Thesis 125

Round top and flat top humps
The influence of design on the effects

Sigurður Bjarnason
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LUND UNIVERSITY
Lund Institute of Technology
Department of Technology and Society
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Sigurður Bjarnason

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Keywords:
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Abstract:
The best way to influence drivers speed is through traffic calming measures. The best way to influence crossing speed over a road hump is through the discomfort that drivers experience when crossing. There is a great variety of road humps used today but in fact, an ideal road hump could replace them all. This ideal road hump would be comfortable to cross at low speed but discomfort would increase rapidly with speed above 20 km/h. The purpose of this thesis is to study how physical identities of road humps such as length, height, length of ramps etc, affect driving comfort and crossing speed. Vertical acceleration has often been used to describe the comfort of road humps. To study the connection between physical identities, vertical acceleration and crossing speed, different measurements were conducted. Vertical acceleration was measured with a specially instrumented vehicle, speed was measured with a radar gun and physical identities were measured with a total station. One of the main conclusions from this thesis is that each and every road hump has a special connection between vertical acceleration and crossing speed that is unique. Another conclusion is that there can be a conflict between driving comfort and crossing speed. If one physical identity is changed to increase or decrease vertical acceleration, it can have the unwanted effect that crossing speed would increase. It is therefore important to be aware of this possible conflict when designing road humps.

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Institutionen för Teknik och samhälle
Lunds Tekniska Högskola
Avdelning Trafikteknik
Box 118, 221 00 LUND, Sverige

Department of Technology and Society
Lund Institute of Technology
Traffic Technology
Box 118, SE-221 00 Lund, Sweden

Preface

I would like to thank the personnel at department of technology and society LTH for all their help and patience. They were so kind to help me solve all of the problems that I came across during the work of this thesis. I would though especially like to thank Karin Brundell-Freij for her help with the data analyzes and pointing me into the right direction.

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Lund, November 2004

Sigurður Bjarnason

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Summary

Traffic safety is a problem all over the world. Each year millions of people die or are severely injured in traffic accidents. The majority of all accidents happen in urban areas. The reason for this is the constant interaction between vehicles and vulnerable road users. Accidents come with a great cost for the victims and for the society. Speed plays a central role in traffic safety, more and more traffic researchers come to that conclusion. The reason for the strong influence of speed on traffic safety is the many negative effects that speed produces. The stopping distance of a vehicle increases rapidly with increased speed. How important speed is for traffic safety, comes into perspective when looking at the consequences of accidents related to collision speed. With increased collision speed, the probability of fatality for a pedestrian increase dramatically. Most drivers know this fact and take this fact under consideration when choosing their speed.

Different measures can be used to reduce speed especially in residential areas. Vertical shift of the street is one method that has been used to reduce speed. Round top humps and flat top humps are two measures that fall under that category. Studies show that these measures can reduce speed and accidents if they are installed in residential streets. The most common round top hump is the Watts hump. Watts introduced this hump after conducting a study with the purpose of finding an ideal road hump. This ideal hump was supposed to be comfortable to cross at low speed but with increased crossing speed the driving discomfort was intended to increase. This ideal hump was meant to keep speed under 25 km/h.

In general people are positive toward traffic calming measures. Many people think that road humps are an effective way of reducing speed and increasing traffic safety in residential areas. Even if people think that road humps are an effective method to increase traffic safety, most people feel that they are uncomfortable to cross. Buss drivers and rescue personnel are in most cases very negative towards traffic calming measures and especially towards road humps. Buss drivers are negative towards road humps, because this type of measure can increase stress on the driver's back and neck. Rescue personnel are negative towards road humps because they think that road humps increase their response time.

There is a great variety of road humps and different designs are often used. The characteristics of road humps can be described with how the driver experiences comfort when crossing a road hump and through crossing speed. Vertical acceleration has been used to describe the driving comfort when crossing a road hump. If a road hump is designed in a way so that the vertical acceleration does not increase very rapidly with increased speed, drivers see no reason to slow down before crossing a road hump. A road hump is made from several different physical identities such as length, height, length of ramps etc. How each physical identity affects driving comfort and crossing speed is an interesting question. To better understand how physical identities of road humps affect driving comfort and crossing speed, a study was performed with the purpose of describing the following:

- Difference between road humps
- The connection between vertical acceleration and crossing speed
- The connection between physical identities and vertical acceleration
- The connection between physical identities and crossing speed

To study the connection between physical identities, vertical acceleration and crossing speed, 14 flat top humps and 4 round top humps were selected. Vertical acceleration was measured with a specially instrumented vehicle, speed was measured with regular radar gun and physical identities were measured with a total station.

When looking at the connection between vertical acceleration and crossing speed, it is obvious that each road hump is unique. A linear regression line was used to describe the connection between vertical acceleration and crossing speed after 30 km/h. The slope of this line is one of many factors that can be used to explain the characteristics of road humps. The road humps were divided into groups according to their physical identities. Five groups were created. One group for round top humps and the remaining flat top humps were divided into four groups.

The study reveals that there is a difference between each and every road hump group. Some road humps are gentle, some are not. The speed around some road hump is quite low while the speed around others is higher. After dividing the road humps into groups according to type and their physical identities, the study reveals that when comparing vertical acceleration and speed, round top humps are in most cases different from flat top humps. The crossing speed is lower and vertical acceleration is higher for round top humps.

It was hard to statistically connect vertical acceleration and physical identities. It was though possible in some cases to establish this connection and one of these cases was between vertical acceleration and total length for round top humps. The vertical acceleration increased with increased total length. It was easier to establish a statistical connection between physical acceleration and crossing speed. There are probably many reasons why a connection between vertical acceleration and physical identities was so hard to establish. One of them can be that the number of road humps involved in the study was not high enough. Another reason can be that the connection between vertical acceleration and physical identities is not that simple. A simple linear regression between vertical acceleration and each physical identity is probably not suitable to describe this connection. The interaction between all the physical identities is probably needed to explain the influence of design on vertical acceleration.

The main conclusion from this thesis is that there is a conflict between driving comfort and speed reduction. The study shows that physical identities affect both vertical acceleration and crossing speed. This can lead to a conflict between these two basic characteristics of road humps. If a physical identity is changed, for example, to decrease vertical acceleration it can increase the crossing speed. The study reveals this in more then one occasion.

Sammanfattning

Trafiksäkerhet är ett problem i hela världen. Varje år blir tusentals människor dödade eller allvarligt skadade på grund av trafikolyckor. Majoriteten av alla olyckor sker i tätorter. Anledningen är den konstanta interaktionen mellan fordon och oskyddade trafikanter. Dessa olyckor för med sig en stor kostnad för de skadade men även för samhället. Hastigheten spelar en viktig roll i trafiksäkerheten, fler och fler trafikforskare har kommit fram till den slutsatsen. Anledningen för hastighetens starka påverkan på trafiksäkerheten är att hastigheten medför många negativa effekter. Stoppsträckan är direkt påverkad av hastigheten. Relationen mellan hastighet och stoppsträcka blir tydlig när man ser på konsekvenserna som hastigheten har på olyckor. Sannolikheten för en dödsolycka ökar dramatiskt när hastigheten ökar. De flesta förarna är medvetna om detta och tar hänsyn till dessa fakta när de väljer hastighet.

Olika åtgärder kan användas för att reducera hastigheten i bostadsområden. En metod är att lyfta upp vägbanan. Två åtgärder som härstammar från denna kategori är gupp och platågupp. Forskning visar att dessa åtgärder både kan reducera hastigheten och olyckor på bostadsgator. Det vanligaste guppet är det så kallade Watts gupp som används över hela världen. Watts introducerade denna typ av gupp efter en genomförd studie där han sökte efter det ideala guppet. Det ideala guppet skulle vara bekvämt vid låga hastigheter men vid 20 km/h skulle det snabbt börja bli obekvämt och tvinga förarna att köra under 25 km/h.

Människor är generellt sätt positiva till trafiklugnande åtgärder och tycker att väggupp är ett effektivt sätt att reducera hastigheten och öka trafiksäkerheten i bostadsområden. Även om många anser att väggupp är en effektiv metod för att öka trafiksäkerheten tycker de flesta att de är obekväma att köra över. Det är kanske inte vanliga förare som klagar mest på trafiklugnande åtgärder utan yrkesförare. Bussförare och räddningspersonal är i de flesta fall negativa till trafiklugnande åtgärder. Bussförare är negativa mot väggupp på grund av ökad risk för arbetsskada medan räddningspersonal klagar mest på ökad körtid.

Trafiklugnande åtgärder är ganska vanliga i det moderna samhället. Målsättningen är att reducera hastighet och att skapa en säker trafikmiljö. Där finns en stor variation av väggupp och det händer ofta att varje modell har flera olika utformningar. Om inte vägguppet är utformat så att det blir mer obekvämt ju fortare man kör finns det ingen anledning för föraren att sänka hastigheten. Ett väggupp har olika fysiska element så som t.ex. längd och höjd. Hur olika fysiska element påverkar bekvämlighet och hastighet är en intressant fråga. För att bättre förstå hur guppets utformning påverkar bekvämligheten och hastigheten har en studie genomförts med syftet att beskriva följande:

- Sambandet mellan vertikal acceleration och hastighet
- Skillnaden mellan olika väggupp
- Sambandet mellan utformning av gupp och vertikal acceleration
- Sambandet mellan utformning och hastighet

För att studera sambandet mellan guppets utformning, vertikal acceleration och hastighet valdes 18 olika väggupp valts ut. De utvalda vägguppen består av 14 platågupp och 4 gupp. För att mäta vertikal acceleration användes ett speciellt utrustat fordon, hastigheten blev mätt med en vanlig radarpistol och utformningen uppmättes med en totalstation.

Sambandet mellan vertikal acceleration och hastighet är unik för varje väggupp. En linjär regressionslinje användes för att beskriva sambandet mellan vertikal acceleration och hastigheten efter 30 km/h. Linjens lutning är en av många faktorer som kan användas för att beskriva vägguppets egenskaper. Vägguppen delades in i olika grupper beroende på deras utformning. Det blev fem grupper, en med gupp och fyra med platågupp.

Undersökningen visar att varje grupp är olika. Vissa väggupp är bekväma att köra över, andra är det inte. Hastigheten för en del av vägguppen var ganska låg medan hastigheten var högre för andra väggupp. Efter gruppindelningen som berodde på typ av gupp och utformning visade undersökningen att vid en jämförelse med vertikal acceleration och hastighet var det i de flesta fall en skillnad på gupp och platågupp. Hastigheten var lägre och den vertikala accelerationen högre vid gupp.

Det visade sig vara svårt att statistiskt säkerställa sambandet mellan vertikal acceleration och utformning. Dock fanns det vissa fall när det gick att åstadkomma detta samband. Ett av dessa fall var sambandet mellan vertikal acceleration och den totala längden för gupp. Det var lättare att åstadkomma ett statistiskt samband mellan utformning och hastighet. Antagligen finns det många anledningar till att sambandet mellan vertikal acceleration och utformning var svårt att åstadkomma. En anledning kan vara att antalet väggupp i undersökningen inte var tillräckligt stort. Ytterligare en anledning kan vara att sambandet mellan vertikal acceleration och utformning är komplicerat. En enkel linjär regression mellan vertikal acceleration och utformning är antagligen inte användbar för att beskriva detta samband. Antagligen behöver man flera element, t.ex. både längd och höjd, för att förklara sambandet med vertikal acceleration.

Huvudslutsatsen från detta examensarbete är att det finns en konflikt mellan förarkomfort och hastighetsreduktion. Det har visat sig att utformningen har betydelse för både vertikal acceleration och hastighet. Om utformningen ändras för att minska den vertikala accelerationen kan effekten bli att hastigheten ökar.

1. Introduction

1.1. Background and purpose

Traffic calming measures are quite common in modern society. The main purpose of traffic calming measures is to reduce speed and create a safer traffic environment in urban areas. Road humps are one type of measure that is frequently used to reduce speed in residential areas. There is a great variety of road humps and different designs are often used. The reason for this is in many cases that the public has an opinion about traffic calming measures and is not afraid to express it to appropriate authorities. This has of course contributed to the development of traffic calming measures but there is no need for such variety in design. Traffic calming measures have to adapt to the specific condition of each location but in principle only one design of road humps is needed. This design should lead to a comfortable crossing at speed lower then 20 km/h but as soon as the speed increases it should be more uncomfortable to cross the road hump. The design of this ideal road hump would make drivers hold there speed below 25 – 30 km/h, at least when crossing a road hump.

Figure 1.1 describes roughly how road humps influence crossing speed. The designs of road humps influences experienced driving comfort and through that drivers speed. If a road hump is designed in a way so that the driving discomfort does not increase very much as the speed increases, drivers see no reason to slow down before crossing a road hump. In many cases, drivers estimate the discomfort of crossing against decreased travel time. Drivers are prepared to experience more discomfort if it will decrease their travel time, at least to some level. Road humps are installed in different environments, on streets that have different characters. The environment and the character of the street have an affect on how drivers choose their speed. Car parking, interaction with vulnerable road users and other things that make up the character of a street have an affect on drivers and their speed choice.

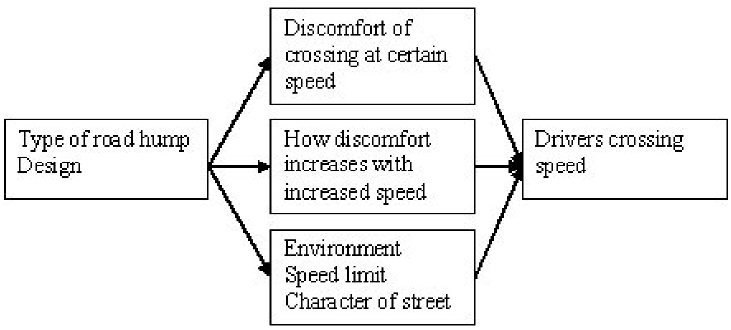


Figure 1.1 Theory about how design of road humps influences drivers crossing speed.

The best way to influence drivers speed is through traffic calming measures. The best way to influence crossing speed over a road humps is through discomfort that drivers experience when crossing. A road hump is made from several different physical identities such as length, height, length of ramps etc. Physical identities control the discomfort that road humps produce, and the characteristics of road humps can be described with how the driver experiences comfort when crossing a road hump and through crossing speed. Vertical acceleration has been used to describe driving comfort when crossing road humps. The connection between physical identities and characteristics of road humps is shown in figure 1.2.

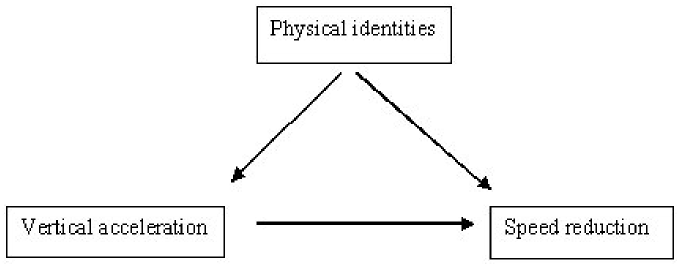


Figure 1.2 Connection between physical identities and characteristics of road humps.

How each physical identity affects driving comfort and crossing speed is an interesting question. To be able to come close to the ideal road hump, the connection between physical identities, driving comfort and crossing speed is needed. To better understand this connection a study was conducted with the purpose describing the following:

- The difference between road humps
- The connection between vertical acceleration and crossing speed
- The connection between physical identities and vertical acceleration
- The connection between physical identities and crossing speed

To study the connections between vertical acceleration and crossing speed a basic diagram was needed that describes the effects of road humps. By adding the speed measurements and information about physical identities, a connection can be made between these factors. By linking these factors together it is possible to see how each and every physical identity affects vertical acceleration and crossing speed.

To study the connection between physical identities and characteristics of road humps, a number of different measures were conducted. The measurements involved:

- Vertical acceleration measurements with specially instrumented vehicle
- Speed measurements around each road hump with radar gun
- Measurements of physical identities with precision measuring instrument

1.2. Traffic safety and traffic calming

1.2.1. Traffic accidents

Traffic safety is a problem all over the world. Each year millions of people die or are severely injured after traffic accidents in the world. To have a better understanding of the traffic safety problem, it is necessary to realize the location of the accidents and what traffic groups are at most risk of being in an accident. In table 1.1 accidents in 1996 that ended up in a fatality or in severe injury are divided between traffic categories and traffic environment. Table 1.1 shows that more then half of all accidents happen in urban areas. It is also clear from table 1.1 that the majority of accidents regarding vulnerable road users happen in urban areas. This is not surprising because of the continuous interaction between different road users in urban areas (Englund et al, 1998).

Table 1.1 Fatalities and injuries for each traffic category and environment in 1996 (Englund et al, 1998).

	Car driver/ passenger	MC-driver/ passenger	LMC-driver/ passenger	Cyclist	Pedestrian	Other	Total
Urban area							
Number	6233	476	632	2783	1282	35	11441
Percent	41%	54%	77%	91%	87%	26%	53%
Rural area							
Number	9149	401	188	275	192	99	10304
Percent	59%	46%	23%	9%	13%	74%	47%
Percent for category	71%	4%	5%	15%	8%	2%	100%

The majority of all accidents with personal injury happen on roads with speed limit 50, 70 and 90 km/h. The majority of all accidents with serious personal injury happen on roads with 90 km/h while the majority of all accidents with minor personal injury happen on streets with 50 km/h. Even if the majority of accidents that end in fatalities or serious injury happen on roads with speed limit more than 50 km/h the risk of being involved in an accident is higher at streets or roads with speed limit 50 km/h. As mentioned before, interaction between different road users is the main reason for this risk. Urban streets with speed limit 30 km/h have only a small percentage of all injuries and fatalities (Englund et al, 1998).

It was estimated in 1995 that the cost of traffic accidents for the society was 14,8 billions of crowns in Sweden. Fatalities are about 1% of all accidents but they stand for about 18% of the society cost. Severe personal injuries are about 19% of all accidents but their cost for the society is about 33%. Minor personal inquiries are about 80% of all accidents but are only responsible for about 15% of the society cost. Accidents with personal injury are responsible for about 66% of the cost for the society while accidents with only material damage stand for the remaining 34%. In national economics the cost of a fatality is estimated to be 12,9 million Swedish crowns, a severe injury is estimated to cost 2,4 millions and a minor personal injury is estimated to cost the society 140 000 Swedish crowns (Englund et al, 1998).

1.2.2. Traffic safety and speed

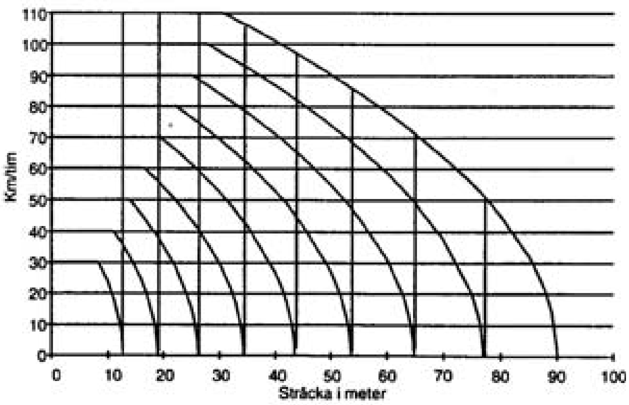


Figure 1.3 Breaking distance and collision speed on a dry road with reaction time of 1 second (Englund et al, 1998).

It has been mentioned that traffic safety is a problem in modern society and comes with great cost, both for people involved and the society. The main reason for this is speed. Speed plays a central role in traffic safety, more and more traffic researchers come to that conclusion. The reason for the strong influence of speed on traffic safety is that speed comes with many negative side effects. There are number of physical elements that are directly related to speed. The breaking distance increases with the square of speed. The centrifugal force is proportional to the square of speed. Kinetic energy is proportional to the square of speed. Increased speed influences the vehicle and tire wear along with the noise and the exhaustion coming from vehicles (Várhelyi, 1996). The most important physical element of speed is the influence on breaking distance. This has been demonstrated in a number of studies and is shown in figure 1.3. In figure 1.3 it is assumed that a driver is travelling on a dry road and has a reaction time of 1 second. If a driver is travelling at 70 km/h, the breaking distance is more than 40 meters. However, if the driver is travelling at a speed of 50 km/h the breaking distance is about 27 meters. Let's suppose a vehicle is travelling at 70 km/h and a pedestrian is crossing the street 35 m in front of the vehicle. If the driver sees the pedestrian and breaks, the vehicle would hit the pedestrian at 40 km/h. If the driver would have been travelling at 50 km/h, he would have been able to stop the vehicle without hitting the pedestrian (Englund et al, 1998).

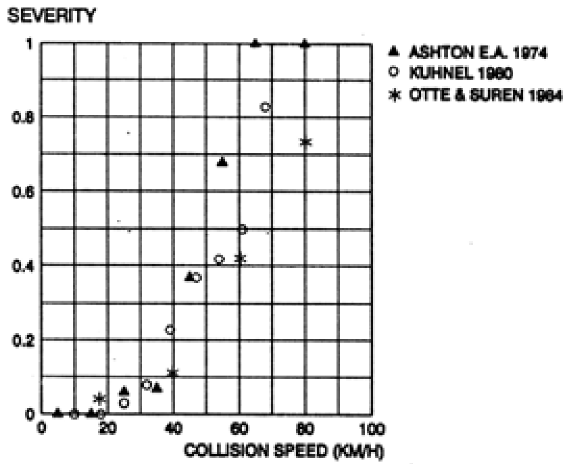


Figure 1.4 Collision speed and severity of pedestrian accident (Pasanen, 1992).

The meaning of speed and breaking distance comes into perspective when looking at the consequences of accidents related to speed. The connection between speed and the consequences of accidents has been studied by (Pasanen, 1992). Figure 1.4 shows the connection between the severity of a pedestrian accident and collision speed. Pasanen is referring to three different studies when presenting this result. From figure 1.4 it is possible to see that the severity of accidents increases slowly from 0 to about 40 km/h. After that the severity increases quite rapidly as the speed increases. Pasanen explains this by saying that the pedestrian body is capable of absorbing energy from the collision. Because the kinetic energy is proportional with the square of speed, the severity of the accident increases with speed. The body can only absorb a limited amount of energy from a collision without severe injury. When the speed of the vehicle is about 70 – 80 km/h the severity of the accident is so high that it will more likely end in fatality.

The connection between the probability of death and collision speed has been studied in a number of different studies. (Pasanen, 1992) mentions Ashton publication in 1982 and figure 1.6 is from that publication. The probability of death when a pedestrian is hit by a vehicle at 30 km/h is about 5 percent. If a vehicle is travelling at a speed of 50 km/h and hits a pedestrian, there is about 60 percent chance that the pedestrian survives. If a vehicle is travelling at 60 km/h or more the probability of death is more then 70 percent (Pasanen, 1992). This is interesting when considering the example that was mentioned earlier. If a driver is travelling at 70 km/h and notice a pedestrian crossing the street in about 35 meters distance, the vehicle would hit the pedestrian at a speed of about 40 km/h. The consequences of this would be that there is a 17% chance that the pedestrian would die. If the driver would have been travelling at 50 km/h then the driver would have been able to stop the vehicle before hitting the pedestrian. This illustrates how important speed is for traffic safety.

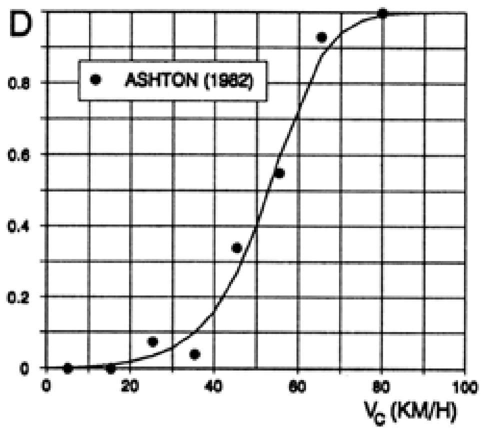


Figure 1.5 The influence of collision speed (Vc) on the probability of death (D) for a pedestrian (Pasanen, 1992).

It is not only the actual speed that is relevant to traffic safety but also the variance of speed. Studies in America have shown that the risk of a car accident is related to the variance of speed around the average speed of the traffic flow. This is true in both directions, the risk will increase if the speed is above the average and also when the speed is below the average speed. Of course the consequences of an accident are more severe when the speed is higher then the average speed. Some studies show that if the variance of speed is decreased by 3 km/h then the total number of accidents will decrease by 10% (Englund et al, 1998, referring to Salusjärvi, 1981).

1.2.3. Drivers speed choice

From the information above it is interesting to wonder about the factors that influence drivers speed choice. All drivers make their speed choice from different factors that each individual has to estimate and rank according to their personal judgement. According to (Spolander, 1979) there are a number of factors that influence drivers speed choice. These factors can be road and vehicle characteristics, weather and visibility conditions, current traffic situation, time (weekday, time of day), travel time and the drivers desire to minimize it, subjective accident risk, valuation of travel cost (fuel and vehicle costs), comfort claim and the drivers own characteristics (speed claim, driving experience). Drivers make a speed choice after weighing these factors together and in the end the speed choice depends on if the driver has the correct information about the appropriate speed, can judge the appropriate speed at different situations, can estimate his speed correctly and has the motivation and willingness to adapt his speed to the appropriate level (Spolander, 1979). It is hard to build a model describing the factors that influence driving behaviour. In general it can be said that vehicle factors, road geometry, road conditions and speed limits are well documented factors that have an influence of speed choice (Englund et al, 1998, referring to Haglund et al, 1990).

It is not only physical factors like road characteristics that influence drivers speed choice. Drivers' age and experience has an effect on speed choice. Social factors affect drivers speed choice as well. Passengers that are in the vehicle with the driver can have an influence on the speed choice in both directions. They can encourage the driver to drive faster but also to stay inside the speed limit. Studies have shown that it is more likely for a driver to exceed the speed limit if he is driving a new vehicle. The performance and age of the vehicle is also important in drivers speed behaviour. All sorts of helping aid such as anti-break systems and other electronic devices increase speed by giving drivers more confidence then they can live up to (Várhelyi, 1996).

1.2.4. Traffic calming

It has been mentioned that speed plays a central role in traffic safety. To reduce speed especially in residential areas, a number of different measures can be used. One popular term that has been used over these measures is traffic calming but what is traffic calming? There has been a lively debate about the definition of traffic calming and some specialists prefer a narrow approach on the matter while others prefer a wide approach (Brindle, 1996). Institute of Transportation Engineers (ITE) has come up with a definition of traffic calming after a long debate. According to their definition, "traffic calming is the combination of mainly physical measures that reduce the negative effects of motor vehicles use, alter driver behaviour and improve conditions for non-motorized street users" (Ewing, 1999). This is one definition of traffic calming but there are others (Fehr & Peers, 2004):

Canadian Guide to Neighbourhood Traffic Calming:

> "Traffic calming involves altering of motorist behaviour on a street or on a street network. It also includes traffic management, which involves changing traffic routes or flows within a neighbourhood."

Montgomery County, Maryland:

> "Traffic calming consists of operational measures such as enhanced police enforcement, speed displays, and a community speed watch program, as well as such physical measures as edge lines, chokers, chicanes, traffic circles, and (for the past four years) speed humps and raised crosswalks."

The samples above show that there is no specific definition of traffic calming. Keeping the definition wide it is possible so say that traffic calming is a number of different methods and a way of thinking to reduce speed and traffic volume to promote a better interaction between different road users to improve traffic safety (Brindle, 1996).

It is important to realize that traffic calming can be used at different levels and in different scales. There are generally three levels of traffic calming which can simply be called level I-III. Description of traffic calming levels can be seen in figure 1.6. The methods that are used at level 1 mainly focus on decreasing speed and traffic impact on local streets where level of service and capacity are not a concern. The second level of traffic calming affects the streets outside the local residential streets, where level of service and capacity is an issue. The third level of traffic calming is mainly focused on the macro level and the effect on the traffic system in large scale (Brindle, 1996).

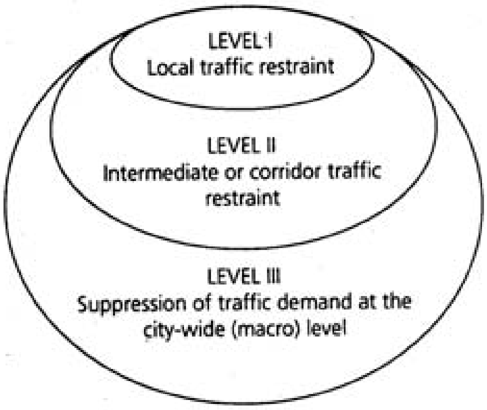


Figure 1.6 Three levels of traffic calming (Brindle, 1996).

1.2.5. Traffic calming measures and their effects

As mentioned above, traffic calming is a term used over a number of different measures. According to (Devon County, 1992) there are two types of measures. On one hand there are measures designed to reduce vehicle speed but on the other hand there are measures that have the purpose of making the street environment more friendly and safe. Table 1.2 provides a list over the most common traffic calming measures.

Table 1.2 Different types of traffic calming measures (Devon County, 1992)

Measures that are mainly aimed to reduce speed	Measures that are focused on improving the street environment and safety
• Vertical shift of the street (road humps, cushions, plateau) • Horizontal shift of the street (with or without islands, chicanes) • Street constrictions • Roundabouts • Small corner radii • Priority management • Road markings • Electronic enforcement	• Optical width • Street narrowing • Occasional strips (to make the street look narrower) • Surface changes –type/colour/location • Entrances and gateways • Central islands • Shared surfaces (Street and sidewalk on the same level) • Footway extensions • Planting/greenery • Street furniture and lightning • Regulations

The effects of traffic calming measures regarding speed and traffic safety varies greatly with type, geometry, location, alternative routs, spacing between measures and many other factors. (Ewing, 1999) has collected hundreds of studies regarding the speed reduction effect of traffic calming measures. Ewing collected information about the average change in 85% speed and then calculated the average percentage change of 85% speed after the introduction of traffic calming measures in residential areas in North America. Ewing's results can be seen in table 1.3. It is obvious from Ewing's results that road humps have a strong influence on speed.

Table 1.3 Speed impacts downstream of traffic calming measures, own reconstruction from (Ewing, 1999).

Speed Impacts of Traffic Calming Measures (standard deviations in parentheses)			
	Sample size	Average change in 85th percentile speed	Average change %
12' Humps	179	-7.6 mph (3.5 mph)	-22 (9%)
14' Humps	15	-7.7 (2.1 mph)	-23 (6)
22' Tables	58	-6.6 (3.2)	-18 (8)
Longer Tables	10	-3.2 (2.4)	-9 (7)
Raised Intersections	3	-0.3 (3.8)	-1 (10)
Narrowing	7	-2.6 (5.5)	-4 (22)
Note: Speeds are measured at midpoints between measures.			

The average speed reduction in the studies that (TØI, 2004) have investigated show that the average speed is reduced from 36,4 to 24,4 km/h, which is about 33% reduction, after introduction of road humps in residential areas. According to (VGU, 2004) and (Webster, 1993) road humps are the most effective way of controlling vehicle speed.

Traffic calming measures are not only judged by their influence on speed but also by their impact on traffic safety. By slowing down the traffic speed, the traffic environment is improved and a better interaction is established between vehicles and vulnerable road users. (Zein, 1997) has studied the safety benefits of traffic calming measure in the Great Vancouver area. The main conclusion from Zeins study was that traffic calming projects reduced collision frequency, severity and annual collision claim cost. The reduction is on the average about 40%. Similar results can be found in Europe. According to British studies, traffic calming techniques are an effective way to reduce collisions and some studies show that collisions can be reduced by 60 - 70%. Traffic calming measures that have been used in Denmark have reduced accidents that resulted in injury in some cases by 60%. Similar results can be found in studies from North America. In 85 studies from Europe, Australia and North America there was a reduction of collision ranging from about 6 percent and up to 100 percent which truly states the safety benefits of traffic calming (Zein, 1997).

It is interesting to see the contribution of specific traffic calming measures to traffic safety. In the Vancouver study (Zein, 1997), information about specific measures was collected and the reduction in collisions directly linked to them. The result from the Zein study can be seen in table 1.4. The specific reduction ability of each measure ranged from 30% and up to 82%. Table 1.4 indicate that traffic circles/roundabouts, chicanes and speed humps are the most effective traffic calming measures when considering collision reduction.

Table 1.4 Average percent reduction in collisions per measure (Zein, 1997)

Measures	Change in collision frequency (%)
Traffic circles	-82
Chicanes	-82
Road humps	-75
Narrowing	-74
Stop signs	-70
Multiple	-65
Refuges	-57
Speed limit reductions	-30

The effect of humps in residential areas is, according to (TØI, 2004), significant. It can be seen from table 1.5 that the experience of humps is quite good and in all cases the number of accidents decreased. According to table 1.5, road humps reduce injury accidents by up to 50%. Road humps also have an effect on the traffic volume. Some studies show that traffic volume decreases up to 25% after installation of humps in residential areas.

Table 1.5 Affect of physical speed measures on accidents. Percent change in number accidents (TØI, 2004)

The seriousness of accident	Type of accident	Best result	Confidence interval
Humps - effect on roads with humps			
person injury	all accidents	-48	(-54; -42)
Humps - effect on surrounding roads			
person injury	all accidents	-6	(-9; -2)
Speed zones (30 km/h) zones in residential area with humps			
Person injury	all accidents	-27	(-30; -24)
Material accidents	all accidents	-16	(-19; -12)

1.2.6. Road humps

As mentioned above, road humps are the most effective traffic calming measure when considering speed reduction and speed control. A road hump works by transferring an upward force to a vehicle, and its occupants, as it crosses the hump. The force produces a front-to-back pitching acceleration in vehicles having a wheelbase similar to the length of the hump that increases as the vehicle travels faster (Weber et al, 1999). Many studies have been conducted to determine a geometrical standard for road humps. (Watts, 1973) conducted an experiment in England to study the design of humps. The purpose of Watts study was to find the best design that would effectively reduce the crossing speeds of most vehicles to a level of about 25 km/h. Watts was trying to find a design that would be comfortable at low speed and not dangerous.

Watts had in mind an ideal hump that would be comfortable at low speed but at a speed of about 20 km/h the discomfort would increase, forcing driver to drive at 25 km/h or less. The effect from an ideal hump is described in the figure 1.7 (Watts, 1973).

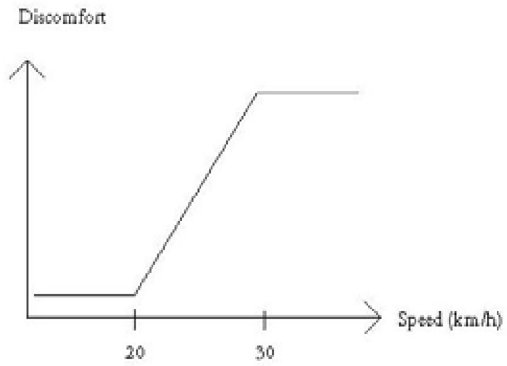


Figure 1.7 The discomfort – speed relation for an ideal hump. Own reconstruction from (Watts, 1973)

To study the relation between discomfort and design of humps, Watts tested fifteen humps. Drivers and passengers were asked to select a hump at random and cross it at various speeds. People recorded how uncomfortable the ride over the hump was on a scale from 0 to 6, 0 being comfortable and 6 very uncomfortable. Maximum vertical acceleration was also measured with special vehicles that crossed the humps. The results from these measurements can be seen in the figure 1.8. Even if the correlation is not that good, it is possible to see a tendency. People describe their discomfort in a correlation with measured vertical acceleration. This means that people are likely to feel more uncomfortable as the peak vertical acceleration increases.

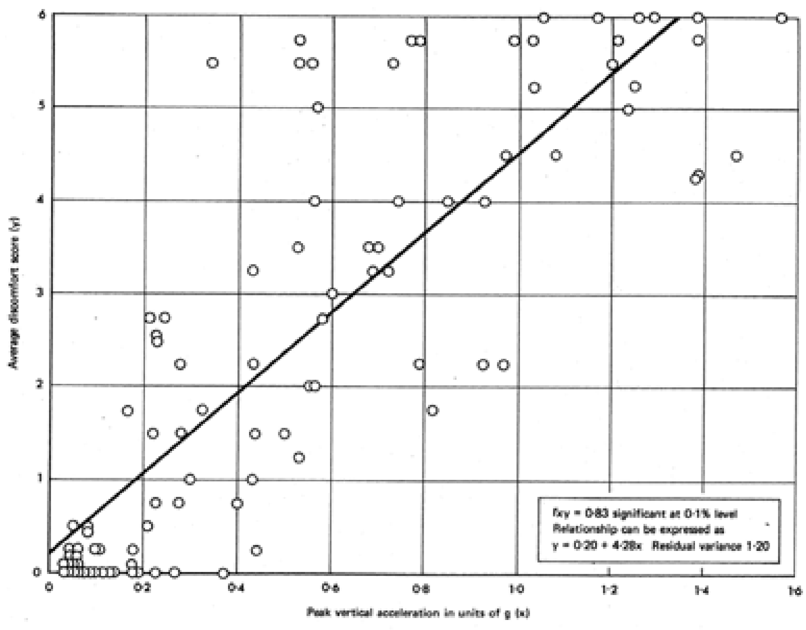


Figure 1.8 Relation between peak acceleration values and average discomfort score for mini clubman estate (Watts, 1973)

Watts used a number of different vehicles to measure both discomfort and vertical acceleration. The study revealed that it was more uncomfortable to cross a hump at low speed in a heavy vehicle then it was in a car or a minibus. This confirmed that heavy vehicles are more sensitive than cars and minibuses to humps. The comparison between different types of vehicles can be seen in the figure 1.9.

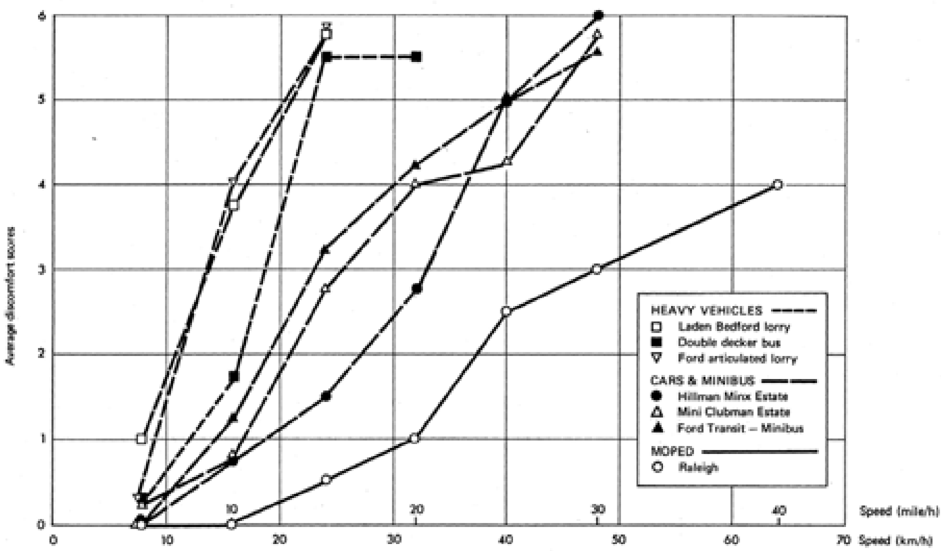
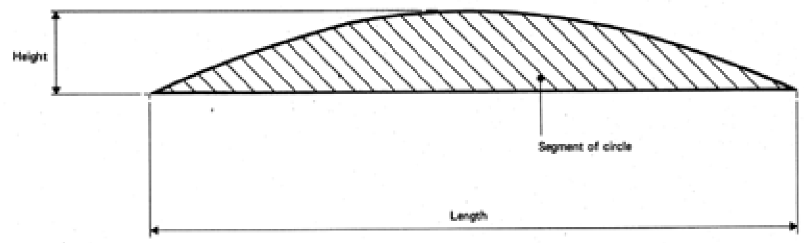


Figure 1.9 Variation of discomfort with speed for vehicles traversing a 12ft x 4in (3,66m x 0,10m) hump (Watts, 1973)

The main conclusion that Watts drew from his research was that a hump 3,66 m long and 0,10 m high produced an uncomfortable ride in most of the vehicles tested at speed higher than 32 km/h. At low speed of 8 km/h all drivers could cross the hump with reasonable comfort. Watts concluded that this kind of hump was able to keep speed below 25 km/h with reasonable comfort and was therefore recommended (Watts, 1973). The profile of this hump can be seen in figure 1.10 and this type of hump has been used all over the world and has become the most popular speed reduction measure used in traffic calming. The result from (Watts, 1973) showed that higher humps were too severe and that low/short humps became less effective as the crossing speed increased.



Length	2in (51mm)	4in (102mm)	6in (152mm)	6in (152mm)	6in (152mm)	2ft (610mm)	4ft (1·22m)	4ft (1·22m)	4ft (1·22m)	8ft (2·44m)	8ft (2·44m)	8ft (2·44m)	12ft (3·66m)	12ft (3·66m)	12ft (3·66m)
Height	0·5 in (13mm)	0·5 in (13mm)	0·75in (19mm)	1·5in (38mm)	3in (76mm)	3in (76mm)	2in (0·05m)	3in (0·08m)	4in (0·10m)	2in (0·05m)	3in (0·08m)	4in (0·10m)	4in (0·10m)	5in (0·13m)	6in (0·15m)

Figure 1.10 Typical cross section and dimension of round top hump (Watts, 1973)

Flat top humps can be used as an alternative to circular profile humps. Flat top humps provide flat crossing places and are often regarded as more environmentally acceptable, particularly by pedestrians. Flat top humps are mainly 5 – 10 cm high and with a minimum length of 3,7 m but with no maximum length. The length of the crown should be more then 2,5 m and 0,6 m long ramps are minimum. The slope of the ramps should be about 1:10 or 1:12 but ramps shallower than 1:20 may not be effective enough (Webster, 1993).

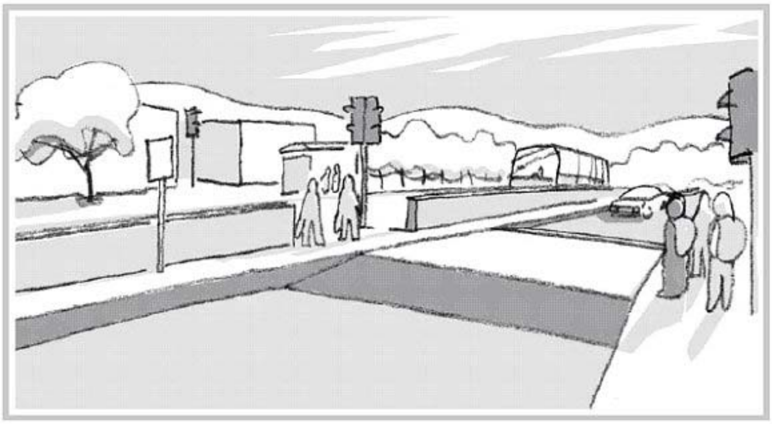


Figure 1.11 Flat top hump (VGU, 2004)

According to (Devon county, 1992), flat top humps should be designed depending mainly on the desired speed. For a given design speed, effectiveness depends on three factors: height of shift, gradient of ramp or profile of slope and distance between measures. Figure 1.12 describes the results from a number of researches that have studied the connection between these three factors and the goal to achieve an 85 percentile traffic speed of 32 km/h. To achieve an 85 percentile speed of 26 km/h more severe shifts are required and maximum distance between measures should be 30 m (Devon county, 1992).

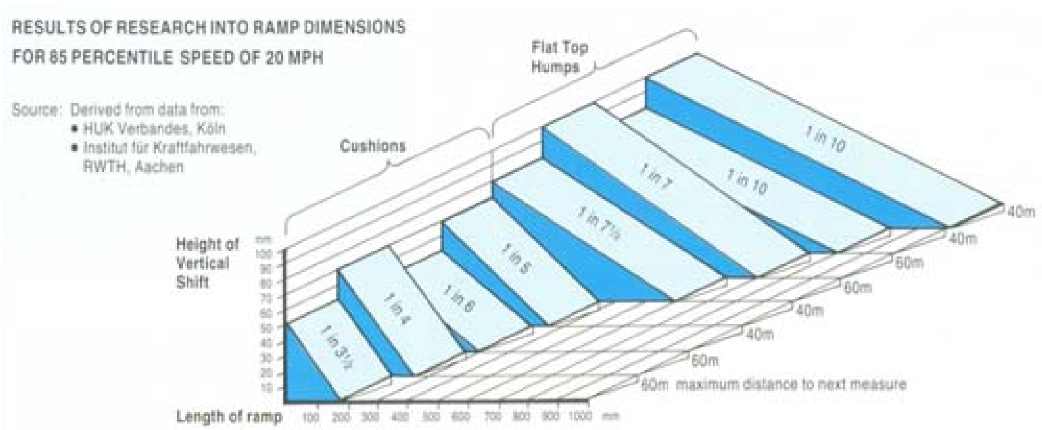


Figure 1.12 Results of research into ramp dimensions for 85 percentile speed of 32 km/h (20 MPH), (Devon county, 1992)

The most common design is the Watts profile or circular hump. Most vehicles can cross them safely at 25 to 30 km/h. These speeds are often considered unrealistically low for many streets in North America that could benefit from traffic calming. (Weber et al, 1999) conducted a study with the purpose of contributing to the development of speed-hump geometric design standards for North America, where vehicle characteristic, environmental conditions and motorist expectations may be different from those in other countries. The main difference between (Watts, 1973) and (Weber et al, 1999) regarding design standards for circular road humps, is that in North American circular road humps are in general longer then European circular road humps.

1.2.7. Peoples opinion about traffic calming

People's opinion about traffic calming measures is important for the development of these measures. Traffic calming measures are installed for the public and it is therefore vital for the effects of traffic calming measures that the public is well informed about the purpose of these measures. In general people are positive towards traffic safety measures. Peoples' approval of speed hump schemes range from 47% to 93%, and is on the average 73%. In general it can be said that round top humps seem to be more popular then flat top humps. It is also interesting that people living in the neighbourhood where the humps are located are more likely to approve them than people that are visiting the area (Webster, 1998). The majority of people think that round top humps are an effective safety measure but even if people think that round top humps are an effective safety measure, most people find them quite uncomfortable. This demonstrates the conflict between the traffic safety aspect of traffic calming measures and the comfort aspect. Since the installation of traffic calming measures is a political one, a decision has to be made often between comfort and traffic safety. In many cases a compromise has to be made between those two factors that often can lead to unsatisfactory results from the traffic calming measure.

It is perhaps not regular drivers that complain the most about traffic calming measures. Buss drivers and rescue personnel are in most cases very negative towards traffic calming measures. It is understandable that it can be rather disturbing for bus drivers to cross hundreds of road humps every day. This additional upward motion can put extra stress on there back and neck. (Steen et al, 2000) conducted a research that studied the effects of traffic calming measures on public transport. The main objective of the project was to give politicians, municipal authorities, public transport principals and others a better insight into the interaction between public transport and traffic calming measures. The final conclusion of the study was that if a good driving comfort for bus drivers is the main objective, then road humps should be designed considering the characteristics of buses (Steen et al, 2000). Different designs have been used to make road humps more comfortable, especially for buses. Speed cushions are on type of design that has become more and more popular to use on streets that are involved in the bus net.

Rescue personnel are in general negative towards traffic calming measures. It is their understanding that road humps increase travel time and therefore the response time for fire-rescue units. According to (Ewing, 1999) each second is important for ambulances and fire fighting vehicles and traffic calming measures take away vital seconds that could have been used in saving peoples lives. Several studies have been conducted to estimate the delay of response time that traffic calming measures produce. Table 1.6 shows results from a study that was conducted in several communities in North America. Multiple runs were made with multiple vehicles driven by multiple drivers to estimate average travel times with traffic calming measures in place. Results from these studies were then compared with travel times on untreated streets to obtain delay estimates.

Table 1.6 Emergency response time study results (Ewing, 1999)

Community	Measure	Delay at Slow Point (seconds)
Austin, TX	12-foot speed humps	2.8 (fire engine)
		3.0 (ladder truck)
		2.3 (ambulance without patient)
		9.7 (ambulance with patient)
Berkeley, CA	12-foot speed humps	10.7 (fire engine)
		9.2 (ladder truck)
	22-foot speed tables	3.0 (fire engine)
		13.5 (ladder truck)
Boulder, CO	8-foot speed hump	4.7 (fire engine)
	12-foot speed hump	2.8 (fire engine)
	37-foot speed table (6-inch rise)	3.8 (fire engine)
	40-foot speed table (6-inch rise)	3.8 (fire engine)
	25-foot-diameter traffic circle	7.5 (fire engine)
Sarasota, FL	12-foot humps	9.5 (ambulance)

Table 1.6 reveals that regardless of the traffic calming measure or fire rescue vehicle, the delay per measure is nearly always less than 10 seconds. That does not seem to be much but if there are several measures along an emergency response route this delay time can add up. It is therefore understandable that fire and rescue units are negative towards traffic calming measures. It is obvious that traffic calming measures can increase response time and therefore waste valuable seconds that could have been used in saving people. Many strategies have been used to address fire-rescue concerns about traffic calming. In many cases it has been avoided to install traffic calming measures on emergency response routs. Instead of road humps, alternative traffic calming measures like narrowing or chicanes have been installed. Road humps have also been redesigned to make them more suitable for fire-rescue vehicles (Ewing, 1999). Even if traffic calming measures can in some cases increase response time, it is worth mentioning that traffic calming measures have prevented many accidents to happen and therefore saved valuable time for fire and rescue units.

1.3. Location of study

To study the connection between physical identities, vertical acceleration and crossing speed, 18 different road humps were selected. When selecting road humps their location on the street was most important. Road humps that were located in the middle of a segment were preferred. It was important that speed was undisturbed from intersections so that the drivers could choose their own speed without being affected by intersections. The road humps are all located in Lund, Sweden, and were chosen after consulting with Lund community (David Edman, 2004). The studied road humps consist of 14 flat top humps and 4 round top humps. The location of the road humps can be seen in figure 1.13.

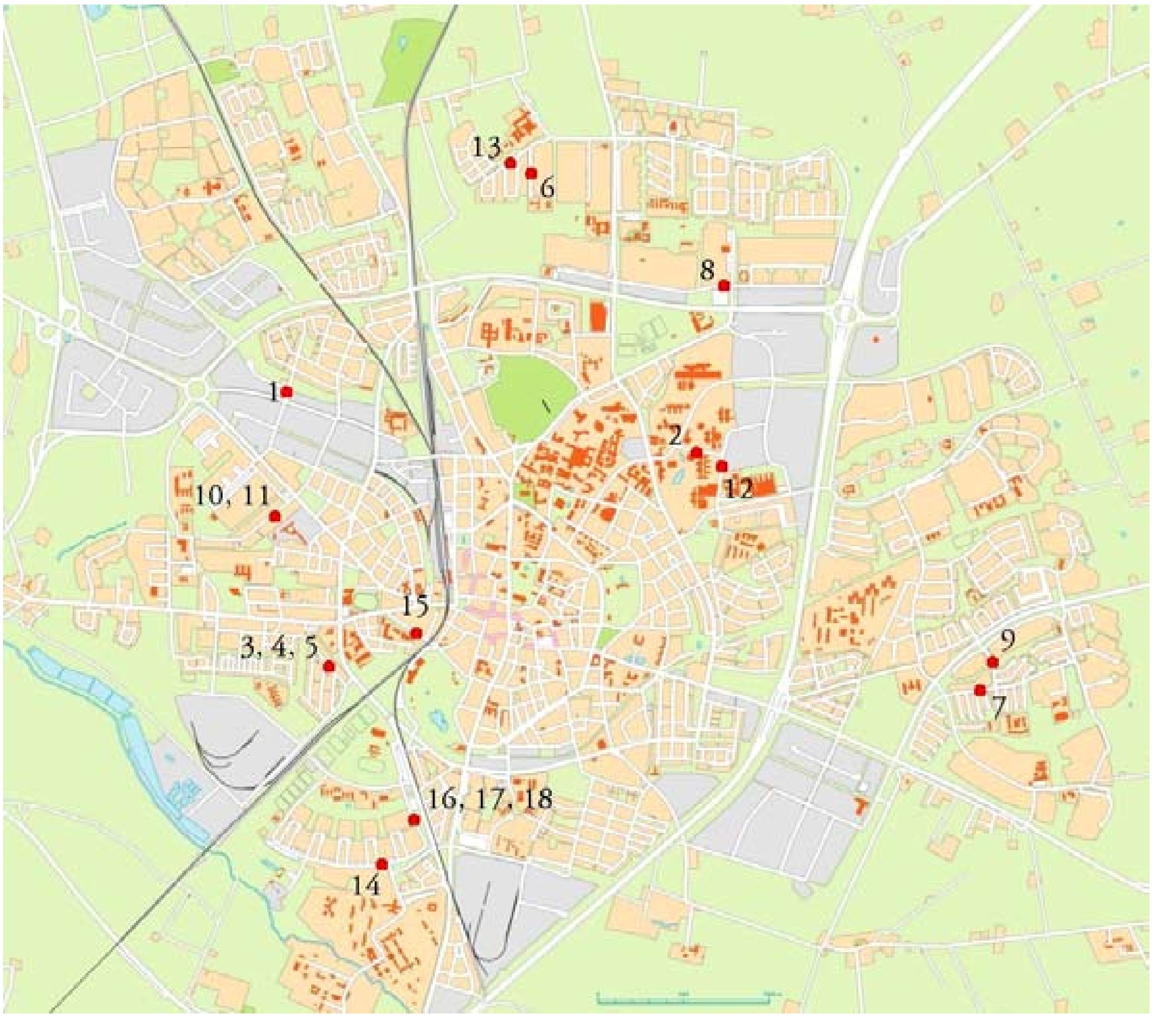


Figure 1.13 Location of studied road humps in Lund

The road humps that were studied are located on following streets:

- Bondevägen, flat top hump (road hump nr. 1)
- John Ericssons väg, flat top hump (road hump nr. 2)
- Kakelvägen, two flat top humps and one round top hump (road hump nr. 3, 4, 5)
- Kulgränden, round top hump (road hump nr. 6)
- Linerovägen, flat top hump (road hump nr. 7)
- Magistratsvägen, flat top hump (road hump nr. 8)
- Melins väg, flat top hump (road hump nr. 9)
- Måsvägen, two round top humps (road hump nr. 10, 11)
- Ole Römers väg, flat top hump (road hump nr. 12)
- Skjutbanevägen, flat top hump (road hump nr. 13)
- Sunnanväg, flat top hump (road hump nr. 14)
- Svanevägen, flat top hump (road hump nr. 15)
- Östanväg, three flat top hump (road hump nr. 16, 17, 18)

To have a better understanding of the traffic situation and the environment, a short description is given of each studied road hump in appendix 1 along with information about measured physical identities. A drawing of each road hump can be seen in appendix 2.

2. Methods and material

To study the connection between vertical acceleration, speed reduction and physical identities, three types of measurements were conducted. To measure vertical acceleration a specially instrumented vehicle was used, speed was measured with regular radar gun and physical identities were measured with a precision measuring instrument.

2.1. Instrumented vehicle

Vertical acceleration was measured with a special vehicle that is equipped with acceleration sensors. This vehicle is an average personal vehicle, a Toyota Corolla, with wheel base of 2,46 meters and with tyres 175/65 R 14. The acceleration is measured by a three axis sensor situated in the bottom of the storage locker between the front seats. The sensors produce a voltage signal proportional to the linear accelerations along X, Y an Z axis of the Cartesian coordinates. A computer that is situated in the trunk of the vehicle registers in a file the speed, distance travelled and acceleration. This file is easily accessed and can be worked with in computer programs like Excel. The frequency of this registering was set to 200 Hz. This was done to get as much data as possible. The vehicle is also equipped with video camera that is situated behind the grill in the front of the vehicle. This camera allows for the measurements to be recorded and then later to be looked at. This recording makes it easier to identify the data from the measurement.

The instrumented vehicle was driven over each road hump at a speed ranging from 15 km/h to about 60 km/h. It was not always possible to drive the vehicle at a speed about 60 km/h due to the specific street environment and the danger that it could cause to others. The vehicle crossed each road hump between 20-25 times for each direction. In figure 2.1, a result from a typical vertical acceleration measurement can be seen. The vertical acceleration is on the vertical axis while the distance travelled in the vehicle is on the horizontal axis. The vehicle enters the road hump at 1921 m and drives off the road hump after about 1930 m. The vertical acceleration moves from being negative to being positive all according to the vehicles position on the road hump. When the vehicle has passed the road humps the vertical acceleration slowly comes to rest and move towards zero.

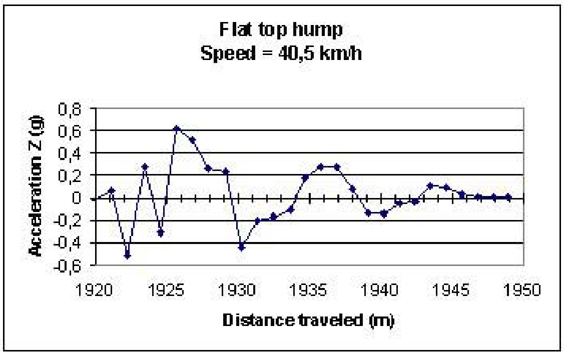


Figure 2.1 Typical result from an vertical acceleration measurement

For each crossing of the road hump an absolute maximum vertical acceleration value can be found. When crossing a road hump, the speed is not constant. It is therefore necessary to calculate an average speed for each crossing. The absolute maximum vertical acceleration and average speed was found for each crossing and direction. If these data pairs are then plotted in a graph, a basic characteristic of each road hump is exposed. This graph describes how the vertical acceleration changes for each road hump according to a certain crossing speed. Figure 2.2 describes a typical vertical acceleration and crossing speed relationship for a flat top hump. It can be seen from figure 2.2 that as the crossing speed increases the vertical acceleration also increases. It can also be seen that the vertical acceleration increases more rapidly after 30 km/h. This describes the basic thought behind road humps; it should be more uncomfortable to cross a road hump with increased speed. Vertical acceleration and crossing speed graphs will be given for each road hump in the results chapter.

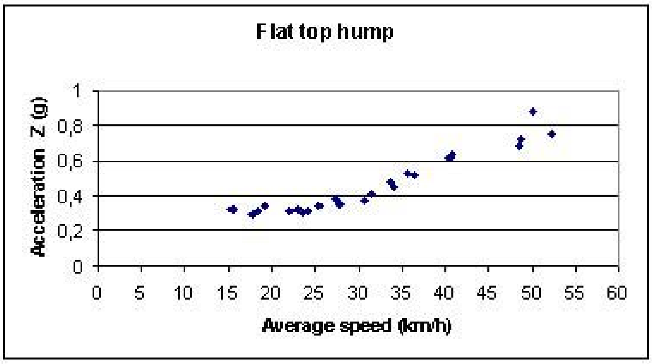


Figure 2.2 Typical connection between vertical acceleration and crossing speed for a flat top hump

2.2. Speed measurements

The vehicle speed was measured around each road hump. The speed was measured with a traditional radar gun like the one in figure 2.3. Only free vehicles were measured. This was done to get the speed that drivers would choose on there own, without any disturbance from other drivers. According to (Jonsson, 2000) a free vehicle is a vehicle that is not in queue with other vehicles. The definition of free vehicle is that the distance between two vehicles is more than 3 seconds. Accidents are normally caused by free vehicles because if the distance between two vehicles is less than 3 seconds a pedestrian, that is about to cross the street, is not likely to use this gap to cross the street. The best way of measuring free vehicles is to measure speed out side of rush hour. The time of day does not matter when considering speed measurements because the variance of speed is not that high during the day in Lund (Jonsson, 2000).

Figure 2.3 Radar gun used for speed measurements

The vehicle speed was measured about 50 – 60 meters away from each road hump and then again when vehicles were crossing the road humps. This means that four spots around each road hump were measured, two spots for each direction. The speed measurements were conducted in a way so that drivers would not realize that they were being measured. This means that the person that was conducting the speed measurements had to keep a low profile. At least 20 vehicles had to be measured at each point so it would be possible to calculate confidence intervals. Since the speed measurements were conducted outside of rush hour the traffic was not always so high. On some streets the traffic was so low that the necessary amount of vehicles was only nearly achieved. On other streets the traffic was so high that the requirement was not a problem.

A special program called speed-boot was used to analyse the speed measurements. Speed-boot has been developed by the department of traffic technology at Lund's Institute of Technology. Speed-boot calculates accumulated speed curves and also confidence intervals for each spot. The confidence interval gives the idea of how accurate the speed measurements are. If the number of observations is small then the confidence interval will be large. Speed-boot presents information about the average speed along with the 85% speed. The 85% speed is in many cases more interesting than the average speed. 15% of the vehicles drive faster then the 85% speed and are therefore the most dangerous ones for other road users. An example of a result from speed-boot can be seen in the following figure 2.4. In figure 2.4 the accumulated speed, in wide line, is presented along with the confidence intervals. This kind of presentation directly gives an idea of the variance of speed at each spot. If the slope of the lines is steep then the variance of speed in that spot is small. If the slope of the lines is flat then the variance is large. The results from the speed measurements for each road hump can be seen in appendix 3.

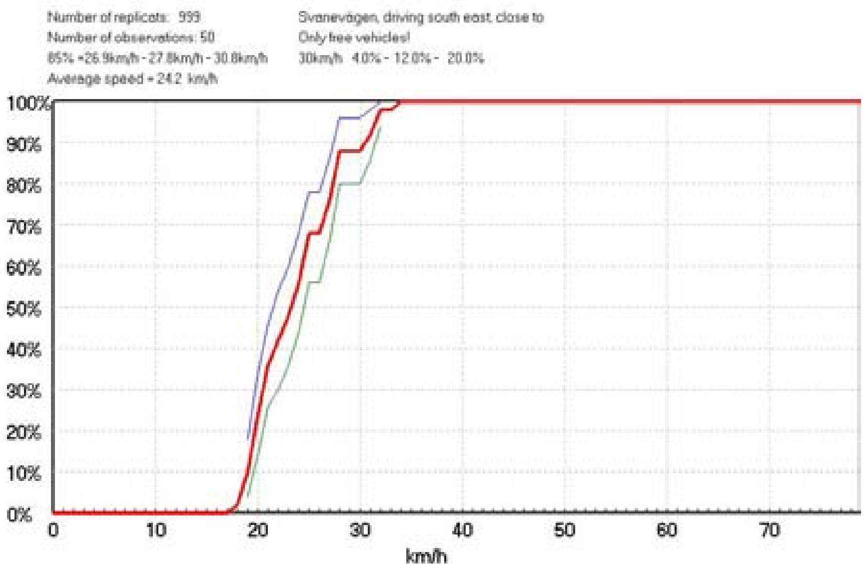


Figure 2.4 Presentation of speed measurements using Speedboot

2.3. Physical measurements

Each road hump was measured with a total station. Each road hump was measured in a way that would represent the profile as well as possible. To determine the physical identity of each road hump a line was drawn through the profile that represented the right wheels of a vehicle. The physical identities were then measured according to this line. The following physical identities were measured:

Figure 2.5 Total station similar to the one that was used

- Total length
- Length of crown for flat top humps
- Length of first ramp
- Height difference from the street and up to the road hump
- Length of the second ramp
- Height difference from the top of the road hump and down to the street
- Change in directions 1-4 for the profile
- Street width

To better explain what is meant by physical identities the following figures have been drawn. Each physical identity is shown in figure 2.6 – 2.9.

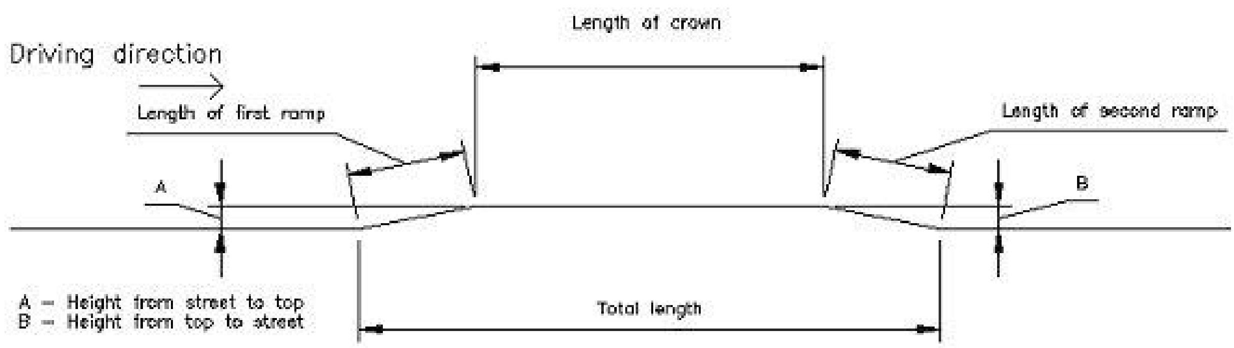


Figure 2.6 Definition of physical identities for a flat top hump

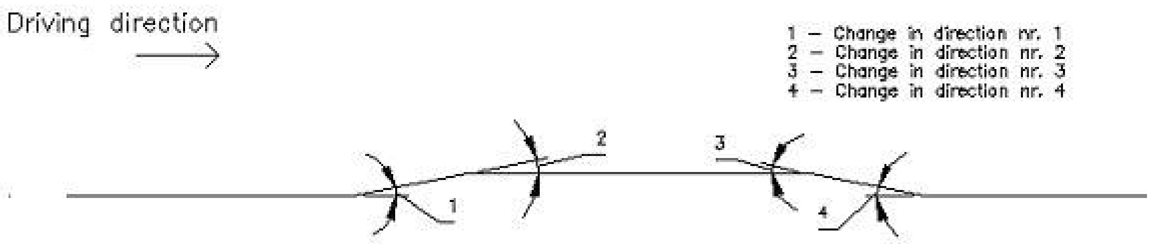


Figure 2.7 Definition of physical identities for a flat top hump

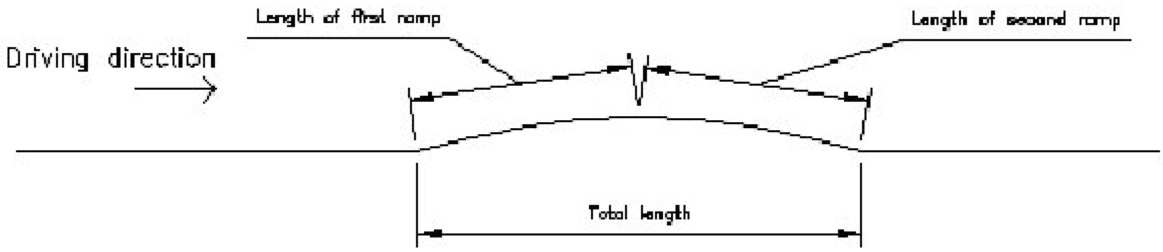


Figure 2.8 Definition of physical identities for a round top hump

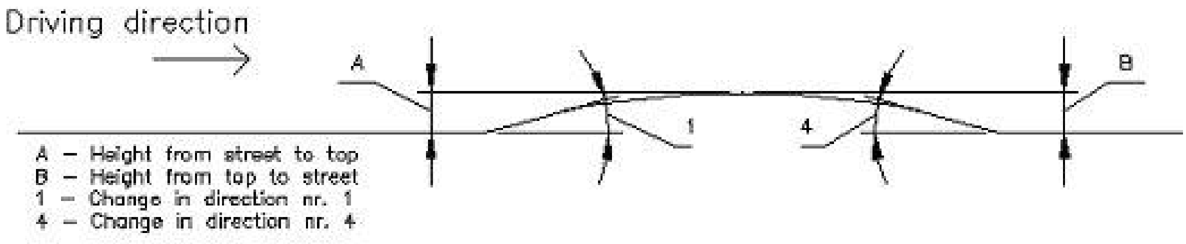


Figure 2.9 Definition of physical identities for a round top hump

2.4. Analyzing the material

2.4.1. Describing the vertical acceleration and crossing speed relationship

When looking at the vertical acceleration and crossing speed connection it is obvious that this connection is unique for each road hump. For some road humps the vertical acceleration increases very slowly while for others the vertical acceleration increases very fast as speed increases. After consulting with (Karin Brundell-Freij, 2004), it was decided that the best way to describe the connection between vertical acceleration and crossing speed would be to use a linear regression line. Since the wanted speed after installation of road humps is lower than 30 km/h the plot was divided there. A linear regression line was then used on the data before and after 30 km/h, as can be seen in figure 2.10. The equation for the linear regression line after 30 km/h, $y = K_1x - K_0$, was used to describe the characteristics of each road hump. The parameter K_1 is the slope of the regression line and describes how fast the vertical acceleration increases as speed increases. K_1 can therefore be used as a description of character of each road hump. The values for the linear regression line for each road hump can be seen in appendix 4.

Figure 2.10 Vertical acceleration and speed diagram divided by the 30 km/h line

2.4.2. Dividing road humps into groups

After consulting with (Karin Brundell-Freij, 2004) it was decided to divide the road humps into groups according to their physical identities. Since there were so few round top humps and they all have similar identities they were all put into the same group. The flat top humps were divided into 4 groups according to the total length and change in direction nr. 1. Flat top humps that are shorter than 10 m were put in one group while flat top humps that were longer than 10 m were put in another group. The reason for this is that if flat top humps are shorter than 10 m then both ramps have an affect on the vertical acceleration. If flat top humps are much longer than that, then the first ramp will not have any effect on the vertical acceleration when the vehicle is going down the second ramp. This can be seen in following figures 2.11 and 2.12. From figure 2.11 it is possible to see that the vertical acceleration is working over the total length of the flat top humps. The wide horizontal line represents the length of the road hump.

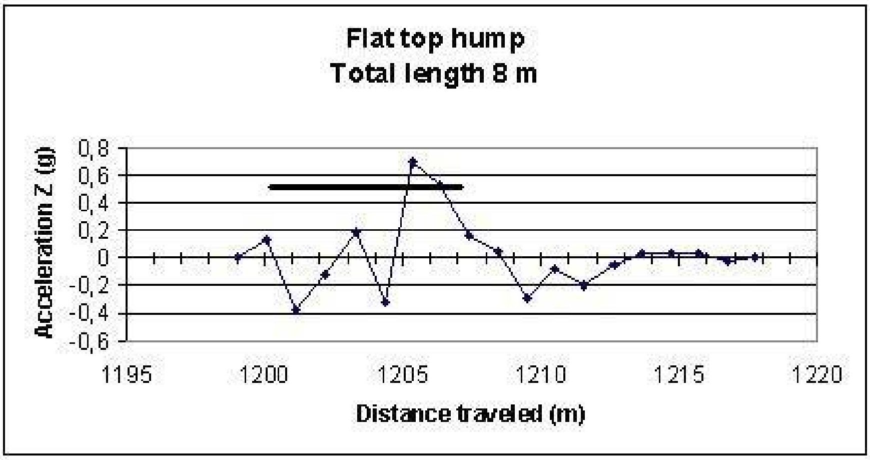


Figure 2.11 Vertical acceleration over 8 m long flat top hump

When the flat top hump is longer, the vertical acceleration that is produced by the first ramp slowly comes to rest before the vehicle drives off the second ramp. This can be seen in figure 2.12. The ramps can be seen as individual sources of vertical acceleration when flat top humps are very long but when they are short, both the ramps work together to produce the vertical acceleration.

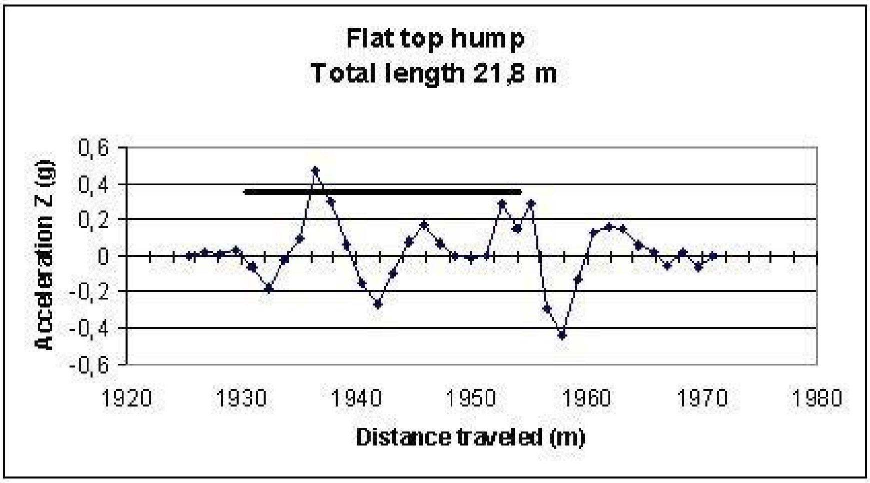


Figure 2.12 Vertical acceleration over 21 m long flat top hump

The second criteria for dividing the flat top humps into groups, was the change in direction nr. 1. If the first angle is lower than 4,5° the ramps were considered gentle and therefore comfortable. After using the criteria on the road humps 5 different groups were created.

The groups were as follows:

- Round top humps
- Flat top humps, group nr.1 (steep and short)

- Flat top humps, group nr. 2 (steep and long)
- Flat top humps, group nr. 3 (gentle and short)
- Flat top humps, group nr. 4 (gentle and long)

Round top humps are the first group and the round top humps that belong to this group are located in:

- Kakelvägen nr. 3
- Kulgränden
- Måsvägen nr. 1 and 2

The remaining road humps are all flat top humps and were divided into four groups. Table 2.1 below provides information about the groups and belonging streets. Each group contains 6 – 8 flat top humps.

Table 2.1 Flat top humps, groups

	Short < ~ 10 m		Long > ~ 10 m	
Steep, first ramp > 4,5°	Linerovägen	Driving east	John Ericssons väg	Driving east
	Linerovägen	Driving west	Skjutbanevägen	Driving north-east
	Melinsväg	Drivingn north	Östanväg nr. 1	Driving south
	Melinsväg	Driving south	Östanväg nr. 1	Driving north
	Sunnanväg	Driving east	Östanväg nr. 2	Driving south
	Svanevägen	Driving south-east	Östanväg nr. 2	Driving north
			Östanväg nr. 3	Driving south
	(1)		Östanväg nr. 3	(2) Driving north
Gentle, first ramp < 4,5°		(3)		(4)
	Bondevägen	Driving south	John Ericssons väg	Driving west
	Bondevägen	Driving north	Magistratsvägen	Driving east
	Kakelvägen nr. 1	Driving north-west	Magistratsvägen	Driving west
	Kakelvägen nr. 1	Driving south-east	Ole Römers väg	Driving south
	Kakelvägen nr. 2	Driving north-west	Ole Römers väg	Driving north
	Kakelvägen nr. 2	Driving south-east	Skjutbanevägen	Drivign south-west
	Sunnanväg	Driving west		
	Svanevägen	Driving north-west		

2.4.3. Testing the equality of means of two normal populations, t-test

To test if the average value of two measurements are statistically equal or not, a t-test can be used. After consulting with (Karin Brundell-Freij, 2004) the following method described by Sheldon was used to conduct the t-test (Sheldon, 1987, page 225):

> Let us now suppose that the population variances σ_x^2 and σ_y^2 are not only unknown but also cannot be considered to be equal. In this situation, since S_x^2 is the natural estimator of σ_x^2 and S_y^2 of σ_y^2, it would seem reasonable to base our test of
>
> $$H_0: \mu_x = \mu_y \text{ versus } H_1: \mu_x \neq \mu_y$$
>
> On the test statistic
>
> $$\frac{\overline{X} - \overline{Y}}{\sqrt{\frac{S_x^2}{n} + \frac{S_y^2}{m}}}$$
>
> For in this case, it can be shown that when H_0 is true, the equation above will have approximately a unit normal distribution. Hence, when n and m are large an approximate level α test of $H_0: \mu_x = \mu_y$ versus $H_1: \mu_x \neq \mu_y$ is to
>
> Accept H_0 if $-z_{\alpha/2} < \frac{\overline{X} - \overline{Y}}{\sqrt{\frac{S_x^2}{n} + \frac{S_y^2}{m}}} < z_{\alpha/2}$
>
> Reject otherwise

A significance level α = 0,1 was used that means that if the calculated value was larger than 1,8 it was possible to say with a significance level of 10% that the average value of one measurement is not equal to the average value of another measurement. The probability for t-random variables can be seen in appendix 5.

2.4.4. Statistical inferences about the regression parameters

When considering if there is a connection between two factors a diagram can be drawn with each factor on one axel. A linear regression analyses can then be used to draw a line between the data pairs that these two factors produce. It can be difficult to see from this diagram if the linear regression line is tilting or not. A statistical test can be used to see if the slope of the regression line is zero. If the slope is close to zero, it is safe to say that there is no statistical connection between those two factors. This can depend on a number of things. One thing can be that there is just not a connection between those two factors. Another reason can be that the number of samples is just so low that it can not, statistically, be proven that there is a connection between those two factors. The slope of the linear regression line was tested with a method that is described in (Sheldon, 1987, page 255):

> An important hypothesis to consider regarding the simple linear regression model
>
> $$Y = \alpha + \beta x + e$$
>
> is the hypothesis that β = 0. Its importance derives from fact that it is equivalent to stating that the mean response does not depend on the input, or equivalently, that there is no regression on the input variable. To test
>
> H_0: β = 0 against H_1: β ≠ 0.
>
> A significance level γ test of H_0 is to
>
> Reject H_0 if $\sqrt{\frac{(n-2)S_{xx}}{SS_R}}|B| > t_{\gamma/2,n-2}$
>
> Accept H_0 otherwise
>
> Were
>
> $$S_{xY} = \sum_{i=1}^{n} x_i Y_i - n\overline{x}\overline{Y}$$
>
> $$S_{xx} = \sum_{i=1}^{n} x_i^2 - n\overline{Y}^2$$
>
> $$S_{YY} = \sum_{i=1}^{n} Y_i^2 - n\overline{Y}^2$$
>
> $$B = \frac{S_{xY}}{S_{xx}}$$
>
> $$A = \overline{Y} - B\overline{x}$$
>
> $$SS_R = \frac{S_{xx}S_{YY} - (S_{xY})^2}{S_{xx}}$$

A significance level of γ = 0,1 was used. The criteria for rejecting H_0 can be seen in appendix 5. Depending on the size of each group, the calculated value had to be larger then 1,94 or 2,13. If the calculated value was larger, H_0 was rejected and it could be said that the response depends on the input.

3. Results

3.1. Vertical acceleration and crossing speed

By drawing a graph with vertical acceleration on one axis and average crossing speed of the instrumented vehicle on the other, basic information about the characteristic of each road hump can be provided. Vertical acceleration and average crossing speed diagrams are presented below for each road hump along with results from the speed measurements. A vertical line is drawn in the graphs that represent the measured 85% crossing speed. It is interesting to see where the measured 85% crossing speed lies related to the connection between vertical acceleration and average crossing speed. Detailed information regarding the speed measurements for each road hump can be seen in appendix 3.

3.1.1. Bondevägen (road hump nr. 1)

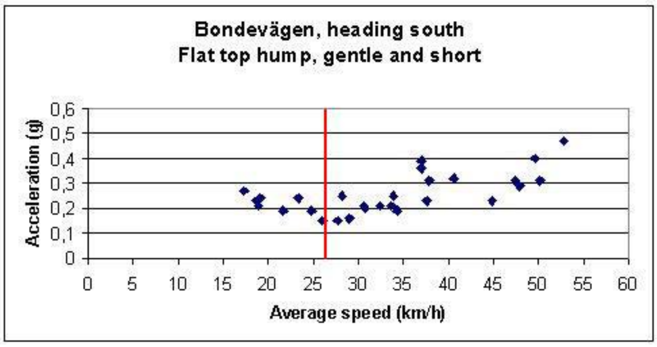


Figure 3.1 Vertical acceleration and crossing speed diagram for Bondevägen, heading south

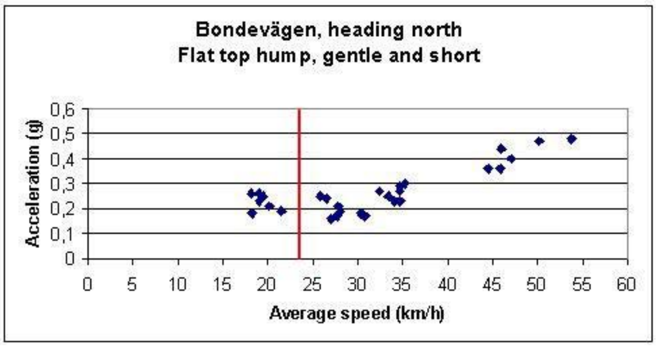


Figure 3.2 Vertical acceleration and crossing speed diagram for Bondevägen, heading north

When heading south the vertical acceleration seams to decrease a little bit from 15 - 25 km/h. After 30 km/h the vertical acceleration increases as speed increases. The acceleration value under 30 km/h is about 0,20 g but the maximum value is just under 0,50 g at a speed about 53 km/h.

When heading north on Bondevägen the vertical acceleration and crossing speed connection is quite flat until reaching the 30 km/h point. After that the vertical acceleration increases as speed increases. The basic value of vertical acceleration below 30 km/h is about 0,20 - 0,25 g which is pretty gentle. At about 50 – 55 km/h the vertical acceleration is at 0,5 g which is the maximum value.

The results from the speed measurements can be seen in table 3.1. The average speed along with the variance and 85% speed are similar close to the flat top hump for both directions. There is a difference between the speeds away from the flat top hump and when driving north the speed is higher before the flat top hump. The variance of speed before the flat top hump is also higher when driving north.

Table 3.1 Speed measurements for Bondevägen

Bondevägen		Average speed [km/h]	Variance ([km/h])^2	85% speed [km/h]
Close to measure	Driving south	21,6	23,7	26,9
	Driving north	20,6	28,7	23,8
~ 50 m before measure	Driving south	30,4	13,7	33,4
	Driving north	38,3	67,8	48,0

3.1.2. John Ericssons väg (road hump nr. 2)

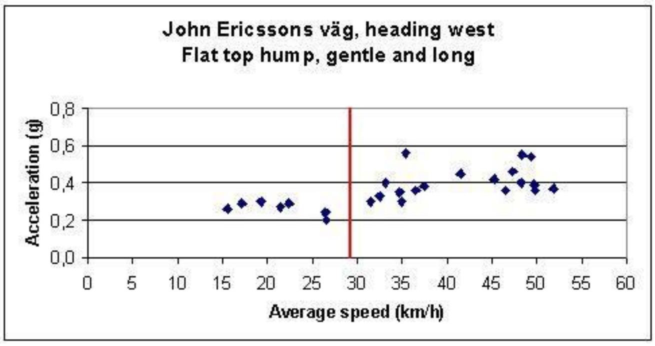


Figure 3.3 Vertical acceleration and crossing speed diagram for John Ericssons väg, heading west

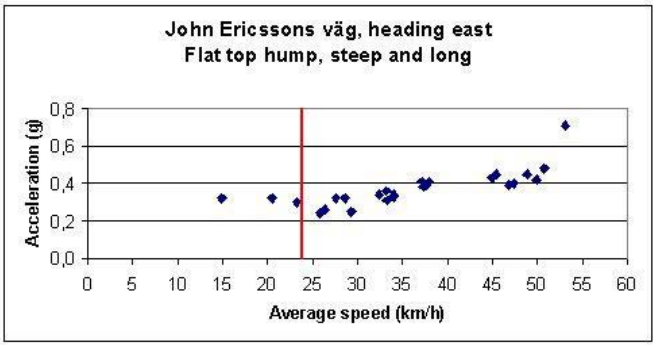


Figure 3.4 Vertical acceleration and crossing speed diagram for John Ericssons väg, heading east

When heading west the vertical acceleration diagram is quite flat but there is a tendency for increased vertical acceleration as speed increases. It is hard to say that there is a breakpoint in the diagram, where the vertical acceleration starts to increase rapidly. The basic value of vertical acceleration under 30 km/h is just under 0,30 g. Then the vertical acceleration slowly rises and is between 0,40 – 0,55 g at a speed of 50 km/h

When heading east the vertical acceleration is steady around 0,30 g up till 30 km/h when it increases rapidly as speed increases. The maximum value is between 0,40 – 0,50 g but there is one measurement that shows vertical acceleration value of over 0,70 g at a speed just under 55 km/h. The reason for this is unknown but it is possible that the vehicle had not been driven in the same tracks for all of the measurements. This could lead to this unusual value.

The speed measurements for John Ericssons väg are presented in table 3.2. From table 3.2 it can be seen that when drivers are going west they have a tendency of driving a little bit faster then when they are driving east. The variance of speed close to the flat top hump is rather high for both directions.

Table 3.2 Speed measurements for John Ericssons väg

John Ericssons väg		Average speed [km/h]	Variance ([km/h])²	85% speed [km/h]
Close to measure	Driving west	23,8	48,6	28,9
	Driving east	20,5	32,2	23,8
~ 50 m before measure	Driving west	37,5	47,8	45,9
	Driving east	36,6	37,3	43,5

3.1.3. Kakelvägen (road humps nr. 3, 4, 5)

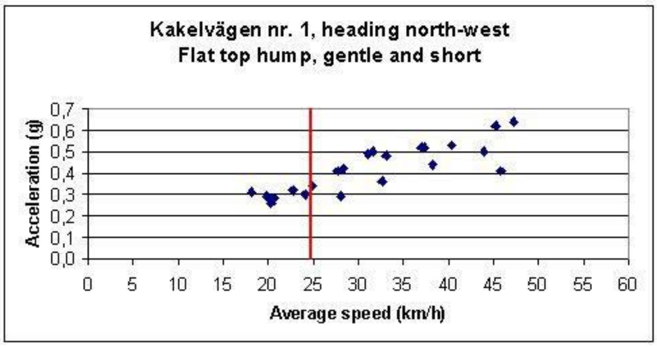


Figure 3.5 Vertical acceleration and crossing speed diagram for Kakelvägen nr.1, heading north-west

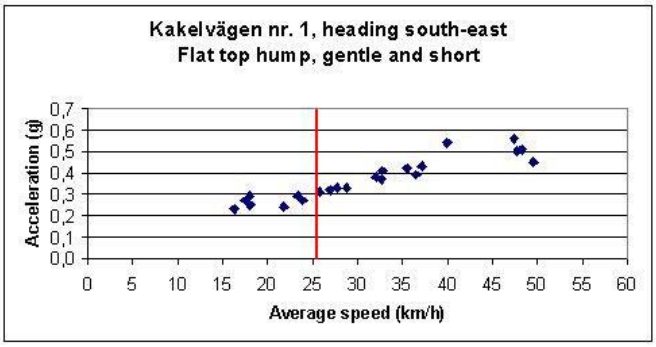


Figure 3.6 Vertical acceleration and crossing speed diagram for Kakelvägen nr.1, heading south-east

When heading north-west the vertical acceleration increases rapidly with increased speed for flat top hump nr. 1 at Kakelvägen. The vertical acceleration is about 0,30 g at speed 20 km/h but then it increases up to a value of over 0,60 g when the speed is about 47 km/h.

When heading south-east the vertical acceleration is in general lower then when driving in the other direction. The vertical acceleration is about 0,25 g at speed about 17 km/h but then increases to a value around 0,50 when the speed is 50 km/h.

The results from the speed measurements are presented in table 3.3 below. In general it can be said that the speed close to the flat top hump is similar for both directions. There is a difference between driving directions when comparing the speed before the flat top hump. The speed is higher when driving south-east.

Table 3.3 Speed measurements for Kakelvägen nr. 1

Kakelvägen nr. 1		Average speed [km/h]	Variance ([km/h])^2	85% speed [km/h]
Close to measure	Driving north-west	20,1	27,6	24,5
	Driving south-east	21,5	30,5	25,5
~ 50 m before measure	Driving north-west	26,2	39,9	33,7
	Driving south-east	32,9	39,3	39,4

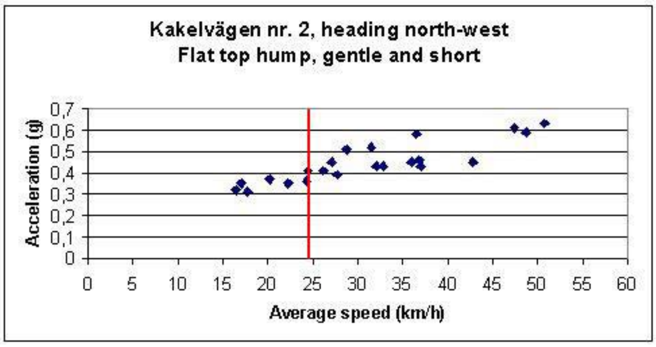


Figure 3.7 Vertical acceleration and crossing speed diagram for Kakelvägen nr.2, heading north-west

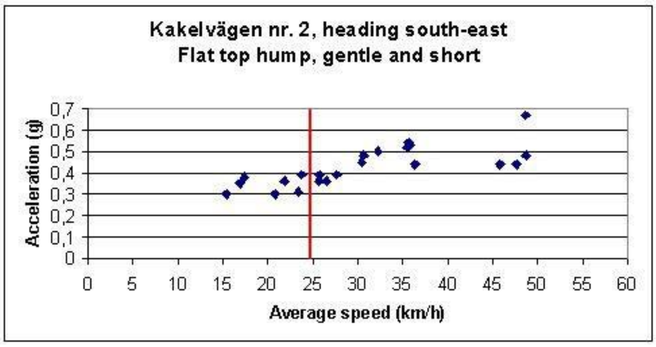


Figure 3.8 Vertical acceleration and crossing speed diagram for Kakelvägen nr.2, heading south-east

When driving north-west the vertical acceleration, for flat top hump nr. 2 at Kakelvägen, starts at a value just over 0,30 g when the speed is about 16 km/h. After that the vertical acceleration increases rapidly to a value that is about 0,65 g when the speed is just over 50 km/h. There is a variance in the measurements, especially for speed from 30 – 45 km/h but in general the tendency of the vertical acceleration is clear.

In general it can be said that when driving south-east it is similar to driving north-west. However there is variance in the measurements especially at speed around 50 km/h. At this speed three measurements show a value just under 0,50 g but one measurement shows a value of nearly 0,70 g. If this one measurement is disregarded then the vertical acceleration is slightly decreasing from a speed about 35 km/h to a speed about 47 km/h.

The speed measurements for Kakelvägen nr. 2 are presented in table 3.4 below. The speed close to the flat top hump is in general similar for both driving directions. The same statement is true for the speed before the flat top hump. The only real difference is in the 85% speed before the flat top hump and then the speed is higher when driving north-west.

Table 3.4 Speed measurement for Kakelvägen nr. 2

Kakelvägen nr. 2		Average speed [km/h]	Variance ([km/h])^2	85% speed [km/h]
Close to measure	Driving north-west	22,6	33,6	24,7
	Driving south-east	21,7	19,0	24,9
~ 50 m before measure	Driving north-west	32,4	46,3	39,3
	Driving south-east	33,7	28,2	33,7

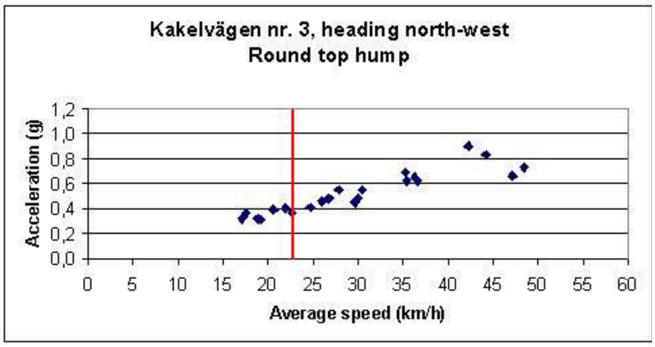


Figure 3.9 Vertical acceleration and crossing speed diagram for Kakelvägen nr.3, heading north-west

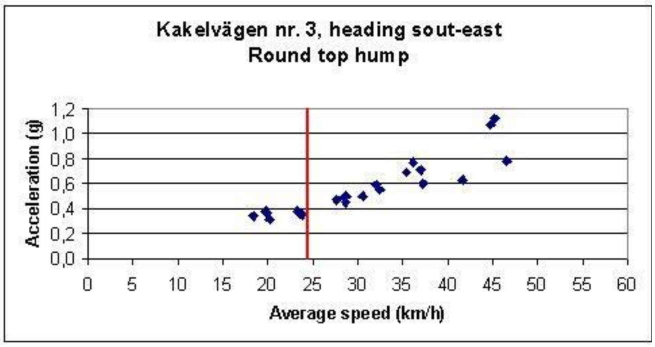


Figure 3.10 Vertical acceleration and crossing speed diagram for Kakelvägen nr.3, heading south-east

When driving north-west over hump nr. 3 at Kakelvägen, the vertical acceleration increases very rapidly with speed. The vertical acceleration starts at a value about 0,30 g when the speed is 17 km/h but then increases to a value around 0,90 g when the speed is about 0,45 km/h. There is a variance in the measurements at high speed but it is fair to say that the maximum value is about 0,90 g.

When driving south-east the driving experience is similar to driving north-west. The only difference is that the maximum value of the vertical acceleration is 1,1 g at speed 45 km/h when driving south-east.

In table 3.5 below, the results from the speed measurements are presented. The speed close to the hump is similar for both driving directions but the speed before is higher when driving north-west.

Table 3.5 Speed measurements for Kakelvägen nr. 3

Kakelvägen nr. 3		Average speed [km/h]	Variance ([km/h])^2	85% speed [km/h]
Close to measure	Driving north-west	19,3	15,0	22,9
	Driving south-east	19,7	22,6	24,5
~ 50 m before measure	Driving north-west	35,5	48,2	35,5
	Driving south-east	28,3	12,7	28,3

3.1.4. Kulgränden (road hump nr. 6)

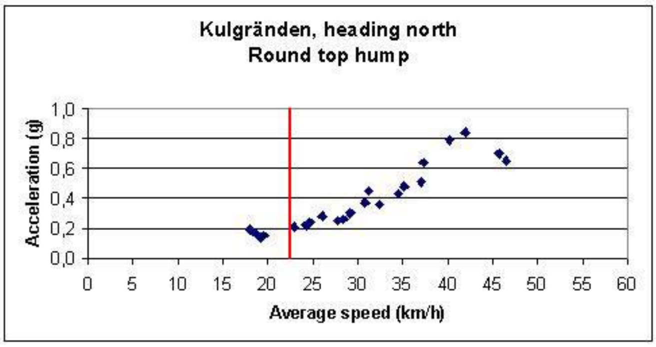


Figure 3.11 Vertical acceleration and crossing speed diagram for Kulgränden, heading north

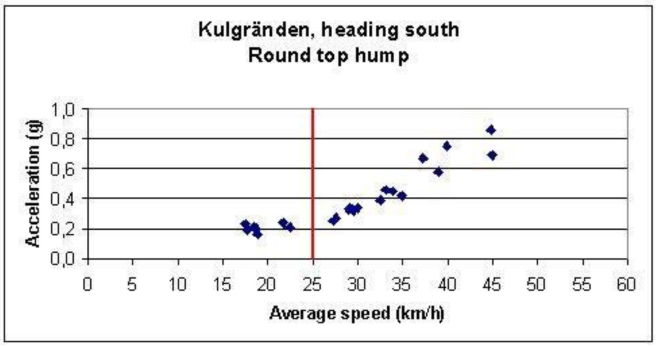


Figure 3.12 Vertical acceleration and crossing speed diagram for Kulgränden, heading south

When driving north the vertical acceleration increases slowly from 0,15 g at 18 km/h to 0,30 g at a speed of 30 km/h. After that the vertical acceleration increases rapidly with speed to its maximum value of 0,85 g at a speed about 42 km/h. After the vertical acceleration has reached its maximum value the vertical acceleration seams to drop down to a value of 0,70 g speed about 47 km/h. It is not clear if the vertical acceleration is decreasing after the speed of 43 km/h or if the values around 43 km/h are just unusual.

When driving south the vertical acceleration is quite steady at 0,20 – 0,25 g but at a speed of 27 km/h the vertical acceleration increases rapidly with speed. The maximum value is about 0,70 – 0,85 g at a speed of 45 km/h.

The results from the speed measurements are presented in table 3.6 below. The speed is higher both close to the hump and also before the hump when driving south.

Table 3.6 Speed measurement for Kulgränden

Kulgränden		Average speed [km/h]	Variance ([km/h])^2	85% speed [km/h]
Close to measure	Driving south	21,0	21,8	25,0
	Driving north	18,7	11,3	22,3
~ 50 m before measure	Driving south	35,8	41,1	40,0
	Driving north	31,9	28,9	37,3

3.1.5. Linerovägen (road hump nr. 7)

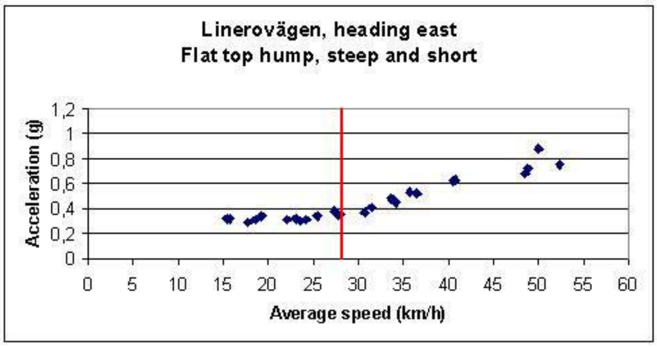


Figure 3.13 Vertical acceleration and crossing speed diagram for Linerovägen, heading east

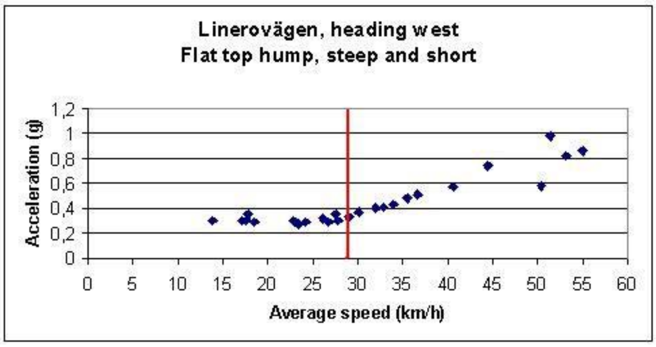


Figure 3.14 Vertical acceleration and crossing speed diagram for Linerovägen, heading west

When heading east the vertical acceleration is quite steady up to a speed of 30 km/h but then it increases rapidly with increased speed. The basic value below 30 km/h is about 0,30 g. The maximum value is from 0,70 – 0,90 g at a speed of 50 km/h.

The vertical acceleration is similar when heading west. The vertical acceleration is steady at 0,30 g up to a speed of 27 km/h but the increases rapidly. There is more variance in the maximum value but at a speed of 55 km/h the vertical acceleration is about 0,90 g.

In table 3.7, the results from the speed measurements are presented. The speed close to the flat top hump and the variance of speed is higher when driving west. The speed before the flat top hump is much higher, both the average speed and 85% speed, when driving east. The variance of speed before the flat top hump is high for both directions. It is also interesting to see that the 85% speed when driving east is over the speed limit which clearly indicates that high speed is a problem at Linerovägen.

Table 3.7 Speed measurements for Linerovägen

Linerovägen		Average speed [km/h]	Variance ([km/h])^2	85% speed [km/h]
Close to measure	Driving east	22,1	18,3	28,1
	Driving west	23,6	37,0	28,6
~ 50 m before measure	Driving east	44,8	56,8	52,6
	Driving west	39,6	63,3	46,3

3.1.6. Magistratsvägen (road hump nr. 8)

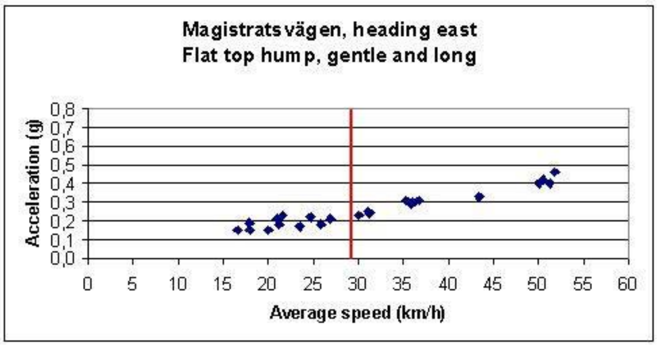


Figure 3.15 Vertical acceleration and crossing speed diagram for Magistratsvägen, heading east

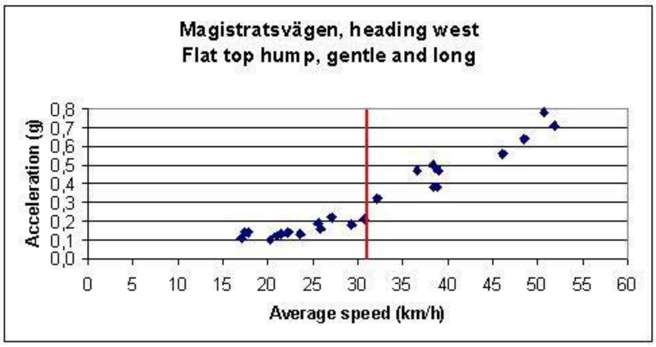


Figure 3.16 Vertical acceleration and crossing speed diagram for Magistratsvägen, heading west

When heading east the vertical acceleration slowly increases with speed. The vertical acceleration starts at a value of about 0,15 g and then increases to the maximum value of 0,45 g at a speed about 51 km/h.

When heading west there is another story. The vertical acceleration increases rapidly from 30 km/h. Before that the vertical acceleration is steady between 0,10 g and 0,20. The maximum vertical acceleration value when heading west is between 0,70 g and 0,80 g at a speed about 52 km/h.

It is very noticeable that there is a large difference between the driving directions. The reason for this could be in the design of the flat top hump at Magistratsvägen, see appendix 1 and 2. When driving east the first ramp is shorter and higher than when driving west. When driving west the second ramp is much longer and higher than when driving east. When driving west angle nr. 1 and 2 are larger than when driving east. This could explain the difference in vertical acceleration between driving directions.

The results from the speed measurements are presented in table 3.8 below. The speed close to the flat top hump is higher when driving west but so is the variance of speed. On the other hand, the speed before the flat top hump is higher when driving east.

Table 3.8 Speed measurements at Magistratsvägen

Magistratsvägen		Average speed [km/h]	Variance ($([km/h])^2$)	85% speed [km/h]
Close to measure	Driving east	25,5	20,2	29,3
	Driving west	27,6	40,9	31,4
~ 50 m before measure	Driving east	42,5	26,3	47,4
	Driving west	38,9	27,1	45,4

3.1.7. Melins väg (road hump nr. 9)

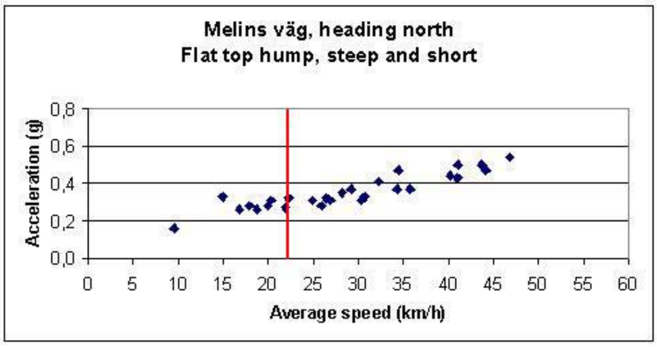


Figure 3.17 Vertical acceleration and crossing speed diagram for Melins väg, heading north

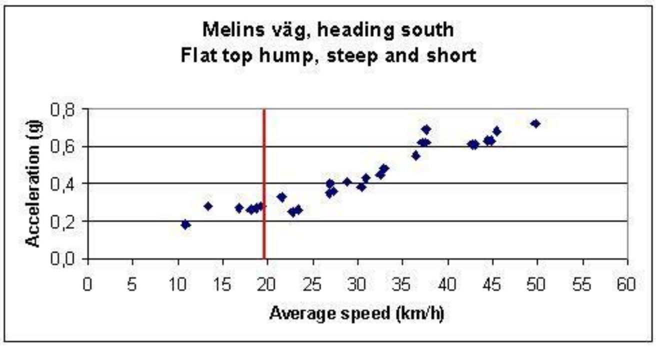


Figure 3.18 Vertical acceleration and crossing speed diagram for Melins väg, heading south

When driving north the vertical acceleration is steady up to a speed about 25 km/h but then it increases more rapidly with speed. The basic value of the vertical acceleration is about 0,30 g but after 25 km/h the vertical acceleration increases to a maximum value of 0,55 g at speed 47 km/h.

When driving south the vertical acceleration is higher. The vertical acceleration is steady up to 25 km/h just like when driving north. The basic value is also around 0,30 g. After 25 km/h the vertical acceleration increases more rapidly then when driving north and the maximum value ends up in 0,75 g at a speed around 55 km/h. It seems to be more comfortable to drive north then it is to drive south.

Table 3.9 below presents the results from the speed measurements at Melins väg. The crossing speed is higher when driving north. It is interesting to see that the variance of speed close to the measure is very small. The speed before the flat top hump is higher when driving south. There is also a large difference in variance of speed before the flat top hump. The variance of speed is much higher when driving south than it is when driving north.

Table 3.9 Speed measurements for Melins väg

Melinsväg		Average speed [km/h]	Variance ([km/h])^2	85% speed [km/h]
Close to measure	Driving north	18,3	11,4	22,1
	Driving south	17,7	6,9	19,8
~ 50 m before measure	Driving north	29,4	20,5	32,6
	Driving south	32,7	55,8	38,9

3.1.8. Måsvägen (road humps nr. 10, 11)

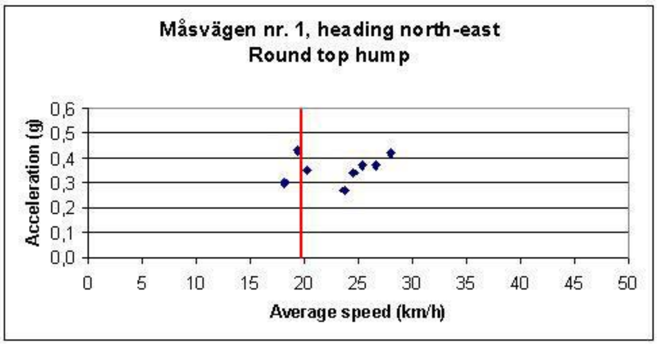


Figure 3.19 Vertical acceleration and crossing speed diagram for Måsvägen nr.1, heading north-east

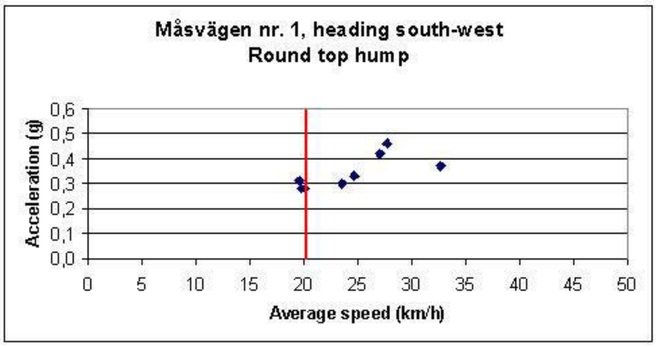


Figure 3.20 Vertical acceleration and crossing speed diagram for Måsvägen nr.1, heading south-west

The reason for the lack of measurements at Måsvägen is that when the instrumented vehicle was driven faster than 35 km/h over the humps, the front end of the car cracked into the street after the hump. It was therefore decided not to precede further with vertical acceleration measurements at Måsvägen. Even if it was not possible to measure vertical acceleration at higher speed then 30 – 35 km/h, the measurement that were collected indicate that the road hump nr. 1 at Måsvägen is very steep. The basic value of the vertical acceleration between 20 – 30 km/h is between 0,25 – 0,45 g.

In table 3.10 the results from the speed measurements are presented. The speed close to hump nr. 1, is similar for both driving directions. It is also interesting to see that the variance of speed close to the hump is very little. This indicates that the hump has an affect on drivers and they try to keep their speed within reasonable limits. Before hump nr. 1 the speed is a bit higher when driving north-east then it is when driving south-east. It is interesting to see that when driving north-east the speed before the hump represents the speed between the two humps at Måsvägen. This means that drivers' increase their speed between the two humps from about 17 km/h, as can be seen in table 3.11, to about 31 km/h.

Table 3.10 Speed measurements for Måsvägen nr. 1

Måsvägen nr. 1		Average speed [km/h]	Variance ([km/h])^2	85% speed [km/h]
Close to measure	Driving south-west	17,0	9,5	20,1
	Driving north-east	18,1	5,9	19,9
~ 50 m before measure	Driving south-west	30,1	23,1	35,0
	Driving north-east	31,1	27,8	36,9

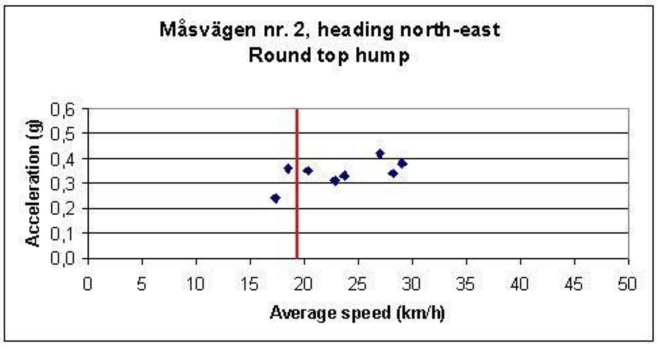


Figure 3.21 Vertical acceleration and crossing speed diagram for Måsvägen nr.2, heading north-east

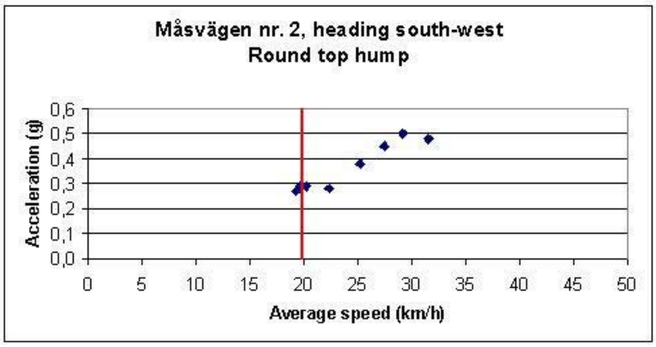


Figure 3.22 Vertical acceleration and crossing speed diagram for Måsvägen nr.2, heading south-west

The same reason can be given for the lack of measurements, as was given for hump nr. 1. If the instrumented vehicle was driven faster than 35 km/h over the humps the front end of the vehicle crashed into the asphalt. That indicates that the humps at Måsvägen are rather steep and uncomfortable. The measurements that were though collected indicate that hump nr. 2 at Måsvägen, is very steep. When driving south-west the vertical acceleration value at 30 km/h is 0,50 g which is very high.

In table 3.11 the results from the speed measurements for hump nr. 2 are presented. The speed close to the hump is similar for both driving directions and as for hump nr. 1 there is little variance of speed close to the hump. The speed before the hump is higher when driving north-east then when driving south-west. The reason for this can be that when driving south-west towards hump nr. 2 at Måsvägen, vehicles have just crossed hump nr. 1 at Måsvägen.

Table 3.11 Speed measurements for Måsvägen nr. 2

Måsvägen nr. 2		Average speed [km/h]	Variance ([km/h])^2	85% speed [km/h]
Close to measure	Driving south-west	17,5	7,8	19,9
	Driving north-east	16,9	8,9	19,3
~ 50 m before measure	Driving south-west	32,4	52,8	37,9
	Driving north-east	35,7	20,6	39,5

3.1.9. Ole Römers väg (road hump nr. 12)

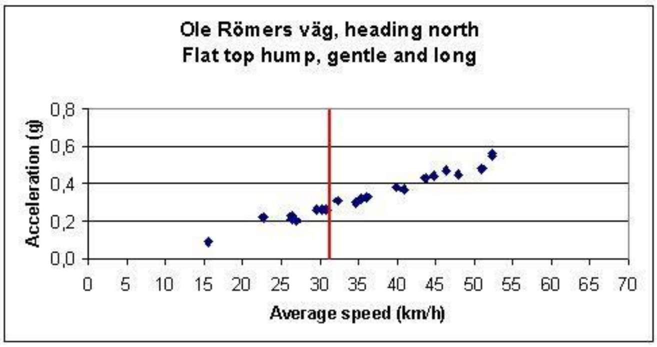


Figure 3.23 Vertical acceleration and crossing speed diagram for Ole Römers väg, heading north

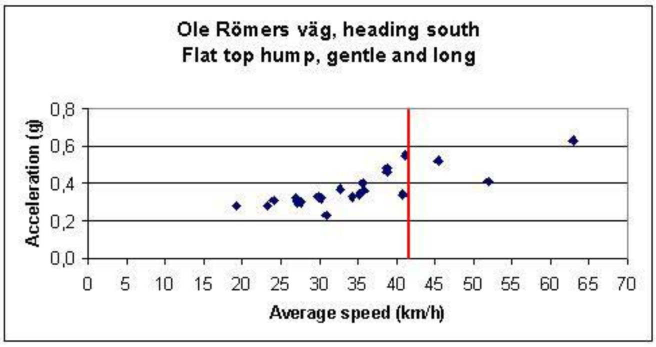


Figure 3.24 Vertical acceleration and crossing speed diagram for Ole Römers väg, heading south

When driving north the vertical acceleration increases almost linear with speed. From a speed of 15 km/h and a vertical acceleration of 0,10 g to a speed of 53 km/h and a vertical acceleration of 0,55 g.

When driving south there is more variance in the measurements but the values are similar. The vertical acceleration starts at 0,26 g at speed 17 km/h and the increases with speed up to the maximum value of 0,63 g at speed 63 km/h.

The results from the speed measurements for Ole Römers väg are presented in table 3.12 below. The speed close to the flat top hump is much higher when driving south then when driving north. The variance of speed is also much higher when driving south. The reason for this could be that when driving south, vehicle travel down hill towards the flat top hump. The speed before the flat top hump is very high for both driving directions. The speed before the flat top hump is similar for both driving direction and the variance is also high.

Table 3.12 Speed measurements for Ole Römers väg

Ole Römers väg		Average speed [km/h]	Variance ([km/h])^2	85% speed [km/h]
Close to measure	Driving south	31,4	86,3	41,6
	Driving north	27,6	35,8	30,6
~ 50 m before measure	Driving south	44,1	40,7	50,5
	Driving north	44,0	62,9	51,4

3.1.10. Skjutbanevägen (road hump nr. 13)

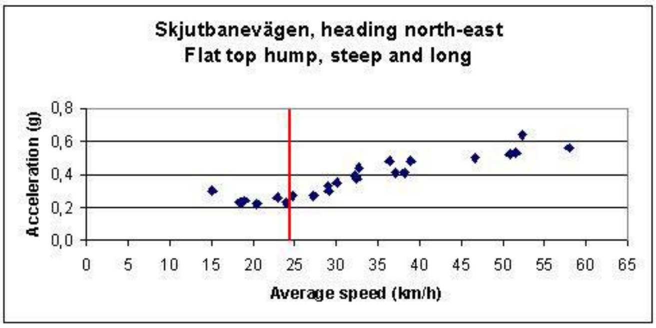


Figure 3.25 Vertical acceleration and crossing speed diagram for Skjutbanevägen, heading north-east

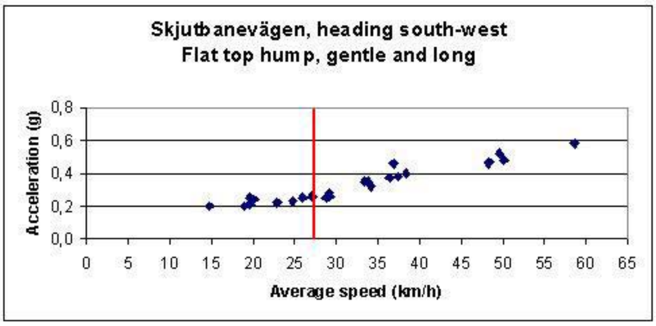


Figure 3.26 Vertical acceleration and crossing speed diagram for Skjutbanevägen, heading south-west

When driving north-east the vertical acceleration seams to decrease from 15 – 25 km/h but after that the vertical acceleration increases rapidly with speed. The maximum value is 0,55 g at speed 60 km/h which is a little bit lower than when driving south-west.

When driving south-west the vertical acceleration is steady between 15 and 25 km/h. After that the vertical acceleration increases more rapidly with speed. The basic value is about 0,20 g at the beginning but the maximum value is about 0,60 g at speed 58 km/h.

In table 3.13 below the results from the speed measurements at Skjutbanevägen are presented. The speed close to the flat top hump is similar for both driving directions but the speed is little bit higher when driving south-west. The speed before the flat top hump is also similar for both driving directions but the variance is higher than for the speed close to the flat top hump. Again the speed is higher when driving south-west than when driving north-east.

Table 3.13 Speed measurements for Skjutbanevägen

Skjutbanevägen		Average speed [km/h]	Variance ([km/h])^2	85% speed [km/h]
Close to measure	Driving south-west	21,7	13,6	27,1
	Driving north-east	20,4	20,2	24,5
~ 50 m before measure	Driving south-west	36,7	48,9	45,1
	Driving north-east	35,7	32,8	40,5

3.1.11. Sunnanväg (road hump nr. 14)

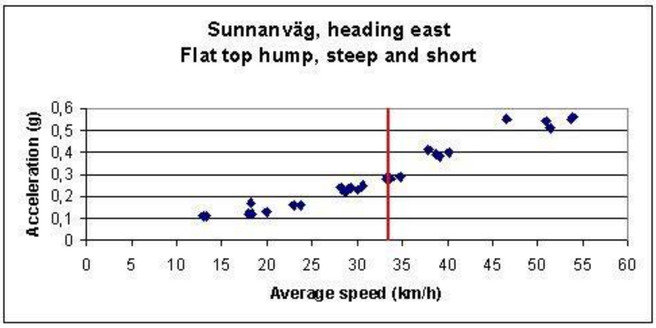


Figure 3.27 Vertical acceleration and crossing speed diagram for Sunnanväg, heading east

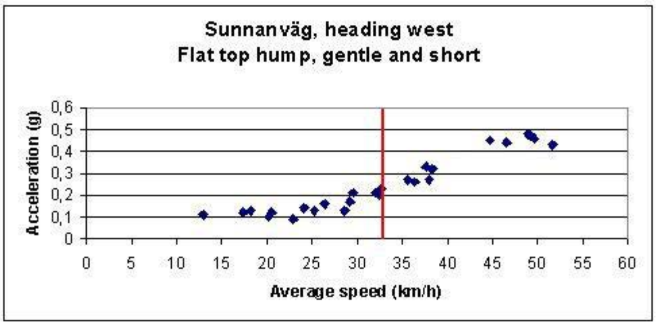


Figure 3.28 Vertical acceleration and crossing speed diagram for Sunnanväg, heading west

When driving east the vertical acceleration seems to increase almost linear from a value of 0,10 g and a speed of 12 km/h to a maximum value of 0,55 g at a speed 53 km/h. The maximum value is therefore higher when driving east than driving west.

When driving west the vertical acceleration is steady from 12 km/h to 25 km/h with a value of 0,10 g. After 30 km/h the vertical acceleration increases rapidly with speed and the maximum value is about 0,45 g at speed 50 km/h.

The results from the speed measurements at Sunnanväg are presented in table 3.14 below. The speed is a bit higher close to the flat top hump when driving east. The variance is also higher than when driving west. The speed before the flat top hump is much higher when driving east than when driving west. The variance of speed before the flat top hump is also higher when driving east. The reason for this is that when driving west the large majority of vehicle are turning west at the intersection that is close to the flat top hump. Driver have simple not been able to accelerate up to their speed before the flat top hump.

Table 3.14 Speed measurements for Sunnanväg

Sunnanväg		Average speed [km/h]	Variance ([km/h])^2	85% speed [km/h]
Close to measure	Driving west	29,2	21,0	33,0
	Driving east	30,5	38,1	33,8
~ 50 m before measure	Driving west	30,2	21,8	33,5
	Driving east	43,1	46,7	51,6

3.1.12. Svanevägen (road hump nr. 15)

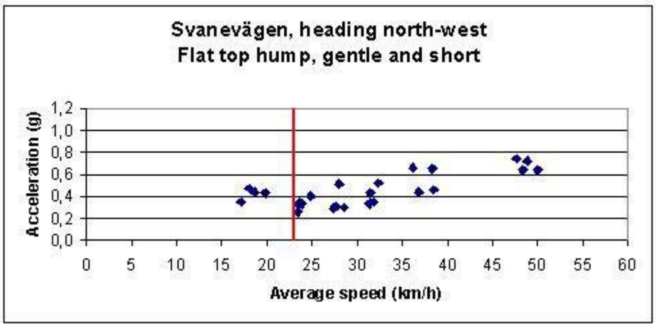


Figure 3.29 Vertical acceleration and crossing speed diagram for Svanevägen, heading north-west

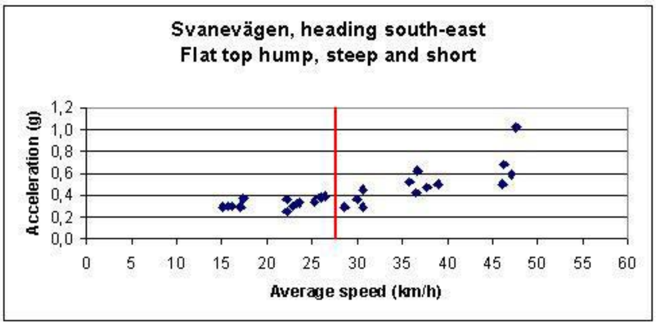


Figure 3.30 Vertical acceleration and crossing speed diagram for Svanevägen, heading south-east

When driving north-west the vertical acceleration seams to decrease from 16 km/h to 25 km/h. After 30 km/h the vertical acceleration increases with speed. Even if there is a variance in the measurements the tendency is in that direction. The maximum value is about 0,70 g at a speed about 50 km/h.

When driving south-east the vertical acceleration is steady between 15 km/h and 30 km/h with a value of about 0,30 g. After 30 km/h the vertical acceleration increases but there is a large variance in the maximum value. At speed 46 km/h the vertical acceleration is from 0,45 g to 1,00 g. It is hard to explain this variance but the use of natural material in the flat top hump can make it more sensible to vertical measurements because with multiple measurements, the vehicle always has to be in the same track.

The results from the speed measurements at Svanevägen are presented in table 3.15. In general the speed is higher when driving south-east than it is when driving north-east. This is true for both speed close to and before the flat top hump. The reason for this is that when drivers are travelling north-west they have just come from Lund centre where the speed limit is 30 km/h.

Table 3.15 Speed measurements for Svanevägen

Svanevägen		Average speed [km/h]	Variance ([km/h])^2	85% speed [km/h]
Close to measure	Driving south-east	24,2	14,1	27,8
	Driving north-west	19,4	15,4	22,8
~ 50 m before measure	Driving south-east	42,7	38,0	48,6
	Driving north-west	39,2	33,2	45,3

3.1.13. Östanväg (road humps nr. 16, 17, 18)

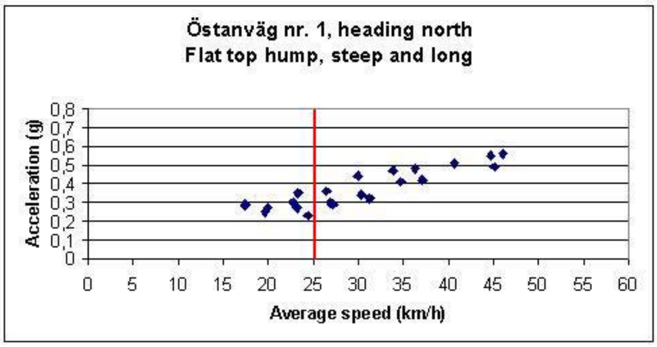


Figure 3.31 Vertical acceleration and crossing speed diagram for Östanväg nr.1, heading north

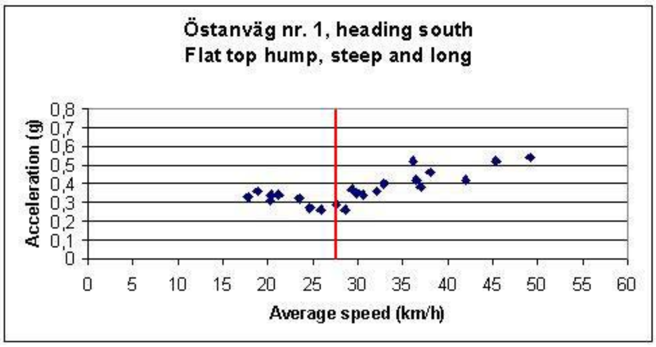


Figure 3.32 Vertical acceleration and crossing speed diagram for Östanväg nr.1, heading south

When driving north the vertical acceleration increases almost linear with speed. Even if there is some variance between measurements the tendency is clear. The vertical acceleration starts at 0,25 g at speed 17 km/h and increases to a maximum value of 0,55 g at 45 km/h.

When driving south the vertical acceleration seems to decrease from 16 km/h to 28 km/h. After 30 km/h the vertical acceleration increases rapidly with speed and the maximum value 0,55 g is at 50 km/h. The driving directions can be looked at as similar.

The results from the speed measurements, for flat top hump nr. 1 at Östanväg, are presented in table 3.16. The speed close to the flat top hump is similar for both driving directions. The 85% speed and the variance are though a bit higher when driving north. The speed before the flat top hump is much higher when driving north than when driving south. The reason for this is that when driving south the vehicles have just passed another flat top hump at Östanväg.

Table 3.16 Speed measurements for Östanväg nr. 1

Östanväg nr. 1		Average speed [km/h]	Variance ([km/h])^2	85% speed [km/h]
Close to measure	Driving south	20,2	13,6	22,6
	Driving north	20,8	21,0	25,1
~ 50 m before measure	Driving south	28,7	30,6	34,7
	Driving north	37,9	30,4	43,0

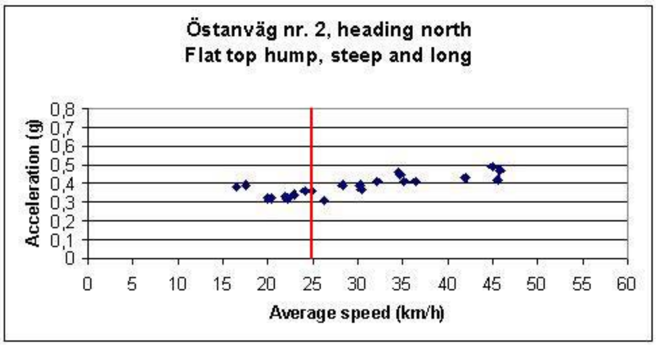


Figure 3.33 Vertical acceleration and crossing speed diagram for Östanväg nr.2, heading north

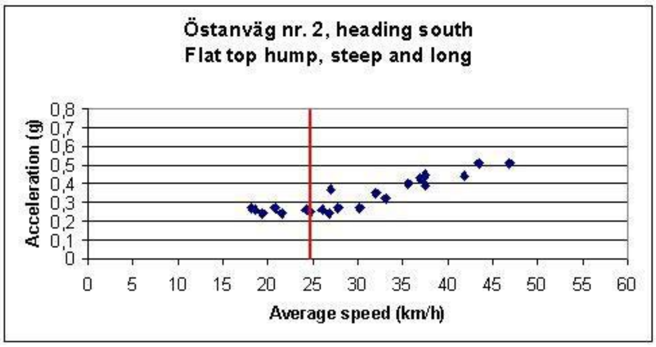


Figure 3.34 Vertical acceleration and crossing speed diagram for Östanväg nr.2, heading south

When driving north the vertical acceleration seams to decrease from 16 km/h to 20 km/h but after that the vertical acceleration increases slowly from 0,30 g at 20 km/h to 0,45 g at 45 km/h.

When driving south the vertical acceleration seems to be stable from 16 km/h to 30 km/h at 0,25 g. After 30 km/h the vertical acceleration increases rapidly to a maximum value of 0,50 at 48 km/h.

The results from the speed measurements for flat top hump nr. 2 at Östanväg are presented in table 3.17 below. The speed close to the flat top hump is similar for both driving directions but the average speed is a bit higher when driving north. The speed before the flat top hump is much higher when driving north than it is when driving south. The variance of the speed, before the flat top hump when driving north, is also higher than when driving south.

Table 3.17 Speed measurements for Östanväg nr. 2

Östanväg nr. 2		Average speed [km/h]	Variance $([km/h])^2$	85% speed [km/h]
Close to measure	Driving south	20,6	17,83	24,6
	Driving north	22	15,1	24,9
~ 50 m before measure	Driving south	29,8	21,01	33,8
	Driving north	34,9	37,9	40,7

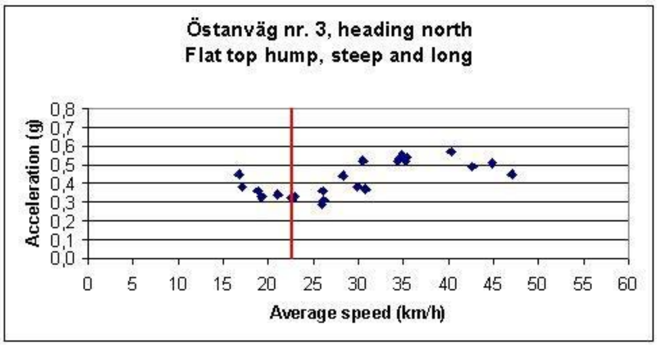


Figure 3.35 Vertical acceleration and crossing speed diagram for Östanväg nr.3, heading north

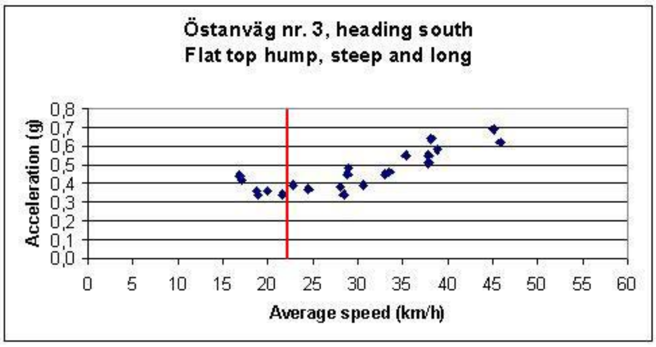


Figure 3.36 Vertical acceleration and crossing speed diagram for Östanväg nr.3, heading south

When driving north the vertical acceleration and speed connections seams to be S-shaped. First the vertical acceleration decreases from 15 km/h to 25 km/h and then increases to 35 km/h and then again decreases to 47 km/h. The maximum vertical acceleration value seems to be about 0,58 g at 40 km/h.

When driving south the vertical acceleration is stable from 15 km/h to 30 km/h with value of 0,35 g. After 30 km/h the vertical acceleration increases rapidly and has a maximum value of about 0,65 at 46 km/h.

The results from the speed measurements for flat top hump nr. 3 at Östanväg are presented in table 3.18. In general, the speed is similar for both driving direction. This can be said both about the speed close to and before the flat to hump. The only difference between driving directions is the variance of speed close to the flat top hump. The variance of speed close to the flat top hump is higher when driving south than when driving north. The reason for this can be that when driving north, vehicles have just passed other flat top humps at Östanväg. It is also possible that when driving south, vehicles have just turned into Östanväg from an intersection.

Table 3.18 Speed measurements for Östanväg nr. 3

Östanväg nr. 3		Average speed [km/h]	Variance $([km/h])^2$	85% speed [km/h]
Close to measure	Driving south	19,8	17,1	22,1
	Driving north	19,5	10,8	22,5
~ 50 m before measure	Driving south	30,1	20,4	34,3
	Driving north	30,8	23,0	35,9

3.2. Comparison between groups

From the information above it is obvious that road humps have different characters. Some road humps are gentle, some are not. The speed around some road humps is quite low while the speed around other road humps is higher. After dividing the road humps into groups according to type and their physical identities it is interesting to see if these groups are in principle different from each other. In table 3.19 the average values of vertical acceleration at 25 km/h and 40 km/h are presented for each group along with average crossing speed, variance of crossing speed, 85% speed, speed before and the average value for the slope of the regression line, K_1.

Table 3.19 Comparison between group regarding vertical acceleration and speed

	$a_{v=25\ km/h}$	$a_{v=40\ km/h}$	$V_{close\ to}$ (km/h)	Variance of $V_{close\ to}$ $(km/h)^2$	$V_{85\%}$ (km/h)	V_{before} (km/h)	Average K_1
Round top humps	0,35	0,69	18,53	12,84	21,74	32,60	0,0236
Flat top humps (steep and short)	0,30	0,52	22,73	20,98	26,70	38,72	0,0165
Flat top humps (steep and long)	0,32	0,47	20,48	18,46	23,76	33,06	0,0092
Flat top humps (gentle and short)	0,29	0,43	22,09	24,93	25,76	32,91	0,0092
Flat top humps (gentle and long)	0,23	0,40	26,27	40,90	31,48	40,62	0,0109

When comparing the vertical acceleration at 25 km/h, round top humps have the highest average value. Round top humps have rather high value while gentle and long flat top humps have very low value. Round top humps have also the highest value when comparing vertical acceleration at 40 km/h. It is interesting to see that gentle flat top hump have very low average vertical acceleration value at 40 km/h or 0,40 – 0,43 g. This value is close to the average vertical acceleration value that round top humps have at 25 km/h.

The speed close to the road humps is lowest for round top humps and then for steep and long flat top humps. The average crossing speed is similar for flat top hump that are short. The absolute highest crossing speed belongs to gentle and long flat top humps. The variance of crossing speed is also lowest for round top humps but highest for flat top humps that are gentle and long. Round top humps have the lowest 85% speed but flat top humps that are gentle and long have the highest 85% speed. When comparing the speed before the road humps, the speed is still lowest for round top humps and highest for gentle and long flat top humps but the interesting thing is how high the speed is before steep and short flat top humps or almost 39 km/h. Care must be taken when considering the speed before the road humps. Since a number of different factors influence the speed at each street, it is not reasonable to compare the speed before between different road humps. It is not possible to say that the circumstances are the same between streets.

When comparing K_1, how rapidly vertical acceleration increases with speed, table 3.19 shows that round top humps have the highest value of K_1 followed by steep and short flat top humps. It is interesting to see that gentle and long flat top humps have higher average value of K_1 than both steep and long flat top humps, and gentle and short flat top humps.

It is clear that there is a difference between the average values in table 3.19 above. Even if the calculated average values are different, it does not mean that the average values are statistically different. A t-test was conducted to see if there was a statistical difference between the groups in table 3.19. A description of the t-test that was used can be seen in chapter 2.4.3. A significance level of 10% was used and from the table in appendix 5, the calculated t value was needed to be higher than 1,94 or 2,13, all depending on the number of road humps in each group. If the calculated value was larger then the values mentioned above, it was possible to say that there was as difference between the groups. Table 3.20 – 3.25 provide the results from the t-test.

Table 3.20 Comparison between groups considering average vertical acceleration at 25 km/h

$a_{v=25\ km/h}$	Round top humps	Flat top humps (steep and short)	Flat top humps (steep and long)	Flat top humps (gentle and short)	Flat top humps (gentle and long)
Round top humps		1,48	1,21	1,57	4,12
Flat top humps (steep and short)			-0,54	0,39	2,61
Flat top humps (steep and long)				0,83	3,79
Flat top humps (gentle and short)					1,62
Flat top humps (gentle and long)					

When considering the vertical acceleration at 25 km/h, table 3.20 above shows that gentle/long flat top humps have a unique position. The t-test reveals that there is a statistical difference between the average values of gentle/long flat top humps and other groups that are considered steeper, that is round top humps, steep/short flat top humps and steep/long flat top humps. The t-test could not show that there was a difference in average values between steep road humps.

Table 3.21 Comparison between groups considering average vertical acceleration at 40 km/h

$a_{v=40\ km/h}$	Round top humps	Flat top humps (steep and short)	Flat top humps (steep and long)	Flat top humps (gentle and short)	Flat top humps (gentle and long)
Round top humps		3,99	7,15	5,81	9,51
Flat top humps (steep and short)			1,37	1,76	3,17
Flat top humps (steep and long)				0,83	2,55
Flat top humps (gentle and short)					0,86
Flat top humps (gentle and long)					

When considering the difference in vertical acceleration at 40 km/h, it can be seen from table 3.21 above that round top humps are unique. The t-test reveals that there is a difference between the average value for round top hump and the average value for all the other groups. The vertical acceleration at 40 km/h is also statistically different for gentle/long flat top humps when comparing them to more steeper flat top humps. Gentle/long flat top humps are different from both steep/short flat top humps and steep/long flat top humps.

Table 3.22 Comparison between groups considering average crossing speed

$V_{close\ to}$ (km/h)	Round top humps	Flat top humps (steep and short)	Flat top humps (steep and long)	Flat top humps (gentle and short)	Flat top humps (gentle and long)
Round top humps		-2,14	-3,41	-2,99	-5,25
Flat top humps (steep and short)			1,18	0,30	-1,50
Flat top humps (steep and long)				-1,45	-4,11
Flat top humps (gentle and short)					-2,38
Flat top humps (gentle and long)					

When considering the average crossing speed, round top humps have again a unique position. The result from the t-test in table 3.22 reveals that the average value for round top humps is different from the average values of all the other groups. Gentle/long flat top humps are also again different from other groups. The t-test also reveals that gentle/long flat top humps are different from both steep/long flat top humps and gentle/short flat top humps. The results from the t-test showed that there is not a statistical difference between steep/short flat top humps and other groups of flat top humps when considering the average crossing speed.

Table 3.23 Comparison between groups considering the average variance of crossing speed

Variance ($V_{close\ to}$ $(km/h)^2$)	Round top humps	Flat top humps (steep and short)	Flat top humps (steep and long)	Flat top humps (gentle and short)	Flat top humps (gentle and long)
Round top humps		-1,38	-1,75	-3,85	-2,61
Flat top humps (steep and short)			0,42	-0,67	-1,68
Flat top humps (steep and long)				-2,04	-2,08
Flat top humps (gentle and short)					-1,49
Flat top humps (gentle and long)					

Table 3.23 shows the results from the t-test when comparing the average values of crossing speed variance between groups. The results from the t-test show that there is a difference between round top humps and gentle flat top humps. The results show that there is a statistical difference between steep/long flat top humps and both gentle/short and gentle/long flat top hump. The t-test also reveals that there is not a difference between steep/short flat top humps and other groups of flat top humps.

Table 3.24 Comparison between groups considering the average 85% crossing speed

$V_{85\%}$ (km/h)	Round top humps	Flat top humps (steep and short)	Flat top humps (steep and long)	Flat top humps (gentle and short)	Flat top humps (gentle and long)
Round top humps		-2,26	-2,25	-2,94	-4,32
Flat top humps (steep and short)			1,40	0,40	-1,63
Flat top humps (steep and long)				-1,67	-3,58
Flat top humps (gentle and short)					-2,39
Flat top humps (gentle and long)					

Table 3.24 above reveals the results from the t-test when considering difference in average values of 85% crossing speed between groups. The t-test shows that there is a statistical difference between round top humps and flat top humps. The t-test also revealed that there is a difference between gentle/long flat top humps and both steep/long and gentle/short flat top humps. The data that the t-test is based on could not show a difference between steep/short flat top humps and other flat top humps.

Table 3.25 Comparison between groups considering average K_1

Average K_1	Round top humps	Flat top humps (steep and short)	Flat top humps (steep and long)	Flat top humps (gentle and short)	Flat top humps (gentle and long)
Round top humps		1,98	3,91	4,06	3,11
Flat top humps (steep and short)			2,99	3,25	1,86
Flat top humps (steep and long)				0,02	-0,53
Flat top humps (gentle and short)					-0,57
Flat top humps (gentle and long)					

When considering average value of K_1, table 3.25 above shows the results from the t-test. From table 3.25 it can bee seen that steep/short road humps have a unique position. This is not surprising since K_1 is an estimate on how rapidly vertical acceleration increases with speed. The t-test shows that there is a statistical difference between round top humps and flat top humps when considering average value of K_1. The t-test also shows that steep/short flat top humps are statistically different from other groups of flat top humps.

When considering table 3.19, it is interesting to see that the average vertical acceleration value at speed 25 km/h for round top humps is quite high. It is also interesting to see that the average vertical acceleration value for flat top hump at speed 40 km/h is quite low. This is interesting when thinking of the ideal road hump that Watts was looking for. In most cases the acceleration at 25 km/h for road humps should be lower and the acceleration value for flat top humps at speed 40 km/h should be higher. It is therefore interesting to find a connection between physical identities of each road hump and vertical acceleration that could explain the reason for this. It would also be interesting to find physical identities that could lower the vertical acceleration at speed 25 km/h for round top humps and make the vertical acceleration for flat top humps at speed 40 km/h be a bit higher.

3.3. Connection between physical identities and vertical acceleration

Physical identities of road humps have an affect on the vertical acceleration. It is interesting to see what each and every physical identity does to the vertical acceleration. A graph can be drawn that shows the connection between K_1, that can be expressed as $K_1 \sim a(v = 40 \text{ km/h}) - a(v = 25 \text{ km/h})$, and physical identities. A linear regression line can then be used to describe the connection between these two factors. An example of the connection between vertical acceleration and physical identities is given in figures 3.37 and 3.38.

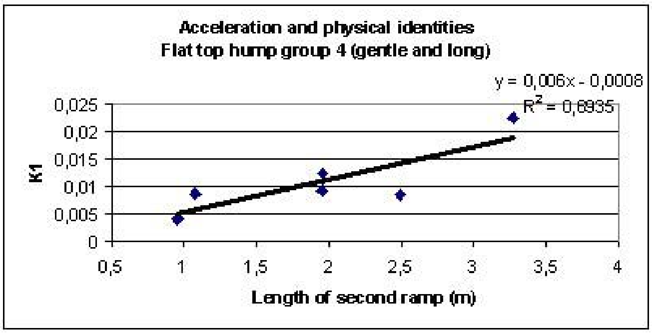


Figure 3.37 Example of the connection between vertical acceleration and physical identities

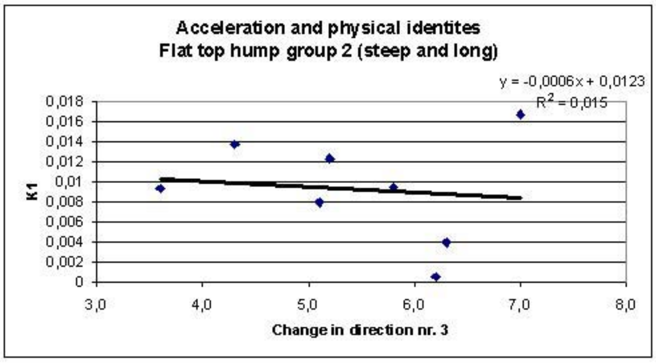


Figure 3.38 Example of the connection between vertical acceleration and physical identities

From figures 3.37 and 3.38 it is apparent that in some cases the connection between vertical acceleration and physical identities is clear. In some cases this connection is not so clear. To determine if there is a connection between vertical acceleration and physical identities a statistical test was used. A description of the statistical test can be seen in chapter 2.4.4. This statistical test can determine if the linear regression line is tilting or not. A significant level of 10% was used and the slope of the linear regression lines was not equal to zero if the calculated value was larger then 1,94 or 2,13, all depending on the number of road humps in each group. See appendix 5 for values of t in the t-test. If the number of road humps was 6 when the calculated value had to be larger then 2,13 and if the number of road humps in a group was 8 then the calculated value had to be larger than 1,94.

Table 3.26 provides the results from this statistical test. The black cells in the table mark the physical identities that are connected to the vertical acceleration while the grey cells mark the physical identities that are close to the limit of being statistically accepted. A minimum value of 1,20 was set as a limit for physical identities to be marked grey. Physical identities that had higher value than 1,20 showed a tendency and were worth mentioning. For round top humps the connection between vertical acceleration at 25 km/h and physical identities was tested. For flat top hump the connection between K_1, that can be expressed as $K_1 \sim a(v = 40 \text{ km/h}) - a(v = 25 \text{ km/h})$, and physical identities was tested.

Table 3.26 Connection between physical identities and vertical acceleration

	Total length [m]	Length of top [m]	Length of first ramp [m]	Height difference [m] (up to hump)	Length of second ramp [m]	Height difference [m] (down to street)	Change in direction nr. 1 [°]	Change in direction nr. 2 [°]	Change in direction nr. 3 [°]	Change in direction nr. 4 [°]	Street width [m]
Round top humps	2,14	-	1,71	0,69	1,92	0,28	1,53	-	-	1,50	4,80
Flat top humps (steep and short)	0,43	0,23	1,36	0,38	0,32	0,92	0,06	0,51	0,88	0,07	0,48
Flat top humps (steep and long)	0,10	0,12	1,65	1,22	0,12	0,51	0,99	0,89	0,30	0,30	0,01
Flat top humps (gentle and short)	1,35	1,04	0,09	1,94	1,93	0,02	0,77	1,21	1,25	1,50	1,02
Flat top humps (gentle and long)	0,20	0,33	2,12	0,94	3,01	5,09	0,03	0,19	1,48	1,49	0,31

From table 3.26 it can be seen that there is a connection between total length of round top humps and vertical acceleration at 25 km/h. It can also be seen that the street width is connected to the vertical acceleration at 25 km/h, though it is hard to explain what street width has to do with vertical acceleration. There are also some physical identities that are close to being statistically connected to vertical acceleration such as the length of first and second ramp and change in direction nr. 1 and 4.

In the second row in table 3.26 it can be seen that flat top humps that are steep and short have no statistical connection between K_1 and their physical identities. At least this connection can not be established with the data that was collected. The only physical identity that comes close to being statistically connected to $K_{,1}$, for steep and short flat top humps, is the length of first ramp. The data does not support this connection enough so it can not be said that the response depends on the input.

In the third row in table 3.26 it can be seen that flat top hump that are steep and long have no statistical connection between K_1 and physical identity. The physical identities that come close to be connected to K_1 are the length of the first ramp and the height difference from the street and up to the flat top hump.

For flat top humps that are gentle and short a connection could be found between K_1 and the height difference from the street and up to the flat top hump. The fifth row in table 3.26 reveals that. The length of the second ramp came close to be statically connected to K_1. Other physical identities like the total length and change in direction nr. 2-4 showed some signs of connection but not nearly enough so it could be said that the response depended on the input.

The last row in table 3.26 shows that for flat top humps that are gentle and long, a statistical connection could be found with three physical identities. These physical identities are the length of first and second ramp along with the height difference between the top of the flat top hump and down to the street. Other factors like change in direction nr. 3 and 4 showed some tendency but not nearly enough to say that they were statistically connected to K_1.

3.4. Connection between physical identities and crossing speed

Physical identities have an effect on the crossing speed for each road hump. If a graph is drawn with physical identities on one axel and crossing speed on the other, a connection can be made. This connection can be clear or not, just like for physical identities and vertical acceleration. The same statistical test was used to see if there was a connection between physical identities and crossing speed as was used for the connection between K_1 and physical identities in chapter 3.3. A linear regression line was used to describe the connection between physical identities and crossing speed, and then the statistical test was used to test if there was a statistical connection between physical identities and crossing speed. The result from the statistical test can be seen in table 3.27 below. As before, the black cells in the table mark the physical identities that have a statistical connection to the crossing speed while the grey cells mark the physical identities that are close to having a statistical connection to the crossing speed.

Table 3.27 Connection between physical identities and crossing speed

	Total length [m]	Length of top [m]	Length of first ramp [m]	Height difference [m] (up to hump)	Length of second ramp [m]	Height difference [m] (down to street)	Change in direction nr. 1 [°]	Change in direction nr. 2 [°]	Change in direction nr. 3 [°]	Change in direction nr. 4 [°]	Street width[m]
Round top humps	0,92	-	1,07	0,61	1,29	3,12	2,42	-	-	2,21	1,84
Flat top humps (steep and short)	1,70	2,23	1,07	1,87	1,64	1,17	1,96	1,29	0,67	2,25	3,17
Flat top humps (steep and long)	0,08	0,07	0,71	0,79	0,38	0,65	0,62	0,53	0,35	0,27	0,00
Flat top humps (gentle and short)	0,31	0,15	1,32	0,28	0,36	0,22	2,51	1,04	2,32	2,05	6,80
Flat top humps (gentle and long)	1,17	0,95	2,05	0,61	1,25	0,26	0,09	2,33	2,19	0,80	0,27

From table 3.27 above it can be seen that the crossing speed for round top humps is statistically connected to three physical identities. These physical identities are height difference between the top of the round top hump and the street, change in direction nr. 1 and change in direction nr. 4. Other physical identities that are close to having a statistical connection to the crossing speed are the width of the street and length of second ramp.

The crossing speed for flat top humps that are steep and short is statistically connected to three physical identities, as can be seen in the second row in table 3.27. These identities are the length of top, change in direction nr. 4 and the street width. Other physical identities like the total length, the height difference from the street to the top of the flat top hump, the length of the second ramp and change in direction nr. 1 and 2, come close to having a statistical connection to the crossing speed but the data does not support this connection.

The third row in table 3.27 shows that for flat top humps that are steep and long, there is no statistical connection between crossing speed and any physical identity and there are no physical identities that are even close to having a statistical connection to the crossing speed.

The crossing speed for flat top humps that are gentle and short is statistically connected to four physical identities; this can be seen in the fourth row in table 3.27. These physical identities are change in direction nr. 1, 3 and 4 along with the street width. The length of the first ramp comes close to being statistically connected to the crossing speed but the data does not support this connection.

The last row in table 3.27 reveals that flat top humps that are gentle and long have statistical connection between crossing speed and three physical identities. These physical identities are the length of the first ramp and change in direction nr. 2 and 3. Of the remaining physical identities, the length of the second ramp comes closest to being statistically connected to crossing speed.

3.5. Conflict of interest

In table 3.19 different groups were compared. It was mentioned that the vertical acceleration at 25 km/h was a bit high for round top humps. It was also mentioned that the vertical acceleration at 40 km/h was rather low for flat top humps. Now that a connection has been made between physical identities and vertical acceleration for different groups, it is interesting to study further what changes can be made to physical identities so that the vertical acceleration can be lower for round top humps and higher for flat top humps. A connection between physical identities and crossing speed has also been established. It is interesting to study the affects that physical identities have on crossing speed. As well as if they are in conflict with the affects that physical identities have on vertical acceleration. Is it possible, for example that if some physical identity is changed to decrease vertical acceleration that it will have the opposite effect on the crossing speed so that the speed will increase? Figures 3.37 and 3.38 in chapter 3.3 gave an example of the connection between vertical acceleration and physical identities. From these figures it could be seen how increased physical identity affected the vertical acceleration. In some cases the vertical acceleration increased with increased physical identity but in other cases the vertical acceleration decreased. How increased physical identity affects vertical acceleration and crossing speed for each road hump group is shown in tables 3.28 – 3.32.

In table 3.28 below the affects that physical identities have on vertical acceleration and crossing speed for round top humps are listed. It is interesting to see if it is possible to decrease vertical acceleration at 25 km/h. The black cells in table 3.28 mark the physical identities that have been statistically connected to vertical acceleration or crossing speed. The grey cells mark the physical identities that are close to having a statistical connection to either vertical acceleration or crossing speed. Table 3.28 can be explained in the following way: If angle nr. 1 would be increased, for example, then the vertical acceleration would probably increase and the crossing speed would decrease since the cell is marked yellow. It is only possible to say that the vertical acceleration will probably increase since the cell is marked grey.

Table 3.28 The affects that physical identities have on round top humps

If the following physical identity is increased	It will have the following effect on …	
	Acceleration (g)	Crossing speed (km/h)
Total length [m]	increase	-
Length of crown [m]	-	-
Length of first ramp [m]	decrease	-
Height difference [m] (up to hump)	-	-
Length of second ramp [m]	decrease	decrease
Height difference [m] (down to street)	-	decrease
Change in direction nr. 1 [°]	increase	decrease
Change in direction nr. 2 [°]	-	-
Change in direction nr. 3 [°]	-	-
Change in direction nr. 4 [°]	increase	decrease
Street width [m]	decrease	increase

From table 3.28 above it is possible to see that by decreasing the total length of the round top hump the vertical acceleration will decrease along with an unknown effect on the crossing speed. If the length of the first ramp is increased, then the vertical acceleration has the tendency of decreasing with an unknown effect on the crossing speed. This is only a tendency because the length of the first ramp has not been statistically connected to vertical acceleration. The same can be said about the length of the second ramp. If the length of the second ramp is increased then the vertical acceleration has a tendency of decreasing along with the crossing speed. If the first angle is decreased the vertical acceleration has the tendency of decreasing while the crossing speed would increase. This indicates a conflict between vertical acceleration and crossing speed but since the connection between change in direction nr. 1 and vertical acceleration has not been statistically established it is hard say that this is more than a weak tendency. The same can be said about change in direction nr. 4. A statistical connection has been made between street width and vertical acceleration. Since the street width has nothing to do with the vertical acceleration, this result will be disregarded.

The comparison between groups in chapter 3.2 revealed that vertical acceleration at 40 km/h was not that high for flat top humps. It is therefore interesting to study what affects changed physical identities will have on vertical acceleration and crossing speed. By changing physical identities it is possible to increase K_1, which describes how fast the vertical acceleration increases with speed. To make flat top humps more uncomfortable at higher speed it is necessary to increase K_1. Table 3.29 – 3.32 present the connection between physical identities, vertical acceleration and crossing speed for flat top humps.

Table 3.29 The affects that physical identities have on flat top humps, group 1

If the following physical identity is increased	It will have the following effect on …	
	K_1	Crossing speed (km/h)
Total length [m]	-	decrease
Length of crown [m]	-	decrease
Length of first ramp [m]	decrease	-
Height difference [m] (up to hump)	-	decrease
Length of second ramp [m]	-	increase
Height difference [m] (down to street)	-	-
Change in direction nr. 1 [°]	-	decrease
Change in direction nr. 2 [°]	-	decrease
Change in direction nr. 3 [°]	-	-
Change in direction nr. 4 [°]	-	decrease
Street width [m]	-	decrease

The data does not support any statistical connection between physical identities and K_1 for steep and short flat top humps, as can be seen in table 3.29. There is though a tendency for one physical identity. If the length of the first ramp is decreased then K_1 will increase. It was possible to statistically connect three physical identities to crossing speed. These physical identities are length of the crown, change in direction nr. 4 and street width. If all of these physical identities are increased it will decrease the crossing speed.

Table 3.30 The affects that physical identities have on flat top humps, group 2

If the following physical identity is increased	It will have the following effect on …	
	K_1	Average speed (km/h)
Total length [m]	-	-
Length of crown [m]	-	-
Length of first ramp [m]	decrease	-
Height difference [m] (up to hump)	increase	-
Length of second ramp [m]	-	-
Height difference [m] (down to street)	-	-
Change in direction nr. 1 [°]	-	-
Change in direction nr. 2 [°]	-	-
Change in direction nr. 3 [°]	-	-
Change in direction nr. 4 [°]	-	-
Street width [m]	-	-

It can be seen in table 3.30 that there is no statistical connection between any physical identity and K_1 for flat top humps that are steep and long and nothing can be said about the connection between physical identities and crossing speed. However, there is a tendency that decreased length of first ramp will increase K_1 and also if the height difference between the street and the flat top hump is increase it will increase K_1. Since there is no statistical connection, this can only be a tendency.

Table 3.31 The affects that physical identities have on flat top humps, group 3

If the following physical identity is increased	It will have the following effect on …	
	K_1	Crossing speed (km/h)
Total length [m]	increase	-
Length of crown [m]	-	-
Length of first ramp [m]	-	Increase
Height difference [m] (up to hump)	increase	-
Length of second ramp [m]	decrease	-
Height difference [m] (down to street)	-	-
Change in direction nr. 1 [°]	-	decrease
Change in direction nr. 2 [°]	increase	-
Change in direction nr. 3 [°]	increase	decrease
Change in direction nr. 4 [°]	increase	decrease
Street width [m]	-	increase

How physical identities affect vertical acceleration and crossing speed for gentle and short flat top humps can be seen in table 3.31. There is a tendency for increased vertical acceleration if the total length is increased but with an unknown effect on the crossing speed. It was possible to statistically connect height difference between the street and the top of the flat top hump, to K_1. If this height difference is increased it will increase K_1 but with an unknown effect on the crossing speed. The length of the second ramp has the tendency of increasing K_1 if the length is decreased but with an unknown effect on the crossing speed. If the second direction is increased it will have the tendency of increasing K_1, but with an unknown effect on the crossing speed. Since there is not statistical connection between change in direction nr. 2, K_1 and crossing speed, this can only be a tendency. If direction nr. 3 is increase it will probably increase K_1 and decrease the crossing speed. The same thing can be said about change in direction nr.4 and the affect that it will have on K_1 and crossing speed. A statistical connection was found between crossing speed and change in direction nr. 1 and street width. If angle nr. 1 is increased is will decrease the crossing speed but if the street is made wider it will increase the crossing speed.

Table 3.32 The affects that physical identities have on flat top humps, group 4

If the following physical identity is increased	It will have the following effect on …	
	K_1	Crossing speed (km/h)
Total length [m]	-	-
Length of crown [m]	-	-
Length of first ramp [m]	increase	Increase
Height difference [m] (up to hump)	-	-
Length of second ramp [m]	increase	Increase
Height difference [m] (down to street)	increase	-
Change in direction nr. 1 [°]	-	-
Change in direction nr. 2 [°]	-	decrease
Change in direction nr. 3 [°]	decrease	decrease
Change in direction nr. 4 [°]	decrease	-
Street width [m]	-	-

There is a statistical connection between the length of first ramp and both K_1 and crossing speed for flat top humps group 4, table 3.32 reveals that. If the length of the first ramp is increased it will increase K_1 and also the crossing speed. This is a conflict between driving comfort and crossing speed. It is also clear that if the length of the second ramp is increased it will increase K_1 and probably the crossing speed. Since there is no statistical connection between the length of second ramp and the crossing speed, it can only be said that increased length of second ramp will probably increase the crossing speed. If the height difference between the top of the flat top hump and the street is increased, it will increase K_1 but with an unknown effect on the crossing speed. There is a tendency for K_1 to increase as angle nr. 3 is decreased. This will increase the crossing speed since there is a statistical connection between change in direction nr. 3 and the crossing speed. Here again is a conflict between driving comfort and speed.

One theory about peoples speed choice around road humps is that drivers choose their discomfort. Let's suppose that drivers are familiar with some road humps, they live in the neighbourhood and cross this road hump each day. The drivers recognize this road hump and know how comfortable or uncomfortable this road hump is at different speeds. Is it possible that drivers choose their acceleration value when crossing this road hump? According to this theory the vertical acceleration should be the same for all road humps no matter the crossing speed. If the road hump is gentle then the crossing speed should be higher to achieve the chosen vertical acceleration value. If the road hump is steep then the crossing speed should be lower to achieve this same vertical acceleration value. Figure 3.39 below presents the average crossing speed for every road hump that was measured and the calculated vertical acceleration for that crossing speed. Figure 3.39 reveals that the data does not exactly line up to some vertical acceleration value. Instead the majority of the data seems to line up vertically around 20 km/h. It can be said very roughly that the drivers seem to follow some particular speed instead of a specific vertical acceleration value. In this case this particular speed seems to be around 20 km/h.

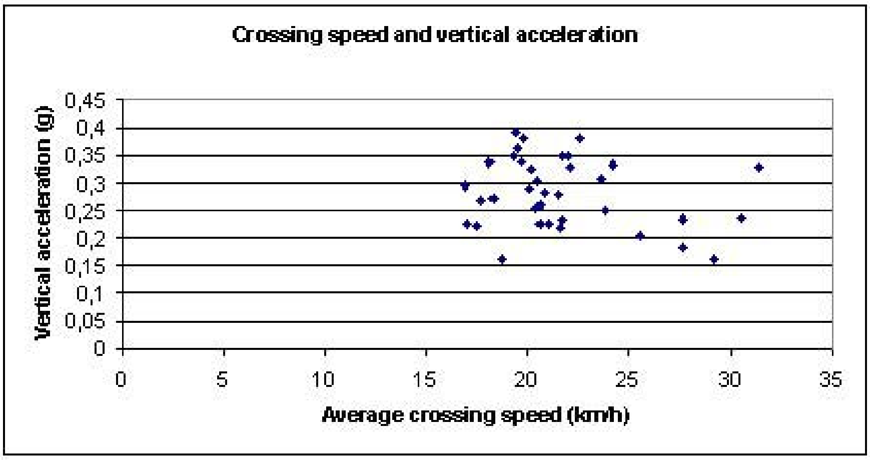


Figure 3.39 Vertical acceleration and crossing speed

Maybe it is hard to expect that all drivers choose the same vertical acceleration value. Each individual experiences driving comfort in their own way. The vertical acceleration measurements were conducted with one particular vehicle but there is a great variety of vehicles and each vehicle absorbs the impact from the road hump differently. What might be uncomfortable for one driver is perhaps comfortable for other drivers. It is not too hard to imagine that drivers choose some specific speed instead of vertical acceleration value. It is more likely that drivers have similar feeling for speed then for driving comfort.

Round top and flat top humps

4. Conclusions and Discussion

The study reveals that, when comparing different groups, round top humps and gentle/long flat top humps are in many cases unique. Round top humps have the highest vertical acceleration at 25 km/h and 40 km/h, and also the lowest crossing speed. Gentle/long flat top humps are situated on the other end of the spectrum. Gentle/long flat top humps have the lowest vertical acceleration at 25 km/h and 40 km/h and also the highest crossing speed. The study shows that there is a clear difference in average crossing speed between round top humps and gentler flat top humps. The comparison between these groups shows that this difference was between 4 and 8 km/h. Such a large difference in average speed has a great influence on the number and seriousness of accidents. When comparing the average values, the study shows that these two types of road humps are in most cases statistically different from other types of road humps. The study shows that when comparing K1, how rapidly the vertical acceleration increases with crossing speed, round top humps and steep/short flat top humps are statistically different from road humps that are gentler or longer. This makes these road humps more suitable than other gentler road humps for speed reduction. When comparing different groups to the ideal road hump, the study shows that round top humps have rather high vertical acceleration at 25 km/h. When comparing flat top humps to the ideal road hump, the study shows that flat top humps have low vertical acceleration at 40 km/h.

The study shows that the connection between vertical acceleration and crossing speed is special for each road hump. The study reveals that in most cases the vertical acceleration is steady up to 30 km/h but after that, increases very rapidly. The majority of studied road humps have the ability to increase the driving discomfort as crossing speed increases. The vertical acceleration does not increase very rapidly for some road humps so a vertical acceleration value of 0,45 g at 50 km/h is a fact. Other road humps, especially round top humps, are more uncomfortable and have a vertical acceleration value of 0,45 g at a speed around 25 km/h, like the round top humps at Måsvägen. The maximum value of vertical acceleration is also different between road humps. While some road humps have a maximum value at 0,40 – 0,50 g, others have a maximum vertical acceleration value around 1,00 g at speed over 50 km/h. Some of the road humps that have low vertical acceleration are located on streets that are used by local or regional buses. This could be the reason for why these road humps are so gentle. This has in many cases resulted in higher speed at these streets because the crossing speed is higher for gentler road humps. The main conclusion about the vertical acceleration and crossing speed connection is that each road hump has its own special connection that is unique for each and every road hump.

The study reveals that it was hard to statistically connect vertical acceleration and physical identities. It was though possible in some cases to establish this connection. One of these cases was the connection between round top humps and total length. There are probably many reasons why it was so hard to establish a connection between vertical acceleration and physical identities. One of them can be that the number of road humps involved in the study was not high enough. Another reason can be that the connection between vertical acceleration and physical identities is not that simple. A simple linear regression between vertical acceleration and each physical identity is probably not suitable to describe this connection. It is likely that a connection between more than two physical identities is needed to explain the relationship with vertical acceleration.

The study shows that it was easier to establish a statistical connection between physical identities and crossing speed. The majority of these connections were between crossing speed and change in direction nr. 1 – 4. The reason for this could be that it is easier for drivers to estimate how uncomfortable an road hump is by looking at the change in direction. In many cases it is harder for drivers to estimate the length of ramp or the height of the road hump when deciding if the road hump is uncomfortable or not. A connection was found between the streets width and crossing speed for two groups, steep/short flat top humps and gentle/short flat top humps. The reason for this can be that the streets that are in these groups are all very wide or parking is allowed along the street. Sometimes there are many cars parked along the street and in other cases there are fewer. If there are many cars parked along the street, that can make the street very narrow and drivers have to be more careful and drive slower. On the other hand, if there are not so many cars parked along the street, it makes the street very wide and that influences the drivers and they tend to drive faster.

One of the main conclusions from this thesis is that there is a conflict between driving comfort and speed reduction. The study shows that physical identities affect both vertical acceleration and crossing speed. In most cases the vertical acceleration and crossing speed work together. If a physical identity is increased for example, it can decrease both vertical acceleration and crossing speed. This would be the perfect situation when trying to decrease the vertical acceleration for round top humps at low speed. On the other hand, the study shows that in some cases there can be a conflict between these two characteristics of road humps. If a physical identity is changed to decrease vertical acceleration, it can have the affect that the crossing speed will increase. This was for example shown with the length of first ramp for gentle and long flat top humps. If the length of the first ramp is increased, it will increase K_1 and also the crossing speed. This reveals the fact that there is a conflict between comfort and speed reduction. It is understandable that road humps are designed to make them more comfortable, especially for bus drivers. This action can though have the affect that road humps will not have the wanted speed reduction ability. It is therefore important for those who design road humps to realize that there can be a conflict between driving comfort and speed. This is important to understand since increased speed raises the number of accidents.

Finally, the study shows that the 85% speed was in many cases very close to the point where the vertical acceleration started to increase rapidly. This can be seen for example at Linerovägen. This indicates that if there is a clear break point in the vertical acceleration and crossing speed connection, say around 30 km/h, then the 85% speed will be around that point. If it is possible to move this break point to a lower speed than the 85% speed will be lower. For some of the gentler flat top humps there was no clear break point in the vertical acceleration and crossing speed connection. The study shows that the 85% speed was not concentrated to any specific point for those flat top humps. In the end, it is worth mentioning that the vertical acceleration measurements were done with one specific vehicle and if the measurements are to be repeated with another vehicle, the results could be different.

5. References

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Appendix 1, Description of studied road humps

Bondevägen (road hump nr. 1)

Figure 1 Flat top hump at Bondevägen, looking south

Bondevägen is located in the west part of Lund. A flat top hump is situated in the middle of Bondevägen. The speed limit on Bondevägen is 50 km/h but close to the flat top hump the speed limit is dropped down to 30 km/h. Bondevägen connects a residential area with a business area. A green area is close to Bondevägen with path for pedestrians and cyclists. This path crosses Bondevägen and the flat top hump is used as a crossing for pedestrians and cyclists. The traffic is not that high on Bondevägen but the flow of vulnerable road user is quite high on the path that crosses Bondevägen. The flat top hump is about 7,4 m long and is quite gentle with height difference for the street and up to the hump of only 2 – 3 cm when driving south. The reason for this could be that the street is involved in the bus traffic.

Table 1 Physical identities for a flat top hump at Bondevägen

Bondevägen	Driving south	Driving north
Total length [m]	7,386	7,387
Length of top [m]	5,932	6,018
Length of first ramp [m]	0,665	0,747
Height difference [m] (up to hump)	0,025	0,080
Length of second ramp [m]	0,794	0,627
Height difference [m] (down to street)	0,085	0,034
Change in direction nr. 1 [°]	3,2	4,3
Change in direction nr. 2 [°]	3,4	4,0
Change in direction nr. 3 [°]	4,4	4,8
Change in direction nr. 4 [°]	4,1	5,2
Street width [m]	7,07	7,13

The flat top hump is made of stone slap and is clearly marked with white paint so the flat top humps should be very visible to drivers. The street is surrounded by trees which makes is difficult for drivers to see if someone is about to cross the street. This can be dangerous especially because cyclist expect the traffic to be calm and therefore often assume that they can cross the street without stopping. Since most of the drivers are familiar with cyclists' behavior, they drive more careful when they see a crossing on the street.

John Ericssons väg (road hump nr. 2)

Figure 2 Flat top hump at John Ericssons väg, looking east

Table 2 Physical identities for flat top hump at John Ericssons väg

John Ericssons väg	Driving east	Driving west
Total length [m]	11,668	11,631
Length of top [m]	9,234	9,250
Length of first ramp [m]	0,981	1,432
Height difference [m] (up to hump)	0,067	0,118
Length of second ramp [m]	1,483	0,955
Height difference [m] (down to street)	0,149	0,051
Change in direction nr. 1 [°]	6,2	2,9
Change in direction nr. 2 [°]	4,0	2,7
Change in direction nr. 3 [°]	3,6	4,9
Change in direction nr. 4 [°]	4,3	5,4
Street width [m]	6,62	6,61

John Ericssons väg is located in north Lund close to Lund Institute of Technology. John Ericssons väg splits the University area in half. The speed limit on John Ericssons väg is 50 km/h. The flat top hump situated in middle of John Ericssons väg is used as a crossing for pedestrians and cyclist. The closeness to the University creates a large flow of vulnerable road user that have to cross the street each day. John Ericssons väg is also used by public transport both by local buses and also regional buses. Even if the street is used by public transport it has not had an effect on the design of the flat top hump. The design of the flat top hump has much to do with the large amount of people that have to cross the street each day. The flat top hump on John Ericssons väg is about 11,6 m long and the ramps are quite steep. The height of the flat top hump is from 5 – 12 cm depending on the driving direction. The ramps are made of natural stones while the crown is made of stone slab. The area around the flat top hump is quite open. This means that drivers have a good view over the flat top hump and on any pedestrian or cyclist that is about to cross the street.

Kakelvägen (road humps nr. 3, 4, 5)

Figure 3 Flat top hump nr. 1 at Kakelvägen, looking south-east

Table 3 Physical identities for a flat top hump nr. 1 at Kakelvägen

Kakelvägen nr. 1	Driving south-east	Driving north-west
Total length [m]	5,256	5,142
Length of top [m]	3,114	3,082
Length of first ramp [m]	1,065	1,038
Height difference [m] (up to hump)	0,058	0,068
Length of second ramp [m]	1,079	1,027
Height difference [m] (down to street)	0,059	0,076
Change in direction nr. 1 [°]	3,2	3,6
Change in direction nr. 2 [°]	3,2	3,5
Change in direction nr. 3 [°]	2,6	4,3
Change in direction nr. 4 [°]	3,0	4,3
Street width [m]	6,56	6,53

Kakelvägen is located in south west side of Lund. There are 3 road humps on Kakelvägen, one round top hump and 2 flat top humps. Kakelvägen is in a calm residential area and the traffic is not so high, the speed limit is 30 km/h. Kakelvägen is a 6,5 m wide street and parking is allowed on one side of the street. The parking leaves only about 4 meters left for vehicles. If two vehicles meet, one of them must stop while the other drives through. This generates a calm traffic environment around Kakelvägen. Since this is a residential area there are a lot of pedestrians and cyclists. Children that live in this area have to cross Kakelvägen when going to school. Road hump nr. 3 at Kakelvägen is used as a crossing for pedestrians and cyclists. The flat top humps at Kakelvägen are not very long; the total length is about 5 m. They are almost identical with height of around 5 – 9 cm. They are both made of the same material. The ramps are made of asphalt while the crown is made of stone slab. The ramps are quite gentle and both flat top humps are marked with white paint so they are quite visible. The paint is though getting a little bit old so it can be harder to see the flat top humps at night. Road hump nr. 3 at Kakelvägen is a round top hump with total length of about 4,4 m and is quite gentle if the vehicles are going south east but otherwise not. The street is quite narrow close to the round top hump because this road hump is used as a crossing. The round top hump is well marked with white paint and signs so it should be quite visible to drivers. Since the hump is so close to houses it can be difficult for drivers to see especially cyclists that are about to cross the street.

Figure 4 Flat top hump nr. 2 at Kakelvägen, looking south-east

Table 4 Physical identities of flat top hump nr. 2 at Kakelvägen

Kakelvägen nr. 2	Driving south-east	Driving north-west
Total length [m]	5,146	5,314
Length of top [m]	2,997	3,031
Length of first ramp [m]	0,997	1,166
Height difference [m] (up to hump)	0,058	0,067
Length of second ramp [m]	2,550	1,121
Height difference [m] (down to street)	0,090	0,063
Change in direction nr. 1 [°]	3,5	3,1
Change in direction nr. 2 [°]	3,4	2,5
Change in direction nr. 3 [°]	2,3	3,1
Change in direction nr. 4 [°]	2,2	2,4
Street width [m]	6,57	6,58

Figure 5 Road hump nr. 3 at Kakelvägen, looking north-west

Table 1.5 Physical identities of hump nr. 3 at Kakelvägen

Kakelvägen nr. 3	Driving south-east	Driving north-west
Total length [m]	4,410	4,373
Length of top [m]	2,826	2,824
Length of first ramp [m]	0,931	0,656
Height difference [m] (up to hump)	0,059	0,065
Length of second ramp [m]	0,658	0,898
Height difference [m] (down to street)	0,068	0,060
Change in direction nr. 1 [°]	4,0	5,5
Change in direction nr. 2 [°]	4,2	4,4
Change in direction nr. 3 [°]	5,1	3,6
Change in direction nr. 4 [°]	5,3	4,1
Street width [m]	6,62	6,43

Kulgränden (road hump nr. 6)

Figure 6 Hump at Kulgränden, looking north

Table 6 Physical identities for a hump at Kulgränden

Kulgränden	Driving north	Driving south
Total length [m]	3,574	3,498
Length of top [m]	-	-
Length of first ramp [m]	1,779	1,730
Height difference [m] (up to hump)	0,072	0,107
Length of second ramp [m]	1,798	1,772
Height difference [m] (down to street)	0,096	0,047
Change in direction nr. 1 [°]	4,3	3,1
Change in direction nr. 2 [°]	-	-
Change in direction nr. 3 [°]	-	-
Change in direction nr. 4 [°]	4,1	3,1
Street width [m]	8,86	8,96

Kulgränden is located in northern Lund. Kulgränden is in a residential area but is a wide street, almost 9 m . The reason for this is that parking is allowed on one side of the street. The speed limit on Kulgränden is 50 km/h. Kulgränden is the only street that goes to a local school so the traffic on the street can be quite high especially when parents are dropping their children to school in the morning and picking them up in the evening. There are no buses that use this street. A round to hump is located in the middle of the segment. The round top hump is of standard design with total length about 3,5 m and a height ranging from 5 – 10 cm. Even if the round top hump is a standard design it is quite gentle. The round top hump has been painted with white paint to make it more visible but the paint is getting old so it can be difficult to see the round top hump especially in the dark. The area around the round top hump is quite open and that makes it easier for drivers to monitor the movement of pedestrians and cyclists around the street. Even if the round top hump is not used as a crossing there are a lot of vulnerable road users that use this street because of the school. These vulnerable road users are mainly young children that are not always paying an attention to traffic on the street.

Linerovägen (road hump nr. 7)

Figure 7 Flat top hump at Linerovägen, looking east

Table 7 Physical identities of a hump on Kulgränden

Linerovägen	Driving west	Driving east
Total length [m]	8,106	8,155
Length of top [m]	6,026	6,001
Length of first ramp [m]	0,916	1,113
Height difference [m] (up to hump)	0,073	0,134
Length of second ramp [m]	1,192	1,052
Height difference [m] (down to street)	0,139	0,075
Change in direction nr. 1 [°]	6,8	4,9
Change in direction nr. 2 [°]	6,3	4,7
Change in direction nr. 3 [°]	6,8	5,9
Change in direction nr. 4 [°]	4,3	6,4
Street width [m]	8,02	7,81

Linerovägen is located in east Lund. Linerovägen is not directly a residential street because other regular residential streets are connected to Linerovägen. Linerovägen is a wide street but parking is not allowed on the street. The width of the street can influence drivers speed and since Linerovägen is not a residential street the speed is quite high. In the middle of Linerovägen a flat top hump is situated. The speed limit on Linerovägen is 50 km/h but around the flat top hump the speed limit is dropped down to 30 km/h. Since Linerovägen is located in the middle of a residential area there are a lot of pedestrians and cyclists that need to cross the street. The flat top hump is used as a crossing. The flat top hump has a total length of about 8,1 m and the ramps are quite steep with a height of 7 – 13 cm. The material used in the flat top hump is stone slab and the flat top hump is very visible with white paint and signs. The area around the flat top hump is quite open so it is easy for drivers so see a pedestrian or cyclists if they are about to cross the street.

Magistratsvägen (road hump nr. 8)

Figure 8 Flat top hump at Magistratsvägen, looking east

Table 8 Physical identities of a flat top hump at Magistratsvägen

Magistratsvägen	Driving west	Driving east
Total length [m]	11,147	11,146
Length of top [m]	6,562	6,609
Length of first ramp [m]	2,498	2,046
Height difference [m] (up to hump)	0,072	0,133
Length of second ramp [m]	3,275	2,495
Height difference [m] (down to street)	0,175	0,041
Change in direction nr. 1 [°]	3,2	2,6
Change in direction nr. 2 [°]	3,3	2,6
Change in direction nr. 3 [°]	1,9	1,9
Change in direction nr. 4 [°]	2,3	2,4
Street width [m]	10,11	15,46

Magistratsvägen is located in northern part of Lund. Magistratsvägen is a wide street that collects traffic from residential streets. Since Magistratsvägen is located in a large residential area the traffic can be quite high on the street. The speed limit on Magistratsvägen is 50 km/h. A flat top hump is situated in the middle of Magistratsvägen. Magistratsvägen is located between the University area and a large student housing area. This leads to a large flow of pedestrians and cyclists. These vulnerable road users have to cross Magistratsvägen and the flat top hump is used as a crossing. The total length of the flat top hump is about 11 m and the ramps are very long which leads to, even if the height of the flat top hump is from 4 – 17 cm, a gentle flat top hump. The reason for this gentle touch can be that both local buses and regional buses use the street. To make it more comfortable for them the flat top hump has been design in this way. The flat top hump is situated close to an intersection. This location can cause a difficult traffic situation between vulnerable road users and vehicles. The material used in the flat top hump is stone slabs and some part of the flat top hump is red to make it more visible. The area around the flat top hump is open but due to the complicated traffic situation, drivers really have to pay attention.

Melins väg (road hump nr. 9)

Figure 9 Flat top hump at Melinsväg, looking north

Table 9 Physical identities of a flat top hump at Melins väg

Melinsväg	Driving south	Driving north
Total length [m]	7,966	8,080
Length of top [m]	5,929	5,951
Length of first ramp [m]	0,992	1,058
Height difference [m] (up to hump)	0,120	0,108
Length of second ramp [m]	1,056	1,082
Height difference [m] (down to street)	0,090	0,101
Change in direction nr. 1 [°]	7,9	6,1
Change in direction nr. 2 [°]	7,3	5,1
Change in direction nr. 3 [°]	3,8	5,5
Change in direction nr. 4 [°]	5,1	6,0
Street width [m]	8,15	8,06

Melins väg is located in east Lund. Melins väg connects a residential area to a larger road. Traffic is not so high at Melins väg, at least not during the day but can be higher at rush hours. In the middle of Melins väg there is a flat top hump. The speed limit is 50 km/h but around the flat top hump the speed limit is decreased to 30 km/h. Melins väg is 8 m wide but parking is not allowed on the street. The flat top hump is used as a crossing for pedestrians and cyclists. The flat top hump is about 8 m long with quite steep ramps and height of about 10 cm. The flat top hump is made of stone slab but the flat top hump is not painted white and that can make it difficult for drivers to see the flat top hump especially in the dark. The flat top hump is located in a curve so the visibility is not the best. There are also a lot of trees that may influence the visibility. A lot of signs indicate the location of the flat top hump. Even if the speed limit is 30 km/h, it can be difficult for drivers to see the sign that indicate the speed limit, because of the trees that block the signs. It can be hard to see vulnerable road users that are about to cross the street because of the area around the hump is pretty closed.

Måsvägen (road humps nr. 10, 11)

Figure 10 Hump nr. 1 at Måsvägen, looking south-west

Table 10 Physical identities of hump nr. 1 at Måsvägen

Måsvägen nr. 1	Driving north-east	Driving south-west
Total length [m]	3,571	3,596
Length of top [m]	-	-
Length of first ramp [m]	1,785	1,734
Height difference [m] (up to hump)	0,122	0,091
Length of second ramp [m]	1,792	1,868
Height difference [m] (down to street)	0,088	0,119
Change in direction nr. 1 [°]	5,1	4,9
Change in direction nr. 2 [°]	-	-
Change in direction nr. 3 [°]	-	-
Change in direction nr. 4 [°]	4,7	4,4
Street width [m]	6,30	6,09

Måsvägen is located in west Lund. Måsvägen is a residential street that only serves the area. The street is about 6 m wide and parking is allowed on one side of the street. This creates a calming traffic environment because when two vehicles come from the opposite direction one of them has to stop while the other drives through. The speed limit is 50 km/h. There are two round top humps located on the street. These are regular round top humps about 3,6 m long and with a height of 9 – 12 cm. The street is quite open so the drivers have a good visibility of the street. The round top humps are not used as a crossing but the flow of pedestrians and cyclists is quite high on the street. The round top humps are very visible and are painted with white paint. Since the street is so narrow and it is possible to park vehicles along the street, the visibility for drivers can be limited. This has especially to do with young children that may cross the street with out paying an attention to the traffic on the street.

Figure 11 Hump nr. 2 at Måsvägen, looking north-east

Table 11 Physical identities of hump nr. 2 at Måsvägen

Måsvägen nr. 2	Driving north-east	Driving south-west
Total length [m]	3,602	3,566
Length of top [m]	-	-
Length of first ramp [m]	1,625	1,985
Height difference [m] (up to hump)	0,147	0,049
Length of second ramp [m]	1,984	1,587
Height difference [m] (down to street)	0,085	0,139
Change in direction nr. 1 [°]	5,4	4,5
Change in direction nr. 2 [°]	-	-
Change in direction nr. 3 [°]	-	-
Change in direction nr. 4 [°]	5,8	5,4
Street width [m]	6,63	6,63

Ole Römers väg (road hump nr. 12)

Figure 12 Flat top hump at Ole Römers väg, looking south

Table 12 Physical identities of flat top hump at Ole Römers väg

Ole Römers väg	Driving north	Driving south
Total length [m]	31,743	32,527
Length of top [m]	27,746	28,612
Length of first ramp [m]	2,042	1,962
Height difference [m] (up to hump)	0,056	0,064
Length of second ramp [m]	1,958	1,955
Height difference [m] (down to street)	0,088	0,062
Change in direction nr. 1 [°]	2,8	3,7
Change in direction nr. 2 [°]	1,4	1,6
Change in direction nr. 3 [°]	2,2	1,8
Change in direction nr. 4 [°]	4,6	3,2
Street width [m]	8,07	7,33

Ole Römers väg is located in northern Lund. The street is located on the border between the university area and an industrial area. Because of this location, traffic on Ole Römers väg is rather high. In the middle of Ole Römers väg there is a raised intersection that can be treated as a flat top hump. The speed limit on Ole Römers väg is 50 km/h. Both local and regional buses use the street. The traffic of pedestrians and cyclists is high because of the university. This flat top hump is very long, over 32 m. The ramps of the flat top hump are not very steep and the main reason for that is the public transport traffic. The visibility around the flat top hump is good but because of the intersection, the traffic situation can sometimes be quite difficult. This can be especially difficult during rush hour in the morning. The flat top hump is newly rebuilt and is made of stone slap. The flat top hump is also well marked with sign and white paint so visibility should not be a problem. The area around the flat top hump is open so it should not be difficult for drivers to see pedestrians or cyclists that are about to cross the street.

Skjutbanevägen (road hump nr. 13)

Figure 13 Flat top hump at Skjutbanevägen, looking north-east

Table 13 Physical identities of a flat top hump at Skjutbanevägen

Skjutbanevägen	Driving north-east	Driving south-west
Total length [m]	21,817	21,787
Length of top [m]	19,768	19,669
Length of first ramp [m]	1,033	1,047
Height difference [m] (up to hump)	0,110	0,059
Length of second ramp [m]	1,025	1,077
Height difference [m] (down to street)	0,078	0,089
Change in direction nr. 1 [°]	5,2	4,0
Change in direction nr. 2 [°]	4,8	4,4
Change in direction nr. 3 [°]	5,1	3,8
Change in direction nr. 4 [°]	5,4	4,0
Street width [m]	9,03	8,95

Skjutbanevägen is located in northern Lund. Skjutbanevägen serves the purpose of collecting traffic from residential street. The street is about 9 m wide and car parking is allowed on one side of the street. The speed limit is 50 km/h. In the middle of Skjutbanevägen there is almost an 21,8 m long flat top hump with pretty steep ramps. Since children have to cross the street to go to school, there is a high flow of pedestrians and cyclists crossing the street. The flat top hump is therefore used as a crossing for vulnerable road users. This specially applies to younger children. Since the street is wide the speed can be quite high at Skjutbanevägen. Car parking along the street can though reduce speed. The flat top hump is made of stone slab but is not painted white so it can be difficult for drivers to see the flat top hump especially in the dark. The area around the flat top hump is open so the visibility for drivers is good. It should not be a problem for drivers to see vulnerable road users crossing the street.

Sunnanväg (road hump nr. 14)

Figure 14 Flat top hump at Sunnanväg, looking east

Table 14 Physical identites of a flat top hump at Sunnanväg

Sunnanväg	Driving east	Driving west
Total length [m]	6,511	6,436
Length of top [m]	4,045	4,007
Length of first ramp [m]	1,244	1,185
Height difference [m] (up to hump)	0,074	0,080
Length of second ramp [m]	1,225	1,249
Height difference [m] (down to street)	0,037	0,084
Change in direction nr. 1 [°]	4,5	2,8
Change in direction nr. 2 [°]	4,4	3,3
Change in direction nr. 3 [°]	3,2	1,9
Change in direction nr. 4 [°]	3,3	2,2
Street width [m]	7,10	9,93

Sunnanväg is located in south Lund. Sunnanväg serves as an collecting street for other residential streets and the speed limit is 50 km/h. This character of Sunnanväg produces a rather high traffic flow. The street is wide or between 7 and 10 m. This can increase speed and make it more difficult for vulnerable road user to cross the street. A flat top hump is situated on Sunnanväg to make it easier for vulnerable road users to cross the street. The flat top hump is located near an intersection that makes the traffic situation more difficult. The flat top hump is 6,5 m long and has a height ranging from 4 – 8 cm. The flat top hump can be classified as gentle and the main reason for this design on this particular street is public transport. Sunnanväg is involved in the local bus net. The flat top hump is made of stone slab and the crown is in red stones to make it more visible. The area around the flat top hump is open and that makes it easier for drivers to see vulnerable road user when they are about to cross the street. The only thing that might take away drivers attention is the closeness to the intersection. Drivers might be thinking about turning at the intersection before even crossing the flat top hump.

Svanevägen (road hump nr. 15)

Figure 15 Flat top hump at Svanevägen, looking south-east

Table 15 Physical identities for a flat top hump at Svanevägen

Svanevägen	Driving north-west	Driving south-east
Total length [m]	5,965	5,918
Length of top [m]	4,008	4,002
Length of first ramp [m]	0,983	0,912
Height difference [m] (up to hump)	0,087	0,087
Length of second ramp [m]	0,983	1,013
Height difference [m] (down to street)	0,103	0,099
Change in direction nr. 1 [°]	4,3	6,0
Change in direction nr. 2 [°]	4,2	6,0
Change in direction nr. 3 [°]	6,5	4,4
Change in direction nr. 4 [°]	6,5	5,0
Street width [m]	6,09	8,08

Svanevägen is located close to the center of Lund. Since this is one of the streets that are connected to the center the traffic is quite high at Svanevägen. The street is 8 m wide but the one end of the street is narrower as it enters the Lund center. The speed limit on Svanevägen is 50 km/h but as vehicle enter Lund center the speed limit is 30 km/h. Since the street is wide the speed can be high. Svanevägen is close to a school so the flow of pedestrians and cyclists is high. In the middle of Svanevägen there is a flat top hump. The flat top hump is situated to make it easier for vulnerable road user to cross the street, especially school children. The flat top hump on Svanevägen is about 6 m long and has a height of 9 – 10 cm. Svanevägen is narrowed down close to the flat top hump to make the walking distance for vulnerable road users shorter. The flat top hump is made of natural stone and has been painted white but with time this paint has fainted. There are trees along the street that could influence the visibility around the flat top hump but in general the visibility is good and drivers should be able to see pedestrians and cyclists that are about to cross the street on the flat top hump.

Östanväg (road humps nr. 16, 17, 18)

Figure 16 Flat top hump nr. 1 at Östanväg, looking south

Table 16 Physical identities of flat top hump nr. 1 at Östanväg

Östanväg nr. 1	Driving north	Driving south
Total length [m]	17,529	17,621
Length of top [m]	15,548	15,521
Length of first ramp [m]	1,022	1,054
Height difference [m] (up to hump)	0,11	0,083
Length of second ramp [m]	0,968	1,056
Height difference [m] (down to street)	0,085	0,119
Change in direction nr. 1 [°]	5,7	5,1
Change in direction nr. 2 [°]	5,4	4,8
Change in direction nr. 3 [°]	5,2	5,8
Change in direction nr. 4 [°]	5,5	5,8
Street width [m]	7,32	7,19

Östanväg is located in south Lund. The street is a residential street. The street is about 7 m wide and car parking is allowed on one side of the street. This creates a calm traffic environment because vehicles have to slow down when they are passing each other. On Östanväg there are three flat top humps that are very long and steep. The total length of the flat top humps varies from 11 – 21 m and the height from 8 – 14 cm. Since Östanväg is located close to a large residential area, the flow of pedestrians and cyclists is high. To make it easier for vulnerable road user to cross the street all the flat top humps are used as crossings. The flow of pedestrians and cyclists is high but since the traffic is quite calm the traffic situation at Östanväg is good. All the flat top humps are made of stone slab. The flat top humps have not been painted with any white paint and that can make it more difficult for drivers to see them especially when it is dark. The visibility around the flat top hump is fairly good but since parking is allowed along the street, it could cause a problem for drivers. It can be difficult for drivers to see especially children that appear between parked cars and run across the street.

Figure 17 Flat top hump nr . 2 at Östanväg, looking north

Table 17 Physical identities of flat top hump nr. 2 at Östanväg

Östanväg nr. 2	Driving north	Driving south
Total length [m]	11,499	11,633
Length of top [m]	9,355	9,451
Length of first ramp [m]	1,164	1,067
Height difference [m] (up to hump)	0,118	0,085
Length of second ramp [m]	0,992	1,122
Height difference [m] (down to street)	0,104	0,096
Change in direction nr. 1 [°]	5,5	4,9
Change in direction nr. 2 [°]	5,4	4,9
Change in direction nr. 3 [°]	6,3	4,3
Change in direction nr. 4 [°]	6,5	4,6
Street width [m]	7,46	7,33

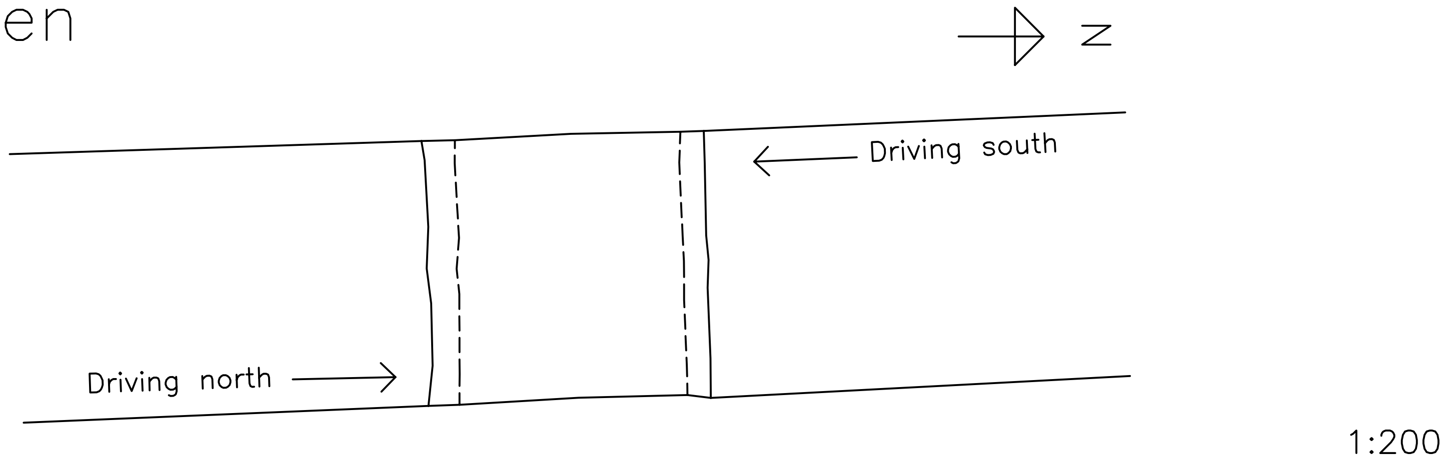
Figure 18 Flat top hump nr. 3 at Östanväg, looking north

Table 18 Physical identities of fla top hump nr. 3 at Östanväg

Östanväg nr. 3	Driving north	Driving south
Total length [m]	11,655	11,543
Length of top [m]	9,430	9,475
Length of first ramp [m]	1,126	1,060
Height difference [m] (up to hump)	0,109	0,092
Length of second ramp [m]	1,109	1,020
Height difference [m] (down to street)	0,106	0,138
Change in direction nr. 1 [°]	4,8	5,8
Change in direction nr. 2 [°]	4,7	5,7
Change in direction nr. 3 [°]	6,2	7,0
Change in direction nr. 4 [°]	6,3	7,1
Street width [m]	7,23	7,61

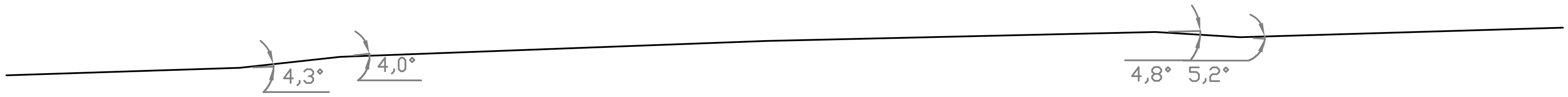
Appendix 2, Road humps profiles

Bondevägen



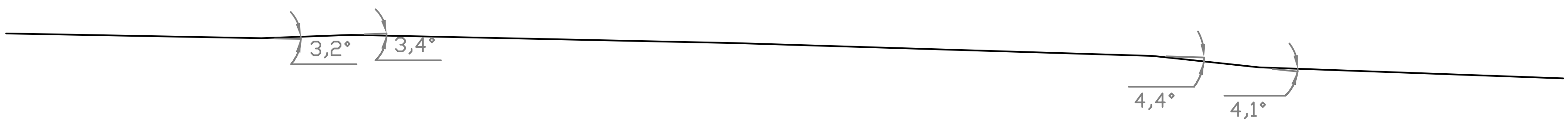
Profile driving north

St.	Height
0,000	48.736
10,833	49,083
11,576	49,163
14,720	49,163
17,594	49,345
18,220	49,307
29,289	49,632



Profile driving south

St.	Height
0,000	49.520
11,097	49,313
11,762	49,338
14,595	49,277
17,694	49,182
18,483	49,097
29,332	48,705



Driving north

Length of hump: 7,387 m
Lenght of top: 6,018 m
Street wide north: 7,07 m
Street wide south: 7,13 m
Car parking on street: NO

First ramp
Ramp length: 0,747 m
Height change: 0,080 m

Second ramp
Ramp length: 0,627 m
Height change: 0,038 m

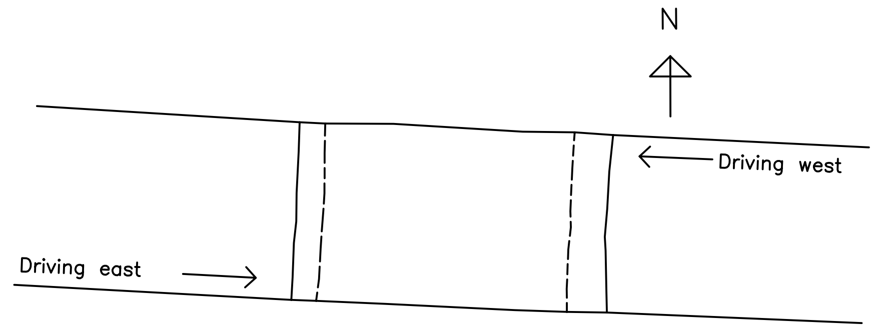
Driving south

Length of hump: 7,386 m
Lenght of top: 5,932 m
Street wide north: 7,07 m
Street wide south: 7,13 m
Car parking on street: NO

First ramp
Ramp length: 0,665 m
Height change: 0,025 m

Second ramp
Ramp length: 0,794 m
Height change: 0,085 m

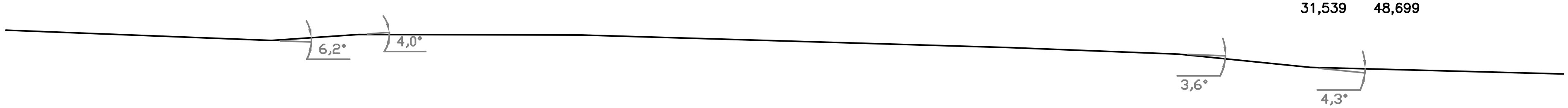
John Ericssons väg



1:200

Profile driving east

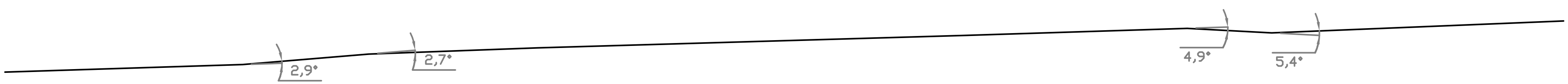
St.	Height
0,000	49,652
10,243	49,252
11,222	49,319
13,735	49,314
18,543	49,172
20,456	49,098
21,931	48,949
31,539	48,699



1:50

Profile driving west

St.	Height
0,000	48,772
9,547	49,074
10,974	49,192
12,882	49,261
17,716	49,402
20,224	49,481
21,178	49,430
31,009	49,828



1:50

Driving east

Length of hump: 11,668 m
Lenght of top: 9,234 m
Street wide east: 6,61 m
Street wide west: 6,62 m
Car parking on street: NO

First ramp
Ramp length: 0,981 m
Height change: 0,067 m

Second ramp
Ramp length: 1,483 m
Height change: 0,149 m

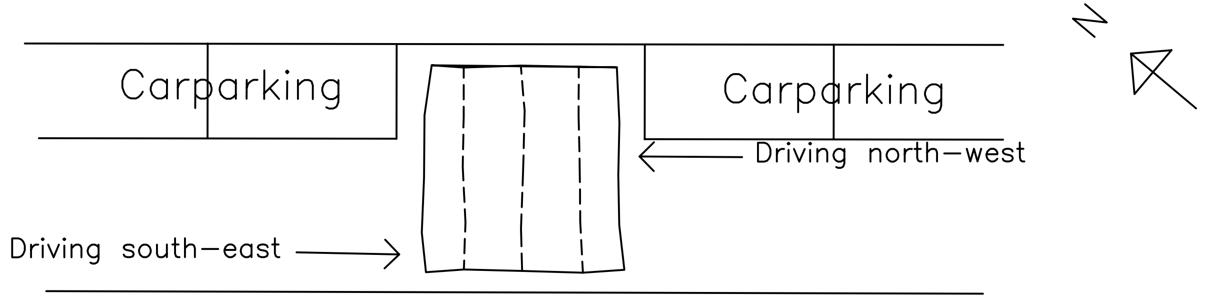
Driving west

Length of hump: 11,631 m
Lenght of top: 9,250 m
Street wide east: 6,61 m
Street wide west: 6,62 m
Car parking on street: NO

First ramp
Ramp length: 1,432 m
Height change: 0,118 m

Second ramp
Ramp length: 0,955 m
Height change: 0,051 m

Kakelvägen nr. 1



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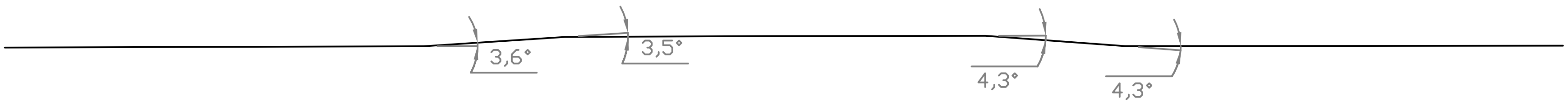
Profile driving north–west

St.	Height
0,000	49,859
10,091	49,888
11,127	49,956
12,603	49,963
14,209	49,965
15,233	49,889
25,378	49,901



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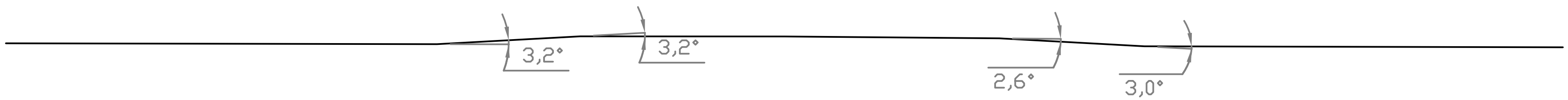
Profile driving south–east

St.	Height
0,000	49,869
10,063	49,849
11,127	49,907
12,645	49,906
14,241	49,892
15,319	49,833
25,004	49,808



1:50

Driving NW

Length of hump: 5,142 m
Lenght of top: 3,082 m
Street wide NW: 6,53 m
Street wide SE: 6,56 m
Car parking on street: YES

First ramp
Ramp length: 1,038 m
Height change: 0,068 m

Second ramp
Ramp length: 1,027 m
Height change: 0,076 m

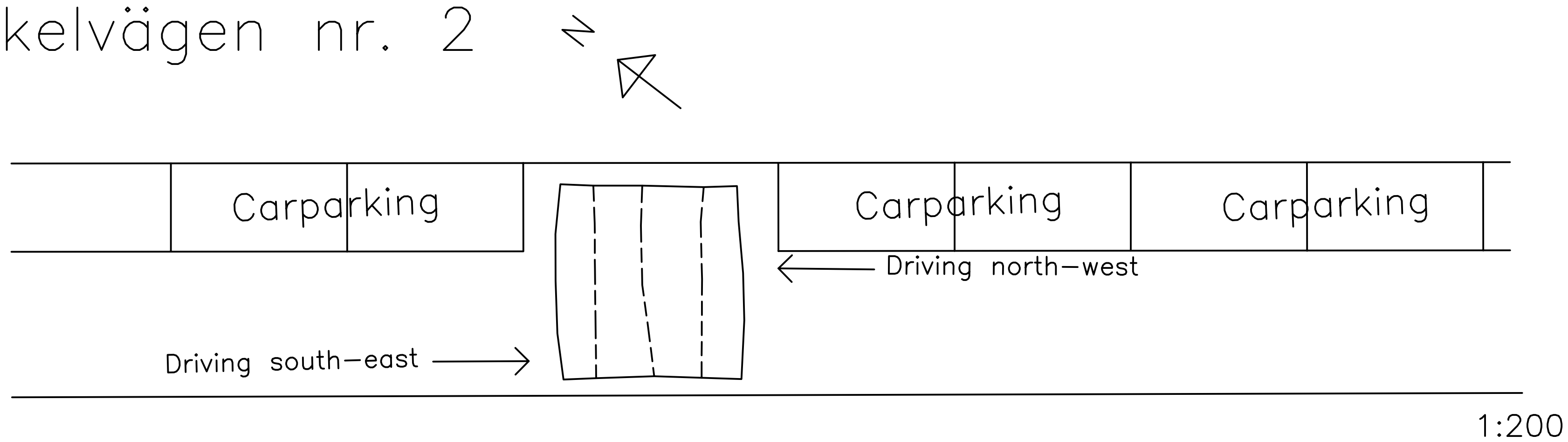
Driving SE

Length of hump: 5,256 m
Lenght of top: 3,114 m
Street wide NW: 6,53 m
Street wide SE: 6,56 m
Car parking on street: NO

First ramp
Ramp length: 1,065 m
Height change: 0,058 m

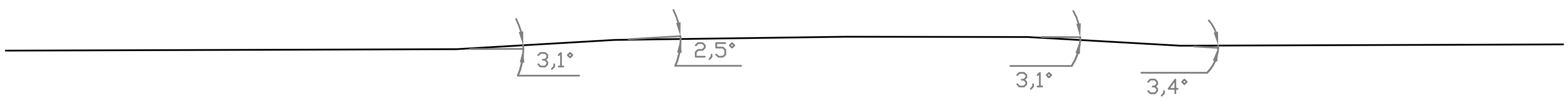
Second ramp
Ramp length: 1,079 m
Height change: 0,059 m

Kakelvägen nr. 2



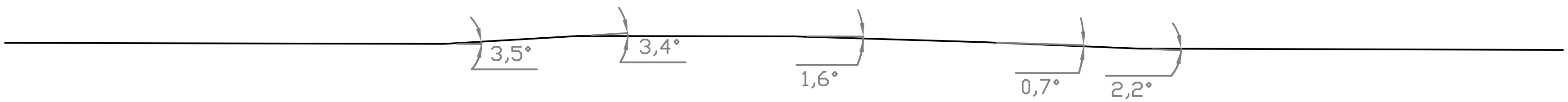
Profile driving north–west

St.	Height
0,000	50,145
22,000	50,222
23,164	50,289
24,861	50,312
26,195	50,310
27,314	50,247
42,706	50,296



Profile driving south–east

St.	Height
0,000	50,222
15,537	50,183
16,532	50,241
18,131	50,238
19,529	50,196
20,683	50,148
42,794	50,083



Driving NW

Length of hump: 5,314 m
Lenght of top: 3,031 m
Street wide NW: 6,58 m
Street wide SE: 6,57 m
Car parking on street: YES

First ramp
Ramp length: 1,166 m
Height change: 0,067 m

Second ramp
Ramp length: 1,121 m
Height change: 0,063 m

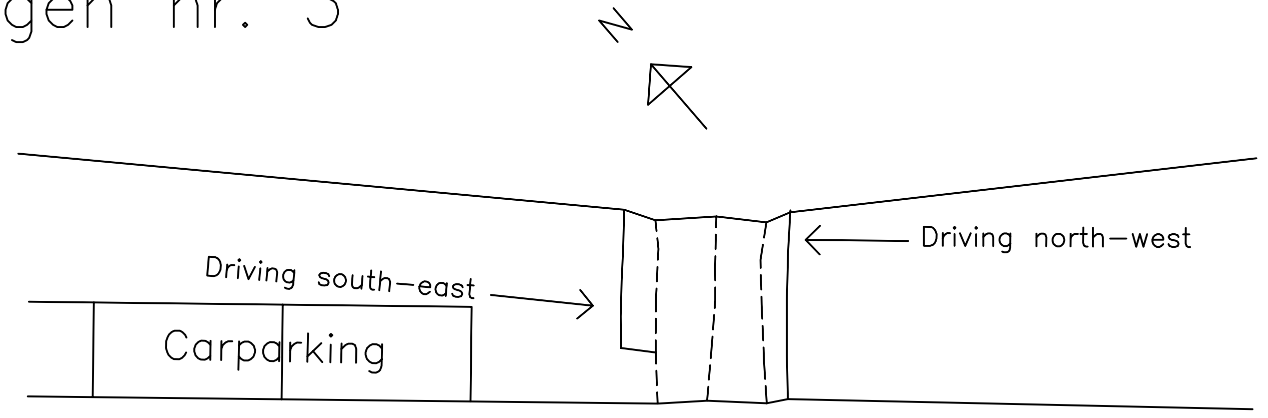
Driving SE

Length of hump: 5,146 m
Lenght of top: 2,997 m
Street wide NW: 6,58 m
Street wide SE: 6,57 m
Car parking on street: NO

First ramp
Ramp length: 0,997 m
Height change: 0,058 m

Second ramp
Ramp length: 2,550 m
Height change: 0,090 m

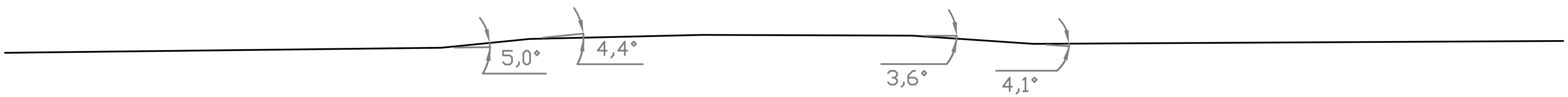
Kakelvägen nr. 3



1:200

Profile driving north-west

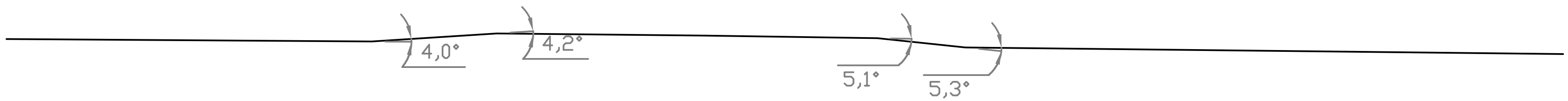
St.	Height
0,000	50,293
12,438	50,433
13,091	50,498
14,366	50,527
15,915	50,522
16,811	50,462
32,747	50,547



1:50

Profile driving south-east

St.	Height
0,000	50,570
15,863	50,467
16,792	50,526
18,340	50,510
19,618	50,491
20,273	50,423
32,659	50,286



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Driving NW

Length of hump: 4,373 m
Lenght of top: 2,824 m
Street wide NW: 6,43 m
Street wide SE: 6,62 m
Car parking on street: NO

First ramp
Ramp length: 0,656 m
Height change: 0,065 m

Second ramp
Ramp length: 0,898 m
Height change: 0,060 m

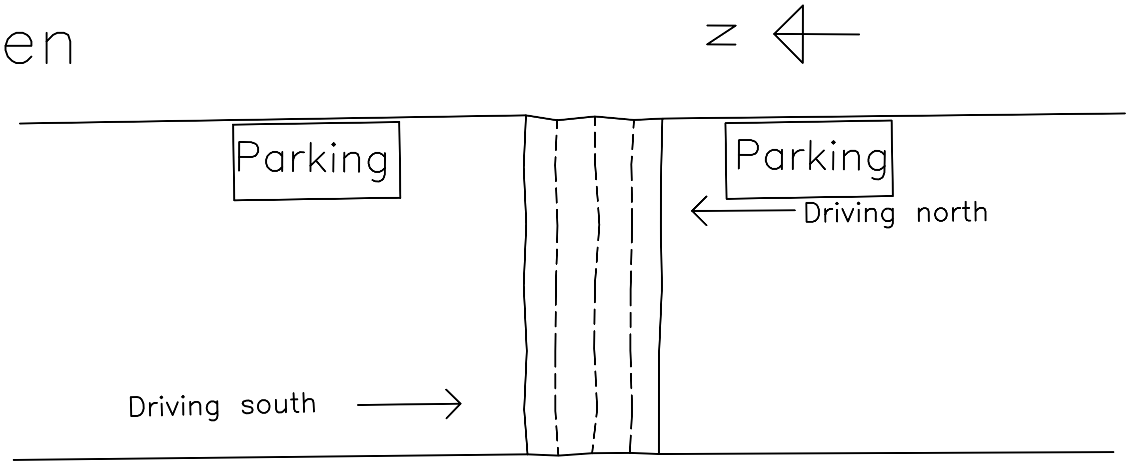
Driving SE

Length of hump: 4,410 m
Lenght of top: 2,826 m
Street wide NW: 6,43 m
Street wide SE: 6,62 m
Car parking on street: YES

First ramp
Ramp length: 0,931 m
Height change: 0,059 m

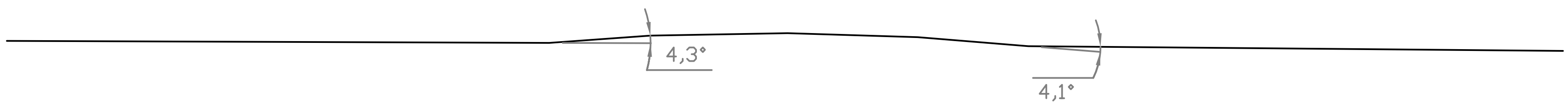
Second ramp
Ramp length: 0,658 m
Height change: 0,068 m

Kulgränden



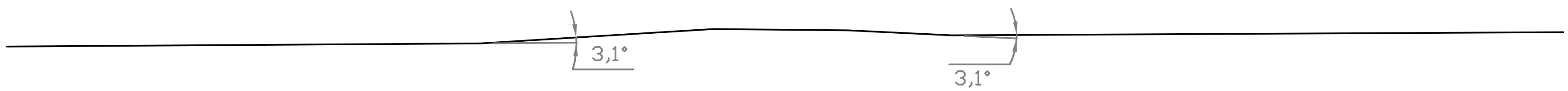
Profile driving north

St.	Height
0,000	50,084
12,983	50,037
13,738	50,091
14,761	50,109
15,732	50,079
16,557	50,013
29,925	49,893



Profile driving south

St.	Height
0,000	49,873
13,556	49,965
14,372	50,015
15,283	50,072
16,288	50,062
17,054	50,025
29,116	50,086



Driving north

Length of hump: 3,574 m
Lenght of top: – m
Street wide north: 8,958 m
Street wide south: 8,863 m
Car parking on street: YES

First ramp
Ramp length: 1,779 m
Height change: 0,072 m

Second ramp
Ramp length: 1,798 m
Height change: 0,096 m

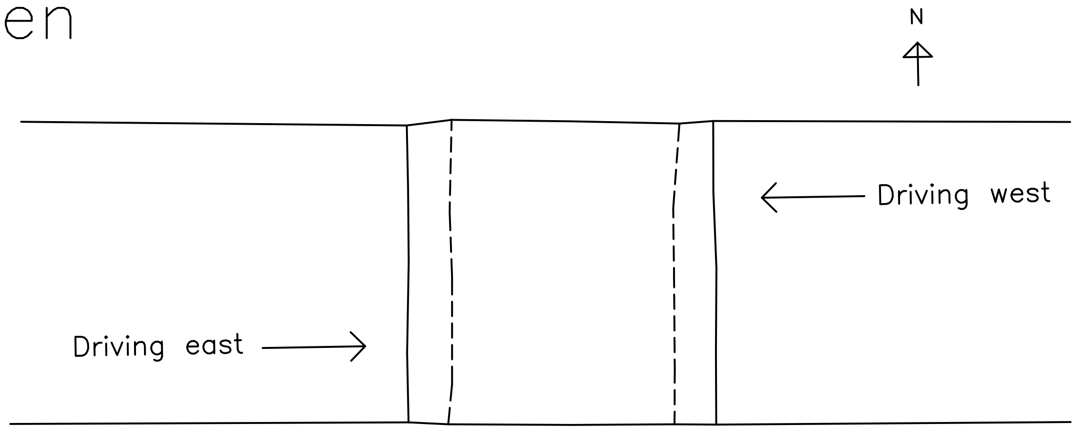
Driving south

Length of hump: 3,498 m
Lenght of top: – m
Street wide north: 8,958 m
Street wide south: 8,863 m
Car parking on street: NO

First ramp
Ramp length: 1,730 m
Height change: 0,107 m

Second ramp
Ramp length: 1,772 m
Height change: 0,047 m

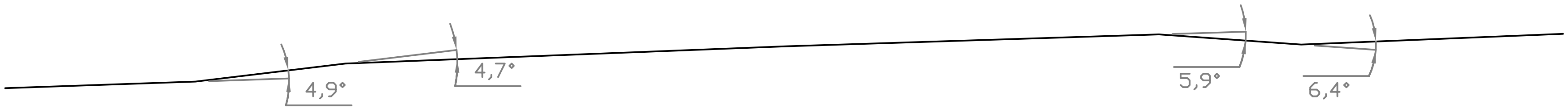
Linerovägen



1:200

Profile driving east

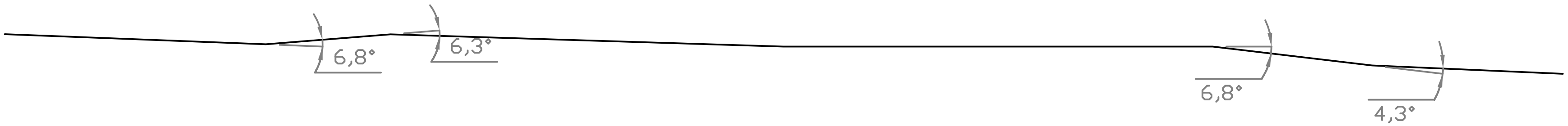
St.	Height
0,000	50,352
10,454	50,714
11,559	50,848
14,817	50,975
17,560	51,988
18,609	50,988
28,000	51,372



1:50

Profile driving west

St.	Height
0,000	51,372
9,436	51,004
10,349	51,077
13,227	50,988
16,375	50,886
17,542	50,747
27,787	50,400



1:50

Driving east

Length of hump: 8,155 m
Lenght of top: 6,001 m
Street wide west: 7,810 m
Street wide east: 8,018 m
Car parking on street: NO

First ramp
Ramp length: 1,113 m
Height change: 0,134 m

Second ramp
Ramp length: 1,052 m
Height change: 0,075 m

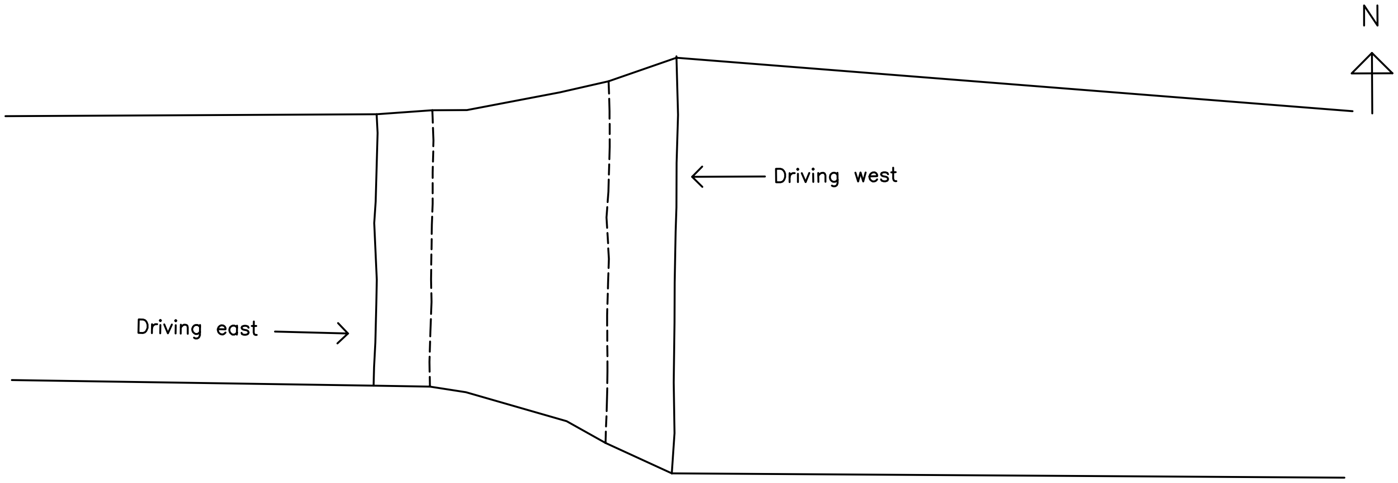
Driving west

Length of hump: 8,106 m
Lenght of top: 6,026 m
Street wide west: 7,810 m
Street wide east: 8,018 m
Car parking on street: NO

First ramp
Ramp length: 0,916 m
Height change: 0,073 m

Second ramp
Ramp length: 1,192 m
Height change: 0,139 m

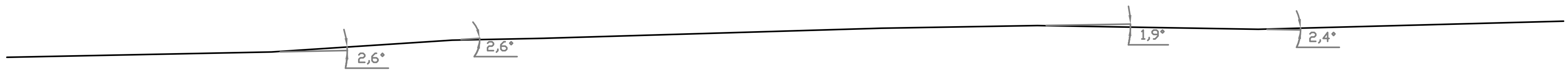
Magistratsvägen



1:200

Profile driving east

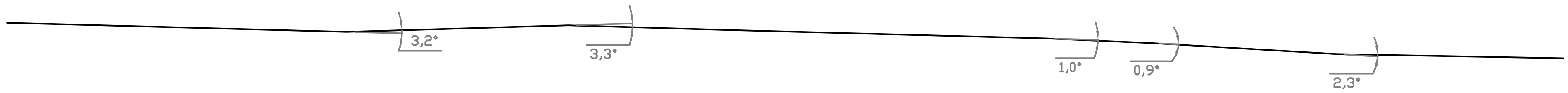
St.	Height
0,000	50,525
13,333	50,789
15,375	50,922
16,407	50,943
20,222	51,056
21,984	51,085
24,479	51,044
49,689	51,704



1:50

Profile driving west

St.	Height
0,000	51,652
25,121	50,991
27,618	51,063
29,421	51,011
32,998	50,917
34,180	50,866
36,268	50,742
50,099	50,484



1:50

Driving east

Length of hump: 11,146 m
Lenght of top: 6,609 m
Street wide east: 10,110 m
Street wide west: 15,458 m
Car parking on street: NO

First ramp
Ramp length: 2,046 m
Height change: 0,133 m

Second ramp
Ramp length: 2,495 m
Height change: 0,041 m

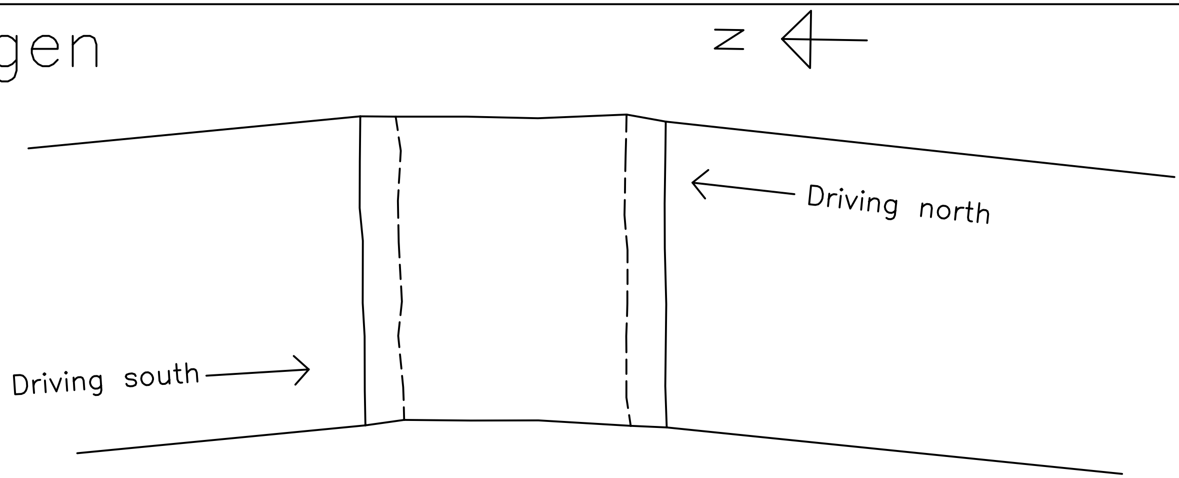
Driving west

Length of hump: 11,147 m
Lenght of top: 6,562 m
Street wide east: 10,110 m
Street wide west: 15,458 m
Car parking on street: NO

First ramp
Ramp length: 2,498 m
Height change: 0,072 m

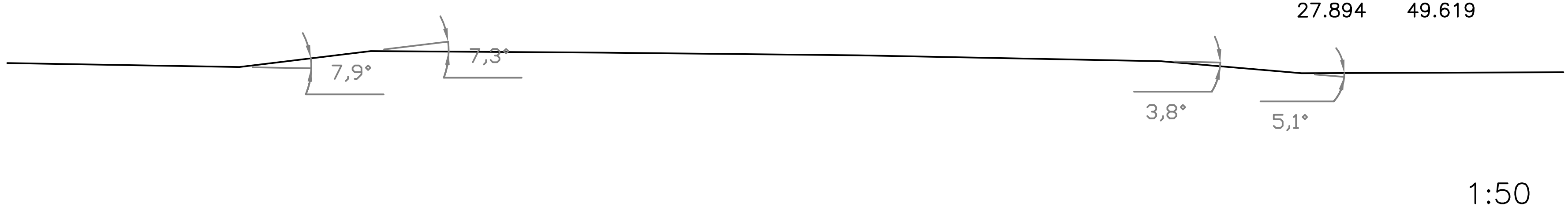
Second ramp
Ramp length: 3,275 m
Height change: 0,175 m

Melinsvägen



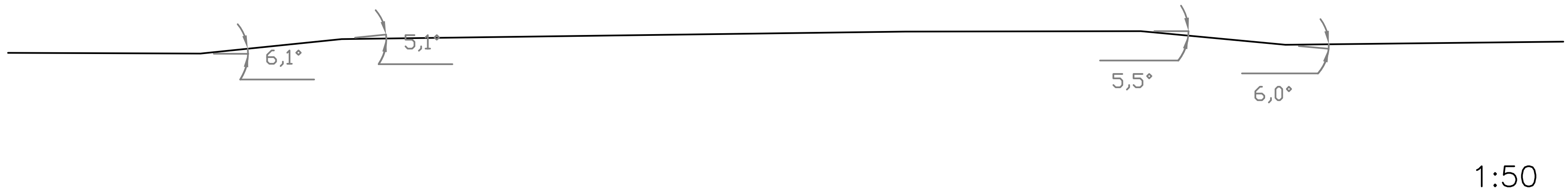
Profile driving south

St.	Height
0,000	49.749
7.676	49.616
8.661	49.736
10.396	49.724
12.319	49.704
14.590	49.659
15.642	49.569
27.894	49.619



Profile driving north

St.	Height
0,000	49,616
13,060	49,564
14,112	49,672
16,409	49,703
18,308	49,728
20,063	49,731
21,140	49,630
29,726	49,728



Driving south

Length of hump: 7,966 m
Lenght of top: 5,929 m
Street wide sout: 8,064 m
Street wide north: 8,152 m
Car parking on street: YES

First ramp
Ramp length: 0,992 m
Height change: 0,120 m

Second ramp
Ramp length: 1,056 m
Height change: 0,090 m

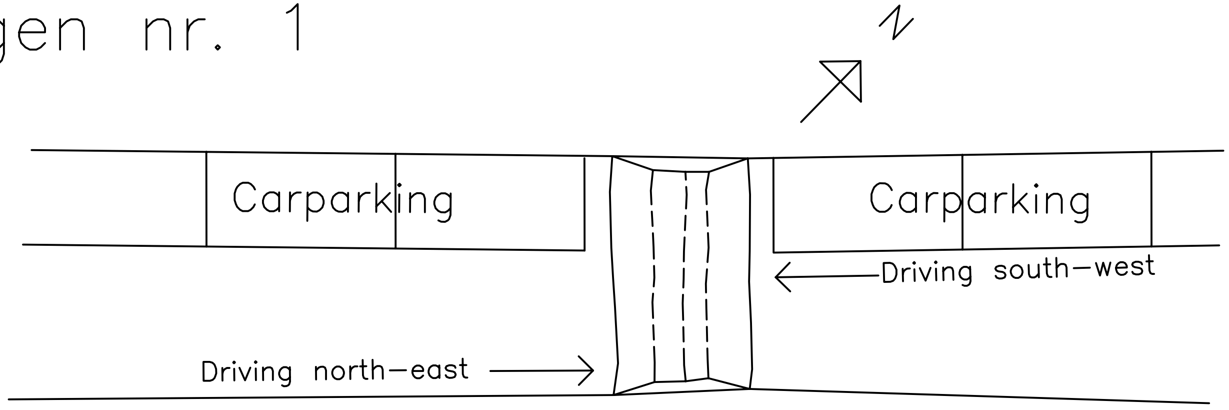
Driving north

Length of hump: 8,080 m
Lenght of top: 5,951 m
Street wide sout: 8,064 m
Street wide north: 8,152 m
Car parking on street: NO

First ramp
Ramp length: 1,058 m
Height change: 0,108 m

Second ramp
Ramp length: 1,082 m
Height change: 0,101 m

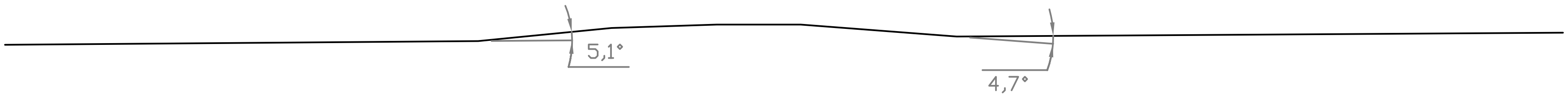
Måsvägen nr. 1



1:200

Profile driving north-east

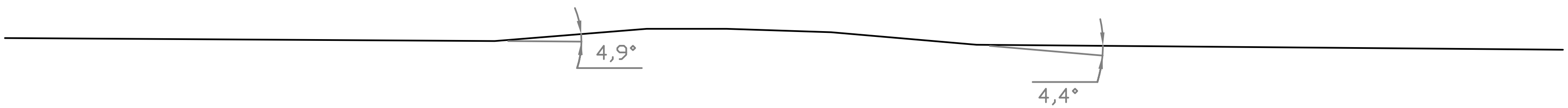
St.	Height
0,000	50,213
15,997	50,339
16,991	50,436
17,778	50,461
18,404	50,461
19,568	50,373
31,715	50,449



1:50

Profile driving south-west

St.	Height
0,000	50,510
12,433	50,433
13,567	50,515
14,165	50,524
14,943	50,498
16,029	50,405
31,727	50,274



1:50

Driving NE

Length of hump: 3,571 m
Lenght of top: – m
Street wide SW: 6,30 m
Street wide NE: 6,09 m
Car parking on street: NO

First ramp
Ramp length: 1,785 m
Height change: 0,122 m

Second ramp
Ramp length: 1,792 m
Height change: 0,088 m

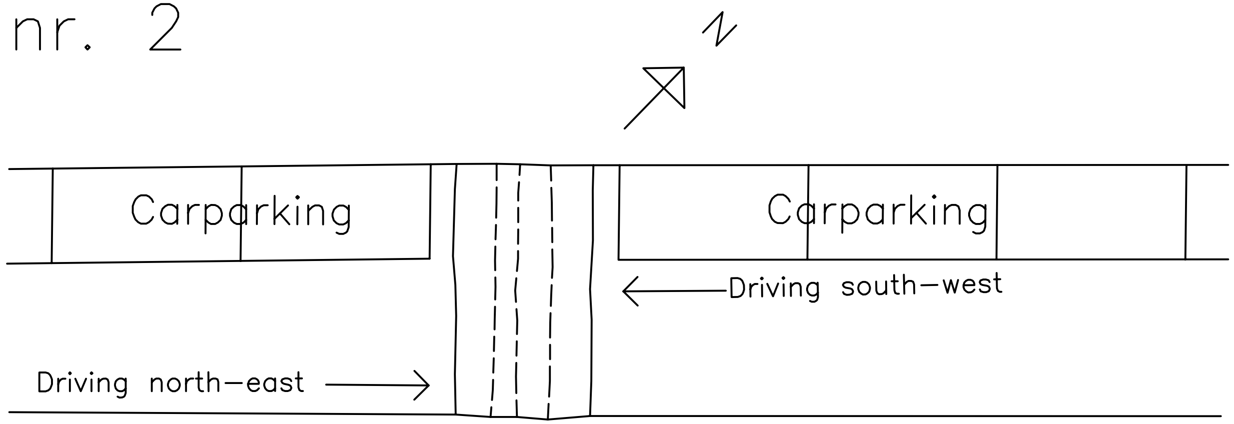
Driving SW

Length of hump: 3,596 m
Lenght of top: – m
Street wide SW: 6,30 m
Street wide NE: 6,09 m
Car parking on street: YES

First ramp
Ramp length: 1,734 m
Height change: 0,091 m

Second ramp
Ramp length: 1,868 m
Height change: 0,119 m

Måsvägen nr. 2



1:200

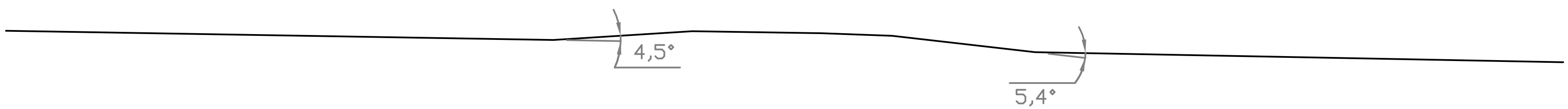
Profile driving north–east

St.	Height
0,000	48,478
11,833	48,707
12,837	48,822
13,452	48,854
14,336	48,861
15,435	48,769
32,151	49,072

1:50

Profile driving south–west

St.	Height
0,000	49.119
16,801	48,837
17,830	48,901
18,786	48,886
19,309	48,867
20,367	48,747
32,273	48,521



1:50

Driving NE

Length of hump: 3,602 m
Lenght of top: – m
Street wide SW: 6,63 m
Street wide NE: 6,63 m
Car parking on street: NO

First ramp
Ramp length: 1,625 m
Height change: 0,147 m

Second ramp
Ramp length: 1,984 m
Height change: 0,085 m

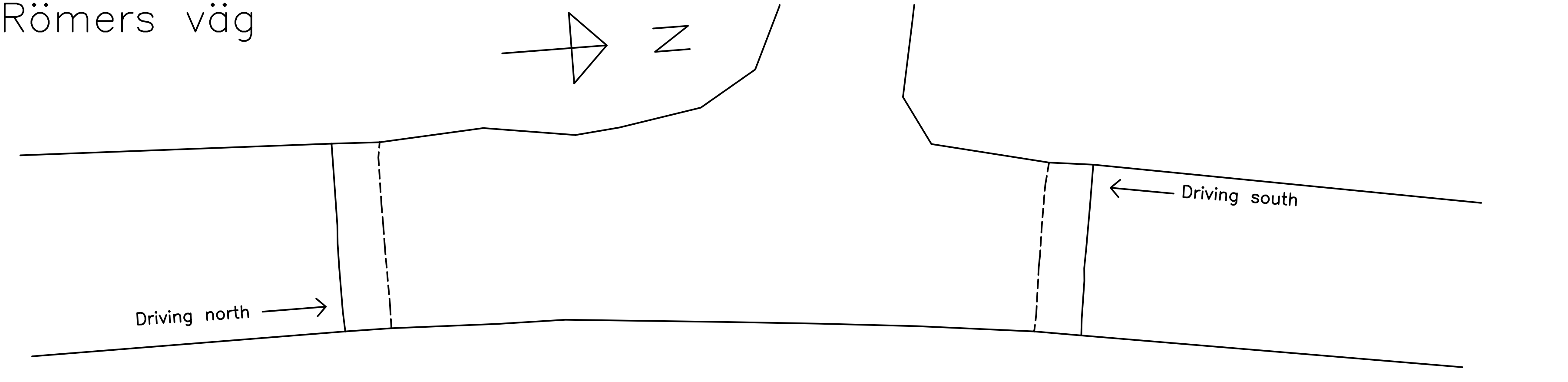
Driving SW

Length of hump: 3,566 m
Lenght of top: – m
Street wide SW: 6,63 m
Street wide NE: 6,63 m
Car parking on street: YES

First ramp
Ramp length: 1,985 m
Height change: 0,049 m

Second ramp
Ramp length: 1,587 m
Height change: 0,139 m

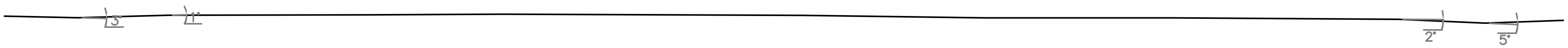
Ole Römers väg



1:200

Profile driving north

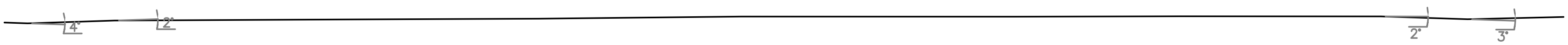
St.	Height
0,000	49,441
13,363	49,146
15,404	49,202
19,911	49,213
22,944	49,228
29,721	49,200
33,813	49,179
38,087	49,144
43,150	49,112
45,106	49,024
61,601	49,601



1:100

Profile driving south

St.	Height
0,000	49,585
16,593	49,049
18,554	49,113
23,581	49,136
28,132	49,155
32,714	49,201
38,860	49,198
42,620	49,206
47,166	49,203
49,120	49,141
62,526	49,456



1:100

Driving north

Length of hump: 31,743 m
Lenght of top: 27,746 m
Street wide north: 7,33 m
Street wide south: 8,07 m
Car parking on street: NO

First ramp
Ramp length: 2,042 m
Height change: 0,056 m

Second ramp
Ramp length: 1,958 m
Height change: 0,088 m

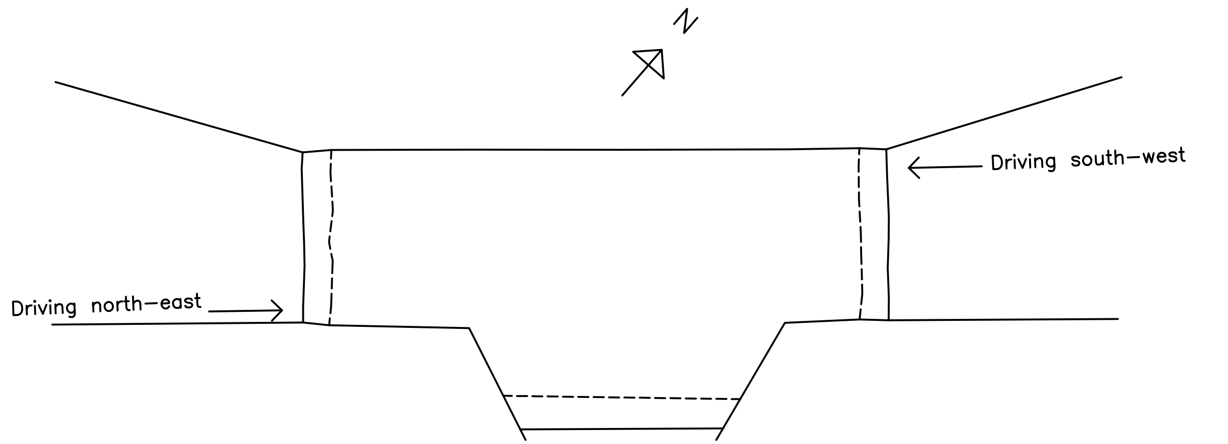
Driving south

Length of hump: 32,527 m
Lenght of top: 28,612 m
Street wide north: 7,33 m
Street wide south: 8,07 m
Car parking on street: NO

First ramp
Ramp length: 1,962 m
Height change: 0,064 m

Second ramp
Ramp length: 1,955 m
Height change: 0,062 m

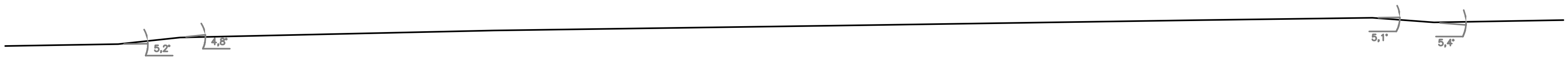
Skjutbanevägen



1:200

Profile driving north–east

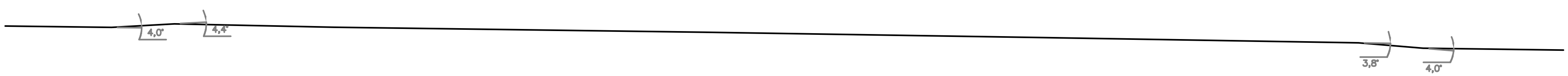
St.	Height
0,000	49,158
9,289	49,309
10,316	49,419
15,517	49,535
21,485	49,619
27,266	49,708
30,084	49,746
31,106	49,668
39,567	49,820



1:75

Profile driving south–west

St.	Height
0,000	49,862
8,805	49,743
9,850	49,802
12,498	49,746
18,632	49,663
24,286	49,574
29,519	49,486
30,592	49,397
39,899	49,270



1:75

Driving NE

Length of hump: 21,817 m
Lenght of top: 19,768 m
Street wide NE: 8,95 m
Street wide SW: 9,03 m
Car parking on street: NO

First ramp
Ramp length: 1,033 m
Height change: 0,110 m

Second ramp
Ramp length: 1,025 m
Height change: 0,078 m

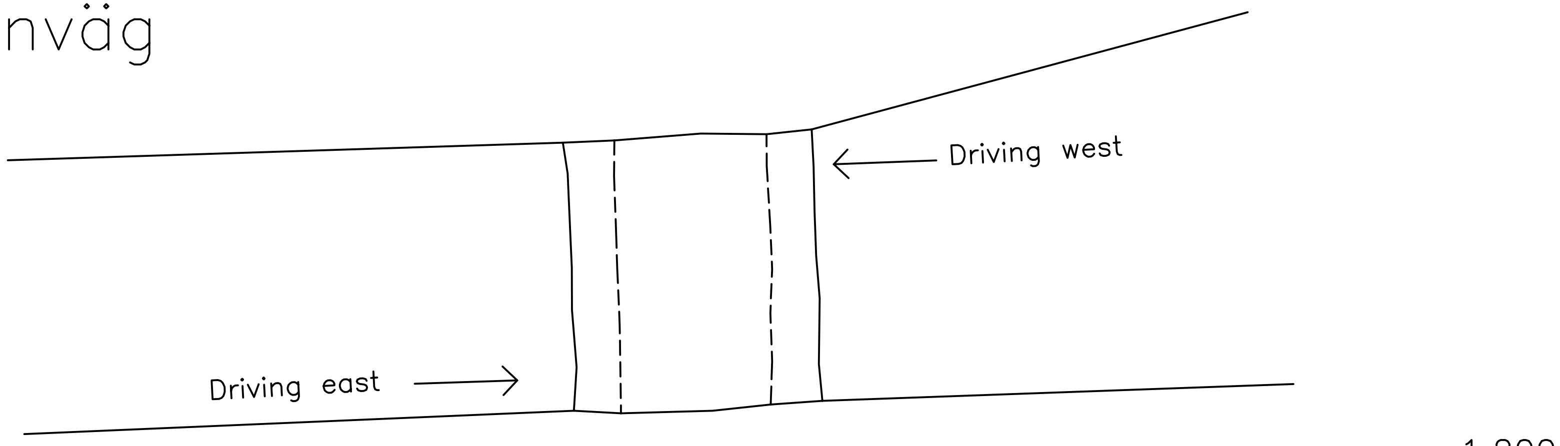
Driving SW

Length of hump: 21,787 m
Lenght of top: 19,669 m
Street wide NE: 8,95 m
Street wide SW: 9,03 m
Car parking on street: NO

First ramp
Ramp length: 1,047 m
Height change: 0,059 m

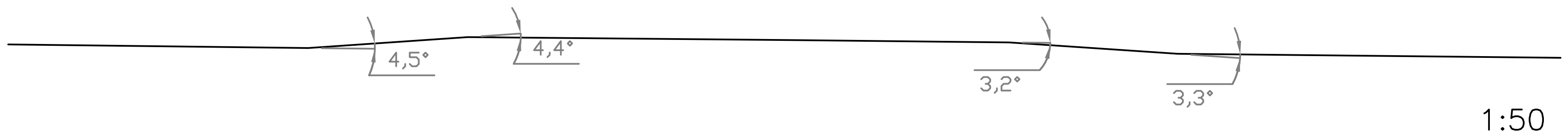
Second ramp
Ramp length: 1,077 m
Height change: 0,089 m

Sunnanväg



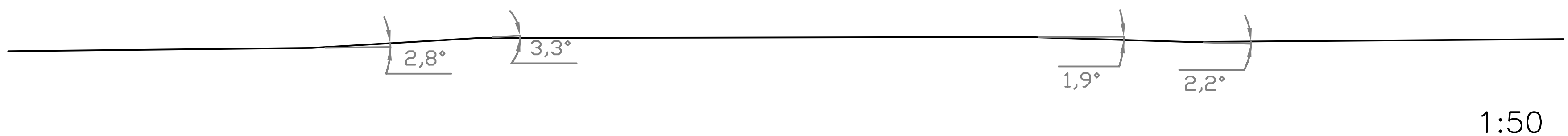
Profile driving east

St.	Height
0,000	50,754
14,694	50,582
15,876	50,662
18,305	50,640
19,883	50,623
21,130	50,539
33,666	50,409



Profile driving west

St.	Height
0,000	50,444
12,481	50,577
13,723	50,651
15,354	50,654
17,768	50,659
18,992	50,622
33,867	50,735



Driving east

Length of hump: 6,511 m
Lenght of top: 4,045 m
Street wide east: 9,93 m
Street wide west: 7,10 m
Car parking on street: NO

First ramp
Ramp length: 1,244 m
Height change: 0,074 m

Second ramp
Ramp length: 1,225 m
Height change: 0,037 m

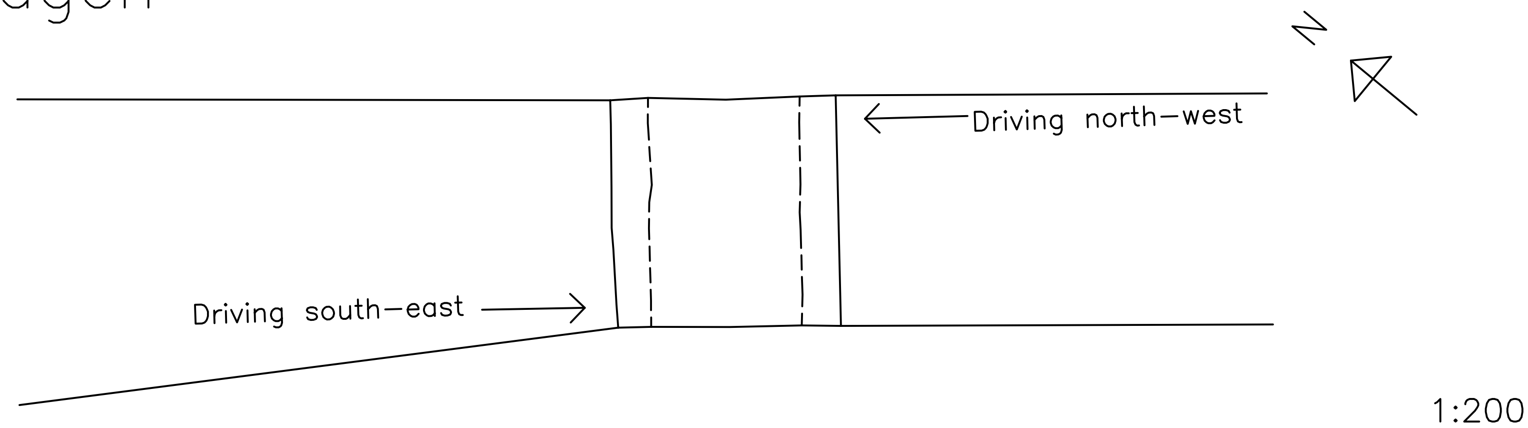
Driving west

Length of hump: 6,436 m
Lenght of top: 4,007 m
Street wide east: 9,93 m
Street wide west: 7,10 m
Car parking on street: NO

First ramp
Ramp length: 1,185 m
Height change: 0,080 m

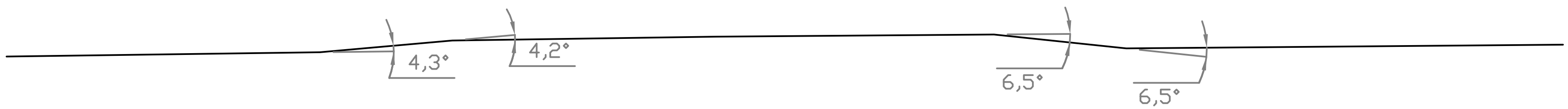
Second ramp
Ramp length: 1,249 m
Height change: 0,084 m

Svanevägen



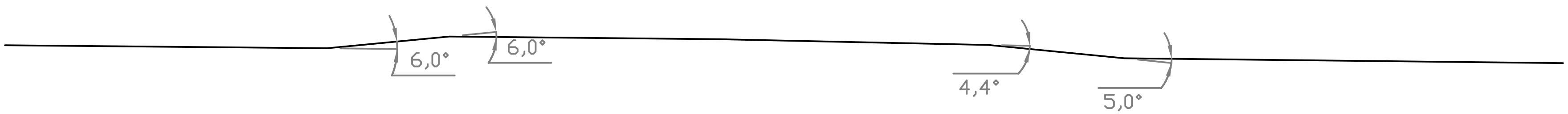
Profile driving north–west

St.	Height
0,000	49,395
11,390	49,548
12,369	49,635
14,323	49,664
16,377	49,680
17,355	49,577
33,107	49,713



Profile driving south–east

St.	Height
0,000	49,756
15,924	49,608
16,832	49,695
18,844	49,675
20,834	49,633
21,842	49,534
33,250	49,407



Driving NW

Length of hump: 5,965 m
Lenght of top: 4,008 m
Street wide SE: 6,09 m
Street wide NW: 8,08 m
Car parking on street: NO

First ramp
Ramp length: 0,983 m
Height change: 0,087 m

Second ramp
Ramp length: 0,983 m
Height change: 0,103 m

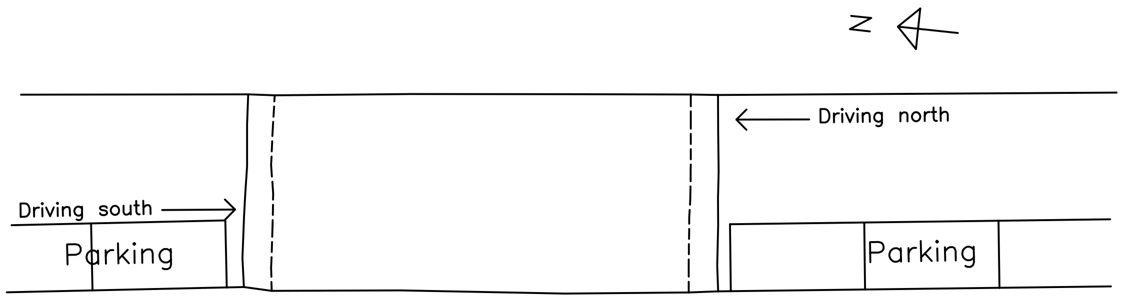
Driving SE

Length of hump: 5,918 m
Lenght of top: 4,002 m
Street wide SE: 6,09 m
Street wide NW: 8,08 m
Car parking on street: NO

First ramp
Ramp length: 0,912 m
Height change: 0,087 m

Second ramp
Ramp length: 1,013 m
Height change: 0,099 m

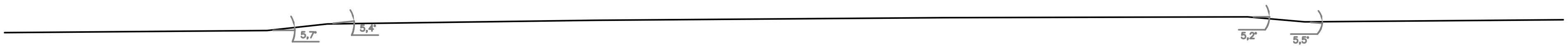
Östanväg nr. 1



1:200

Profile driving north

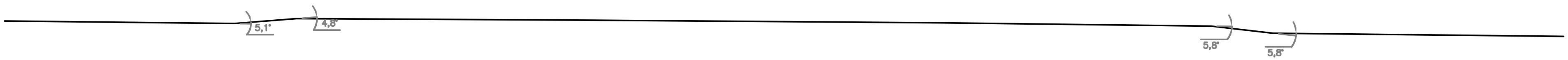
St.	Height
0,000	49,355
14,790	49,476
15,806	49,586
20,317	49,649
26,269	49,693
31,354	49,708
32,319	49,623
40,811	49,693



1:75

Profile driving south

St.	Height
0,000	49,798
8,629	49,704
9,680	49,787
14,710	49,761
20,628	49,715
25,201	49,659
26,250	49,540
40,846	49,381



1:75

Driving north

Length of hump: 17,529 m
Lenght of top: 15,548 m
Street wide north: 7,19 m
Street wide south: 7,32 m
Car parking on street: NO

First ramp
Ramp length: 1,022 m
Height change: 0,110 m

Second ramp
Ramp length: 0,968 m
Height change: 0,085 m

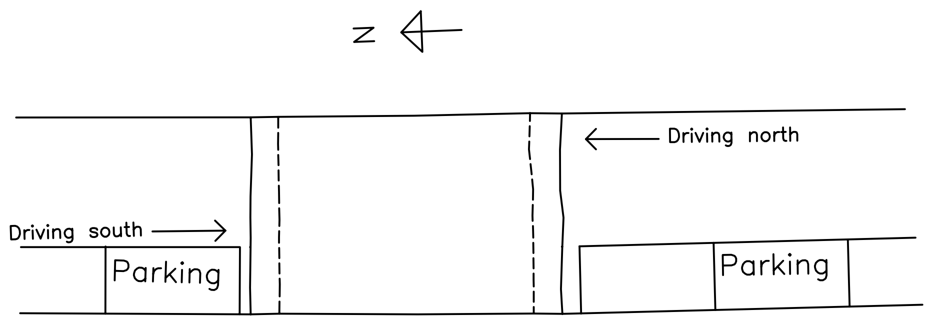
Driving south

Length of hump: 17,621 m
Lenght of top: 15,521 m
Street wide north: 7,19 m
Street wide south: 7,32 m
Car parking on street: YES

First ramp
Ramp length: 1,054 m
Height change: 0,083 m

Second ramp
Ramp length: 1,056 m
Height change: 0,119 m

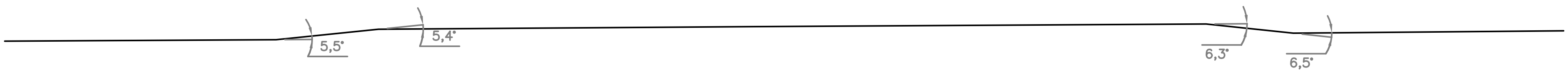
Östanväg nr. 2



1:200

Profile driving north

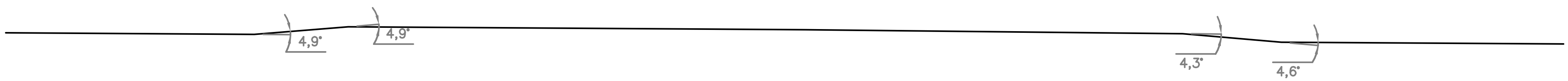
St.	Height
0,000	49,638
12,929	49,708
14,087	49,826
18,348	49,857
23,442	49,886
24,428	49,782
33,226	49,857



1:50

Profile driving south

St.	Height
0,000	49,912
8,597	49,858
9,661	49,943
14,837	49,910
19,112	49,866
20,230	49,770
33,306	49,689



1:50

Driving north

Length of hump: 11,499 m
Lenght of top: 9,355 m
Street wide north: 7,33 m
Street wide south: 7,46 m
Car parking on street: NO

<u>First ramp</u>
Ramp length: 1,164 m
Height change: 0,118 m

<u>Second ramp</u>
Ramp length: 0,992 m
Height change: 0,104 m

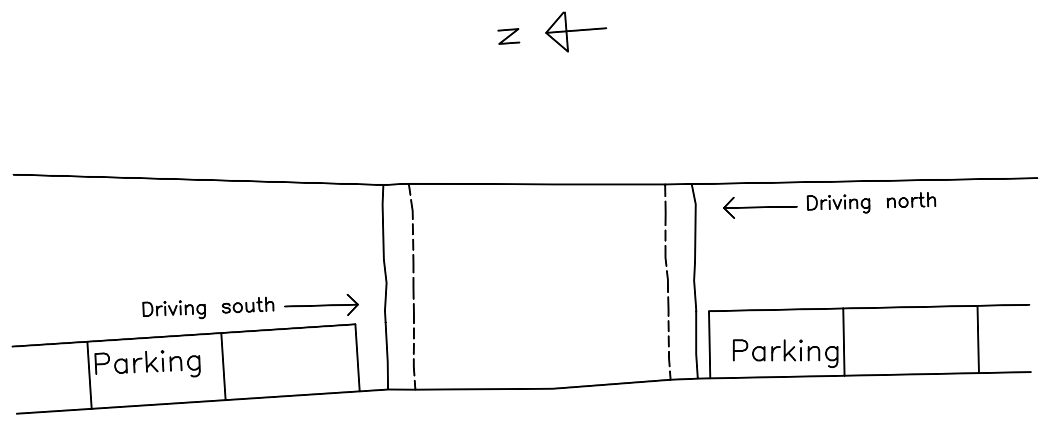
Driving south

Length of hump: 11,633 m
Lenght of top: 9,451 m
Street wide north: 7,33 m
Street wide south: 7,46 m
Car parking on street: YES

<u>First ramp</u>
Ramp length: 1,067 m
Height change: 0,085 m

<u>Second ramp</u>
Ramp length: 1,122 m
Height change: 0,096 m

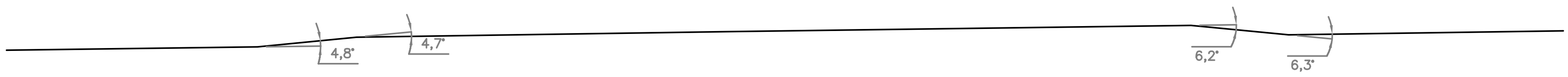
Östanväg nr. 3



1:200

Profile driving north

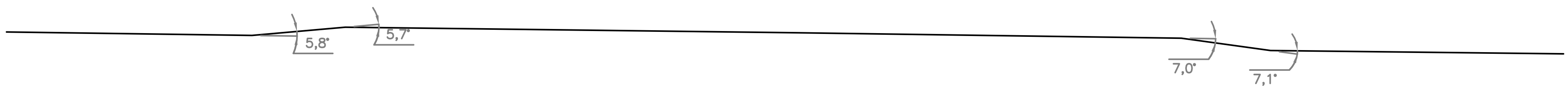
St.	Height
0,000	50,161
12,733	50,325
13,854	50,434
18,043	50,497
23,284	50,567
24,388	50,461
38,109	50,660



1:50

Profile driving south

St.	Height
0,000	50,715
13,862	50,519
14,919	50,611
20,041	50,549
24,394	50,488
25,405	50,350
38,174	50,207



1:50

Driving north

Length of hump: 11,655 m
Lenght of top: 9,430 m
Street wide north: 7,61 m
Street wide south: 7,23 m
Car parking on street: NO

First ramp
Ramp length: 1,126 m
Height change: 0,109 m

Second ramp
Ramp length: 1,109 m
Height change: 0,106 m

Driving south

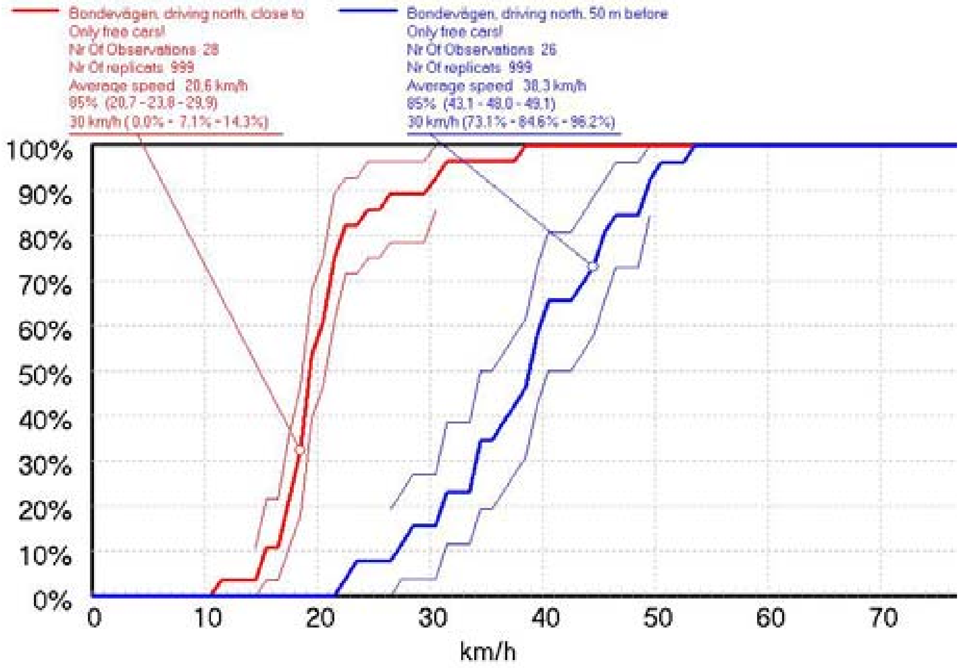
Length of hump: 11,543 m
Lenght of top: 9,475 m
Street wide north: 7,61 m
Street wide south: 7,23 m
Car parking on street: YES

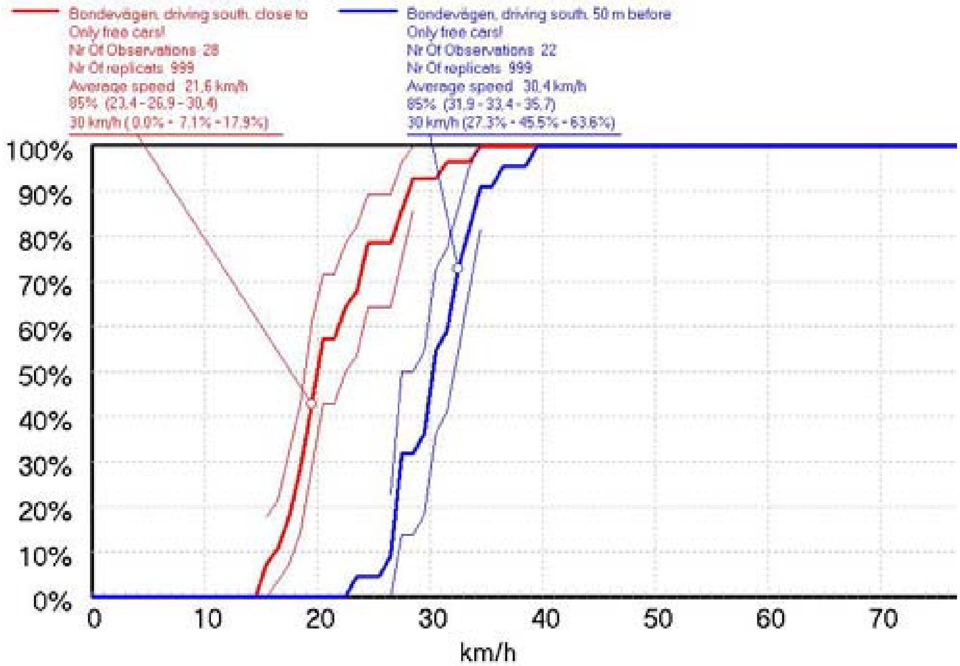
First ramp
Ramp length: 1,060 m
Height change: 0,092 m

Second ramp
Ramp length: 1,020 m
Height change: 0,138 m

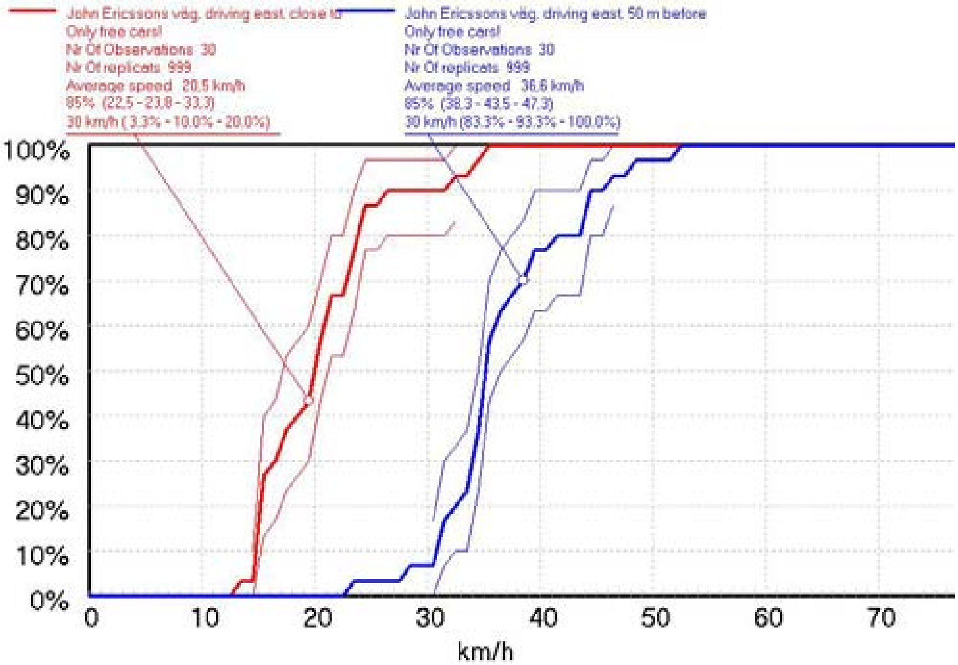
Appendix 3, Speed measurements

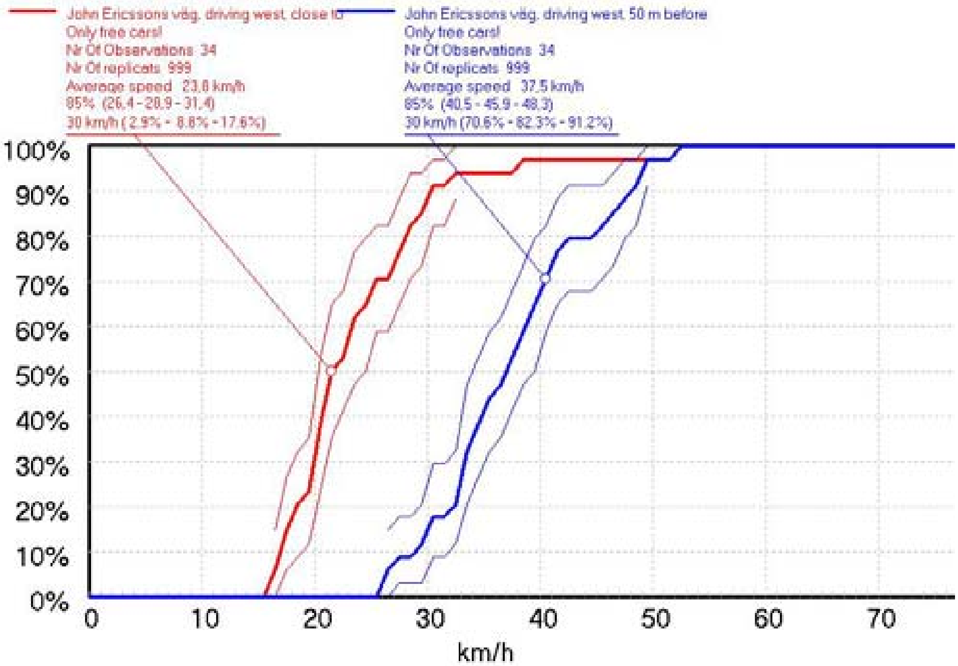
Bondevägen (road hump nr. 1)



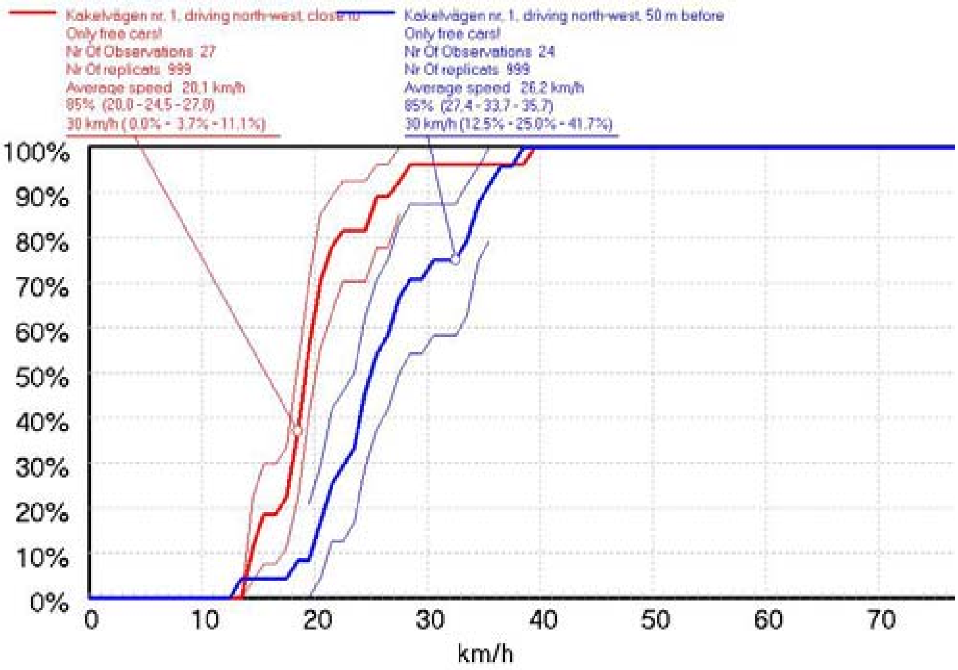


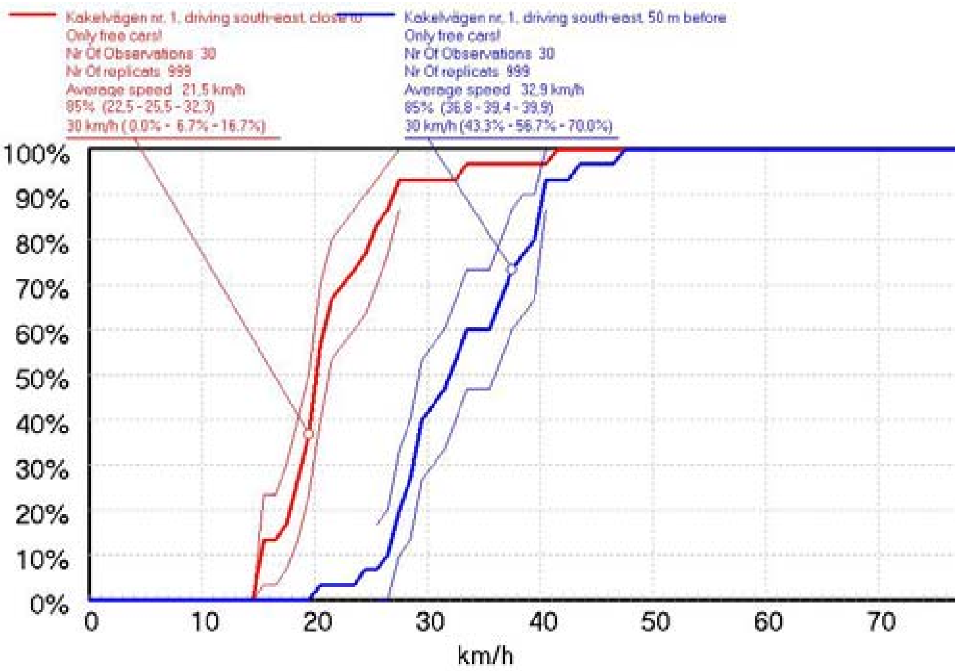
John Ericssons väg (road hump nr. 2)

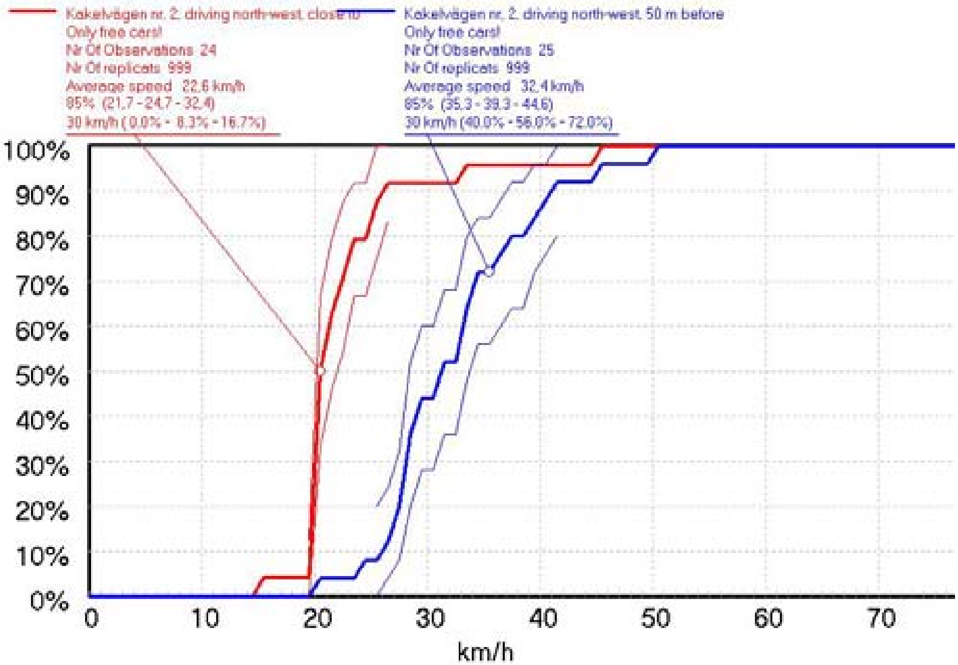


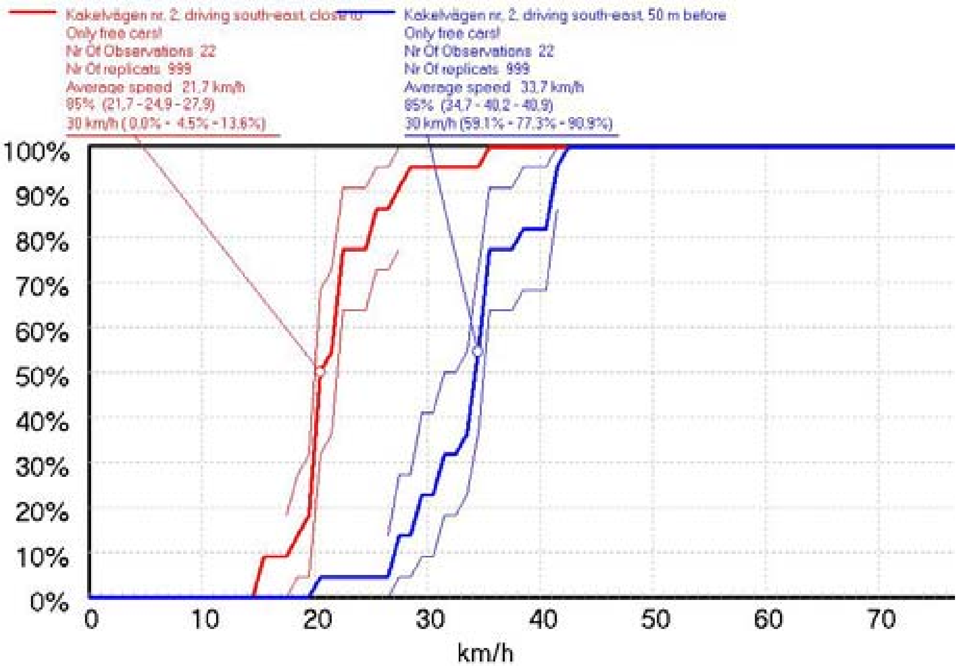


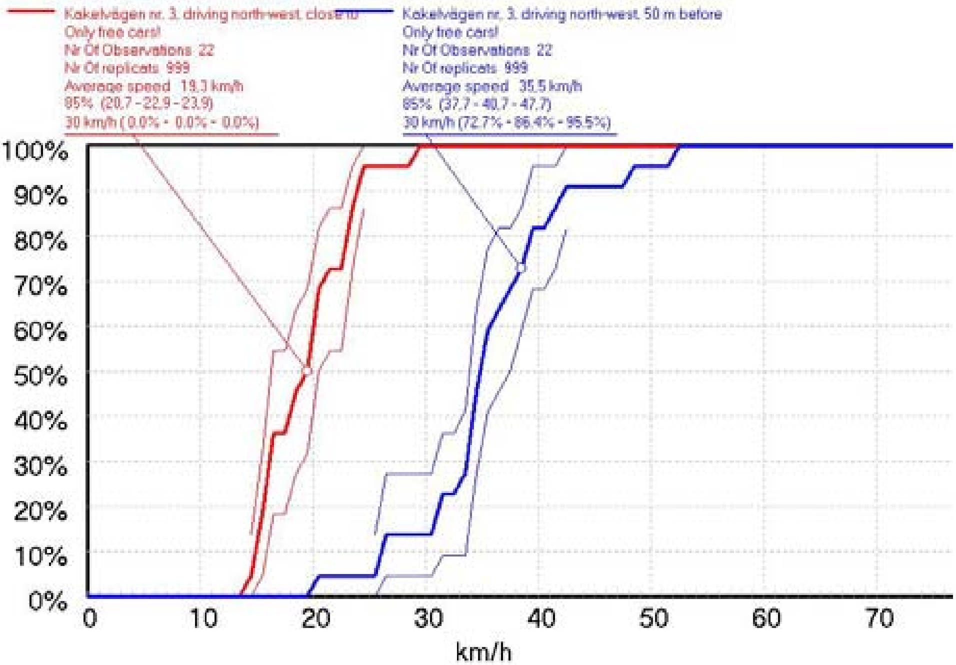
Kakelvägen (road humps nr. 3, 4, 5)

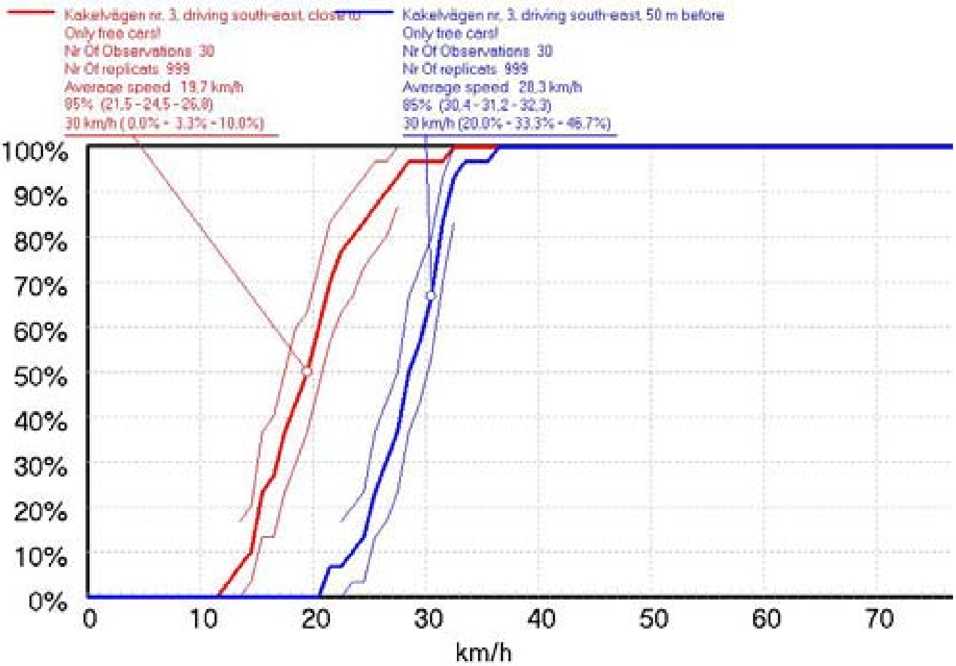




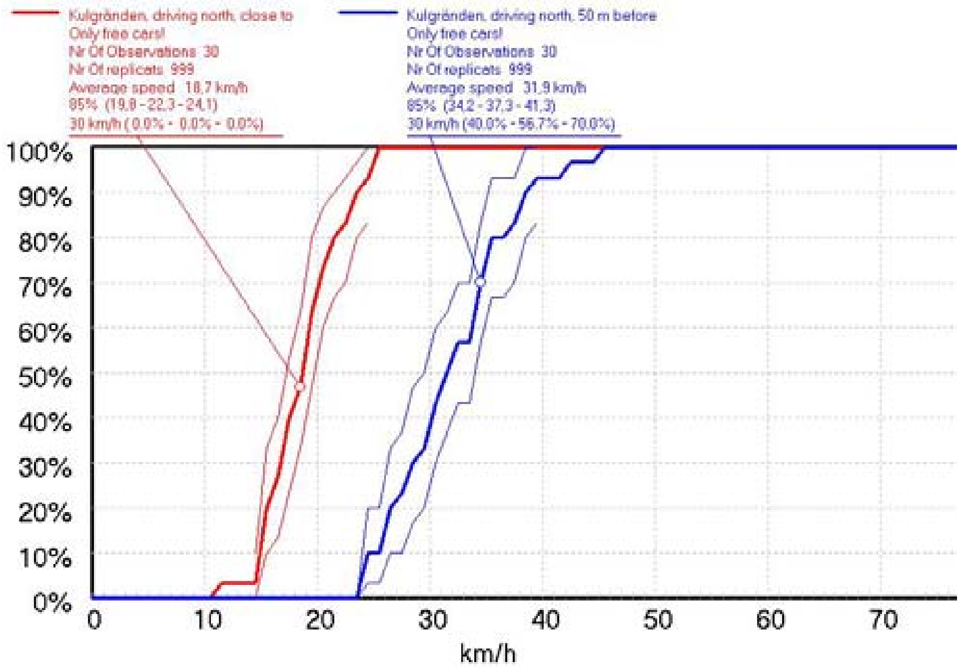

Kakelvägen nr. 2: driving north-west, close to
Only free cars!
Nr Of Observations 24
Nr Of replicats 999
Average speed 22,6 km/h
85% (21,7 - 24,7 - 32,4)
30 km/h (0,0% - 8,3% - 16,7%)
Kakelvägen nr. 2, driving north-west, 50 m before
Only free cars!
Nr Of Observations 25
Nr Of replicats 999
Average speed 32,4 km/h
85% (35,3 - 39,3 - 44,6)
30 km/h (40,0% - 56,0% - 72,0%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
km/h

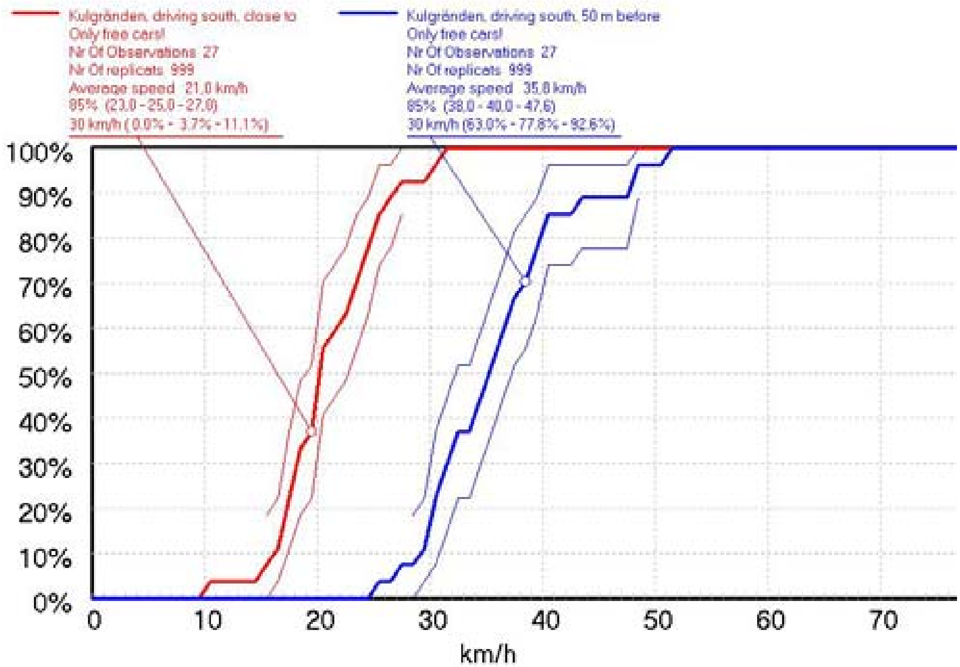

Kakelvägen nr. 2: driving south-east, close to
Only free cars!
Nr Of Observations 22
Nr Of replicats 999
Average speed 21,7 km/h
85% (21,7 - 24,9 - 27,9)
30 km/h (0,0% - 4,5% - 13,6%)
Kakelvägen nr. 2, driving south-east, 50 m before
Only free cars!
Nr Of Observations 22
Nr Of replicats 999
Average speed 33,7 km/h
85% (34,7 - 40,2 - 40,9)
30 km/h (59,1% - 77,3% - 90,9%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
km/h


Kakelvägen nr. 3, driving north-west, close to
Only free cars!
Nr Of Observations 22
Nr Of replicats 999
Average speed 19,3 km/h
85% (20,7 - 22,9 - 23,9)
30 km/h (0.0% - 0.0% - 0.0%)
Kakelvägen nr. 3, driving north-west, 50 m before
Only free cars!
Nr Of Observations 22
Nr Of replicats 999
Average speed 35,5 km/h
85% (37,7 - 40,7 - 47,7)
30 km/h (72.7% - 86.4% - 95.5%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
km/h

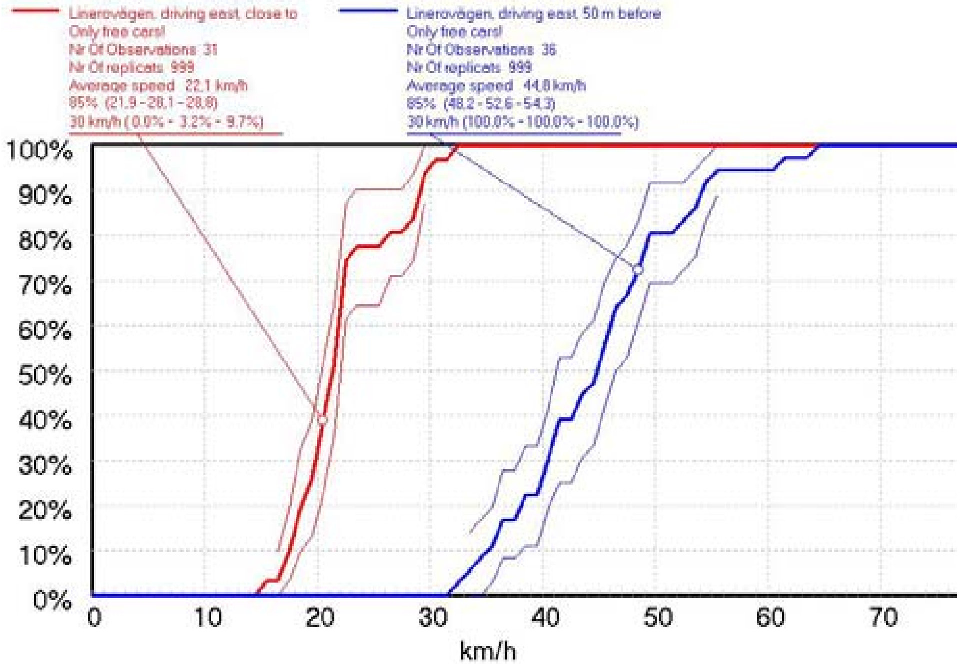

Kakelvägen nr. 3, driving south-east, close to
Only free cars!
Nr Of Observations 30
Nr Of replicats 999
Average speed 19,7 km/h
85% (21,5 - 24,5 - 26,8)
30 km/h (0.0% - 3.3% - 10.0%)
Kakelvägen nr. 3, driving south-east, 50 m before
Only free cars!
Nr Of Observations 30
Nr Of replicats 999
Average speed 28,3 km/h
85% (30,4 - 31,2 - 32,3)
30 km/h (20.0% - 33.3% - 46.7%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
km/h

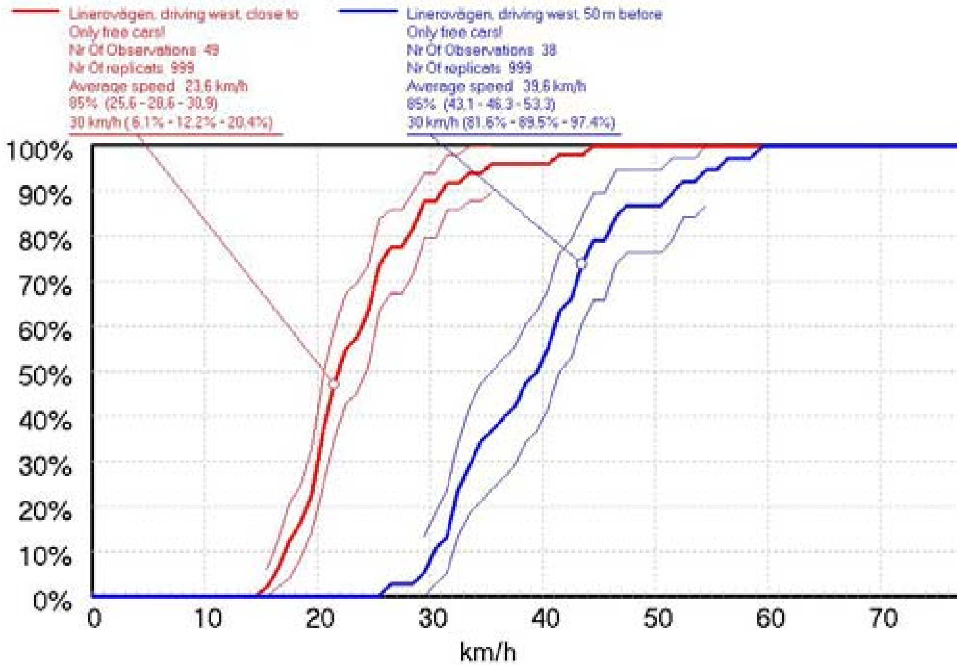
Kulgränden (road hump nr. 6)



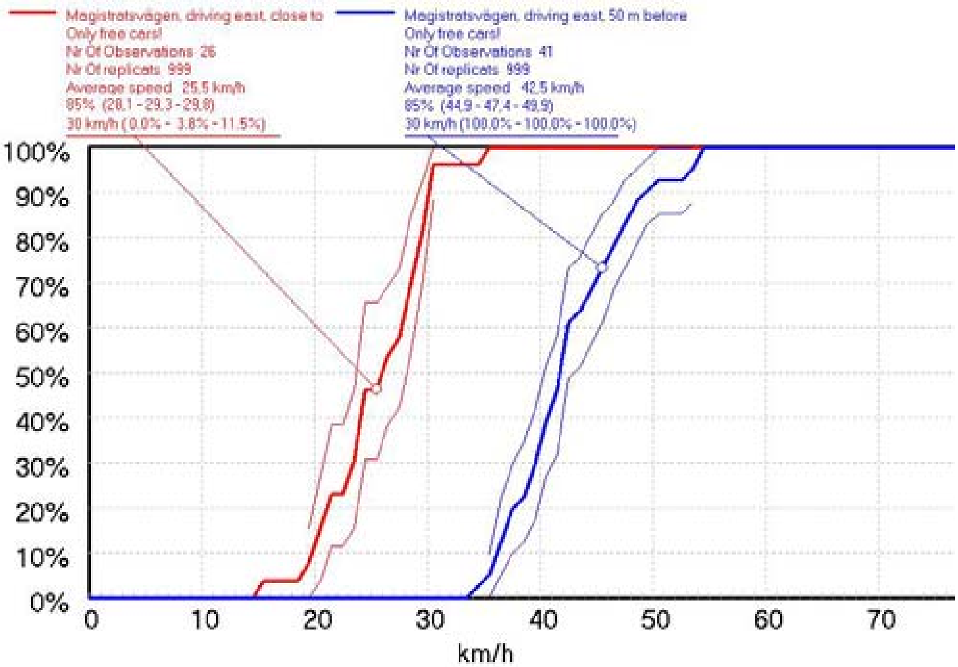


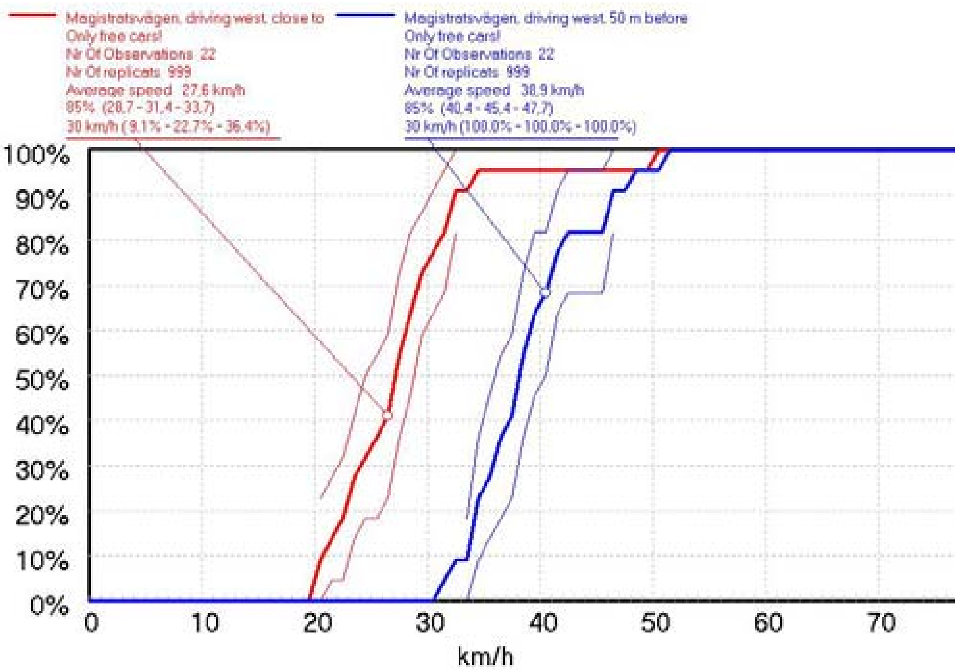
Linerovägen (road hump nr. 7)



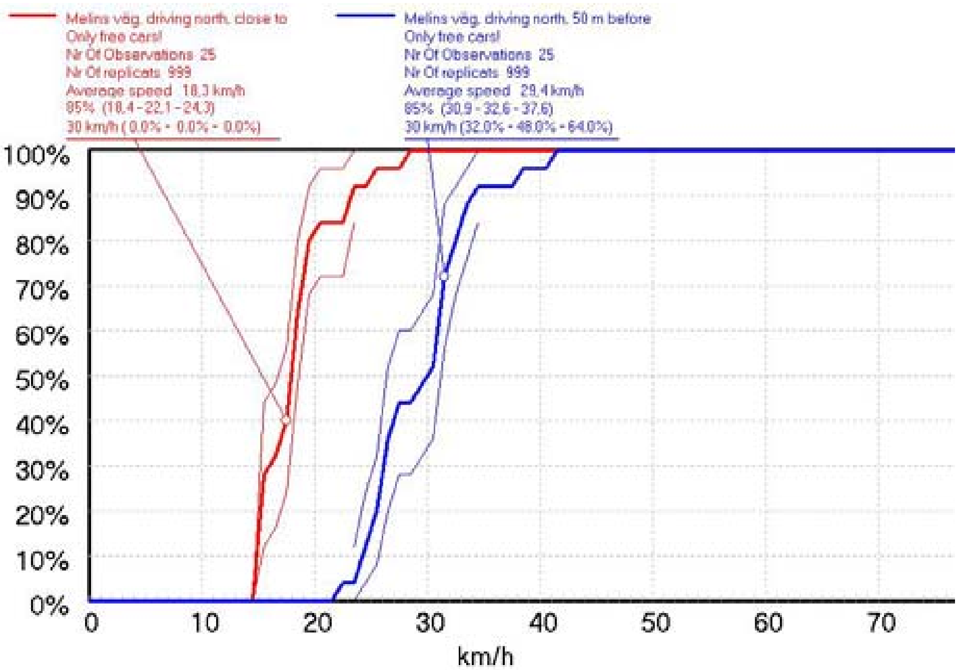


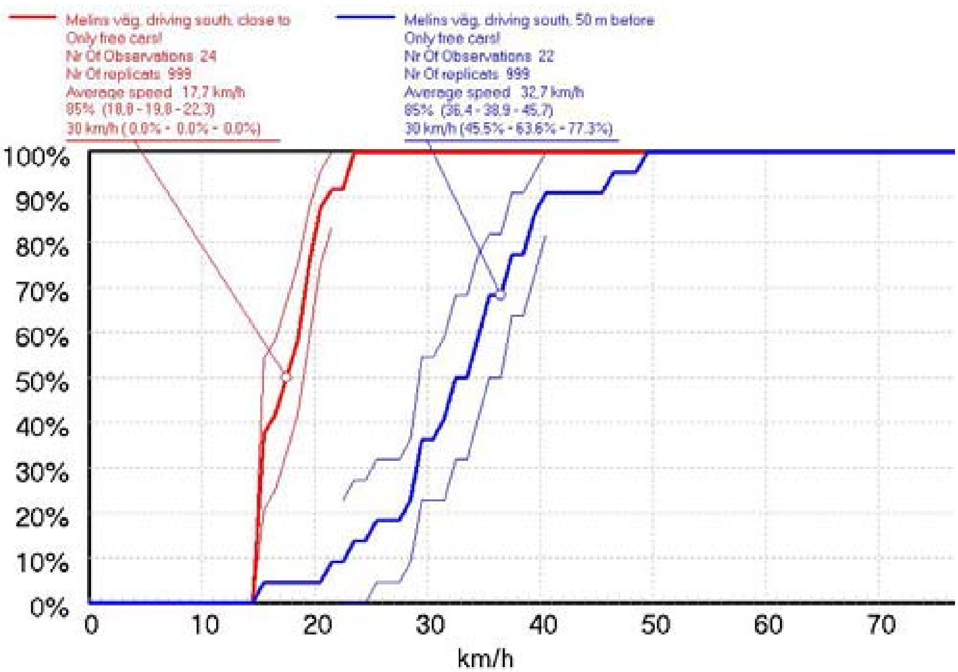
Magistratsvägen (road hump nr. 8)



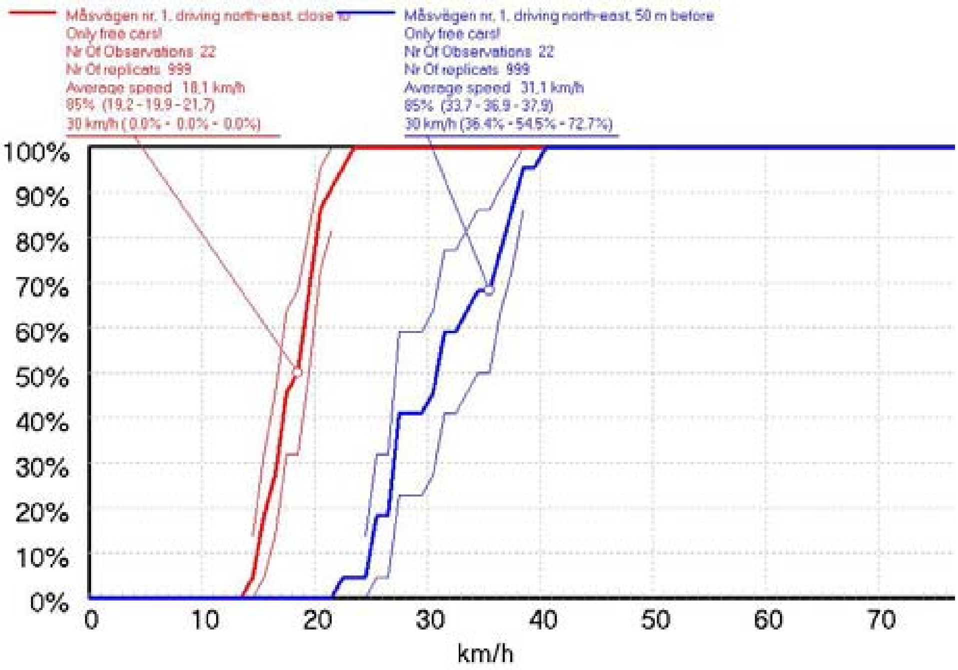


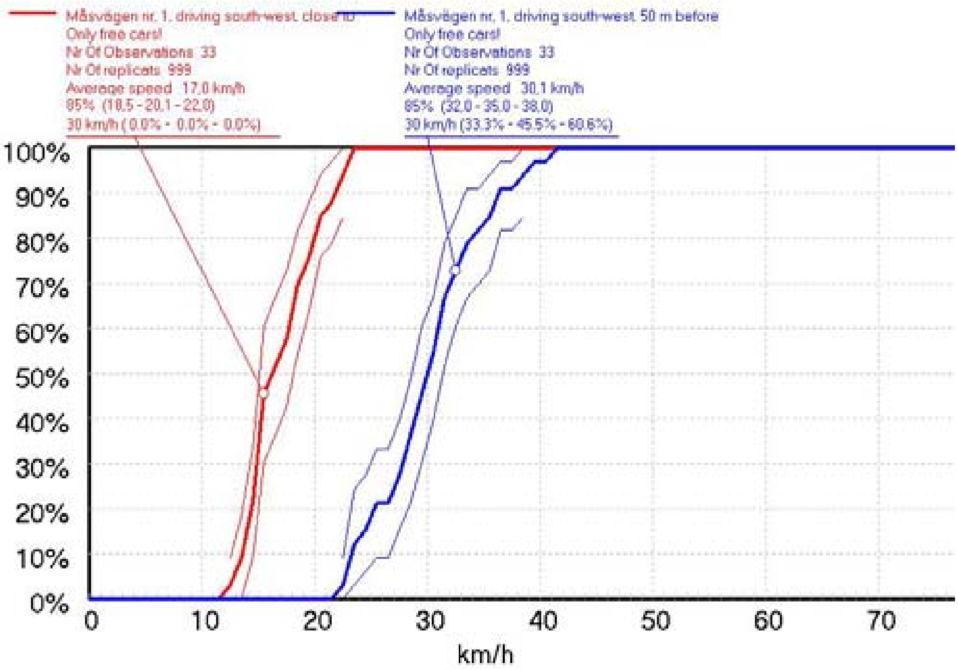
Melins väg (road hump nr. 9)

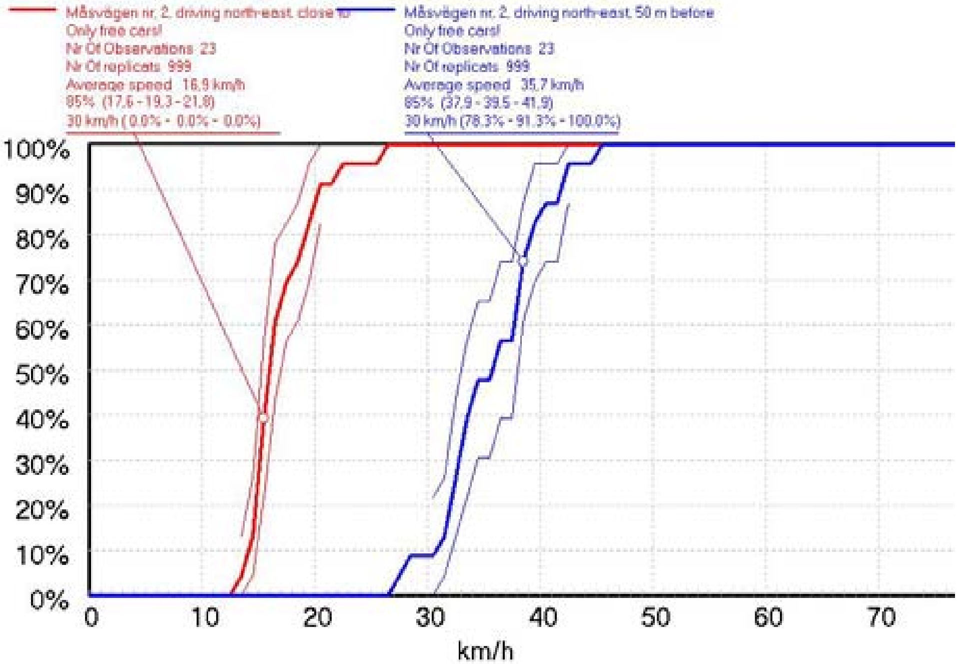


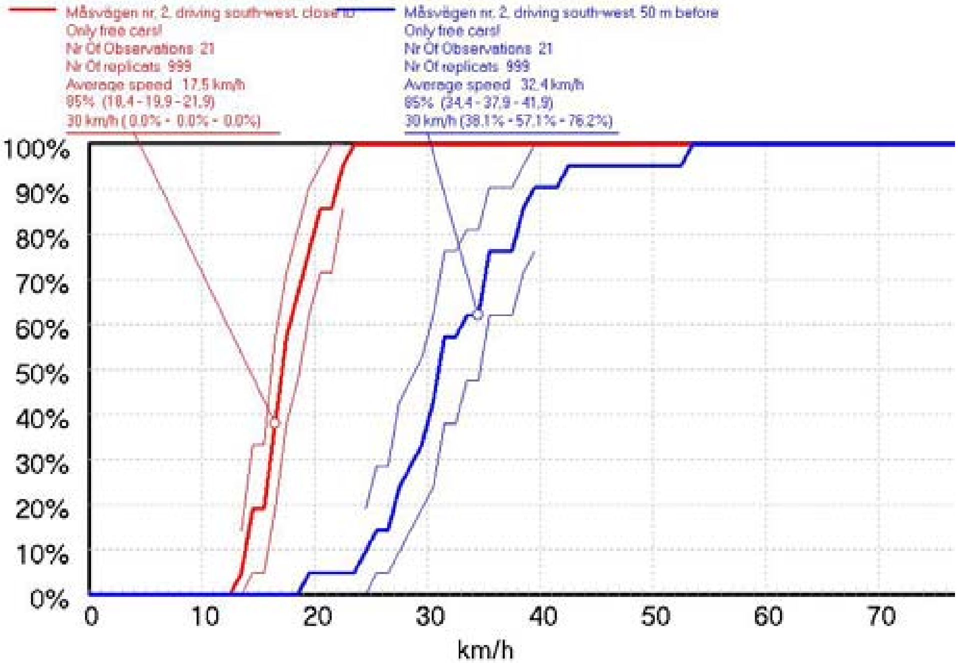


Måsvägen (road humps nr. 10, 11)

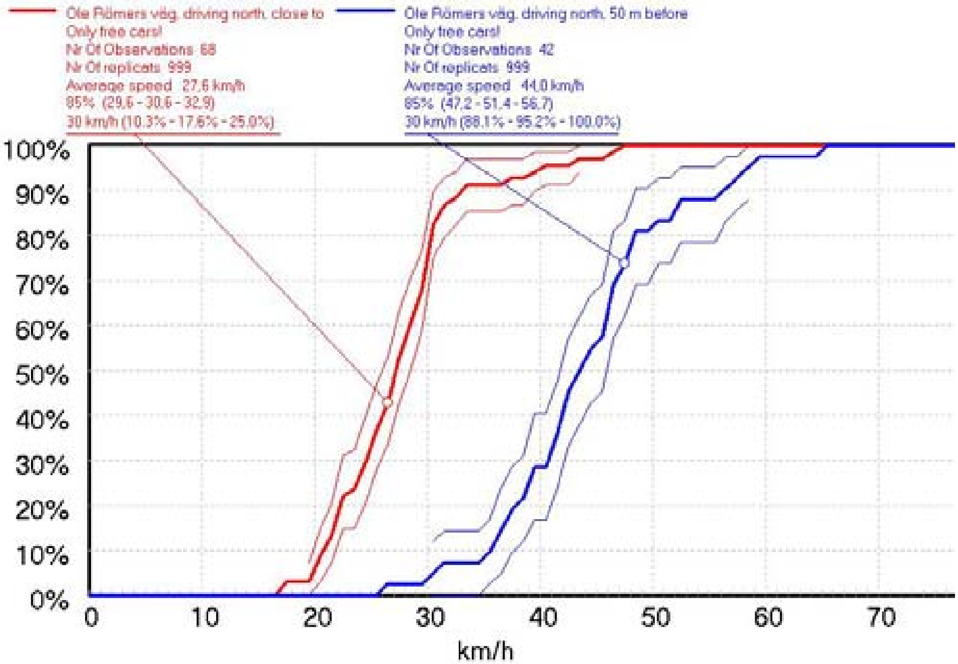


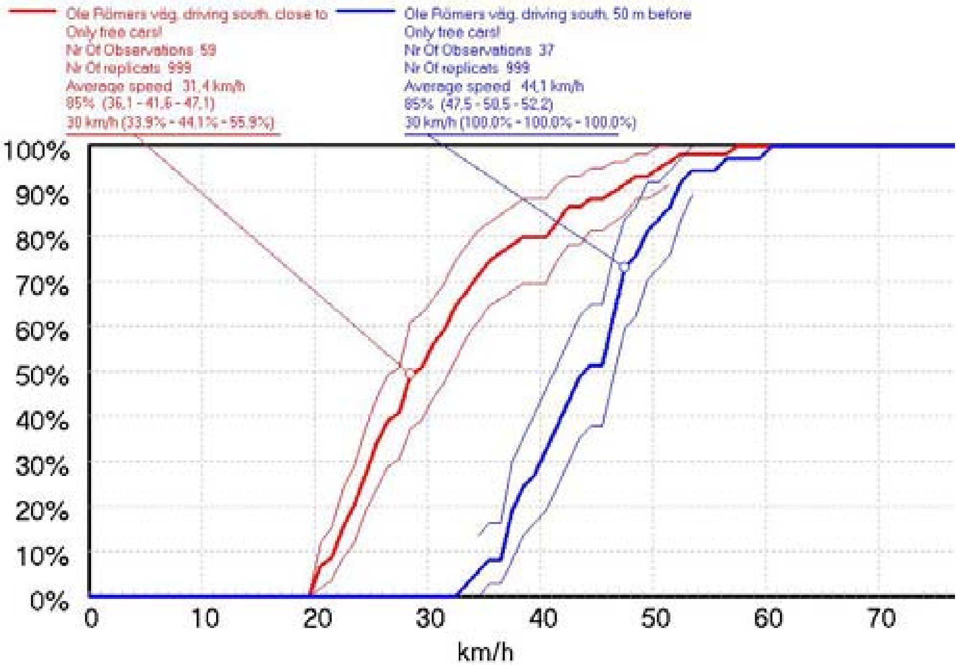



Måsvägen nr, 2, driving north-east, close to
Only free cars!
Nr Of Observations 23
Nr Of replicats 999
Average speed 16,9 km/h
85% (17,6 - 19,3 - 21,8)
30 km/h (0,0% - 0,0% - 0,0%)
Måsvägen nr, 2, driving north-east, 50 m before
Only free cars!
Nr Of Observations 23
Nr Of replicats 999
Average speed 35,7 km/h
85% (37,9 - 39,5 - 41,9)
30 km/h (78,3% - 91,3% - 100,0%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
km/h

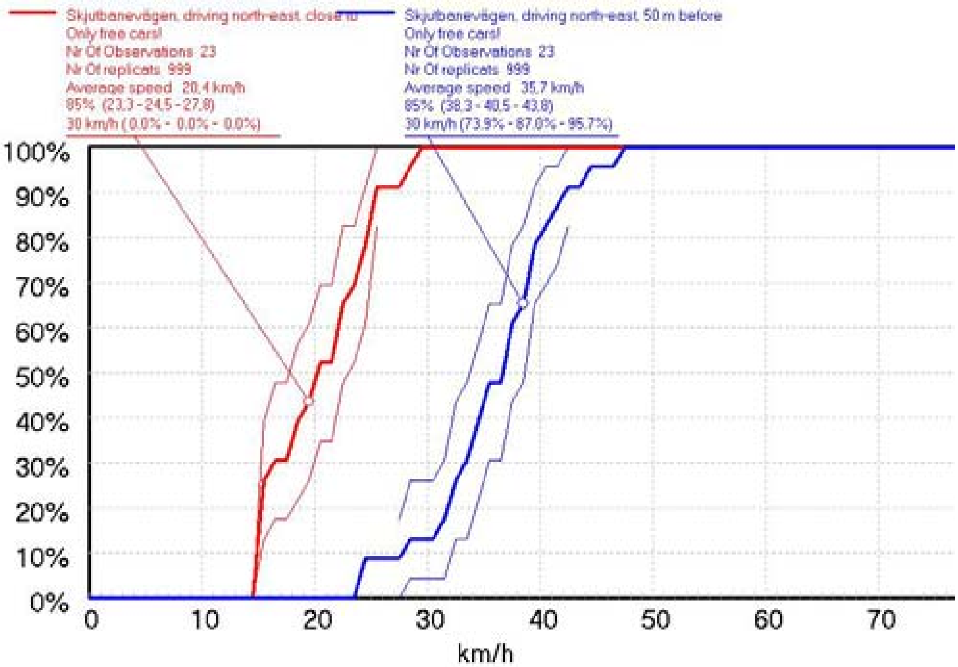

Måsvägen nr, 2, driving south-west, close to
Only free cars!
Nr Of Observations 21
Nr Of replicats 999
Average speed 17,5 km/h
85% (18,4 - 19,9 - 21,9)
30 km/h (0,0% - 0,0% - 0,0%)
Måsvägen nr, 2, driving south-west, 50 m before
Only free cars!
Nr Of Observations 21
Nr Of replicats 999
Average speed 32,4 km/h
85% (34,4 - 37,9 - 41,9)
30 km/h (38,1% - 57,1% - 76,2%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
km/h

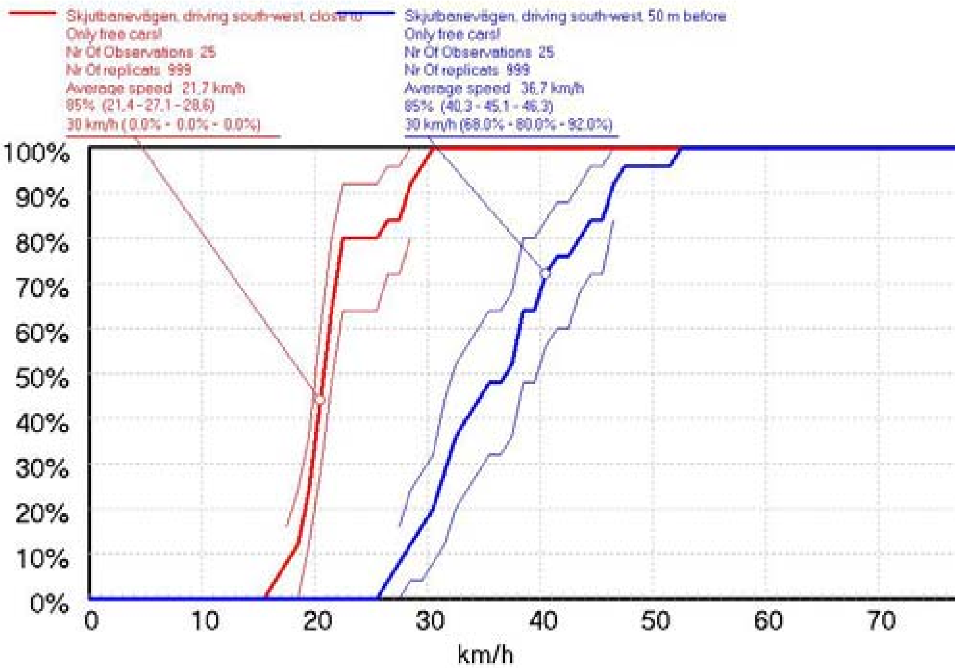
Ole Römers väg (road hump nr. 12)



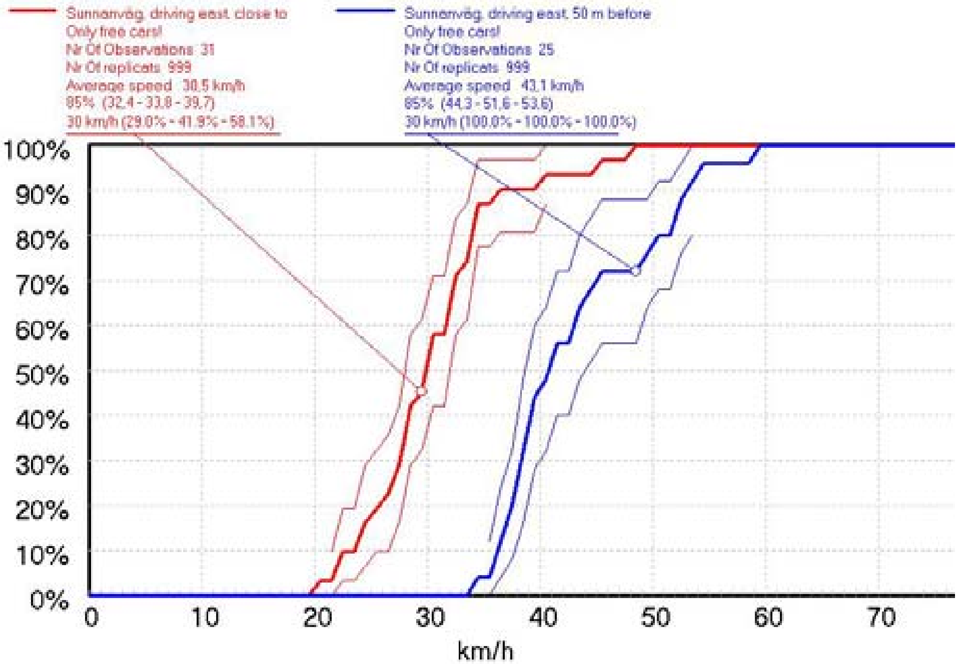


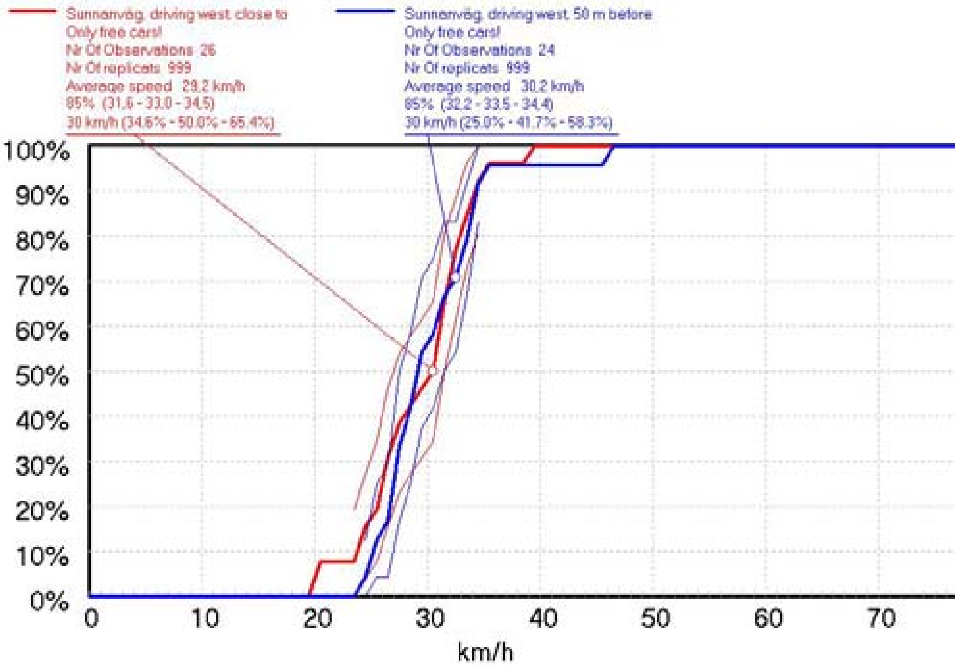
Skjutbanevägen (road hump nr. 13)



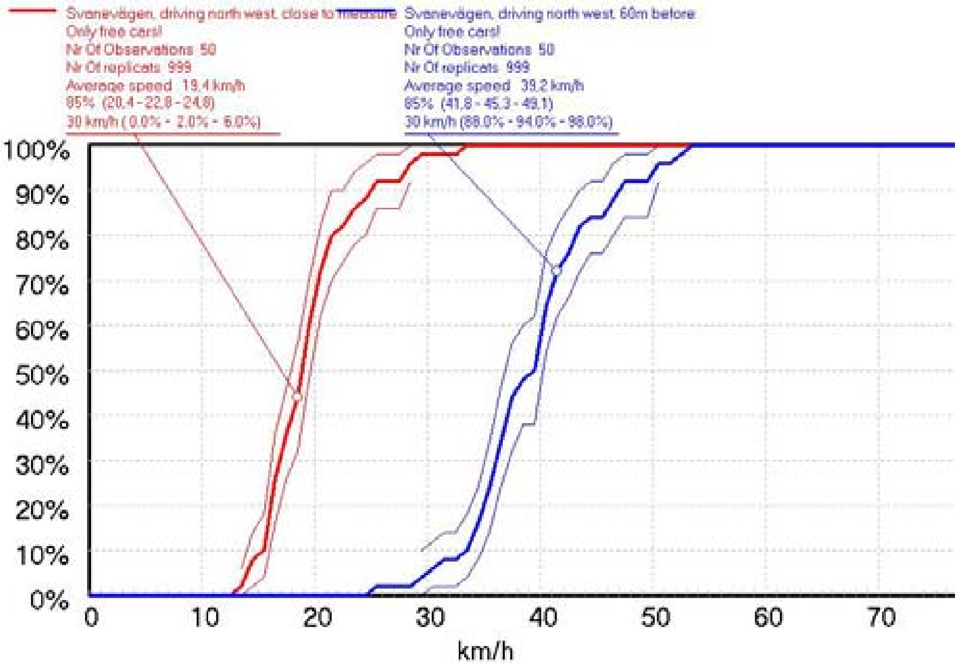


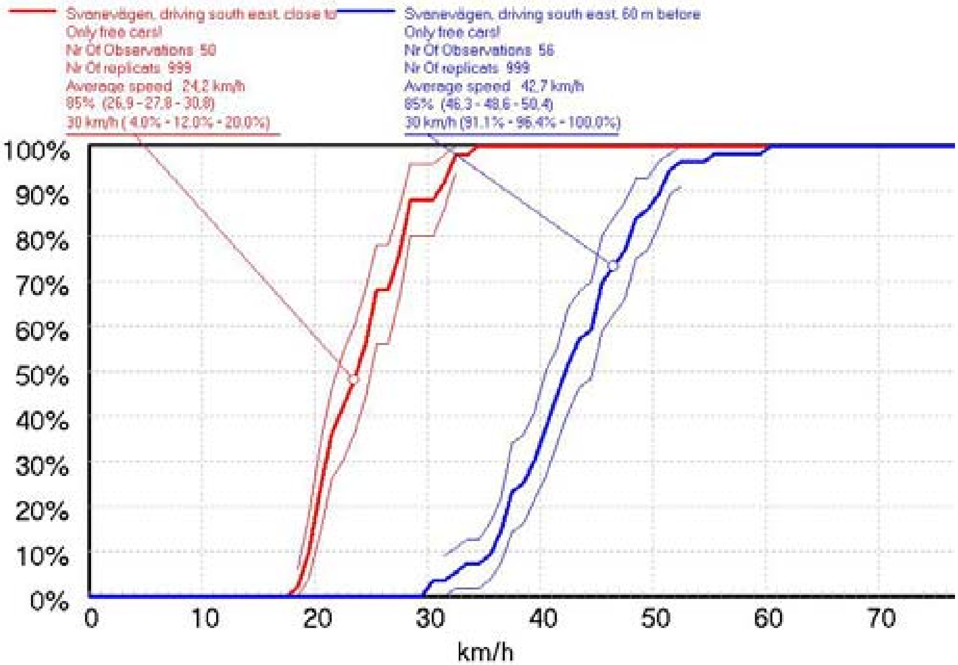
Sunnanväg (road hump nr. 14)



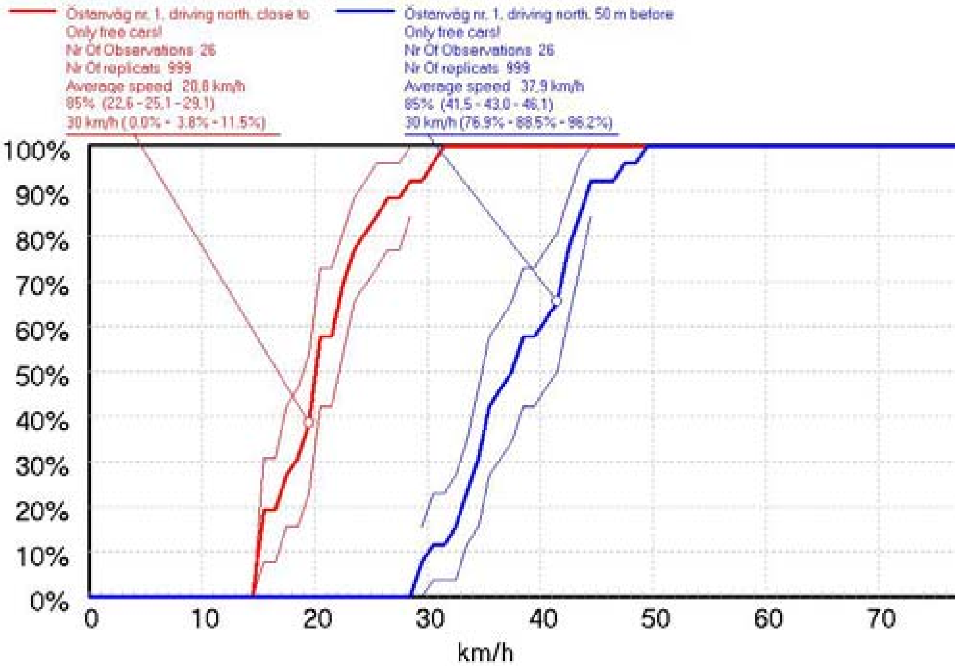


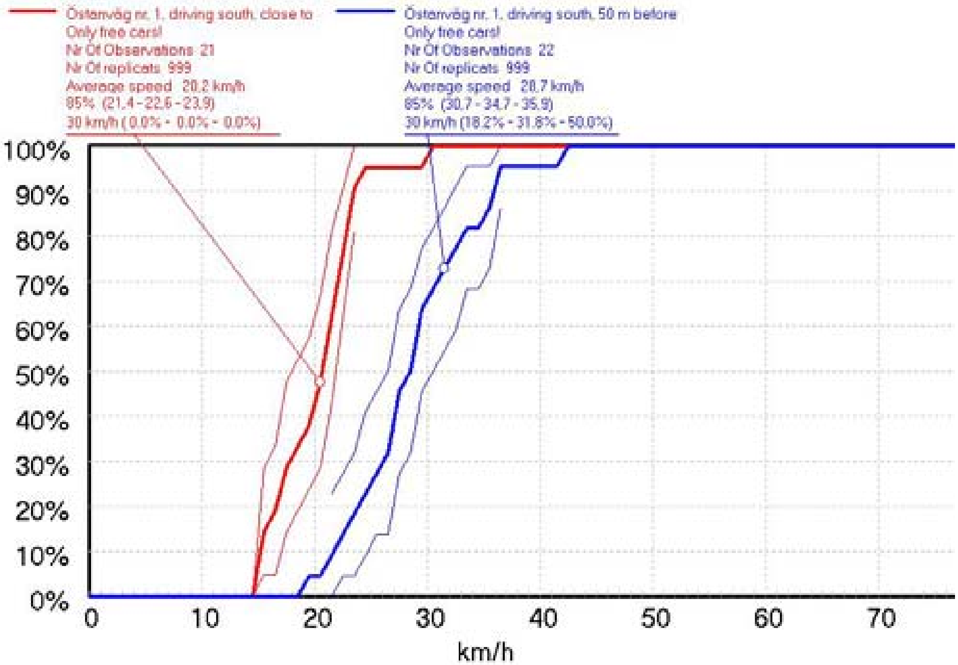
Svanevägen (road hump nr. 15)

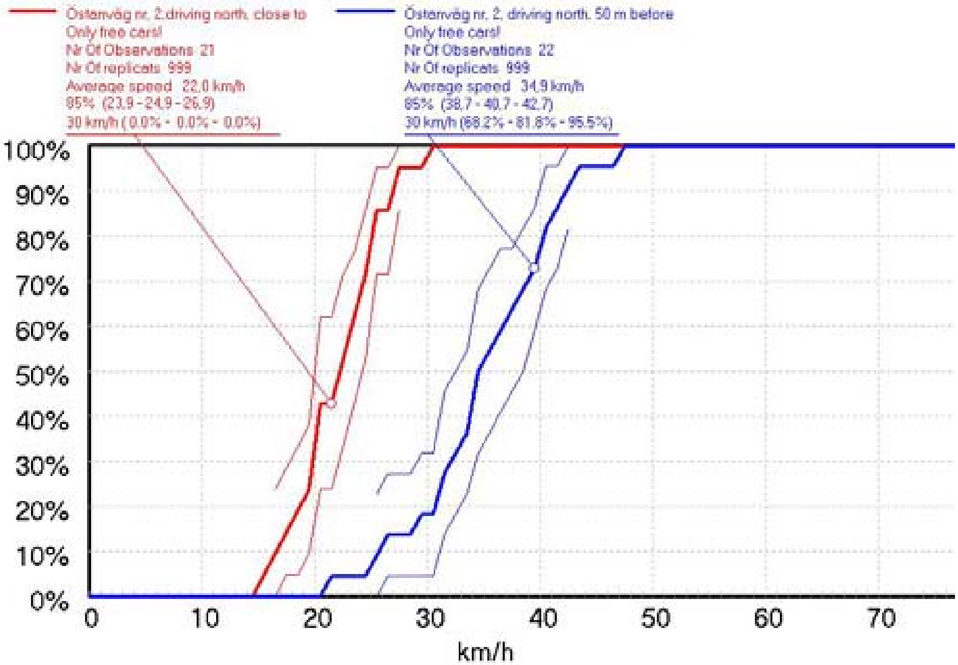


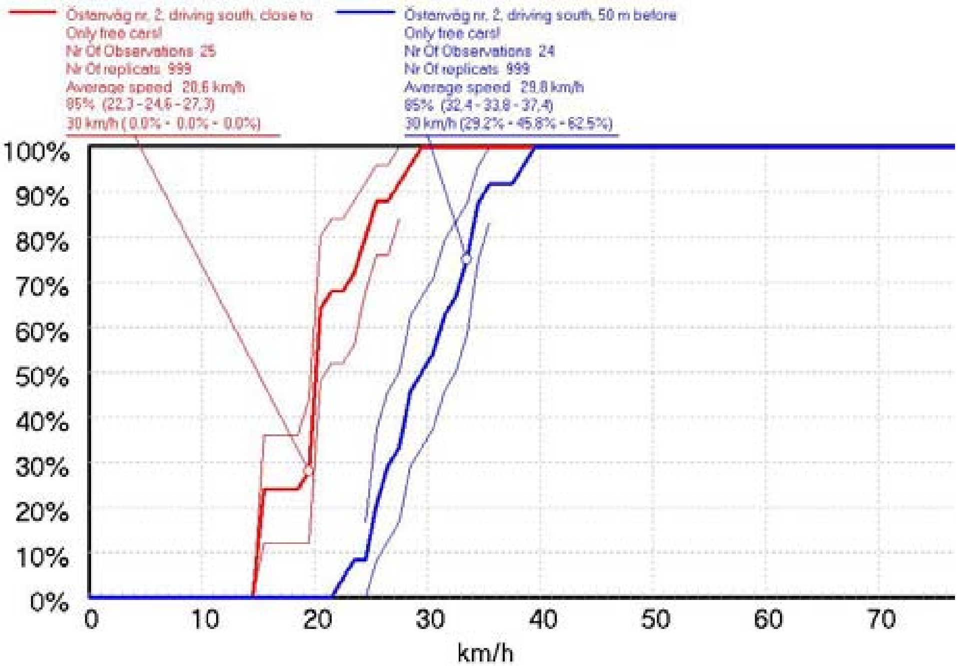


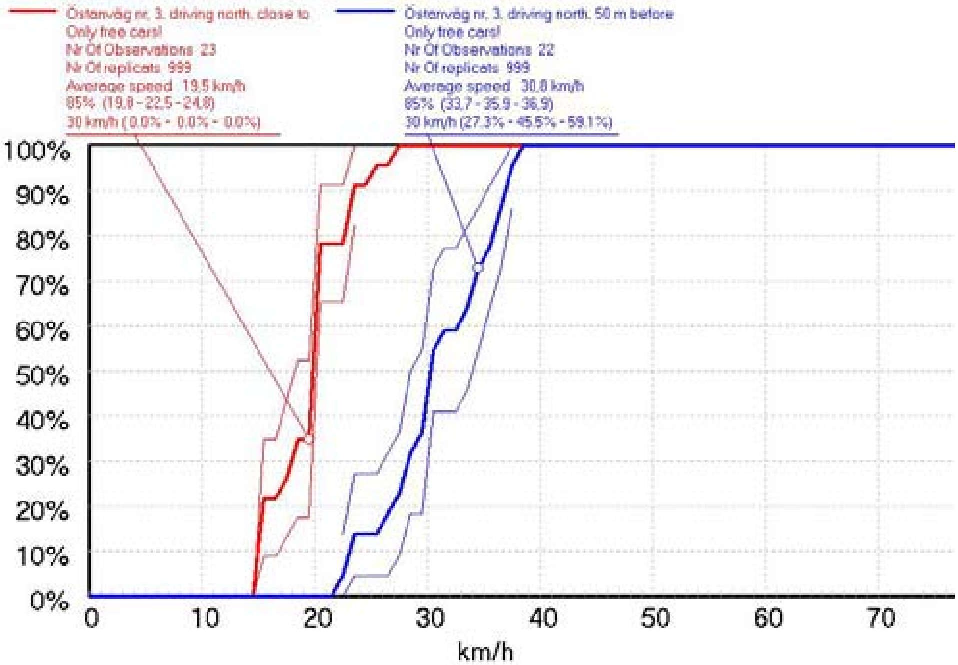
Östanväg (road humps nr. 16, 17, 18)

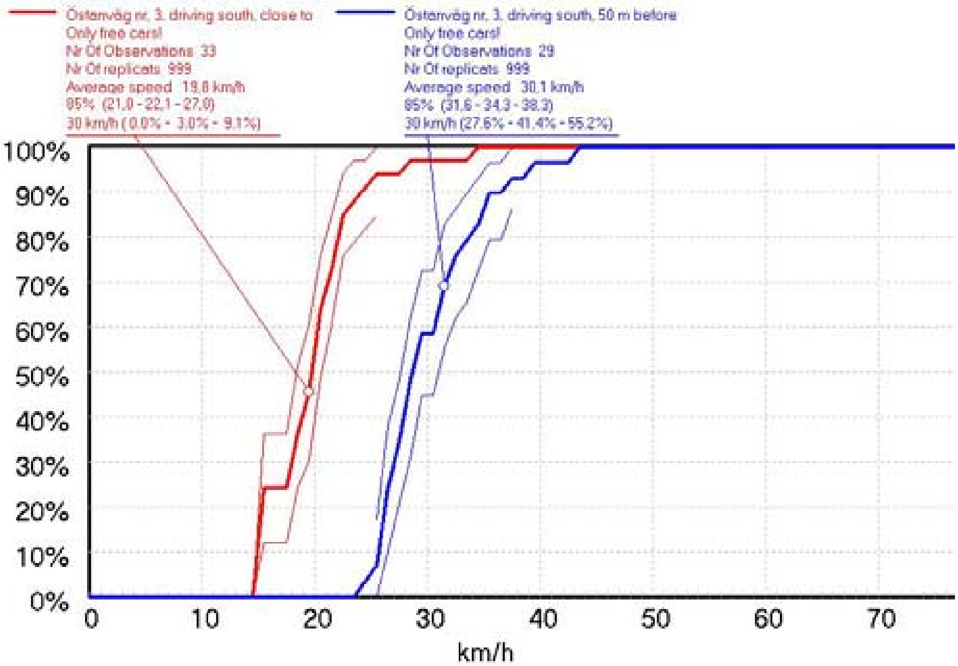





Östanväg nr. 2, driving north, close to
Only free cars!
Nr Of Observations 21
Nr Of replicats 999
Average speed 22,0 km/h
85% (23,9 - 24,9 - 26,9)
30 km/h (0,0% - 0,0% - 0,0%)
Östanväg nr. 2, driving north, 50 m before
Only free cars!
Nr Of Observations 22
Nr Of replicats 999
Average speed 34,9 km/h
85% (38,7 - 40,7 - 42,7)
30 km/h (68,2% - 81,8% - 95,5%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
km/h


Östanväg nr. 2, driving south, close to
Only free cars!
Nr Of Observations 25
Nr Of replicats 999
Average speed 20,6 km/h
85% (22,3 - 24,6 - 27,3)
30 km/h (0,0% - 0,0% - 0,0%)
Östanväg nr. 2, driving south, 50 m before
Only free cars!
Nr Of Observations 24
Nr Of replicats 999
Average speed 29,8 km/h
85% (32,4 - 33,8 - 37,4)
30 km/h (29,2% - 45,8% - 62,5%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
km/h


Östanväg nr, 3. driving north, close to
Only free cars!
Nr Of Observations 23
Nr Of replicats 999
Average speed 19,5 km/h
85% (19,8 - 22,5 - 24,8)
30 km/h (0,0% - 0,0% - 0,0%)
Östanväg nr, 3. driving north, 50 m before
Only free cars!
Nr Of Observations 22
Nr Of replicats 999
Average speed 30,8 km/h
85% (33,7 - 35,9 - 36,9)
30 km/h (27,3% - 45,5% - 59,1%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
km/h


Östanväg nr, 3. driving south, close to
Only free cars!
Nr Of Observations 33
Nr Of replicats 999
Average speed 19,8 km/h
85% (21,0 - 22,1 - 27,0)
30 km/h (0,0% - 3,0% - 9,1%)
Östanväg nr, 3. driving south, 50 m before
Only free cars!
Nr Of Observations 29
Nr Of replicats 999
Average speed 30,1 km/h
85% (31,6 - 34,3 - 38,3)
30 km/h (27,6% - 41,4% - 55,2%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
km/h

Appendix 4, K_1 and vertical acceleration

Round top humps

Street name	Direction	Linear < 30 km/h k_1	k_0	Speed [km/h]	Vertical acceleration [g]
Kakelvägen nr. 3	Driving north-west	0,0142	0,0762	25	0,4312
	Driving south-east	0,0147	0,0495	25	0,417
Kulgränden	Driving south	0,0108	0,0025	25	0,2675
	Driving north	0,012	0,0627	25	0,2373
Måsvägen nr. 1	Driving south-west	0,0185	0,0879	25	0,3746
	Driving north-east	0,0037	0,2703	25	0,3628
Måsvägen nr. 2	Driving south-west	0,0226	0,1752	25	0,3898
	Driving north-east	0,0073	0,1714	25	0,3539

Street name	Direction	Linear > 30 km/h k_1	k_0	Speed [km/h]	Vertical acceleration [g]
Kakelvägen nr. 3	Driving north-west	0,0107	0,2709	40	0,6989
	Driving south-east	0,0279	0,3332	40	0,7828
Kulgränden	Driving south	0,0311	0,5879	40	0,6561
	Driving north	0,0246	-0,356	40	0,628
Måsvägen nr. 1	Driving south-west	-	-	40	-
	Driving north-east	-	-	40	-
Måsvägen nr. 2	Driving south-west	-	-	40	-
	Driving north-east	-	-	40	-

Flat top humps

Group 1 (steep and short)

Street name	Direction	Linear < 30 km/h k_1	k_0	Speed [km/h]	Vertical acceleration [g]
Linerovägen	Driving east	0,0033	0,2539	25	0,3364
Linerovägen	Driving west	0,0008	0,2886	25	0,3086
Melins väg	Driving north	0,0068	0,1481	25	0,3181
Melins väg	Driving south	0,0098	0,0933	25	0,3383
Sunnanväg	Driving east	0,0080	0,0075	25	0,1925
Svanevägen	Driving south-east	0,0034	0,2507	25	0,3357

Street name	Direction	Linear > 30 km/h k_1	k_0	Speed [km/h]	Vertical acceleration [g]
Linerovägen	Driving east	0,0187	0,1645	40	0,5835
Linerovägen	Driving west	0,0204	0,2474	40	0,5686
Melins väg	Driving north	0,0110	0,0112	40	0,4512
Melins väg	Driving south	0,0147	0,0049	40	0,5929
Sunnanväg	Driving east	0,0138	0,1643	40	0,3877
Svanevägen	Driving south-east	0,0206	0,2628	40	0,5612

Group 2 (steep and long)

Street name	Direction	Linear < 30 km/h			
		k_1	k_0	Speed [km/h]	Vertical acceleration [g]
John Ericssons väg	Driving east	0,0032	0,3689	25	0,2889
Skjutbanevägen	Driving north-east	0,0038	0,1754	25	0,2704
Östanväg nr. 1	Driving south	0,0022	0,3689	25	0,3139
Östanväg nr. 1	Driving north	0,0083	0,1101	25	0,3176
Östanväg nr. 2	Driving south	0,0032	0,1932	25	0,2732
Östanväg nr. 2	Driving north	0,0008	0,3662	25	0,3462
Östanväg nr. 3	Driving south	0,0022	0,3388	25	0,3938
Östanväg nr. 3	Driving north	0,0015	0,3916	25	0,3541

Street name	Direction	Linear > 30 km/h			
		k_1	k_0	Speed [km/h]	Vertical acceleration [g]
John Ericssons väg	Driving east	0,0093	0,0247	40	0,3967
Skjutbanevägen	Driving north-east	0,0079	0,1413	40	0,4573
Östanväg nr. 1	Driving south	0,0094	0,0788	40	0,4548
Östanväg nr. 1	Driving north	0,0123	0,0136	40	0,4784
Östanväg nr. 2	Driving south	0,0137	0,1047	40	0,4433
Östanväg nr. 2	Driving north	0,0039	0,2804	40	0,4364
Östanväg nr. 3	Driving south	0,0167	0,0837	40	0,5843
Östanväg nr. 3	Driving north	0,0005	0,4861	40	0,5061

Group 3 (gentle and short)

Street name	Direction	Linear < 30 km/h k_1	k_0	Speed [km/h]	Vertical acceleration [g]
Bondevägen	Driving south	-0,006	0,3463	25	0,1963
Bondevägen	Driving north	0,0036	0,2991	25	0,2091
Kakelvägen nr. 1	Driving north-west	0,0097	0,0949	25	0,3374
Kakelvägen nr. 1	Driving south-east	0,0065	0,1391	25	0,3016
Kakelvägen nr. 2	Driving north-west	0,0109	0,1343	25	0,4068
Kakelvägen nr. 2	Driving south-east	0,004	0,2638	25	0,3638
Sunnanväg	Driving west	0,0042	0,0378	25	0,1428
Svanevägen	Driving north-west	0,0066	0,5212	25	0,3562

Street name	Direction	Linear > 30 km/h k_1	k_0	Speed [km/h]	Vertical acceleration [g]
Bondevägen	Driving south	0,0075	0,0121	40	0,2879
Bondevägen	Driving north	0,0124	0,1717	40	0,3243
Kakelvägen nr. 1	Driving north-west	0,0064	0,255	40	0,511
Kakelvägen nr. 1	Driving south-east	0,0073	0,16	40	0,452
Kakelvägen nr. 2	Driving north-west	0,0084	0,1772	40	0,5132
Kakelvägen nr. 2	Driving south-east	0,0018	0,4283	40	0,5003
Sunnanväg	Driving west	0,0141	0,2354	40	0,3286
Svanevägen	Driving north-west	0,0154	0,0553	40	0,5607

Group 4 (gentle and long)

Street name	Direction	Linear < 30 km/h k_1	k_0	Speed [km/h]	Vertical acceleration [g]
John Ericssons väg	Driving west	0,0054	0,3785	25	0,2435
Magistratsvägen	Driving east	0,0045	0,0882	25	0,2007
Magistratsvägen	Driving west	0,0066	0,0007	25	0,1643
Ole Römers väg	Driving south	0,0041	0,198	25	0,3005
Ole Römers väg	Driving north	0,0108	0,0643	25	0,2057
Skjutbanevägen	Driving south-west	0,0044	0,1357	25	0,2457

Street name	Direction	Linear > 30 km/h k_1	k_0	Speed [km/h]	Vertical acceleration [g]
John Ericssons väg	Driving west	0,004	0,2379	40	0,3979
Magistratsvägen	Driving east	0,0085	0,0157	40	0,3243
Magistratsvägen	Driving west	0,0225	0,4295	40	0,4705
Ole Römers väg	Driving south	0,0092	0,044	40	0,412
Ole Römers väg	Driving north	0,0124	0,1164	40	0,3796
Skjutbanevägen	Driving south-west	0,0087	0,0601	40	0,4081

Appendix 5, Values of $t_{\alpha,n}$ for t-test

Values of $t_{\alpha,n}$

n	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.025$	$\alpha = 0.01$	$\alpha = 0.005$
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.474	4.604
5	1.476	2.015	2.571	3.365	4.032
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.499
8	1.397	1.860	2.306	2.896	3.355
9	1.383	1.833	2.262	2.821	3.250
10	1.372	1.812	2.228	2.764	3.169
11	1.363	1.796	2.201	2.718	3.106
12	1.356	1.782	2.179	2.681	3.055
13	1.350	1.771	2.160	2.650	3.012
14	1.345	1.761	2.145	2.624	2.977
15	1.341	1.753	2.131	2.602	2.947
16	1.337	1.746	2.120	2.583	2.921
17	1.333	1.740	2.110	2.567	2.898
18	1.330	1.734	2.101	2.552	2.878
19	1.328	1.729	2.093	2.539	2.861
20	1.325	1.725	2.086	2.528	2.845
21	1.323	1.721	2.080	2.518	2.831
22	1.321	1.717	2.074	2.508	2.819
23	1.319	1.714	2.069	2.500	2.807
24	1.318	1.711	2.064	2.492	2.797
25	1.316	1.708	2.060	2.485	2.787
26	1.315	1.706	2.056	2.479	2.779
27	1.314	1.703	2.052	2.473	2.771
28	1.313	1.701	2.048	2.467	2.763
29	1.311	1.699	2.045	2.462	2.756
∞	1.282	1.645	1.960	2.326	2.576

Other t Probabilities:
$P\{T_8 < 2.541\} = 0.9825$ $P\{T_8 < 2.7\} = 0.9864$ $P\{T_{11} < 0.7635\} = 0.77$ $P\{T_{11} < 0.934\} = 0.81$ $P\{T_{11} < 1.66\} = 0.94$ $P\{T_{12} < 2.8\} = 0.984$.