1050,003753		1280,461257	1191,435093	2124,839177	1292,540641	1317,830949		236,5783933	221,0405431	346,8487306	277,7348073	221,5650383		109,2738061	116,2081686	100,7977179	99,00633638	101,3112815	
	4214,178383	1394,707334	3146,553533	2351,907031	849,6964421		1818,352859	1060,771031	2050,376287	1371,908805	1274,224504		239,6965573	233,0044103	327,0499025	305,8607838	287,1646477		94,33166266	154,0177389	135,9471319	109,8647348	81,52124242	
	2894,777016	4295,046202	2206,907404	2715,304492	1964,734222		901,2727807	941,2514994	1367,973943	1397,746695	847,5946212		252,2053464	193,6655431	328,3018556	305,7230885	229,9615227		95,24767829	129,2521139	103,3289679	122,7787973	161,7106955	
GUMMI	3309,59922	2942,03038	3128,97911	2385,61894	1450,16202		1314,37844	1173,7763	1782,05422	1314,88068	1270,73134		244,095385	218,246793	319,383887	301,450237	241,538476		104,964575	140,623403	119,352796	116,474891	120,191555	
	73%	105%	34%	69%	135%		128%	114%	86%	79%	113%		106%	99%	87%	101%	91%		118%	108%	103%	105%	127%	
	157%	79%	127%	72%	99%		68%	114%	103%	112%	117%		95%	104%	99%	104%	104%		97%	108%	112%	110%	86%	
	55%	122%	167%	146%	72%		97%	102%	119%	98%	104%		97%	101%	109%	92%	92%		104%	83%	84%	85%	84%	
	127%	47%	101%	99%	59%		138%	90%	115%	104%	100%		98%	107%	102%	101%	119%		90%	110%	114%	94%	68%	
	87%	146%	71%	114%	135%		69%	80%	77%	106%	67%		103%	89%	103%	101%	95%		91%	92%	87%	105%	135%	
	157%	146%	167%	146%	135%	167%	138%	114%	119%	112%	117%	138%	106%	107%	109%	104%	119%	119%	118%	110%	114%	110%	135%	135%
						150%						120%						109%						117%
						148%						134%						113%						115%
																					114%			
									141%															

E

Empe’s vibration measurements

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

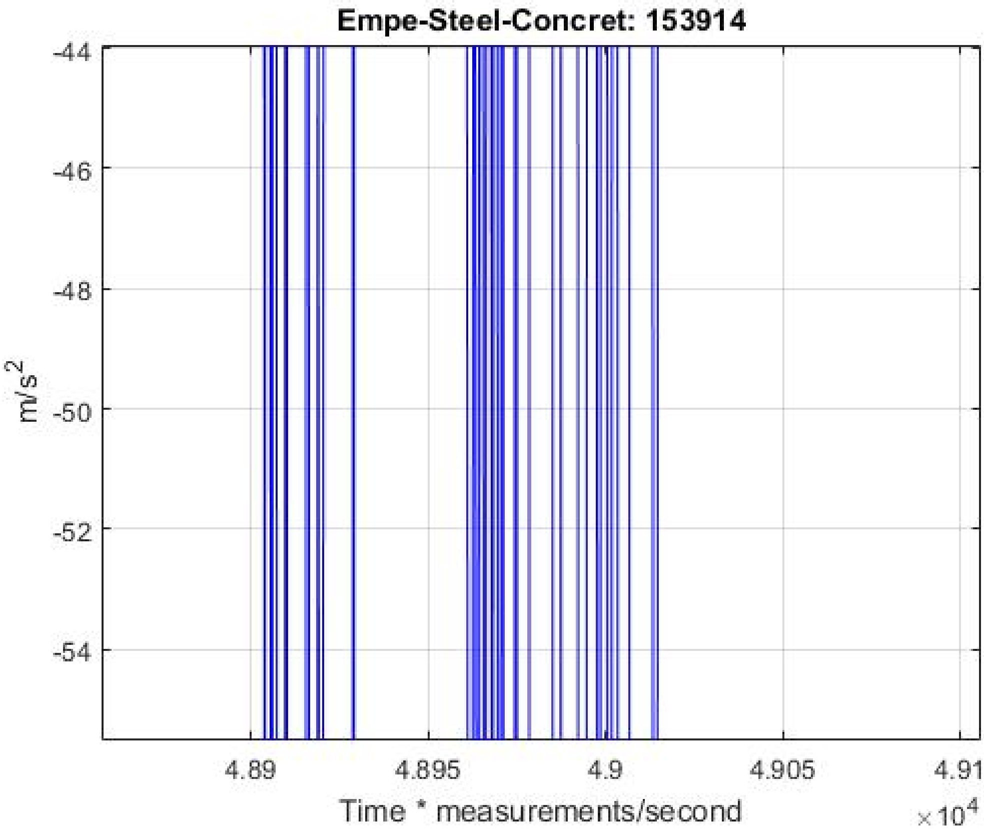

Figure E.1.1: The oscillations in x-direction of the steel shoe hoof on concrete.

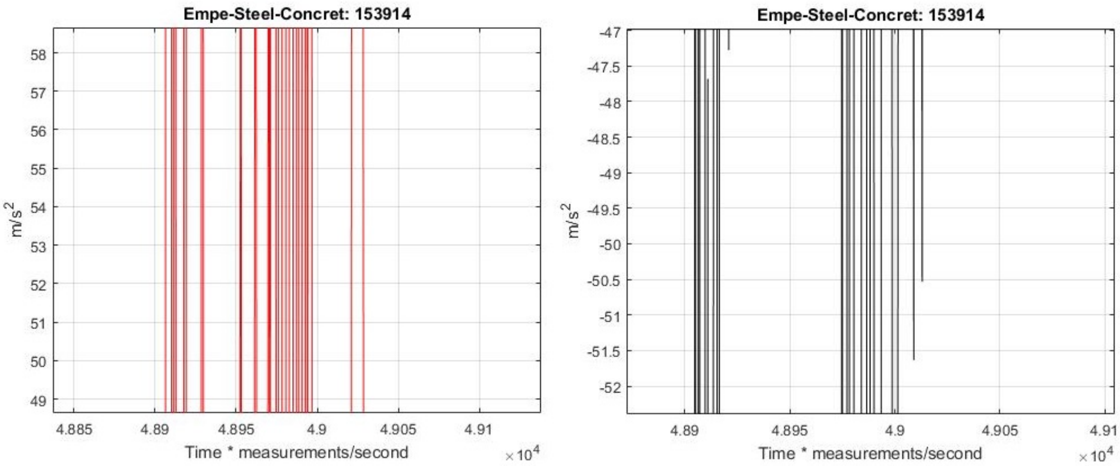

Figure E.1.2: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of steel and concrete.

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

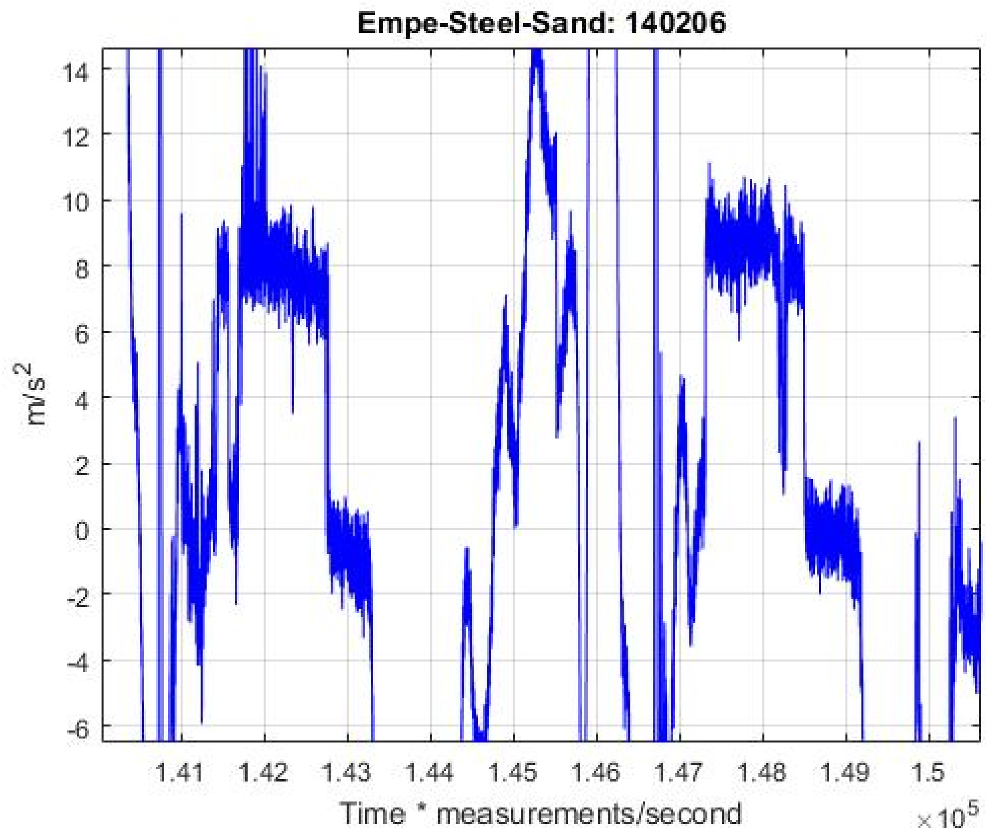

Figure E.2.1: The oscillations in x-direction of the steel shoe on fibre sand.

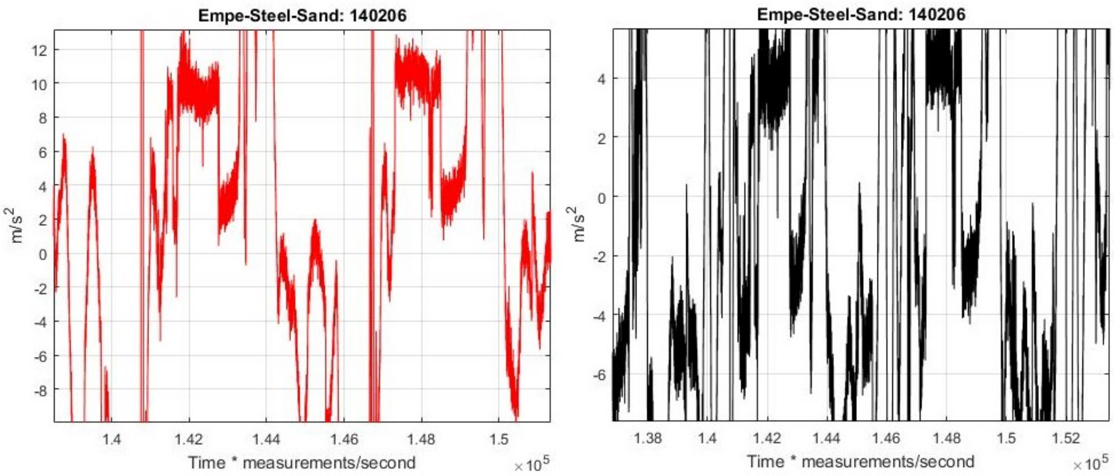

Figure E.2.2: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of steel and fibre sand.

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

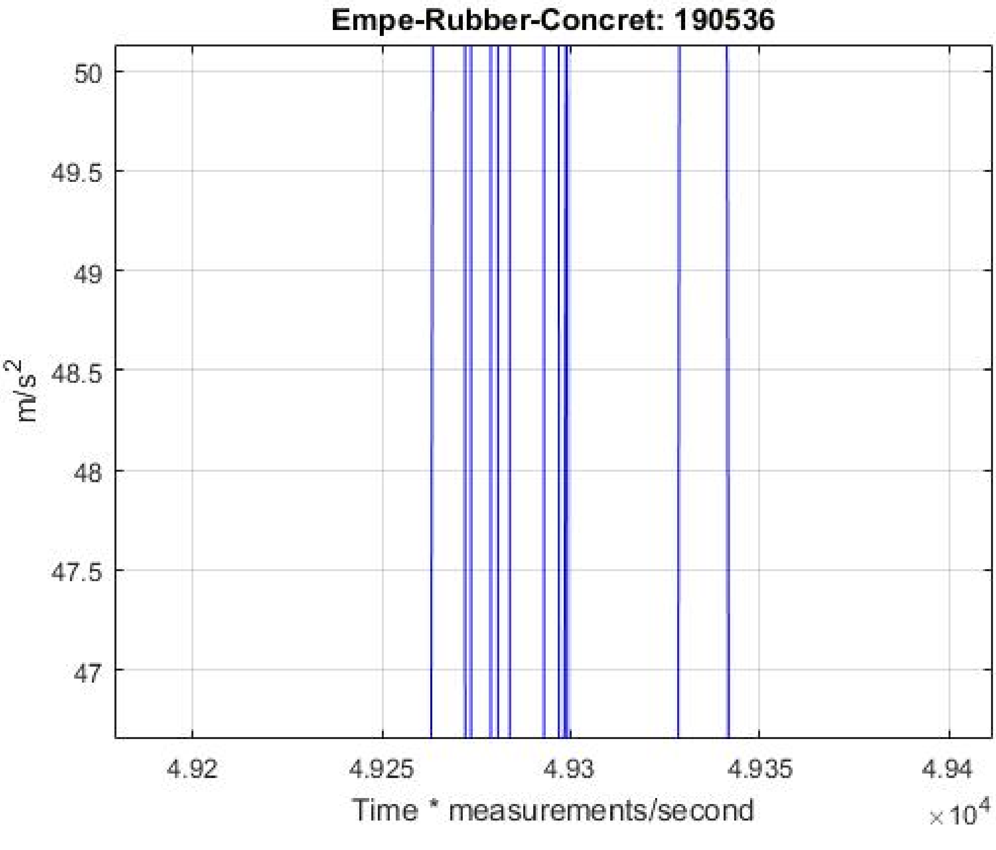

Figure E.3.1: The oscillations in x-direction of Öllöv SoftStep on concrete.

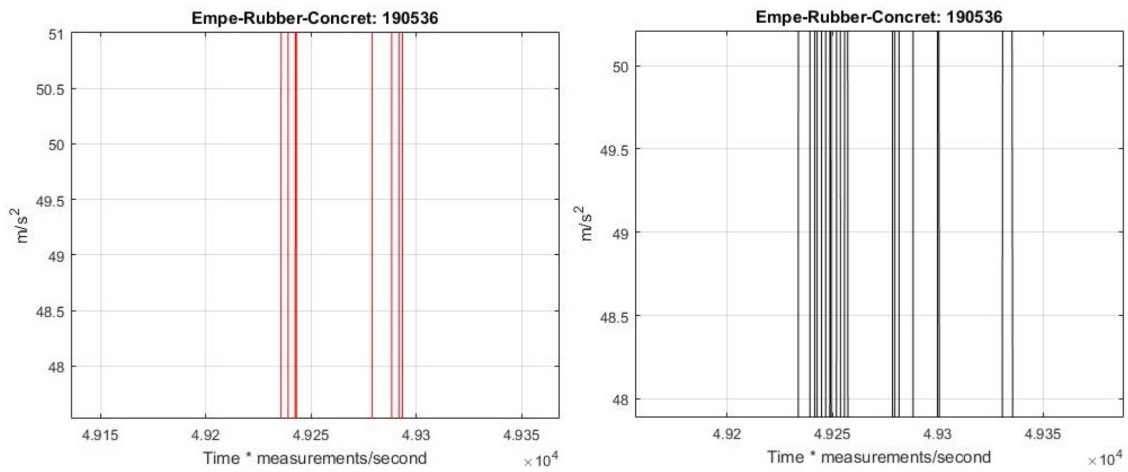

Figure E.3.2: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of Öllöv SoftStep and concrete.

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

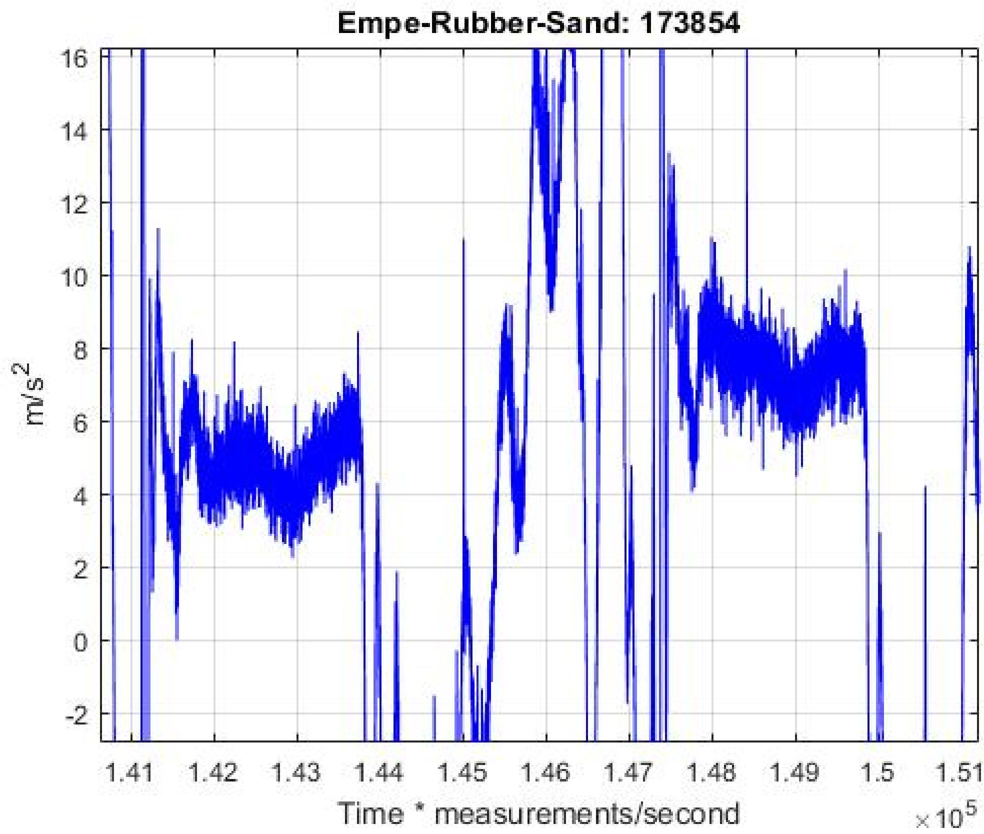

Figure E.4.1: The oscillations in x-direction of Öllöv SoftStep on fibre sand.

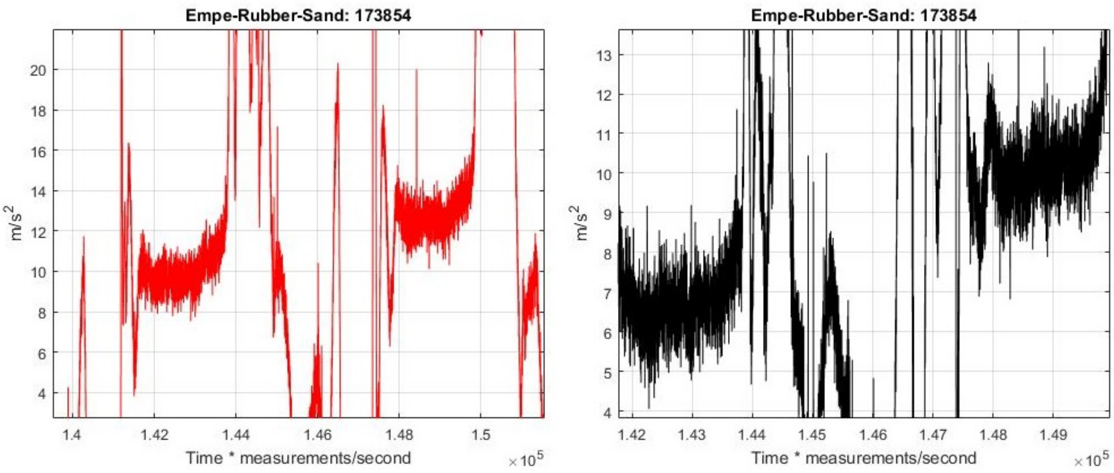

Figure E.4.2: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of Öllöv SoftStep and fibre sand.

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

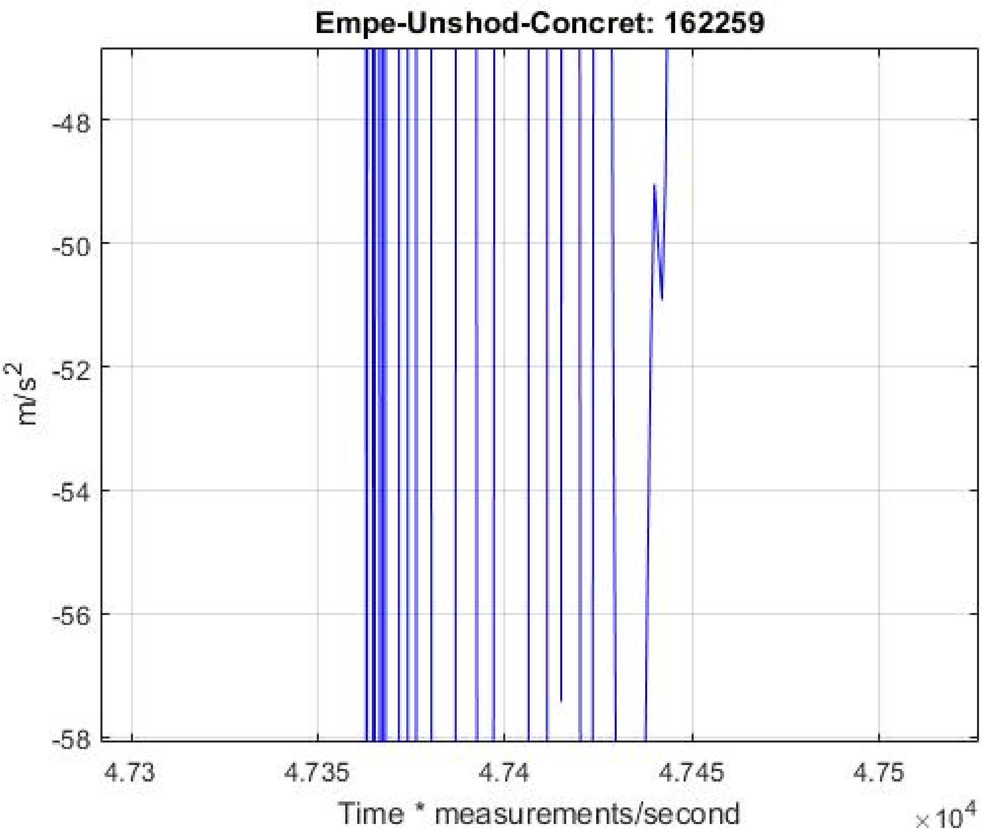

Figure E.5.1: The oscillations in x-direction of the unshod hoof on concrete.

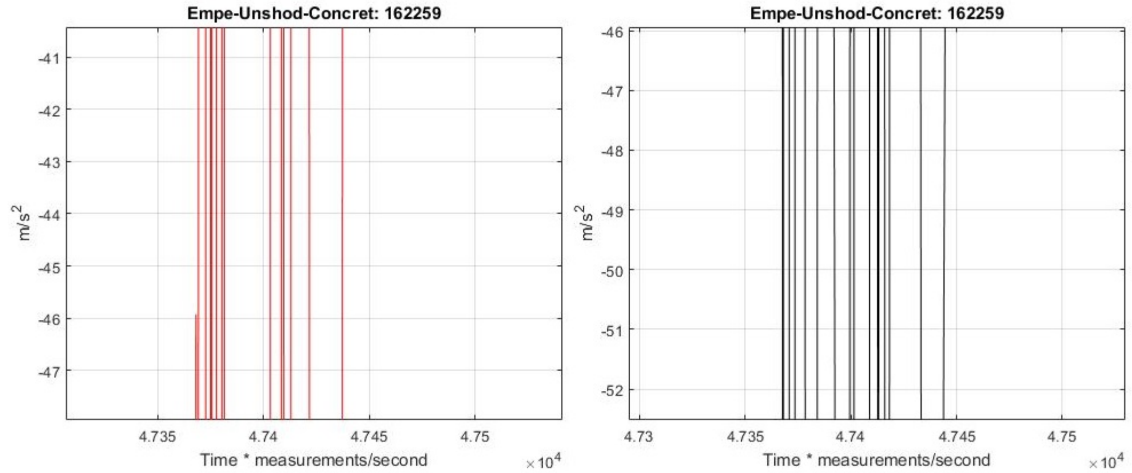

Figure E.5.2: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of the unshod hoof and concrete.

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

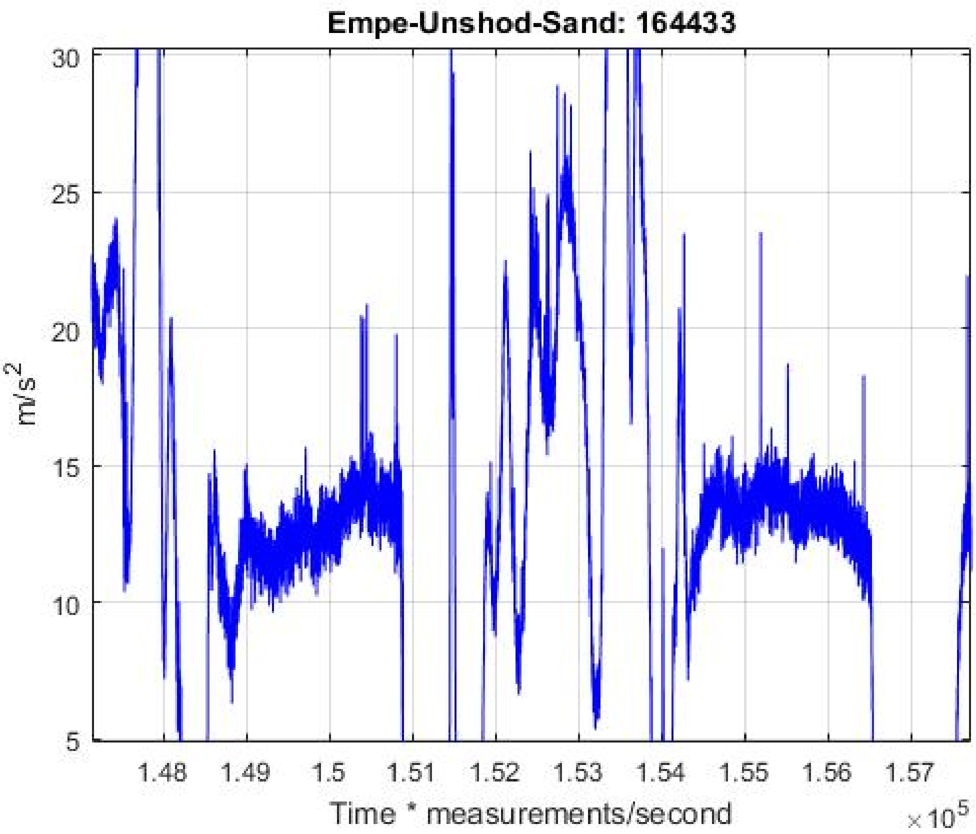

Figure E.6.1: The oscillations in x-direction of the unshod hoof on fibre sand.

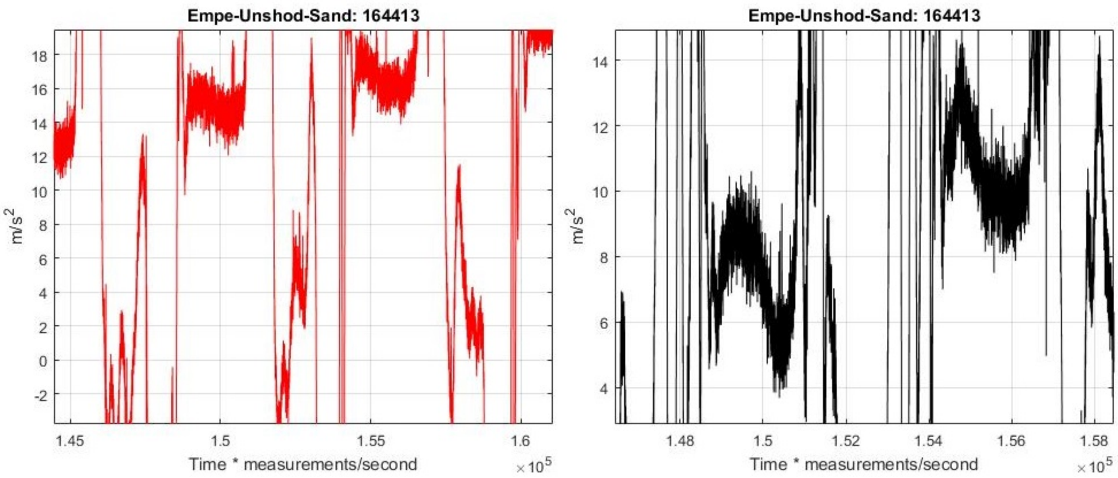

Figure E.6.2: The left shows the character of the oscillation in y-direction and the right in z-direction, in combination of the unshod hoof and fibre sand.