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Öllöv SoftStep movement on different grounds, research of a horseshoe made of rubber

Öllöv SoftStep rörelse på olika underlag, studie på en hästsko av gummi

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Bachelor's thesis in mechanical engineering

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Abstract

This project was on demand of Öllöv in cooperation with AB Halmstad Gummi Fabrik. Öllöv made their first version of this rubber shoe, Öllöv Original, in the 90's and has since then been improved, the newer version is called Öllöv SoftStep. There is a lot of money involved in the equine sport, and the horses depend on the quality of the equipment. Using wrong equipment may lead to injuries. In this project the friction from the Öllöv SoftStep has been examined to obtain support in the theory that the Öllöv SoftStep promote the natural movement of the hoof. This was made possible by two different tests and where compared to steel shoes and the unshod hoof. A test focusing on the coefficient of friction on concrete and asphalt and another test that examine the slide- time and length of hoof in motion on concrete and fiber mixed sand.

By comparing the results from the friction test to earlier reports shows that the coefficients of friction from the Öllöv SoftStep are between -23% to +14% comparing to the unshod hoof. The steel shoe coefficient of friction is -53% to -32% lower than the unshod hoof. Summarizing of the friction tests state with the fact that the friction from Öllöv SoftStep mimic the unshod hoof, by giving the horse traction to the ground similar to the unshod hoof.

Results from the measurements of movement proves that the Öllöv SoftStep are closer to the unshod hoof in terms both slide time and length. This rubber covered shoe differ in a range 1-3 ms and 1-3 mm from the unshod hoof. The steel shoe differ in a range 6-18 ms and 3-35 mm from the unshod hoof, depending on horse and ground. This does not include extreme divergent values.

The conclusion of this study results in the fact that the Öllöv SoftStep mimic the unshod hoof.

Keywords: horses, horseshoe, rubber, slide length, friction, Öllöv, softstep

Sammanfattning

Detta projektet gjordes med Öllöv, AB Halmstad Gummi Fabrik. Öllöv gjorde sin första version av denna gummisko, Öllöv Original under 90-talet och har sen dess blivit förbättrad till dess nyare version som heter Öllöv SoftStep. Det är mycket pengar inblandat i ridsporten, och hästarna är beroende av kvalitén på den utrustning som används. Att använda fel utrustning kan leda ill skador. I detta projekt kommer friktionen från Öllöv SoftStep utvärderas för att få stöd i teorin om att denna sko inte påverkar det naturliga rörelsemönstret för hoven. Detta gjordes i två test och jämfördes sedan med stålskon och den oskodda hoven. Ett test fokuserar på att mäta friktionskoefficienten på betong och asfalt, och det andra tester mäter glidtiden och glidlängden av en hov i rörelse på betong och fibersand.

Genom att jämföra resultatet från friktionstesterna med tidigare rapporter så kan man se att friktionskoefficienten för Öllöv SoftStep är mellan -23% till +14% vid jämförelse med den oskodda hoven. Stålskon har en friktionskoefficient som rör sig mellan -53% till -32% lägre värden än den oskodda hoven. Sammanfattat så visar friktionstesterna att friktionen från Öllöv SoftStep liknar mer den oskodda hoven, vilket innebär att denna skon ger grepp mot underlagen som mer är lika den oskodda hoven.

Resultatet från rörelsemätningarna där glidsträckan och glidlängden mättes visar att Öllöv SoftStep också liknar den oskodda hoven, sett till både längd och tid. Denna gummi beklädda sko skiljer 1-3 ms och 1-3 mm från den oskodda hoven, stålskon skiljer 6-18 ms och 3-35 mm från den oskodda hoven, beroende på häst och underlag. Dessa inkluderar ej avvikande värden.

Slutsatsen av denna studie är att Öllöv SoftStep liknar den oskodda hoven.

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We would also like to thank our work companions, working in another project with the Öllöv SoftStep, Amanda Salfjord and Frida Jönsson, for a good collaboration.

Martin Soffronow, Charlotta Elvind, May 2018

List of abbreviations

fps - frames per second
GB - giga byte
GRF - ground reaction force
HGF - Halmstad Gummi Fabrik
HL - hot load
LED - Light Emitting Diod

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1 Introduction

To minimize damage on horses hooves they are equipped with shoes. These shoes are mainly made of steel and are nailed into place by farriers. This type of shoe has been roughly the same for centuries. There is a fairly new horseshoe on the market made of rubber with a steel core. This innovative shoe has the same basic purpose as the traditional shoe, to protect the hoof from outer damage and wear with the additional function to cushion the step. The friction from this shoe on different grounds will be examined, and the movement on the hoof while running will be observed to determine the slide time and slide length.

1.1 Background

This project is a cooperation between AB Halmstad Gummi Fabrik (HGF) and Chalmers University of Technology. Öllöv is a brand name for the rubber cover shoes and the first version was created during the 90's. This shoe had an unwanted result and went into development. The new product Öllöv Original came after a 2 year study (Yxklinten, 1996). This shoe was their second horseshoe product until December of 2017 when the new improved Öllöv SoftStep was launched.

Horses should be be respected as living beings. Humans carries the utter responsibility for their health and wellness, since they are in general used for hobby- and entertainment purposes. Horse owners care about their horses and spend large amount of money on them. When costumers choose equipment they choose those who has given historical good results without any technical proof. In this type of sport there are a lot of believes with less knowing. A horse itself costs a lot of money, so when training one, technical proven equipment should be used. This so they do not spend their money on equipment who supports a non sustainable movement for the horse. Wrong equipment often leads to injuries, and this may lead to euthanization.

The objective is to test the Öllöv SoftStep against different types of grounds. This task will be carried of by Chalmers University Of Technology.

1.2 Purpose

The purpose of this study is to examine the friction that the rubber shoe obtains against the ground. Two different types of tests will be carried out. The first test will be performed to estimate a coefficient of friction. The second test measures slide time and slide length during the hooves movement on the ground. The first test, measuring friction, will only compare the rubber shoe with a steel shoe. These results will be compared to earlier studies on unshod hooves. The second test will measure the movement of horses hooves when they wear steel shoes and no shoes, and these results will be compared to when the horses wear Öllöv SoftStep. Öllöv strive not to depress the natural pattern of movement of the horses hoof. This because a too low, or too high friction may results in injuries on the horse. The reason for a new study is because the Öllöv Original has gone through a product development. Öllöv SoftStep is the newer version of its predecessor Öllöv Original. One difference is the design who has been changed with a smaller contact area to the ground. This renders the old report outdated. Fiber mixed sand is a fairly new type of ground in the equestrian world. This project will do tests on the fiber mixed sand to determine if the natural pattern of movement is retained.

1.3 Limitations

The tests will be carried out at two occasions, one for friction tests, the other for movement measurements. The values collected at these days will be the only one examined and are expected to be sufficient. This project will examine asphalt and concrete at the friction tests, and fiber mixed sand and concrete at the measurement of movement. The friction tests will be measured with a spring scale, and only horizontal forces will be applied. The type of fiber mixed sand used in this project are 21kg per ton mixed sand and are produced by Expåra AB (Expåra, 2018). The amount of water in the sand is 1,8%. Two different horses will be participating in the study. Discipline tested is trot. The results will be analyzed but improvement of the product is not included.

The health effects of the Öllöv SoftStep will not be covered in this project due to the complexity of the task. The study of the health effect would require a long term study. The project only involves the hoof movement and friction on different grounds. Injuries will only be a part of pilot study for a wider information about the problem.

1.4 Precision of questions

The focus of the project is to examine how the Öllöv SoftStep interacts with the ground in terms of coefficient of friction and the slide time and slide length.

In the first test, the following questions will be answered, by testing a standard steel shoe and Öllöv SoftStep.

- What are the coefficient of friction on asphalt and concrete? Both dynamic and static.
- How does these coefficients differ from the unshod hoof, by comparing to earlier studies?

In the second test of this project the following two questions will be examined when the horses are wearing Öllöv SoftStep.

- How long is the slide time on fiber mixed sand and concrete?
- How long does the hoof move during this time?

These results will be compared to when the horses are wearing steel shoes and no shoes.

2
Theory

In the following section the theoretical frame of reference will be presented. How the horseshoes are constructed, the structure of Öllöv SoftStep, the hoof movement, possible injuries, how the ground surfaces are constructed, the appearance of friction and trot.

2.1 Traditional horseshoe

Traditionally, horseshoes are made of steel. For centuries a farrier has forged shoes by hand to match sizes of the specific hoof. In modern days farriers either forges the shoe by hand or uses a industrial made shoe, usually made of a forged steel, cast iron or aluminum. Handmade shoes are made of a steel bar which are forged to the shape of a shoe. The forging process begins with a steel bar, who is heated in the middle. The bar is hammered from the top to force more material to the middle to compensate extended ware in the front of the shoe, then the general form of the shoe is formed. The smith then punches groves and holes for the nails. Some of the excess material in the middle is formed upwards to create the clip. Rear shoes are equipped with two clips offset of the middle to withstand shear forces operating during movement. The forging process is very time consuming and labour intensive. The industrial made shoes are selected according to the hoof width and length and then hammered into the final size. Industrial forged steel shoes are most commonly used because of lower costs and less time consuming, during the ferrule. The attachment of the shoes may be either cold shod or hot shod. Hot shoeing methods are more expensive than the cold shoeing methods but it will give a perfect interface between the hoof and the shoe. A perfect interface is crucial to eliminate wobbling. This also creates a seal which reduces the risk of getting dirt between shoe and hoof (Williams, 2015).

2.2 Structure of Öllöv SoftStep

Öllöv SoftStep is a product development from the previous product Öllöv Original. The main differences is the shape of the shoes contact area to the ground. Öllöv SoftStep is a construction of two materials, a steel core with an outer layer of rubber. The steel core consists of 5-6,5 mm thick forged steel depending of the shoe size, this is to facilitate the custom shaping and to reinforce the shoe. Forged steel is a development from the former shoe, which had a steel core made of a cut, cold rolled, steel sheet, which is difficult to shape by the farrier with the regular shaping methods. The forged steel is coated with an adhesive paint prior to molding the rubber, this insures a chemical bond between steel and rubber. The adhesive is activated by the heat in the molding process and vulcanizes together with the rubber and acts like a bridge between the rubber and the metal. Rubber covers the steel core, the dimensions between core and hoof is 1 mm of rubber and between core and ground is 6 mm.

The design of the shoe can be seen in figure 2.1 (HGF, 2018). The pattern on the sole is intended to increase the grip. This results in a lower contact area but provides a mechanical lock when the ground fills the crevices. Just like conventional shoes, holes for studs can be drilled at the rear of the shoe. The Öllöv SoftStep is provided with an easy rollover at the front of the shoe.

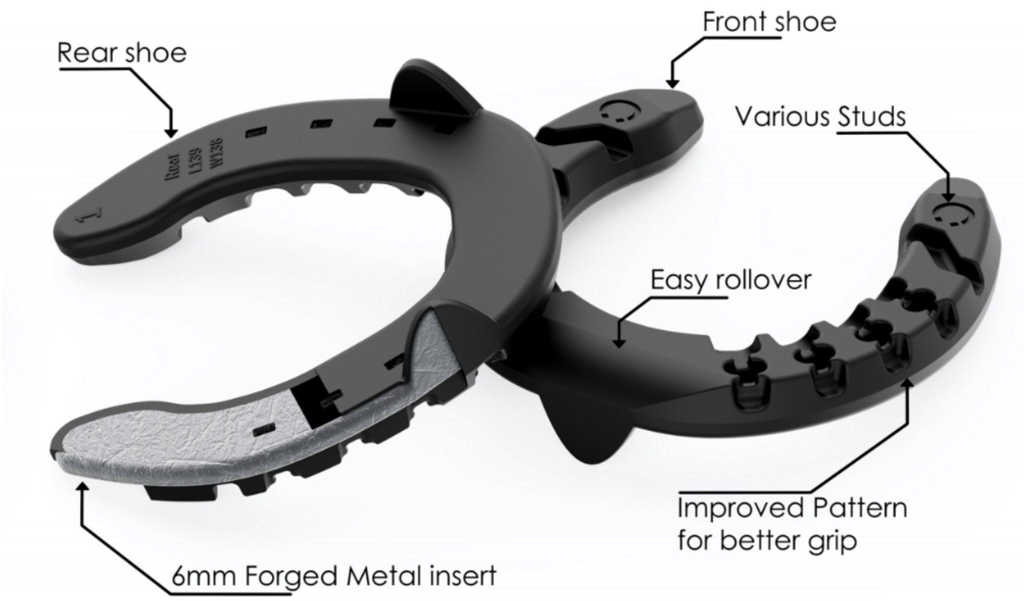

Figure 2.1: The structure of Öllöv SoftStep

2.3 Movement of hooves

Horses are by nature designed not to wear shoes, nor to be used at some of the grounds we use them on today. For example, asphalt is created by human, and the horses would probably not walk on the roads if we did not make them to do so. That is one of the reasons horses hooves are in need of protection, while wild horses and other ungulates survive without having shoes. However, the horses natural movement are created with the unshod hoof. When horses move, there is a sliding in each step which belongs to the natural movement. Shoes interrupts this movement, creating another length of sliding, and therefore exposes the horse for an unnatural movement.

Briefly the movement starts when the hoof is moving downward to touch the ground. The landing is at the hooves heel, toe or lands flat with equal pressure at first contact. This is the landing phase. Next the leg is moving in the horses running-direction, this is called the loading phase and the force from the horse is directed towards the ground. Afterwards the hoof takes off and this last phase is called roll-over/push-off phase. However, the interesting part of the movement due to this project is the landing phase since this is where the sliding occurs. The horses velocity forward is the cause of this. Sliding length and time depends on the type of ground, and on what shoes the horse is wearing. When the hoof slides, the fetlock comes closer to the ground and when the leg is moving in the running direction, force is applied to the fetlock and the more the hoof has slide, the larger is the stress applied here. While walking on a ground of high friction, the hoof would stop to fast and stress occurs. This affect the joints as well (PremierEquestrian, 2016).

The gait of the horses has been studied and the sliding time occurs when the hoof had first contact with the ground. It shows that there is 10% (or 2 ms) difference in time between the Öllöv Original and an unshod hoof on concrete according to a report by U.Yxklinten (Yxklinten, 1996). This means that the Öllöv Original mimic the unshod hoof. The study also include a steel shoe and the sliding time is 40 % (or 12 ms) greater than the unshod hoof. The report states that the Öllöv Original does have more advantageous benefits than the steel shoe. They also did tests in dirt, but there was almost no difference between the steel shoe, rubber shoe and unshod hoof. Today the shoe is used on a daily basis on horses with joint injuries, as hock and knee. It has been proven with convalescence with very good results (Yxklinten, 1996).

2.4 Injuries

Injuries is a damage to the body caused by an unnatural movement, high load, excessive unaccustomed repeated movement, poor balance in locomotion or external force. The most common horse injury in Sweden by far is lameness with more than half of all reported injuries (Agria, 2015). The condition refers to a dysfunction with the locomotion and is mainly caused by excessive high load repeated movement often combined with faulty technique, wrong underlay etcetera. The lameness usually affect the front and rear leg joints but the symptom varies greatly due to the discipline and breed (Dalin, 2012). Temporary lameness can be caused by periostitis which is a sign of too intense training. Local periostitis can lead to splint. Splint is caused by external violence, faulty techniques or intense training and results in boulders on the leg made of bone (Pernes, 2011). The emergence of these boulders is when the periosteum is damaged which surrounds bones and joints. The periosteum contains a dense irregular connective tissue divided into different layers (Modric, 2013). When a damage occur the progenitor cells which can differentiate into a specific type of cell, develop into osteoblasts (Seaberg & der Kooy, 2003). Osteroblast synthesize the production of bone which build up the boulder (Wikipedia, 2018).

2.5 Underlay

The underlay are mixed with materials to absorb shock, provide support and return energy. If the ground is to compact it may result in affecting the bones and joints since the shock is moving up the legs. If it is too soft, the hoof does not have enough support and risk for injuries is non negligible. The optimal underlay absorbs shock during the landing phase and provides support and traction during push-off and turns (PremierEquestrian, 2016).

The ground is constructed in three different layers. A top layer, middle layer and a bottom later. A fixed bottom layer is the most important qualification. The purpose of bottom layer is to give a solid support to the middle layer. The middle layer functions is to be partly firm, but needs to absorb force from the horses maximal loads. Macadam are commonly used or sand with controlled humidity. The middle layer may contain rubber, as small pieces or a carpet. The top layer are often sand, and are also sometimes mixed with fiber or rubber. These layers can sometimes be separated with a thin textile or an equivalent sheet of various material to prevent mixing between the layers during continuous use. In figure **??** a composition of underlay is illustrated. The bottom layer consists of macadam and a rubber carpet. The middle consists of a layer of grit and finally fiber mixed sand as the top layer. In this particular configuration the rubber carpet doubles as a separator and a moisture preserver since the small pits keeps the water contained. Water is also contained in the fibers. This has the structure similar to dishcloth (Roepstorff, 2015).

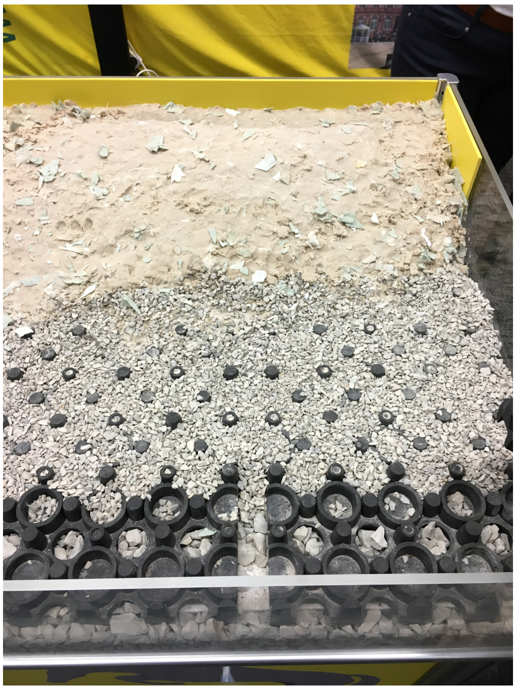

Figure 2.2: Layer configuration

The report from SLU by Roepstorff suggest, it is common to use shred pieces of rubber in the sand to maintain the capacity to absorb shock. Figure 2.3 illustrates this. This is a sample from Värnamobygdens Ryttarförening. The pieces of rubber is approximately one centimeter or smaller. This is mixed with sand, and in this case, this composition is used as top layer. In this project, the field study will not examine this type of top layer.

Figure 2.3: Rubber mixed sand

There is a large span of different compositions of these three layers. Fiber mixed sand is the type that can retain water better. This gives greater traction and stability to the foundation. The sand can be seen in figure 2.4. It seems that the market offers different qualities of fibers in the sand. Often the customers do not know the difference between these qualities and therefor buys the cheapest one. The effect of using low quality fibers are unknown. Another requirement is that the sand has to be well mixed before applied. In some applications rubber is used as fillers. This gives elastic and drainage properties to the ground. The same principles are used here as there are while creating croplands. The area is built with a slightly incline of 1-2%, so the water does not stay to long. The moist level can therefore be controlled easier. The layers can be at different heights depending on the constructor and also composed in many different ways (Renberg, 2012).

Figure 2.4: Fiber mixed sand

In riding schools there are often used a smaller amount of fibers, 10 kg per ton sand. For more professional use, 12-16 kg fiber are used per ton sand. Professional equestrian desires to work with their horses at higher tempo and therefore require a better traction to the ground. Experts recommend not to have higher amounts than 40-45 kg per ton sand because it may give the horse an excessive grip to the ground and may cause damage. The sand needs to be provided with certain amount of water before use. This because the sand only stays together by the friction between the grain of sand. When adding water the sand works more like a unit but only with the right amount of water. To little makes the ground to slippery for the horse, and to much makes the sand act like a lubricator. Water is often spread over the sand, as the attendant wishes. This results in no exact amount of water (Roepstorff, 2015).

2.6 Friction

Friction is a phenomenon that occurs between bodies in contact with applied forces. For horses this means that friction occurs when the shoe slides forward when putting their hooves down at the first phase of movement. This is called the landing phase in section 2.3. A stationary object exerts its underlay with a force, the reaction force that prevent the object to break through the surface is called normal force and are perpendicular to the ground. In bio-mechanics ground reaction force (GRF) is more commonly used. *"GRF is the force exerted by the ground on a body in contact with it"* (Wikipedia, 2017). This is for example the reaction force of the ground relatively to the angular force from the foot pushing of the ground illustrated in figure 2.5 (Pixabay, 2018). The frictional forces is a product of coefficient of friction and the vertical component of the GRF to the surface. Friction itself is independent of the contact area and is characterized in static- and dynamic friction. Static friction corresponds to the force needed just before the movement of the body, while dynamic friction is the force relative to the movement of the body (Vos & Riemersma, 2006). Due to this project the static friction is interesting to evaluate since this is when the shoe starts sliding. When sliding occurs the dynamic friction can be measured.

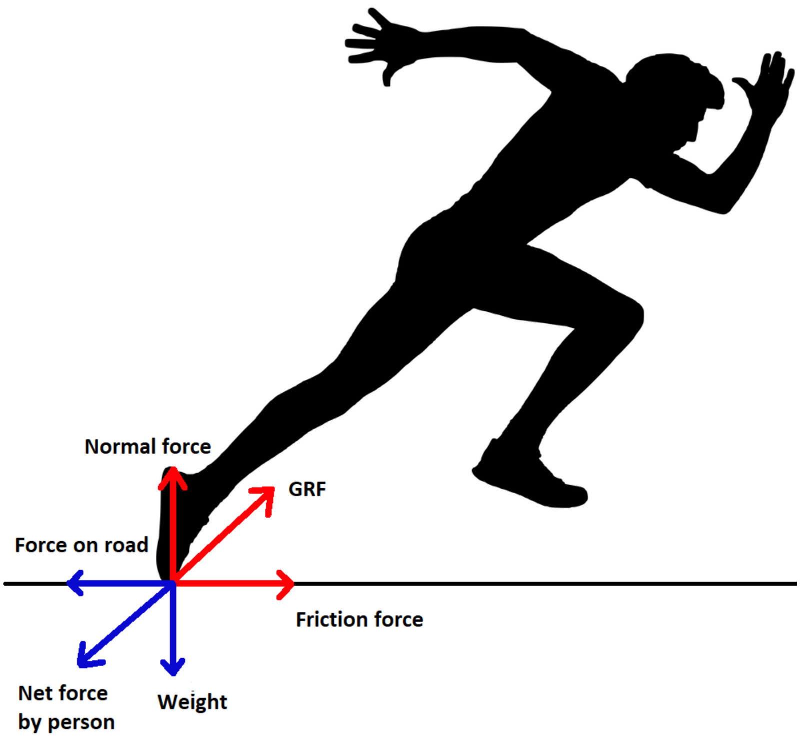

Figure 2.5: Ground reaction force

Tests has been made to determine the dynamic- and static coefficient of friction on both unshod hooves and steel shoes (Vos & Riemersma, 2006). In this report they test many different grounds. To understand their differences the coefficients are listed in table 2.1 for the unshod hooves and in table 2.2 for the steel shoes.

Ground surfaces	$\mu - static$	$\mu - dynamic$
Bare Concrete floor	0.69	0.58
Large concrete bricks	0.87	0.83
Small concrete bricks	0.89	0.83
Concrete pavement slab	0.71	0.70
Smooth tarmarc	0.80	0.76

Table 2.1: Coefficient of friction collected from *Determination of coefficient of friction between the equine foot and different ground surfaces: anin vitrostudy* made on unshod hooves.

The values of different types of concrete bricks does not differ considerably much. However the bare concrete floor has a lower value, specially for the dynamic coefficient. These four types of concrete differ because of their composition. The type of concrete found in a stable assumes to be the concrete pavement slab.

Ground surfaces	$\mu - static$	$\mu - dynamic$
Bare Concrete floor	0.42	0.39
Large concrete bricks	0.56	0.53
Small concrete bricks	0.58	0.55
Concrete pavement slab	0.48	0.47
Smooth tarmarc	0.44	0.42

Table 2.2: Coefficient of friction collected from *Determination of coefficient of friction between the equine foot and different ground surfaces: anin vitrostudy* made on hooves shoed with steel shoes.

Due to table 2.2 the steel shoes are more slippery at concrete surfaces. Using these shoes could clearly interfere the hooves walk along the surface.
In another report, published by Elsevier Ltd, static- and dynamic friction was measured on concrete and asphalt as the same type tested in this project. Follows in table 2.3 collected from Elseviers report (McClinchey & J.J. Thomason, 2004).

Ground surfaces	$\mu - static$	$\mu - dynamic$
Concrete	0.887	0.710
HL3 grade asphalt	1.043	0.638

Table 2.3: Coefficient of friction collected from *Grip and Slippage of the Horse's Hoof on Solid Substrates measured ex Vivo* on unshod hooves.

They also confirm in this report that the dynamic coefficient of friction is always smaller than the static, when tested at the same materials.

2.7 Trot

Trot is a two-stroke movement where the diagonal legs are moving at the same time. They have either two hooves to the ground or no hooves to the ground. Trot makes the hooves work under higher pressure since they work at a higher speed, and often places their back hooves as far forward as possible. They use a smaller stance than in walk, to avoid movement of force in the body and the hooves (Johansson, 2007).

3
Methods

This chapter describes in detail how the project was made during all phases of work. The method is divided in two parts, one describes the work process and another, the field study, containing both friction and movement measurements.

3.1 Work process

The group received a task of measure and analyze the behavior of Öllöv SoftStep with focus on friction and sliding phases. The project was initiated with a compilation of the background to the problem, reason to why this product exists and goal for the product. This compilation was based on a meeting with the client. Because of the possibility to expand the project into a non-realistically large project limitations where made. These limitations are based on resources, groups knowledge and time. A health study, for example, would demand to much time and resources due to the complexity. The precision of the questions where compiled into two basic areas. Finding the coefficient of friction and measuring the sliding time and length. The surfaces examined were also specified.

When the project had a defined structure of what the purpose and problem were, the work needed to be specified in time. A Gantt-chart was made. The purpose was to make the group define their own deadlines for the work progress to move forward. The project was divided in two large reports to be inspected by supervisor two times before hand in of final report.

When chart was set the pilot study started. Old reports of similar projects of the product were evaluated to give the group information of the product and its predecessor. Different types of grounds and its structure were investigated. The horses basic anatomy, gait and hoof movement were defined to gain information of what kind of parameters the group needed to focus on to generate a sufficient test results.

3.2 Field study

This part of the method contains the practical work at the field where different types of equipment were used to obtain values. First testing of the friction was made, second the measurement of movement of horse hoof were made.

3.2.1 Equipment

The newton meter used at the first tests are of a simple type, a spring scale. These were calibrated before use to give as good results as possible. More exact equipment was wished, but not available. Scales with maximum values of 2N, 5N and 10N were used.

To examine the movement, the high speed camera Photron SA2 Fastcam with a Nikon lens where used. A resolution of 2048 x 2048 and a frame rate of 1080 frames per second gave the the best resolution with enough fps to analyze the videos. The camera was equipped with an internal memory of 16 GB. To this camera a software, free to download, where used, called Photron FASTCAM viewer.

3.2.2 Friction measurement

Force created by the friction is proportional to the normal force on the object. To measure this force, a newton meter with a cord was attached to the shoe to apply and read the pulling force, see figure 3.1. To minimize the margin of error different weights where applied to the shoe, to alter the normal force. Both static and dynamic coefficient of friction were to be observed.

Figure 3.1: Öllöv SoftStep, friction test

Measuring the force just before the shoe starts to move gives the static friction. Dynamic friction was obtained by manually drag the shoe with a force created by human. Length of the pulling was approximately 20 cm over both asphalt and concrete. The asphalt was of the type HL3 (OntarioHotMixProducersAssociation, 2015) (HL=hot load, 3=size number of the stones used), this type of asphalt is the most common on medium trafficked roads. The concrete was a worn stable concrete with a smoother surface than a newly cast concrete. These surfaces can be seen in figure 3.2. When the value of the newton meters where stable, it was written down and the test where repeated. These test were made on both rubber- and steel shoes.

Figure 3.2: The asphalt and concrete

A coefficient of friction could be obtained to both static- and dynamic friction by dividing the indicated force from the newton meter with the force from the weight.

3.2.3 Measurement of movement

Initially the riding hall with fiber mixed sand was rigged with all the equipment. The pathway of 10 m was marked out with cones to give a reference point for timing the horses for velocity calculations. The high speed camera was placed off center to the further part of the pathway to ensure a constant velocity. Three high powered LED lights accompanied the high speed camera to ensure sufficient light. The test was performed by three people in interplay. The equestrian trotted in a steady tempo though the specified route. Time was clocked on entry and egress of the chest and one person operated the high speed camera. The slow speed of the data transfer of the high speed videos was a adversity and became the test bottleneck, therefore every test could not be recorded. A minimum of three videos per horse was taken for each shoe. Strides of or partially of frame was discarded. The concrete test was done in the stable hall in the same manner as in the riding hall. Fist series of test were made with steel shoes with two horses on both fiber mixed sand and concrete.

Second series were made with unshod hoof and third with the Öllöv SoftStep. After each shot, the video were reduced to the frame of interest to maintain as small storage as possible since the data was unexpectedly large. The sliding time and length could be determined with the related software. Prior to using the software the occurrence of the sliding phase needed to be defined. On concrete the sliding phase was obvious but on fiber mixed sand, the sliding phase was defined as when the hoof had full contact with the sand. In the software the videos were played frame by frame and cut into the defined start and stop moments and the time was displayed thereafter. Sliding length was analyzed by setting a length of reference in the software, a tracking point together with a coordinate system. Graphs of displacement, velocity and acceleration was displayed together with the pathways of the tracking points. Some adjustment of the tracker was made due to the lack of distinct tracking points.

A sample of the fiber mixed sand was collected to determine the level of water content. This was made by weighting the sand before and after drying in an oven.

4

Results

4.1 Friction measurements

The pulling forces were observed repeated times with the newton meter attached to the horseshoe. Tests with an unstable reading were discarded. These readings were calculated and are presented in table 4.1. Different grounds with calculated coefficient of friction for both static and dynamic are listed, the full result can be seen in appendix A and the specification of the collected values in appendix B.

Tested shoe - ground	$\mu - static$	$\mu - dynamic$
Rubber Shoe - Asphalt	0,795 $\pm 0,038$	0,730 $\pm 0,013$
Rubber Shoe - Concrete	0,809 $\pm 0,070$	0,743 $\pm 0,017$
Steel Shoe - Asphalt	0,489 $\pm 0,072$	0,388 $\pm 0,012$
Steel Shoe - Concrete	0,451 $\pm 0,052$	0,377 $\pm 0,011$

Table 4.1: Results of th coefficient of friction, mean values.

The shoes used to test the friction weigh as table 4.2. All shoes, and weights in use were calculated at the same scale.

Type of shoe	Weight [g]
Rubber Shoe, Öllöv SoftStep	369
Steel Shoe	351

Table 4.2: Weight of the shoes tested.

Table 4.3 compares the steel shoe results from Vos and Riemersma report compared to the steel shoe used in this project. For example, in their report they obtained 0,44, and the results from this project obtained 11% higher value.

Ground surfaces	$\mu - static$	$\mu - dynamic$
Asphalt	0,44 +11%	0,42 -8%
Concrete	0,48 -6%	0,47 -20%

Table 4.3: Coefficient of friction collected from *Determination of coefficient of friction between the equine foot and different ground surfaces: anin vitrostudy* made on steel shoes, compared to this projects result with the steel shoe.

4.1.1 Comparing Öllöv SoftStep to the unshod hoof of earlier studies

Table 4.4 contains coefficients from Vos and Riemersma report. The difference in coefficient of friction of the Öllöv SoftStep is represented in percentage from the unshod hoof.

Ground surfaces	$\mu - static$	$\mu - dynamic$
Asphalt	0,80 -0,6%	0,76 -4%
Concrete	0,71 +14%	0,70 +6%

Table 4.4: Coefficient of friction collected from *Determination of coefficient of friction between the equine foot and different ground surfaces: anin vitrostudy* made on unshod hooves, compared to the study on Öllöv SoftStep in this project.

Table 4.5 contains the coefficient of friction collected from Elseveiers report of the unshod hoof. The percentage represent Öllöv SoftSteps coefficient.

Ground surfaces	$\mu - static$	$\mu - dynamic$
Asphalt	1,043 -23%	0,638 +14%
Concrete	0,887 -9%	0,710 +5%

Table 4.5: Coefficient of friction collected from *Grip and Slippage of the Horse's Hoof on Solid Substrates measuredex Vivo* made on unshod hooves, compared to the study on Öllöv SoftStep in this project.

4.1.2 Comparing the steel shoe to the unshod hoof of earlier studies

To clarify the difference between the Öllöv SoftStep and steel shoe, compared to the unshod hoof of earlier studies a similar comparison is made. Table 4.6 present the difference between the unshod hoof and steel shoe.

Ground surfaces	$\mu - static$	$\mu - dynamic$
Asphalt	0,80 -39%	0,76 -49%
Concrete	0,71 -36%	0,70 -32%

Table 4.6: Coefficient of friction collected from *Determination of coefficient of friction between the equine foot and different ground surfaces: anin vitrostudy* made on unshod hooves, compared to the steel shoe

Following table 4.7 shows the difference between the unshod hoof examined in Elsveiers report to the steel shoe.

Ground surfaces	$\mu - static$	$\mu - dynamic$
Asphalt	1,043 -53%	0,638 -39%
Concrete	0,887 -49%	0,710 -47%

Table 4.7: Coefficient of friction collected from *Grip and Slippage of the Horse's Hoof on Solid Substrates measuredex Vivo* made on unshod hooves, compared to the steel shoe

4.2 Measurement of movement

The two horses are named Dora and Emperador. Their weights are approximately 500 kg and 600 kg. Complete sheet of values with all tests recorded can be collected in appendix C. Only tests with notation on the video column are evaluated, the other tests were noted to make sure the horses worked at a constant velocity. The values marked with red are not evaluated nor a part of the mean value since they deviate. In table 4.8 the mean value of approved slide times on the different types of grounds are presented.

FIBER MIXED SAND	Steel shoes [ms]	Unshod hoof [ms]	Öllöv Softstep [ms]
Dora	39	21	22
Emperador	32	26	21
CONCRETE	Steel Shoes [ms]	Unshod hoof [ms]	Öllöv SoftStep [ms]
Dora	20	5	8
Emperador	17	7	8

Table 4.8: Slide times on fiber mixed sand and concrete floor.

When measuring these length, a point of reference in the program where selected and a length were set to measure the displacements. Following values are therefore created by the program. Summarized in table 4.9.

FIBER MIXED SAND	Steel shoes [mm]	Unshod hoof [mm]	Öllöv SoftStep [mm]
Dora	45	10	12
Emperador	12	9	6
CONCRETE	Steel Shoes [mm]	Unshood hoof [mm]	Öllöv SoftStep [mm]
Dora	12	3	2
Emperador	5	2	1

Table 4.9: Slide length on fiber mixed sand and concrete floor.

4.2.1 Comparing the results with the unshod hoof

Having the unshod hoof as a point of reference, following difference for the time collected, in percentage as table 4.10.

FIBER MIXED SAND	Steel shoes	Öllöv SoftStep
Dora	+86%	+5%
Emperador	+23%	-19%
CONCRETE	Steel Shoes	Öllöv SoftStep
Dora	+300%	+60%
Emperador	+143%	+14%

Table 4.10: Difference in time, with the unshod hoof as reference, measured in percentage.

Same comparisons were calculated in table 4.11 with the values collected while observing the slide length. Also here, the unshod hoof are used as a point of reference.

FIBER MIXED SAND	Steel shoes	Öllöv SoftStep
Dora	+350%	+20%
Emperador	+33%	-33%
CONCRETE	Steel Shoes	Öllöv SoftStep
Dora	+300%	-33%
Emperador	+150%	-50%

Table 4.11: Difference in length, with the unshod hoof as reference, measured in percentage.

5
Discussion

5.1 Friction measurements

When analyzing the results from the friction tests most values where useful except for Öllöv SoftStep when only small weight where applied. The static coefficient of friction on both asphalt and concrete differ $\approx$ 45% from the others with weight applied. This could be because the Öllöv SoftStep pattern was partially in engaged with the irregularities in the ground. The normal force was low, but the drag force where high relative to the normal force, when the shoe was in grip with the asphalt which equals a higher coefficient of friction. A higher weight may have given a more uniform engagement with the ground. In this project there was no possibility to test higher weights because limitations of instruments. Newton meters measuring higher than 10 N was not available. These irregularities effects can be seen in appendix B first column on the first four tables. Applying weight at the shoes gave reasonable coefficients of frictions and comparing these to earlier tests follows.

According to Elsveier Ltd, the coefficient of friction on concrete for dynamic where 0,710 and for static 0,887 with a unshod hooves. Since this project does not cover testing friction on unshod hooves this can not directly be compared with the results in appendix A. These however could be compared to the results collected with Öllöv SoftSteps on concrete. The Öllöv SoftStep has 5% higher coefficient of friction for the dynamic and 9% smaller coefficient of friction for the static. These are quite small differences and could signify that the Öllöv SoftStep acts like an unshod hoof at concrete which promote the natural movement of the horse. The two coefficient of friction on concrete for steel shoes obtained approximately 40% smaller value than the Öllöv SoftStep. For comparison, the steel shoe differs -49% from the unshod hoof. Concrete becomes additional slippery surface for horses wearing steel shoes. And due to the fact that the coefficient of friction differs very small from the unshod hoof, the Öllöv SoftStep acts more like the unshod hoof on concrete floor than steel shoes does.

In the report written by Vos and Riemersma, the unshod hoof has a coefficient of friction for static and dynamic at 0,71 0,70 respectively, on concrete pavement slab. Comparing these values to the Öllöv SoftStep on concrete gives 14% and 6% larger values at the static respective dynamic. These values differ less than the steel shoe does to the unshod hoof, which differ $\approx 32-36\%$ for both static and dynamic friction. With Öllöv SoftSteps the horse obtains a higher friction to the ground, yet walking with steel shoes makes the shoes loose grip to the ground.

The steel shoes tested in Vos and Riemersma report obtained 0,47 and 0,48 for dynamic- and static coefficient of friction respectively, testes on concrete pavement slab. The tests differ 20% for the dynamic forces, and 6% for the static forces gathered during this projects tests on steel shoes. Why these differ could be explained with the fact that they used new steel shoes, and the test made to compare the Öllöv SoftStep were used by an worn steel shoe. Another difference could be the surfaces. The steel shoe therefore may not obtain the same friction to the concrete tested in this project.

In Elsveiers report they name the concrete floor as *concrete* while Vos and Riemersma term the concrete floor as *concrete pavement slab* along with other types of concrete appearances. The difference between these are hard to specify without trying the shoes at more types of concrete surfaces. Although the Öllöv SoftStep clearly acts more like the unshod hoof because its coefficient differs smaller than the steel shoe does to the unshod hoof. Since Elsveier's test on the steel shoe differ from this projects test on steel shoes, may indicate that the surfaces do not have the exact same composition. These floors may not be exact copies to compare shoes on.

In Elsveiers report, same type of asphalt were tested with the unshod hooves. Comparing these values to the Öllöv SoftStep has 23 % smaller static coefficient and 14% larger dynamic coefficient. This may affect the grip at the take of from ground since its lower than the unshod hoof, but maybe not slide as far on the ground as the unshod hoof at phase of landing. In the report they do not specify age of the asphalt. This may make the values to differ, since hot new asphalt may have better grip than old asphalt. The steel shoe differs -39% to -53% compared to the unshod hoof examined in Elsveiers report.

In Vos and Riemersma report they defined the asphalt as smooth and rough tarmac. Comparing these surfaces to this project smooth tarmac assumes to be equivalent with the asphalt surface. The result with steel shoes differ 11% for the static and 8% for the dynamic coefficient compared to the steel shoes used in the friction tests. Comparing the Öllöv SoftStep resulted in only 0,6% smaller coefficient for the static coefficient and only 4% for the dynamic. Öllöv SoftStep, in terms of friction, acts more like the unshod hoof on asphalt. The steel shoes tested have -39% to -49% lower coefficients compared to the unshod hoof from Vos and Riemersma.

The difference that occur between the friction tests made in this project, and earlier studies, could be discussed furthermore. Some significant differences could be the equipment used, in this project simple ones were used. The other studies also examined different types of concrete floors, which this project did not include. At the day of testing friction, only one type of concrete floor could be tested.

5.2 Measurement of movement

While studying the videos, differences of movement of the horses hoof were observed. They did not always land in the same way, is was whether heel, flat or toe first. There were also a difference between the horses. Emperadors tests were very much more difficult to observe than Doras because of randomness in the landing phase of which part of the hoof touched down first. Another difficulty was the definition of the sliding phase in fiber mixed sand though the landing phase and sliding phase occurred simultaneously in some tests and in some other tests had very well defined landing and sliding phases. On concrete the sliding phase could be seen very clearly. As a conclusion of examine all the high speed samples, Dora is the most reliable test of the to horses in terms of continuity. Although more test would be necessary to obtain a certain result, but this project did not have enough time. With more test a normal distribution curve could be established and high fluctuate results would be eliminated giving a lower margin of error. In this test only extremely fluctuating numbers were excluded in the calculations.

When measuring time on fiber mixed sand, Dora obtained with the Öllöv SoftStep, only 5% larger value than the unshod hoof. This corresponds to 1 ms longer slide time. On the other hand, the steel shoes she wore obtained 86% longer slide time. This is 18 ms longer than for the unshod hoof. Studying Emperador at the same way, on fiber mixed sand, the steel shoes and Öllöv SoftStep differ 23% and -19% respectively. Because of his very varying way of walking leaves these results with some uncertainty. At concrete Dora had a 60% longer slide time with the Öllöv SoftStep, and with the steel shoe 300% higher value. Emperador obtained 143% higher with the steel shoes and 14% larger with the Öllöv SoftStep..

The measuring of length was also compared with the unshod hoof as reference. Dora obtained a slide length of 350% and 300% with steel shoe on fiber mixed sand and concrete respectively. She only had a difference of 20% and 33% with the Öllöv SoftStep at same ground. For Doras way of movement, the Öllöv SoftStep mimic the unshod hoof and the steel shoes makes the hoof slide much longer. Emperador walked uneven, especially on fiber mixed sand rendering his results uncertain. The videos examined shows that the way he move his hooves are with no continuity.

As U.Yxklinten confirms, he obtained a difference of 2 ms on concrete between the Öllöv Original and the unshod hoof. It seems like these differences is also where this project obtained since the values differ from 1-3 ms for Doras values on both concrete, and fiber mixed sand. The only values who differ largely from these are Emperador with Öllöv SoftStep on fiber mixed sand. It is unclear if this is because of a disrupt of movement, or the fact that Emperador moves differently and with different steps each time.

While studying table 4.10 and table 4.11, the percentage differential between Öllöv SoftStep and the unshod is much lower than between the steel shoe and unshod. According to this result, the Öllöv SoftStep is close to mimic the unshod hoof on both fiber mixed sand and concrete.

5.3 Recommendations

When testing the friction, coefficients that were comparable to the unshod hoof were obtained, and the conclusion that the Öllöv SoftStep mimic the unshod hoof were obvious. Higher weights and more exact newton meter are recommended to use in future studies. Higher weight would more mimic the wear that horses effect on the shoe. Since higher weights would make the entire shoe work with the friction against the ground.

For a more profound study, the push of phase could be studied and include the GRF from the different shoeing types. This because in this study horizontal forces were only observed. How the shoe work with a non horizontal force would apply a resulting force, using GRF, and grip and friction would be found.

The test made to examine the coefficient of friction needed constant speed on the shoes. Originally the shoes were supposed to be pulled with a power drill, to obtain a constant velocity. This method was substituted by manual pulling because the momentum of the drill was not sufficient, leaving the newton meter unstable. The constant velocity of the shoe gives indication at the newton meter, but still the constant velocity from human could give error at the tests. To lower the margin of error the test where repeated 10 times. Recommendation for friction tests in the future is to have better instrument indicating the force or maybe try to move the ground at a constant speed instead of the shoe, since this turned out to be harder than expected.

While doing the movement measurement, knowledge of how large memory a 2 second film from format of .raww in the high speed camera took approximately 16 GB. This was unknown to the group at start, and were solved by dividing the films between computers available. Next time, be sure to bring a large external hard drive.

Observation of different movement in the landing phase occurred. The same horse used toe, flat and heel landing at same discipline. This means, horses do not always land at the same way on the ground, and the spectra of how horses move differ from step to step, and also from horse to horse. This may be interesting to study, due to the fact that the friction och sliding may depend on this. A horse moving in one way may be more interesting to evaluate than others.

A study with more recorded videos at the same ground are one way of improving this sort of study. To do this, more time for the field study are needed. Tests of movement in this report were recorded during one day. To collect values to maintain a more precisely result would require more time. Although, the results obtained in this study shows clearly that the Öllöv SoftStep mimic the unshod hoof. The interesting thing is to evaluate the small differences, since this might play a part to the movement. As earlier mentioned, a quite large study are needed since horses does not only move different individual, but also moves different depending on each step.

6
Conclusion

Öllöv SoftStep coefficient of frictions are 0,795 and 0,730 on asphalt for static- and dynamic coefficient of friction. On concrete the coefficients are 0,809 and 0,743 respectively. The steel shoe has a coefficient of friction of 0,489 and 0,388 for static and dynamic friction on asphalt and 0,451 and 0,377 on concrete. Comparing to other studies, the Öllöv SoftStep does mimic the unshod hoof on both asphalt and concrete. The coefficient of friction for Öllöv SoftStep are closer to the unshod hoof than the steel shoe are when comparing to earlier studies. The maximum difference to the unshod hoof appeared to be 23%, all the other differences were smaller than these. The steel shoe differs at least 32%, all other values were larger than this.

The slide time on fiber mixed sand and concrete are 22 ms and 8 ms for the horse called Dora in this project. These differ 1 and 3 ms from the unshod hoof and the SoftStep slides longer on both of the grounds than the unshod hoof. The slide times appeared according to figure 6.1. Emperador was a horse who moved uneven and should not used as reliable result.

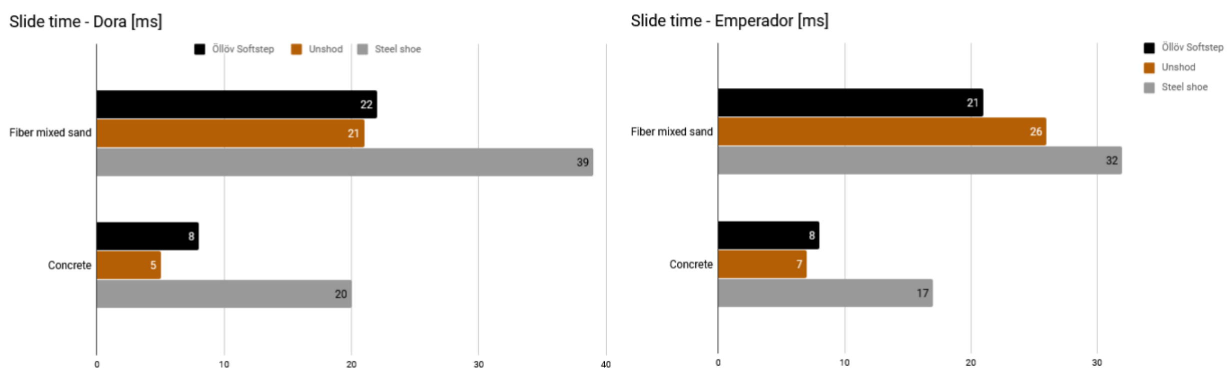

Figure 6.1: Slide time for the shoes tested

Dora slides 12 mm and 2 mm on fiber mixed sand and concrete, and differ 2 respectively 1 mm from the unshod hooves slide length. See figure 6.2. The steel shoe had much longer slide- times and length.

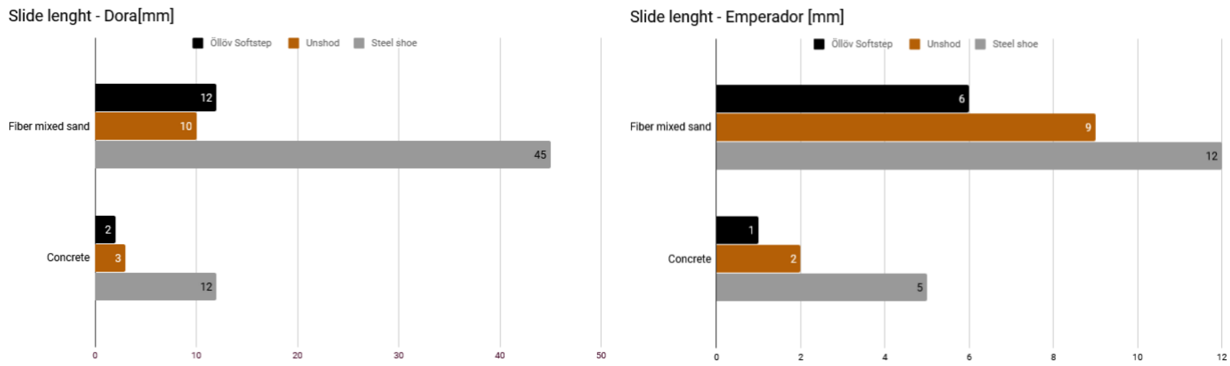

Figure 6.2: Slide length for the shoes tester

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A
Friction tests, a summary of mean values and standard deviation

Mean values:	μ [-]	Standard deviation
Öllöv SoftStep Asphalt - Static	0,7947	0,0376
Öllöv SoftStep Asphalt - Dynamic	0,7300	0,0126
Öllöv SoftStep Concrete - Static	0,8085	0,0704
Öllöv SoftStep Concrete - Dynamic	0,7429	0,0166
Steel Shoe Asphalt - Static	0,4894	0,0725
Steel Shoe Asphalt - Dynamic	0,3878	0,0118
Steel Shoe Concrete - Static	0,4513	0,0515
Steel Shoe Concrete - Dynamic	0,3769	0,0106

B

Specification of friction tests

Öllöv SoftStep Asphalt - Dynamic								
g[m/s^2]=	9,81		g[m/s^2]=	9,81		g[m/s^2]=	9,81	
weight [g]=	375,9		weight [g]=	784		weight [g]=	1260	
N=	3,687579		N=	7,69104		N=	12,3606	
Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]
1	3,20	0,8677780191	1	5,00	0,6501071377	1	8,5	0,6876688834
2	3,10	0,840659956	2	5,10	0,6631092804	2	8,4	0,6795786612
3	3,20	0,8677780191	3	5,20	0,6761114232	3	8,3	0,6714884391
4	3,10	0,840659956	4	5,20	0,6761114232	4	8,5	0,6876688834
5	3,10	0,840659956	5	5,20	0,6761114232	5	8,3	0,6714884391
6		0	6	4,90	0,6371049949	6	8,4	0,6795786612
7		0	7	5,00	0,6501071377	7	8,6	0,6957591055
8		0	8	4,90	0,6371049949	8	8,4	0,6795786612
9		0	9	5,00	0,6501071377	9	8,4	0,6795786612
10		0	10	5,00	0,6501071377	10	8,5	0,6876688834
Mean values:		0,8515071813	Mean values:		0,656608209	Mean values:		0,6820057279
Standard deviation:		0,01485317487	Standard deviation:		0,01532317218	Standard deviation:		0,007675058638
						Mean values:		0,7300403727
						Mean standard deviation:		0,01261713523

Öllöv SoftStep Concrete - Dynamic								
g[m/s^2]=	9,81		g[m/s^2]=	9,81		g[m/s^2]=	9,81	
weight [g]=	375,9		weight [g]=	784		weight [g]=	1260	
N=	3,687579		N=	7,69104		N=	12,3606	
Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]
1	3	0,8135418929	1	4,9	0,6371049949	1	8,0	0,6472177726
2	3,1	0,840659956	2	4,5	0,5850964239	2	7,8	0,6310373283
3	3	0,8135418929	3	4,5	0,5850964239	3	7,9	0,6391275504
4	2,9	0,7864238298	4	4,6	0,5980985666	4	7,9	0,6391275504
5	3	0,8135418929	5	4,8	0,6241028522	5	8,0	0,6472177726
6	2,8	0,7593057667	6	4,9	0,6371049949	6	7,9	0,6391275504
7		0	7	4,7	0,6111007094	7	8,0	0,6472177726
8		0	8	4,9	0,6371049949	8	8,1	0,6553079948
9		0	9	5	0,6501071377	9	7,9	0,6391275504
10		0	10	4,9	0,6371049949	10	8,0	0,6472177726
Mean values:		0,9654030463	Mean values:		0,6202022093	Mean values:		0,6431726615
Standard deviation:		0,01917536631	Standard deviation:		0,02377808762	Standard deviation:		0,006875366775
						Mean values:		0,7429259724
						Mean standard deviation:		0,0166096069

Öllöv SoftStep Asphalt - Static								
g[m/s^2]=	9,81		g[m/s^2]=	9,81		g[m/s^2]=	9,81	
weight [g]=	375,9		weight [g]=	784		weight [g]=	1260	
N=	3,687579		N=	7,69104		N=	12,3606	
Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]
1	3,5	0,9491322084	1	5,5	0,7151178514	1	8,4	0,6795786612
2	3,8	1,030486398	2	5,6	0,7281199942	2	8,9	0,720029772
3	3,6	0,9762502715	3	5,5	0,7151178514	3	7,9	0,6391275504
4	3,6	0,9762502715	4	5,0	0,6501071377	4	8,6	0,6957591055
5	4,0	1,084722524	5	5,5	0,7151178514	5	8,5	0,6876688834
6		0	6	5,5	0,7151178514	6	8,4	0,6795786612
7		0	7	5,4	0,7021157087	7	8,0	0,6472177726
8		0	8	5,4	0,7021157087	8	8,4	0,6795786612
9		0	9	5,1	0,6631092804	9	8,5	0,6876688834
10		0	10	5,0	0,6501071377	10	9,1	0,7362102163
Mean values:		1,003368335	Mean values:		0,6956146373	Mean values:		0,6852418167
Standard deviation:		0,0542361262	Standard deviation:		0,02955426422	Standard deviation:		0,02905730304
						Mean values:		0,7947415962
						Mean standard deviation:		0,03761589782

Öllöv SoftStep Concrete - Static								
g[m/s^2]=	9,81		g[m/s^2]=	9,81		g[m/s^2]=	9,81	
weight [g]=	375,9		weight [g]=	784		weight [g]=	1260	
N=	3,687579		N=	7,69104		N=	12,3606	
Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]
1	3,6	0,9762502715	1	5	0,6501071377	1	8,8	0,7119395499
2	3,4	0,9220141453	2	4,7	0,6111007094	2	8,5	0,6876688834
3	4,3	1,166076713	3	4,8	0,6241028522	3	8,5	0,6876688834
4	3,3	0,8948960822	4	5	0,6501071377	4	9,1	0,7362102163
5	4,1	1,111840587	5	5,6	0,7281199942	5	9,5	0,768571105
6		0	6	5,7	0,7411221369	6	9,4	0,7604808828
7		0	7	5,9	0,7671264224	7	9,3	0,7523906606
8		0	8	5,4	0,7021157087	8	8,3	0,6714884391
9		0	9	4,9	0,6371049949	9	9,6	0,7766613271
10		0	10	5,3	0,6891135659	10	9,4	0,7604808828
Mean values:		1,01421556	Mean values:		0,680012066	Mean values:		0,731356083
Standard deviation:		0,1191344383	Standard deviation:		0,05345130123	Standard deviation:		0,0385549051
						Mean values:		0,808527903
						Mean standard deviation:		0,07038021487

Steel Shoe Asphalt - Dynamic								
g[m/s^2]=	9,81		g[m/s^2]=	9,81		g[m/s^2]=	9,81	
weight [g]=	357,9		weight [g]=	784		weight [g]=	1260	
N=	3,510999		N=	7,69104		N=	12,3606	
Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]
1	1,40	0,3987469094	1	2,8	0,3640599971	1	4,5	0,3640599971
2	1,50	0,4272288315	2	2,9	0,3770621398	2	4,6	0,3721502192
3	1,50	0,4272288315	3	3,0	0,3900642826	3	4,5	0,3640599971
4	1,40	0,3987469094	4	2,8	0,3640599971	4	4,6	0,3721502192
5	1,50	0,4272288315	5	2,8	0,3640599971	5	4,5	0,3640599971
6		0	6	2,9	0,3770621398	6	4,6	0,3721502192
7		0	7	3,0	0,3900642826	7	4,8	0,3883306636
8		0	8	3,0	0,3900642826	8	4,6	0,3721502192
9		0	9	2,8	0,3640599971	9	4,6	0,3721502192
10		0	10	3,0	0,3900642826	10	4,5	0,3640599971
Mean values:		0,4158360626	Mean values:		0,3770621398	Mean values:		0,3705321748
Standard deviation:		0,01560019121	Standard deviation:		0,01225853775	Standard deviation:		0,007434401109
						Mean values:		0,3878101258
						Mean standard deviation:		0,01176437669

Steel Shoe Concrete - Dynamic								
g[m/s^2]=	9,81		g[m/s^2]=	9,81		g[m/s^2]=	9,81	
weight [g]=	357,9		weight [g]=	784		weight [g]=	1260	
N=	3,510999		N=	7,69104		N=	12,3606	
Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]
1	1,41	0,4015951016	1	2,9	0,3770621398	1	4,0	0,3236088863
2	1,39	0,3958987171	2	2,8	0,3640599971	2	4,4	0,3559697749
3	1,43	0,407291486	3	3,0	0,3900642826	3	4,5	0,3640599971
4	1,42	0,4044432938	4	2,9	0,3770621398	4	4,4	0,3559697749
5	1,45	0,4129878704	5	3,0	0,3900642826	5	4,2	0,3397893306
6	1,43	0,407291486	6	3,0	0,3900642826	6	4,2	0,3397893306
7	1,44	0,4101396782	7	2,9	0,3770621398	7	4,2	0,3397893306
8	1,41	0,4015951016	8	3,0	0,3900642826	8	4,5	0,3640599971
9	1,41	0,4015951016	9	2,8	0,3640599971	9	4,4	0,3559697749
10	1,42	0,4044432938	10	2,9	0,3770621398	10	4,0	0,3236088863
Mean values:		0,404728113	Mean values:		0,3796625684	Mean values:		0,3462615083
Standard deviation:		0,006368751394	Standard deviation:		0,01025622852	Standard deviation:		0,01515942519
						Mean values:		0,3768840632
						Mean standard deviation:		0,0105948017

Steel Shoe Asphalt - Static								
g[m/s^2]=	9,81		g[m/s^2]=	9,81		g[m/s^2]=	9,81	
weight [g]=	357,9		weight [g]=	784		weight [g]=	1260	
N=	3,510999		N=	7,69104		N=	12,3606	
Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]
1	2,1	0,598120364	1	5,1	0,6631092804	1	5,7	0,461142663
2	1,8	0,5126745977	2	4,2	0,5460899956	2	5,0	0,4045111079
3	2,0	0,5696384419	3	3,3	0,4290707109	3	5,0	0,4045111079
4	2,0	0,5696384419	4	3,9	0,5070835674	4	5,4	0,4368719965
5	1,5	0,4272288315	5	3,6	0,4680771391	5	6,0	0,4854133295
6		0	6	3,7	0,4810792819	6	5,8	0,4692328851
7		0	7	3,0	0,3900642826	7	4,0	0,3236088863
8		0	8	3,2	0,4160685681	8	6,7	0,5420448846
9		0	9	3,6	0,4680771391	9	7,0	0,566315551
10		0	10	3,6	0,4680771391	10	4,9	0,3964208857
Mean values:		0,5354601354	Mean values:		0,4836797104	Mean values:		0,4490073297
Standard deviation:		0,067999657	Standard deviation:		0,0772385162	Standard deviation:		0,07218505474
						Mean values:		0,4893823919
						Mean standard deviation:		0,07247440931

Steel Shoe Concrete - Static								
g[m/s^2]=	9,81		g[m/s^2]=	9,81		g[m/s^2]=	9,81	
weight [g]=	357,9		weight [g]=	784		weight [g]=	1260	
N=	3,510999		N=	7,69104		N=	12,3606	
Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]	Test nr	F [N]	μ [-]
1	1,7	0,4841926756	1	4,0	0,5200857101	1	5,0	0,4045111079
2	1,8	0,5126745977	2	3,8	0,4940814246	2	4,7	0,3802404414
3	1,6	0,4557107535	3	3,0	0,3900642826	3	4,4	0,3559697749
4	1,5	0,4272288315	4	3,6	0,4680771391	4	4,7	0,3802404414
5	1,6	0,4557107535	5	3,4	0,4420728536	5	6,0	0,4854133295
6		0	6	3,3	0,4290707109	6	5,9	0,4773231073
7		0	7	4,3	0,5590921384	7	4,4	0,3559697749
8		0	8	4,5	0,5850964239	8	4,3	0,3478795528
9		0	9	3,7	0,4810792819	9	6,3	0,5096839959
10		0	10	3,5	0,4550749964	10	4,3	0,3478795528
Mean values:		0,4671035224	Mean values:		0,4823794961	Mean values:		0,4045111079
Standard deviation:		0,03247438763	Standard deviation:		0,0595675385	Standard deviation:		0,06255043447
						Mean values:		0,4513313755
						Mean standard deviation:		0,05153078687

C

Movement Measurements

Fiber mixed sand, steelshoes						
	time	starttime	video	slide time [s]	slide length [mm]	frames
Dora	3,76	14.22.13	x	0,025926	21,567000	28
	3,84	14.23.39				
	3,62	14.24.56				
	3,60	14.25.48				
	3,55	14.26.48				
	3,53	14.29.23	x	0,055556	78,563000	60
	3,63	14.30.54				
	3,55	14.33.37				
	3,61	14.36.17				
	3,65	14.37.17	x	0,036111	33,513000	35
meanvalue	3,63			0,039198	44,547667	
stdv	0,10					
Emperador	3,93	13.35.38				
	3,78	13.35/37				
	3,82	13.37.57				
	3,60	13.42.56	x	0,023148	6,813000	25
	3,65	13.45.05				
	3,56	13.46.45	x	0,030556	12,170000	33
	3,46	13.47.55				
	3,60	13.49.23				
	3,65	13.52.13	x	0,036111	15,193000	39
	3,59	13.56.15	x	0,036111	20,917000	39
	3,72	13.58.20				
	3,77	14.00.06	x	0,037037	11,676000	40
	4,00	14.01.10				
	3,56	14.02.06				
	3,92	14.05.06	x	0,031480	12,683000	34
meanvalue	3,71			0,032407	12,106500	
stdv	0,16					

Fiber mixed sand, unshod						
	time	starttime	video	slide time	slide length [mm]	frames
Dora	3,52	17.13				
	3,43	17.15.10	x	0,024074	8,469000	26
	3,32	17.15.58				
	3,28	17.17.26	x	0,020370	11,788000	22
	3,29	17.18.16				
	3,26	17.20.06	x	0,019444	9,196000	21
meanvalue	3,35			0,021296	9,817667	
stdv	0,10					
Emperador	3,45	16.41.44				
	3,72	16.43.15	x	0,022222	7,245000	24
	3,56	16.44.33				
	3,59	16.45.43				
	3,73	16.47.41				
	3,64	16.48.30	x	0,030556	10,214000	33
	3,45	16.49.25				
	3,78	16.52.03				
	3,63	16.52.53				
	3,60	16.53.44				
meanvalue	3,62			0,026389	8,729500	
stdv	0,11					

Fiber mixed sand, Öllöv SoftStep						
	time	starttime	video	slide time	slide length [mm]	frames
Dora	3,66	18.12.08	x	0,015740	0,640500	14
	3,70	18.13.26				
	3,30	18.14.40	x	0,022222	10,365000	26
	3,20	18.15.54				
	3,36	18.16.48				
	3,39	18.25.00	x	0,026852	14,422000	29
meanvalue	3,44			0,021605	12,393500	
stdv	0,20					
Emperador	3,66	17.38.54	x	0,029630	5,865000	32
	3,63	17.39.46				
	3,66	17.40.50				
	3,78	17.50.25	x	0,016667	6,446000	18
	3,73	17.52.02				
	3,92	17.53.52	x	0,017593	5,829000	19
meanvalue	3,73			0,021297	6,046667	
stdv	0,11					

Concrete, steelshoes						
	time	starttime	video	slide time [s]	slide length [mm]	frames
Dora	3,39	15.05.27	x	0,023148	16,757000	25
	3,64					
	3,59					
	3,42	15.09.25	x	0,022222	7,202000	24
	3,33	15.10.30				
	3,45	15.11.20				
	3,55	15.15.05	x	0,019444	13,280000	21
	3,56	15.16.05	x	0,015741	3,064000	17
meanvalue	3,49			0,020370	12,413	
stdv	0,11					
Emperador	3,48	15.26				
	3,25	15.27.22	x	0,023148	12,730000	25
	3,29	15.28.43				
	3,43	15.29				
	3,53	15.31.00	x	0,012963	2,407000	14
	3,38	15.32.40				
	3,54	15.36.47				
	3,42	15.38				
	3,52	15.39.14				
	3,50	15.40.12				
	3,60	15.41				
	3,39	15.42.30				
	3,25	15.43.42	x	0,015741	1,074000	17
meanvalue	3,43			0,017284	5,403667	
stdv	0,11					

Concrete, unshod						
	time	starttime	video	slide time [s]	slide length [mm]	frames
Dora	3,35	16.03.10	x	0,008330	2,381000	9
	3,18	16.04.37				
	3,19	16.06.16	x	0,006481	1,911000	7
	3,14	16.07.14				
	3,23	16.08.27	x	0,006481	4,000000	7
	3,78	16.09.17				
	3,30	16.10.50				
meanvalue	3,31			0,005323	2,764000	
stdv	0,22					
Emperador	3,50	16.22.59	x	0,009259	2,960000	10
	3,70	16.24.06				
	3,46	16.24.51				
	3,26	16.26.15				
	3,70	16.27.18	x	0,007407	1,531000	8
	3,62	16.28.02				
	3,51	16.29.17	x	0,003704	0,989000	4
meanvalue	3,54			0,006790	1,826667	
stdv	0,16					

Concrete, Öllöv SoftStep						
	time	starttime	video	slide time [s]	slide length [mm]	frames
Dora	3,37	18.49.18	x	0,007407	1,089000	8
	3,38	18.50.21				
	3,32	18.51.21				
	3,18	18.52.26	x	0,007407	2,605	8
	3,27	18.53.22				
	3,13	18.55.56	x	0,008330	3,798000	9
	3,38	18.56.41				
	3,37	18.57.18				
meanvalue	3,30			0,007715	2,497333	
stdv	0,10					
Emperador	3,63	19.05.36				
	3,68	19.06.39	x	0,004630	0,913000	5
	3,78	19.07.45				
	3,72	19.09.04	x	0,008333	1,530000	9
	3,87	19.09.51				
	3,67	19.10.37				
	3,88	19.11.27	x	0,010185	1,700000	11
	3,88	19.12.19				
meanvalue	3,76			0,007716	1,381000	
stdv	0,10					