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MASTER'S THESIS

The Influence of Wire Rope Barriers on Motorcyclists

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The influence of wire rope barriers on motorcyclists

By

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Abstract

The implementation of wire rope barriers on 2+1 roads has significantly improved road safety performance on the Swedish road network. The main purpose of wire rope barriers is to prevent oncoming traffic from head-on collisions by redirecting errant vehicles back onto the carriageway in a controlled manner causing, at most, damage to the vehicle. However, motorcyclists have raised concerns that wire rope barriers pose more danger to them than any other crash barriers. There is not though sufficient accident data and scientific knowledge to support this concern. Nonetheless, it is necessary to determine what influence this type of barrier has on the motorcyclist, especially with the increasing implementation of wire rope barriers and the growth in motorcycle traffic year on year. This is the objective of this study.

The first part of this study introduces general motorcycle safety. Then information on wire rope barriers and their implementation in the rural road network in Sweden is provided. Further on, the study attempts to assess the safety of roads with wire rope barriers with respect to motorcyclists based on accidents contained in the accident data. The main part of this study concerns an assessment of the influence of wire rope barriers on motorcycles, in particular how they affect their speed, performance and choice of travel routes. These were measured by means of traffic volume and speed data analysis, interviews and questionnaires and site study measurements. Finally, future actions that ought to be taken are proposed at the end of the study.

The accident analysis showed that wire rope barrier roads were substantially less safe for motorcycles than they were for any other road users. Moreover, the majority of interviewed motorcyclists were critical of the barriers and felt insecure when riding along them. The results showed that despite their concerns motorcyclists did not tend to avoid roads with wire rope barriers. In terms of speed performance the results were unclear. On one hand there seems to be evidence that road barriers influence the speed at which motorcyclists travel. The site study and statistical data showed that on roads with wire rope barriers motorcycle speeds were rather concentrated around the speed limit. In addition on equivalent roads without barriers motorcycle speeds were rather spread out and in many cases either substantially exceeded the speed limit or were much below it. On the other hand, nearly three quarters of interviewed motorcyclists stated that barriers had no influence on their speed.

In conclusion, this study showed that wire rope barriers could be perceived as a safety issue for motorcyclists. However, this has to be set against the fact that there is not sufficient statistical information available on motorcyclists in any of the areas analysed. Furthermore, there has been no in-depth study of wire rope barrier safety with respect to motorcyclists. Motorcycles are also not included in approval tests of wire rope barriers (or any other crash barriers). Growing motorcycle traffic and barrier implementation and the feeling of insecurity of riders are all factors that significantly justify more research to be carried out in this area.

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1. INTRODUCTION

1.1 BACKGROUND

Wire rope barriers are flexible systems comprising of three or four tensioned wire ropes, supported by posts and ground anchors. They are more flexible than other barrier types, resulting in minimised vehicle damage and occupant injury. Wire rope barriers gradually reduce speed, contain and redirect errant vehicles. While this type of barrier is highly effective for passenger vehicles and even heavy vehicles, there is a concern that motorcyclists are exposed to a "cheese-cutter" effect, literally, from impact with the wires and severe head injuries when colliding with the supporting posts. It is generally recognised that wire ropes are perceived as a potential cause of injury, however there is no record of motorcyclists being "sliced" by wire rope barriers that are present on over 900km of Swedish roads, nor has concurrent research proved such an effect happening [9]. It is thought to be more likely for the supporting posts to be the main hazard to motorcyclists [15].

Researchers claim that there is not enough accident data and scientific knowledge available to support motorcyclists' concern [14]. There is no substantial evidence to state that wire rope barriers pose more injury risk than the objects from which the barrier protects, namely a tree, lamppost or oncoming traffic [14].

Even though there are few riders who crash into wire rope barriers, those who do collide with the post may be at high risk of being killed or seriously injured. This implies that wire rope barriers pose the same level of danger to motorcyclists as any other barrier supported by posts. Therefore, motorcyclists have justification for their concern at least in this accident area. The question is how do motorcyclists react to a system that is very effective for passenger vehicles but potentially dangerous for motorcyclists. Since it is very cost-effective to have the existing barriers installed and maintained in the future, motorcyclists have no other choice than to adapt to the existing road environment.

1.2 OBJECTIVES

The objective of this study is to determine how wire rope barriers influence motorcyclists. Namely, to give answers to the following issues:

- Do motorcyclists choose to use roads without wire rope barriers or have the barriers gained acceptance and have no influence on motorcyclists' choice of routes?
- How the existence of barriers in the road environment affects the speed and performance of motorcyclists? Does the outcome lead to a conclusion that merely the presence of the wire rope barrier is a psychological speed calming measure itself, causing speed reduction?
- However, there exists a group of accidents that happen independently from the driver and the road infrastructure, for example vehicle failure. Consequently, the collision with the barrier may be unavoidable. Therefore, this study will suggest some ideas on how to improve wire rope barriers in order to reduce the potential risk of lethal motorcycle accidents.

1.3 METHOD

The theoretical background in motorcycle safety, wire rope barriers and roads that have these barriers is based on an in-depth literature study.

Motorcyclists' safety assessment on wire rope barrier roads

The motorcycle safety assessment of roads with wire rope barriers is based on literature review and accident data analysis. The assessment is intended to highlight the magnitude of the issue and should not be perceived as a fully reliable safety assessment due to many limitations concerning the analysed data.

The main part of the study, which analyses the influence of wire rope barriers on motorcyclists, is based on several sources and analysis methods. These are outlined below:

"Motorcycle travelling patterns and choice of alternative routes" method

Motorcyclists' preference of roads can be determined by comparing motorcycle traffic flows on roads with wire rope barriers and without, leading to the same destination. The data for this exercise was obtained from the Swedish Road Administration's (SRA) database.

"Before and after" study method

By comparing motorcycle traffic flows and speeds on the same sections of roads before and after implementation of wire rope barriers, the speed performance and exposure can be determined.

"Comparison of equivalent roads" method

Motorcycle traffic flows and speeds can be compared on roads with and without wire rope barriers. These roads will have similar capacities, traffic volumes and speed limits, so the speed performance and exposure can be determined.

Questionnaire

By conducting an internet questionnaire amongst motorcyclists, the data on speed performance, exposure and potential avoidance of wire rope barrier roads can be obtained directly from the source.

Interview

By interviewing motorcyclists, more detailed data can be obtained than from the questionnaire on all aspects concerning the matter of the study.

"Speed and distance measuring" method

By conducting a site study, the influence of wire rope barriers can be observed visually. The main purpose of this method is to evaluate the speed performance and to determine the distance that motorcyclists ride along the barriers.

"Speed and distance change" method

By conducting a site study it is possible to determine how wire rope barriers affect individual motorcyclists. The site study identifies behavioural changes that occur when motorcyclists pass the transition from a stretch of the road with wire rope barriers to one without and vice versa. The speed and the distance from the barrier are to be observed using this method.

1.4 DELIMITATIONS

The study only focuses on Sweden with no information on other countries' experiences. In terms of data limitations, incomplete data is used during the analysis, therefore in some cases the data may not be considered as representative within each group that is analysed. More information can be found in the method description in chapter 5.

1.5 CONTENTS

The study begins with a literature review of motorcycle traffic in Sweden and its safety in chapter 2. Then, wire rope barriers are described in chapter 3. Chapter 4 provides detailed information on wire rope barrier roads. The method is described in chapter 5 and the results are presented in chapter 6. A discussion and general conclusion can be found in chapter 7. Future actions are suggested in chapter 8 based on the results and a literature review of motorcycle-friendly roadside protection devices. The whole of the report is referenced with square brackets e.g. [1]. The list of references can be found at the end of the report in chapter 9.

2. MOTORCYCLISTS' SAFETY

This chapter will give an overview of motorcycle traffic safety in Sweden.

2.1 BACKGROUND

Motorcycle traffic in Sweden has been constantly increasing in recent years and this trend is expected to continue. The number of motorcycles in traffic has doubled between 1995 and 2004 [1]. In July 2004 there were 235,000 motorcycles on the road compared to just 120,000 in 1995. Vehicle mileage between 1998 and 2003 has increased by 70 %, from 450 million vehicle kilometres to 750 million.

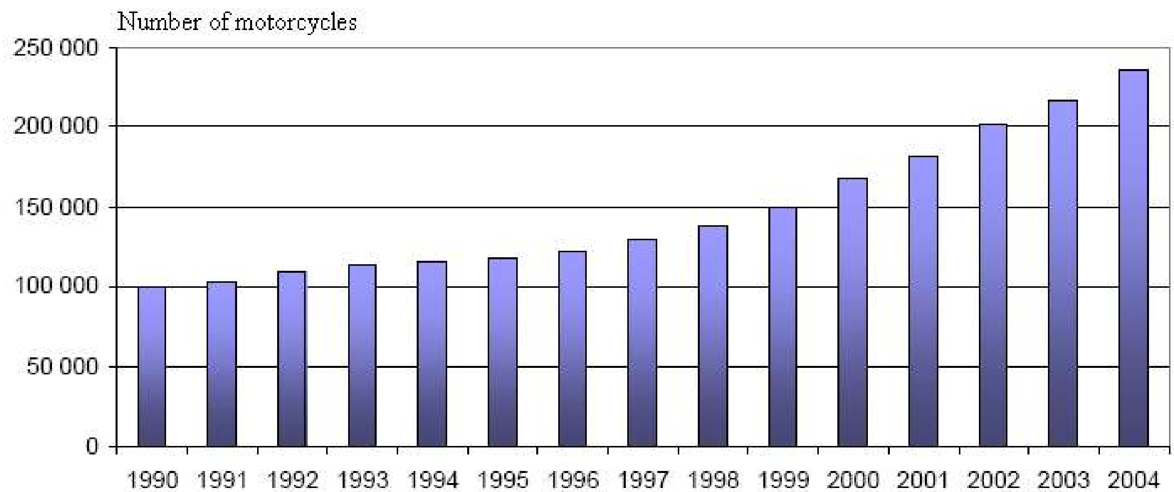


Fig.2.1 Number of motorcycles in traffic in Sweden between years 1990 and 2004 [2]

Surprisingly the increase in motorcycle traffic is not due to an increase in younger riders, those under the age of 35. On the contrary, the number of younger riders has actually dropped by 21 %, from 43,000 to 34,000 between 1995 and 2004. There has, however been a rapid increase among riders of 35 years of age and above, and in those 10 years, the number has risen by 173 %, from 71,000 to 194,000.

2.1.1 Motorcycle types

Motorcycles have engine sizes between 50 and 2,300 cc. Those with over 500 cc generally have four stroke engines. Smaller motorcycles use two stroke engines.
The Federation of European Motorcyclists' Association (FEMA) differentiates between seven motorcycle types depending on purpose of use. All of these types can be seen on Swedish roads. A brief description of each type is quoted below [3]:

"***Standard* -** Traditional motorcycles mainly designed for practical transportation. This category falls in the middle of the spectrum in most areas of ergonomics and performance, including power, handling and braking.

Cruiser (Custom)- Once dominated exclusively by Harley-Davidson, the cruiser category has now attracted competition from all major manufacturers. The profile is long with a low saddle height. The emphasis is on appearance, style and sound, with less emphasis on performance.

Multi-Purpose (Off-road) **-** With long suspension travel, these machines are designed to be used both on asphalt and unmade roads. This category is becoming more and more popular amongst riders. They are often called "adventure bikes", as they offer the comfort, luggage capacity and durability needed for long-distance touring.

Touring **-** Large, often very expensive motorcycles with luggage capacity and weather protection, designed to transport rider and passenger in comfort. Touring bikes are heavy with moderate power outputs. Their intended purpose is comfortable, long-distance travel.

Sport-Touring **-** These motorcycles combine the comfort and some of the luggage capacity of touring bikes with the responsive handling of sport bikes. Usually powerful with high-performance brakes. The purpose of a sport-touring machine is medium and long-distance travel via challenging roads.

Supersport **-** Styled and constructed in the manner of road-racing motorcycles with streamlined bodywork and forward-leaning riding position. The emphasis is on handling, acceleration, top speed, braking and cornering. Often lighter and more technologically advanced than other types of motorcycles, they are favoured for riding on twisting roads.

Scooters **-** These two-wheeled vehicles are often small, mostly low-power designs in moped and light motorcycle categories with small-diameter wheels suitable for use on surface streets in urban environments. Their appearance differs significantly from motorcycles because of their bodywork and the "step-through" frame design. Although less common, a new generation of super scooters with engine capacities of up to 650 cc is becoming increasingly prevalent. They combine the virtues of traditional scooters with a long distance capability."

2.1.2 Motorcycle traffic in different parts of Sweden

The usage of motorcycles is mostly determined by weather conditions. As a result motorcycle traffic is higher in the south of Sweden where the winter period is shorter and milder. Table 2.1 shows the number of motorcycles in different parts of Sweden.

Table 2.1 Motorcycle traffic in different parts of Sweden [4]

	Region (län)	2000	2001	2002	2003	2004
1	*Stockholms län*	24161	26775	29953	31558	34047
3	*Uppsala län*	4905	5647	6403	6958	7433
4	*Södermanlands län*	5227	5825	6608	7140	7901
5	*Östergötlands län*	8583	9202	10219	11121	12110
6	*Jönköpings län*	8068	8693	9386	9991	10626
7	*Kronobergs län*	3912	4216	4737	5230	5765
8	*Kalmar län*	5434	5838	6506	7117	7765
9	*Gotlands län*	1421	1566	1732	1873	2023
10	*Blekinge län*	4011	4353	4688	5077	5370
12	*Skåne län*	22192	23785	26297	28333	30593
13	*Hallands län*	6566	6968	7773	8358	9157
14	*Västra Götalands län*	29397	31715	34440	37234	40230
17	*Värmlands län*	6170	6666	7326	7777	8279
18	*Örebro län*	5342	5856	6404	6832	7428
19	*Västmanlands län*	4844	5347	6074	6718	7219
20	*Dalarnas län*	6008	6647	7498	8272	9087
21	*Gävleborgs län*	6188	6715	7249	7779	8523
22	*Västernorrlands län*	4197	4639	5303	5667	6153
23	*Jämtlands län*	2137	2384	2658	2923	3299
24	*Västerbottens län*	5092	5430	5906	6330	6829
25	*Norrbottens län*	3491	3825	4366	4727	5359
	Total	*167 346*	*182 092*	*201 526*	*217 015*	*235 196*

2.1.3 Other statistical data on motorcyclists and motorcycles in Sweden

By the end of June 2004 there were 24,165 motorcycles owned by women accounting for 10 % of the total motorcycles in use, 203,812 were owned by men and the remaining 7,219 were company's property. The most popular type of motorcycle is the custom bike. The age distribution is shown on figure 2.2, where most motorcycles belong to those above the age of 35. The distribution of motorcycle engine sizes is shown on figure 2.3, where most motorcycles have an engine size more than 600 cc.

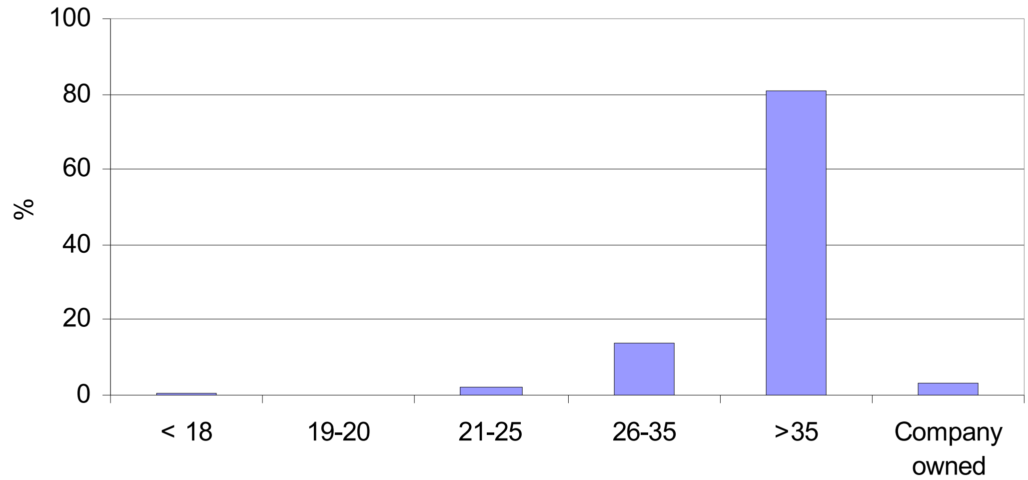


Fig.2.2 The age distribution of motorcycle owners in Sweden in June 2004 [19]

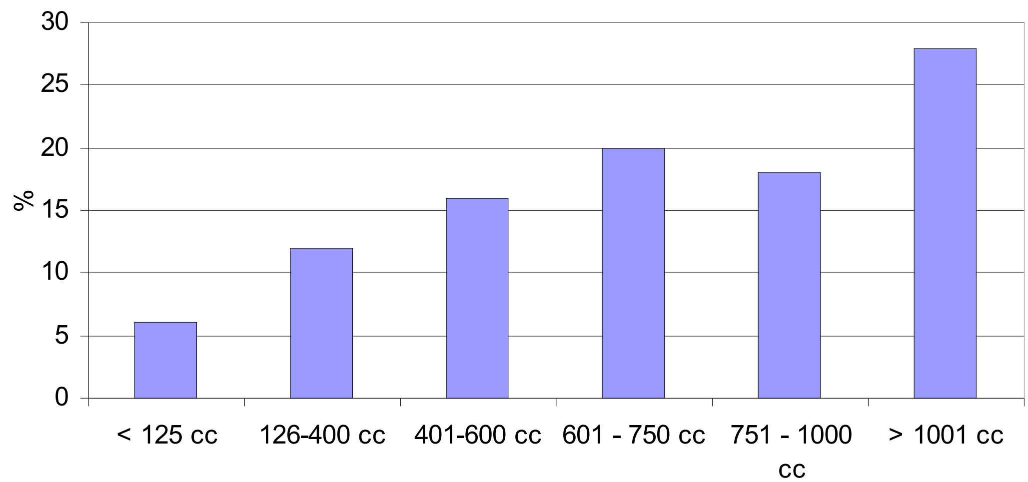


Fig.2.3 The engine size distribution of 235,000 motorcycles registered in Sweden in June 2004 [19]

2.2 MOTORCYCLE SAFETY

2.2.1 Introduction

Motorcyclists are the most vulnerable road users and have a high risk of injury according to accident statistics. Regardless of the type of motorcycle protection, motorcyclists are almost directly exposed to external forces resulting from a collision. A minor collision between two passenger vehicles usually causes material damage only, whereas a similar collision between a car and a motorcycle may result in an injured or killed rider. According to the National Highway and Transportation Research Institute (later referred as to VTI from Swedish *Väg Trafik Inspectionen*) [1] the probability of being killed per kilometre of road, when riding a motorcycle is 13 times higher than when driving a passenger vehicle. When comparing vehicle mileage to the number of fatal accidents, the outcome is 8 times higher for motorcycles and mopeds. According to data from 1994 [5] this risk was even higher than assumed, as shown on figure 2.4.

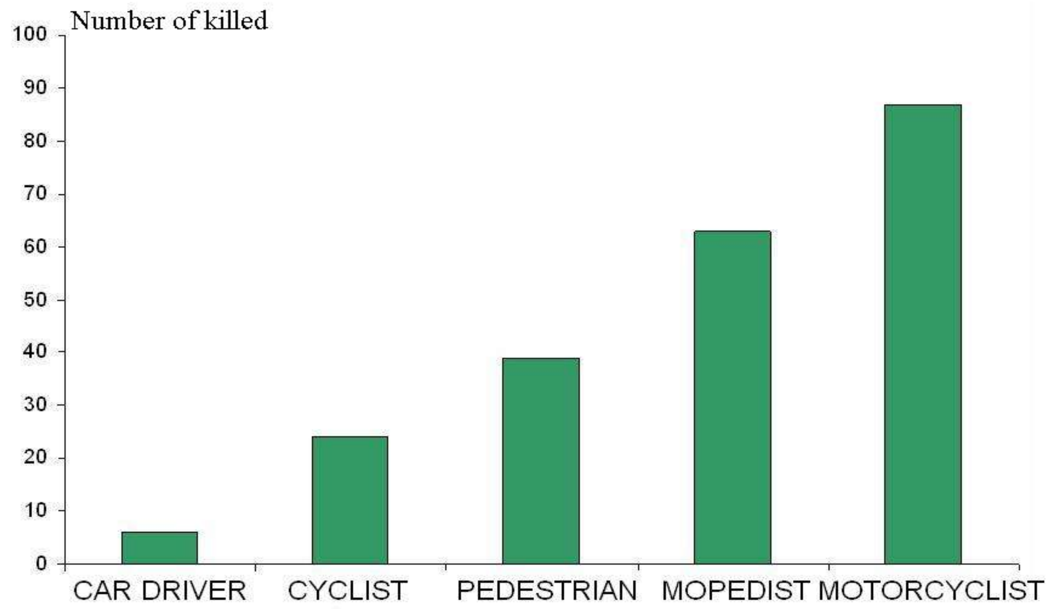


Fig.2.4 Number of killed per modes of transport per billion vehicle kilometres in 1994 [5]

2.2.2 Accident analysis

Despite the increase in traffic, not only motorcycle but road traffic in general, the number of fatal and severely injured motorcycle accidents had a decreasing tendency in recent years and this trend was expected to continue. However, from 2002 the number of fatal accidents began to rise rapidly, and between 2002 and 2004, this number increased by 60 %, from 37 to 59 fatalities per year (fig. 2.5).

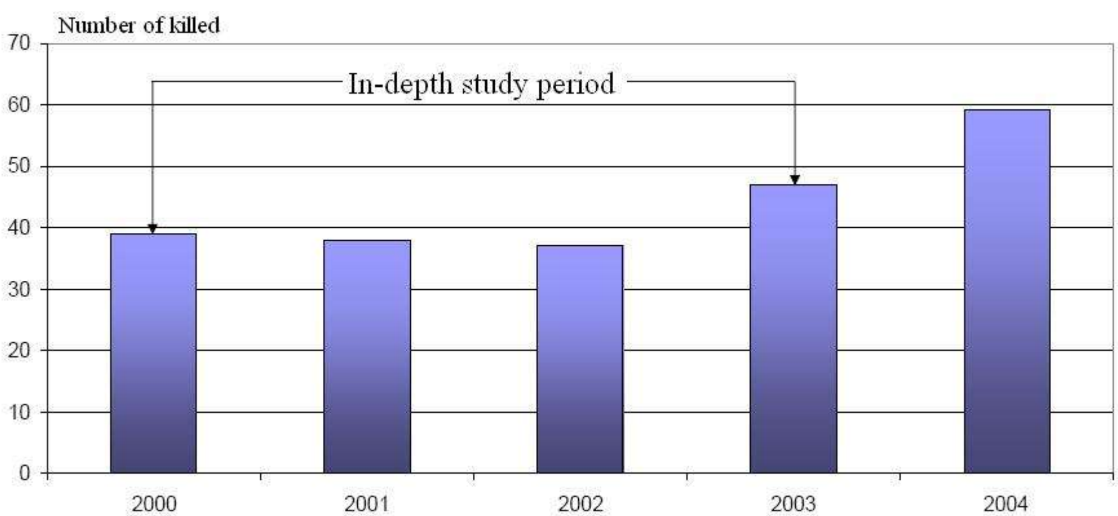


Fig.2.5 Number of motorcyclists being killed between 2000 and 2004 [2]

The Swedish Road Administration (SRA) carried out an in-depth study of motorcycle fatal accidents between the years 2000 and 2003 [2]. Such aspects as type of accidents, alcohol usage and speeding were studied. The study concerned 160 fatal accidents, which involved 158 motorcyclists, 5 pedestrians, 3 passenger vehicle drivers and 2 cyclists. The following sections are based on this study, supplemented with data from other sources when stated.

Time of accident

60 % of accidents occurred between Friday and Sunday. Most fatal accidents took place between August and September.

Visibility

67 % of accidents occurred when there were good sight conditions. 77 % of accidents occurred during daylight hours. However, almost one third of accidents took place when sight conditions were poor. 14 % of motorcycle fatalities occurred during the night.

Gender and age

Out of 158 fatalities, 145 were male riders and 4 male passengers. There were only 2 female riders and 7 female passengers.

Despite the fact that there were fewer young riders in traffic, 40 % of all motorcycle fatalities were riders aged between 20 and 29, whose vehicle mileage accounted for only 28 % of the total studied. Moreover, the group age between 30 and 39, whose vehicle mileage accounted for 10 % of the total, were involved in 25 % of fatal accidents. On the contrary, only 7 % of riders between the age of 50 and 59 were killed. This age group accounts for almost 35 % of all motorcycle vehicle mileage studied (fig.2.6). However, in recent years, especially in 2004, the number of fatalities in riders between the age of 30 and 59 had substantially risen compared to previous years.

The age group between 20-29, that accounted for 40 % of fatal accidents, was in the possession of 6 % of all motorcycles in traffic (fig 2.7). In contrast older motorcyclists, who account for the largest group, represent a relatively small part of those involved in fatal accidents.

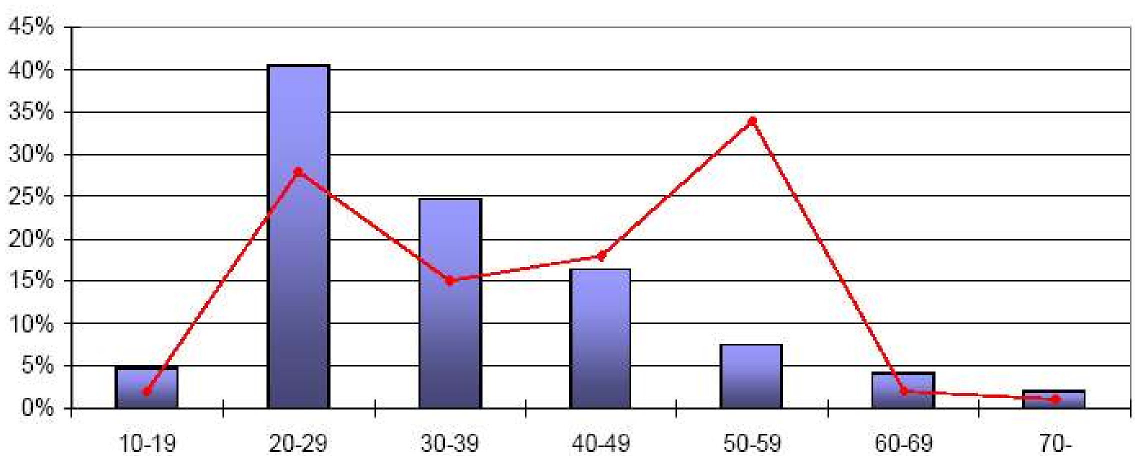


Fig.2.6 Motorcycle accident toll (bar chart) and motorcycle vehicle mileage (line graph) by age 2000-2003 [2]

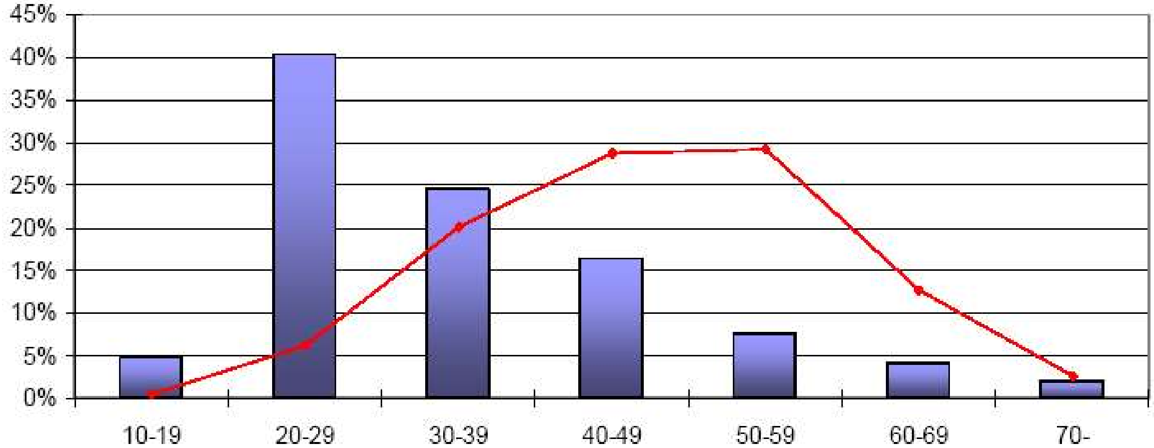


Fig.2.7 Motorcycle accident toll (bar chart) and motorcycle ownership (line graph) by age 2000-2003 [2]

Driving licence

Until 1975, motorcycle driving licence (category A) could be obtained on the basis of a passenger vehicle driving licence. 20 % of all motorcycle fatalities studied involved those who obtained their motorcycle driving licence in such way. Newly qualified riders also have a high death rate. One fifth of those who died obtained their licence within a year of the accident.

Protection wear

77 % of motorcyclists who had died were wearing a helmet. However, 15 % of fatal accidents occurred when a motorcyclist was lacking or lost a helmet, out of which 90 % were under the influence of alcohol.

Influence of alcohol or drugs

About one fifth of fatalities involved motorcyclists being under the influence of drugs or alcohol. Drink riding and drug usage was most common among those aged 20-29.

Fatal injury

Head and chest injuries were the most common cause of death, accounting respectively for 46 % and 32 %. Internal bleeding and abdomen injuries accounted for 15 % and 11 % of deaths.

Motorcycle type

56 % of all motorcycle accidents involved "Supersport" motorcycles, of which 80 % were riders aged between 20 and 39. "Standard" and "Off-road" motorcycles were the next two highest groups and were involved respectively in 17 % and 12 % of all accidents.

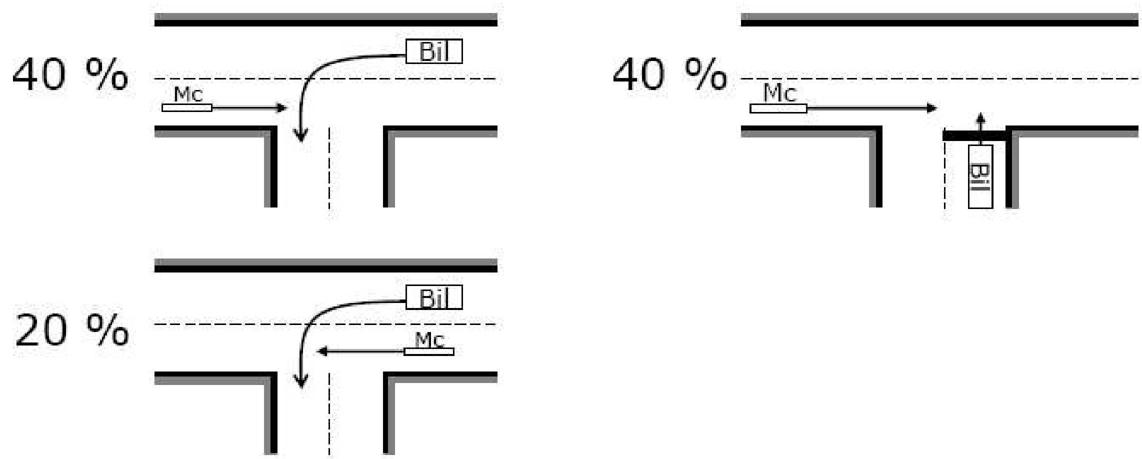
Accident type

Single

The most common accident type amongst motorcyclists was one involving a single vehicle. This accident type does not directly involve any other road user. It occurs usually due to riders (drivers) distraction, loss of concentration or vehicle failure. 45 % of those analysed died in single vehicle accidents. One fifth of those accidents involved a motorcyclist falling onto the carriageway, sliding across the road surface and hitting into a roadside object. The rest of fatal single accidents involved motorcyclists running off the road. 20 % of those who fell onto the carriageway got separated from their motorcycles before hitting roadside objects.

Turn-off and crossing

The second most common type of accident was one that occurred at intersections. There are two subgroups of intersection accidents: turn-off and crossing. The crossing accidents involve a side impact when two or more vehicles drive onto the intersection from different directions. Turn-off accidents are those where both vehicles are travelling along the same carriageway and one of them decides to turn off into a different direction of the intersection. The intersection accidents account for 27 % of all accidents studies, 60 % of which were the turn-off type (fig. 2.8a) and the remainder being crossing accidents (fig. 2.8b).



a) b)

Fig.2.8 a) Turn-off accidents involving a motorcycle (mc) and a passenger vehicle (bil) b) Crossing accident [2]

Head-on

12 % of fatal accidents constituted of head-on collisions. This type of accident is a run-off collision that involves a vehicle travelling in the opposite direction. According to SRA's in-depth study, 90 % of accidents involved motorcycles running into passenger vehicles travelling in the opposite direction, 60 % of which occurred on a bend. Only 10 % were due to the passenger vehicles being at fault (fig 2.9).

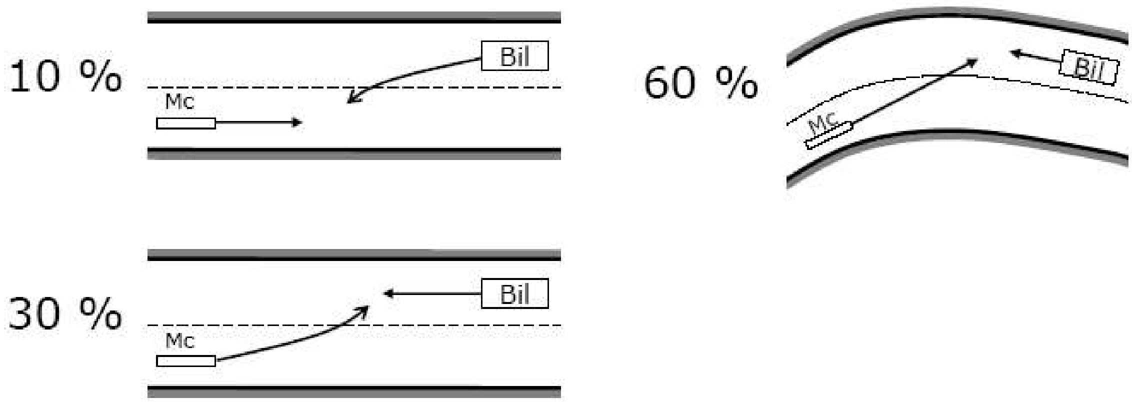


Fig.2.9 Head-on collisions [2]

Overtaking
Collisions due to overtaking accounted for 8 % of all accidents studied, 80 % of which were due to the motorcyclist overtaking causing the fatal accident (fig 2.10).

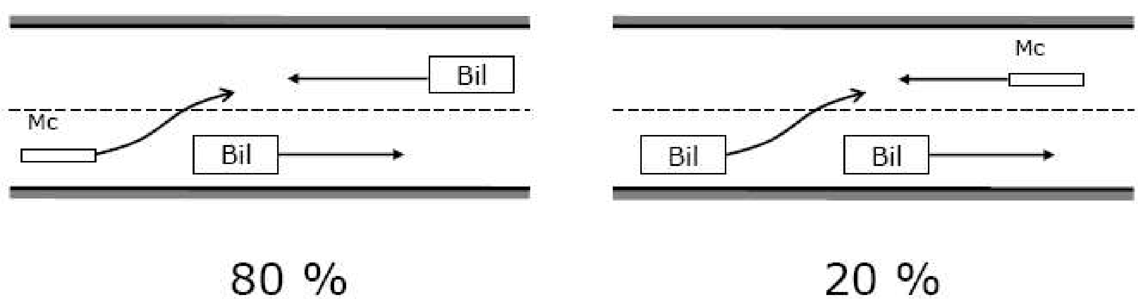


Fig.2.10 Overtaking collisions [2]

Other: Tailgating, with game
The remaining 10% constituted of a number of other types of accidents. These included running into the back of a vehicle in front as a result of tailgating or loss of concentration (5 %) and running into a wild animal (3 %).

Speed
The SRA used the following three scale accident speeds in their study:

- "as speed limit" – at most 10 km/h above the speed limit,
- "over" – in the interval of 10-30 km/h above the speed limit,
- "much over" – more than 30 km/h above the speed limit.

40 % of all fatal accidents studied involved motorcyclists exceeding the speed limit by more than 30 km/h and in 86 % cases this involved a "Supersport" motorcycle. 60 % of these accidents occurred at an intersection.

"As speed limit" accounted for 36 %, "over" for 5 % and the rest 18 % of fatal accidents occurred at unknown impact speeds.

Speed limits
When looking at different road types, split by speed limit, more than half of fatal accidents occurred on 70 km/h roads. 30 % occurred on 50 km/h roads and 20 % on 90 km/h roads. The remainder of motorcycle fatal accidents happened at 30 km/h and 110 km/h roads, respectively with 1 % and 3 % each.

VTI in their study [1] of motorcycle fatal accidents between 1995 and 2004 compared the proportion of fatal accidents of passenger vehicle drivers' and motorcycles to roads with different speed limits (fig.2.11)

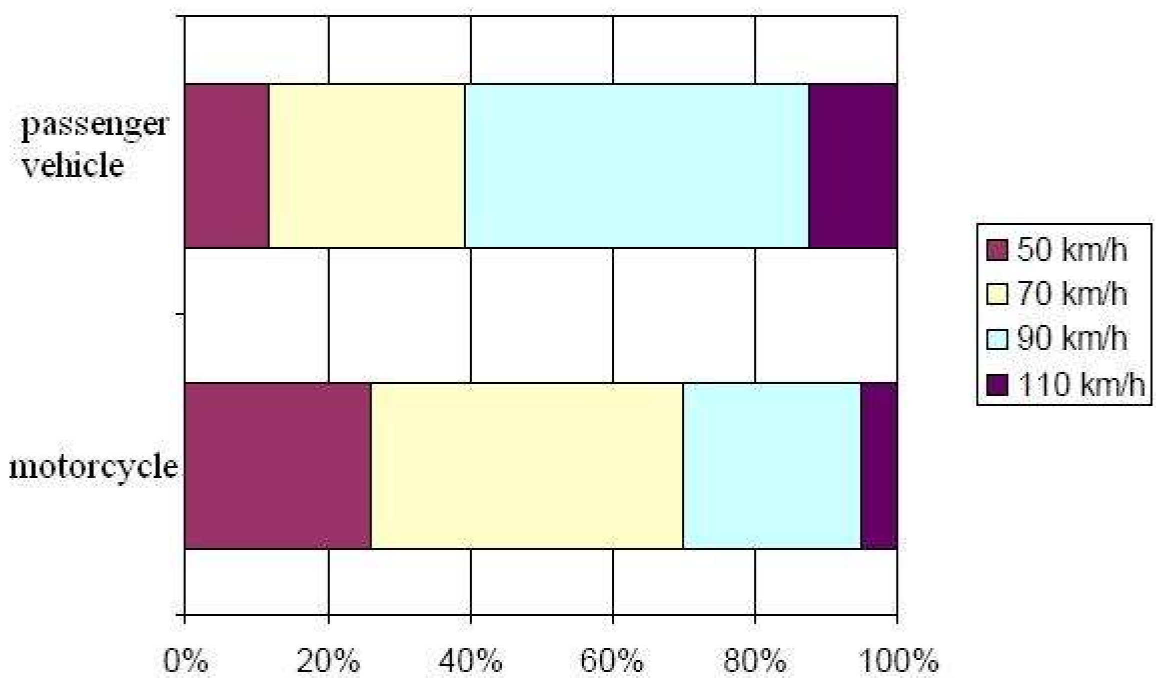


Fig.2.11 Motorcycle and passenger vehicle accident toll on roads with different speed limits in years 1995-2004 [1]

Figure 2.11 shows that motorcyclists in comparison with passenger vehicle drivers tend to die more often on roads with lower speed limits. This might be due to the fact that motorcycles are mainly used for local transportation where roads have lower speed limits. VTI also investigated types of accidents occurring on roads with different speed limits (fig.2.12).

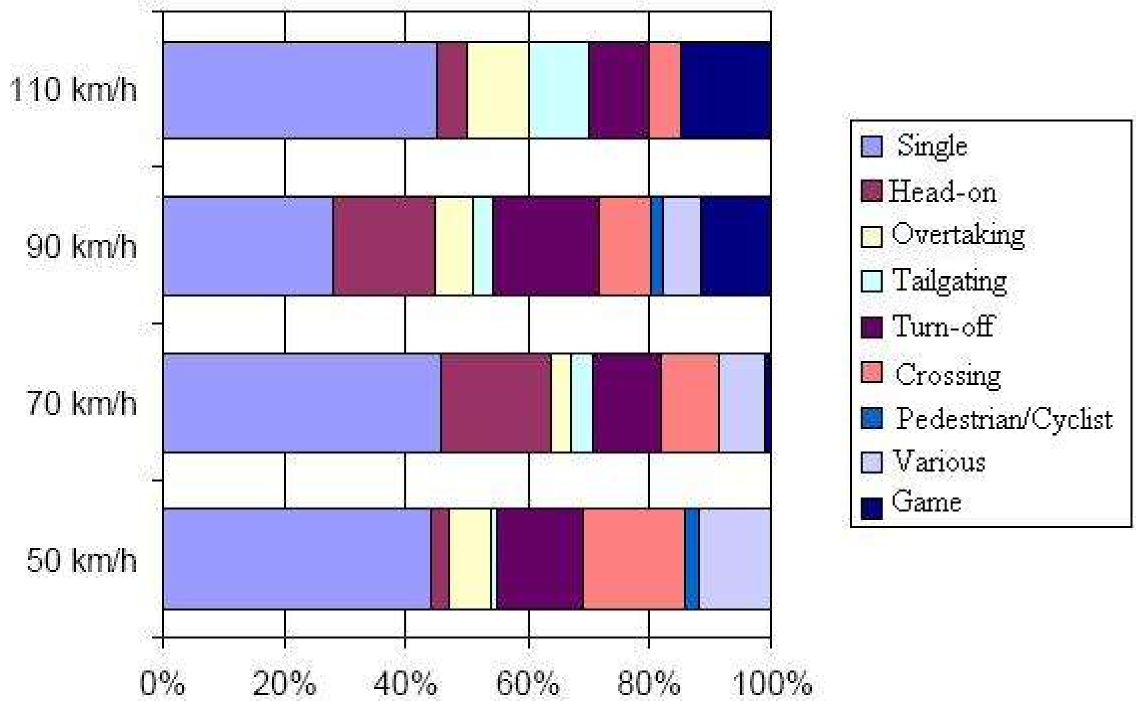


Fig.2.12 Motorcycle fatal accident types on roads with different speed limits in years 1995-2004 [1]

Single vehicle accidents were the most common type of accident in general, but they were predominant on 50, 70 and 110 km/h roads accounting for about 45 % of the total. Most of head-on collisions occurred on 70 and 90 km/h roads, respectively accounting for 18 % and 17 % of all accidents studied. The accidents that occurred at an intersection were most common on 90 and 50 km/h roads. Accidents involving a wild animal seemed to be a problem for roads with higher speeds.

Road type

The SRA's study [2] showed that most of motorcycle fatal accidents occurred on state owned roads, followed by county (communal) roads and then by private roads, which had the least accidents.

The road surface did not seem to have much of impact on the motorcycle accident toll. 93 % of accidents occurred on roads with a good road surface, 3.4 % of roads where the accidents happened had cracks and only 1.4 % of roads had clear deflections. Only one fatal accident took place on a gravel road.

The widths of the roads were also investigated. The ones with the most accidents had a width of between 5.7 – 6.6 m. However, those with a width of more than 11.5 m were second most common to have a fatal motorcycle accident occur (fig.2.13).

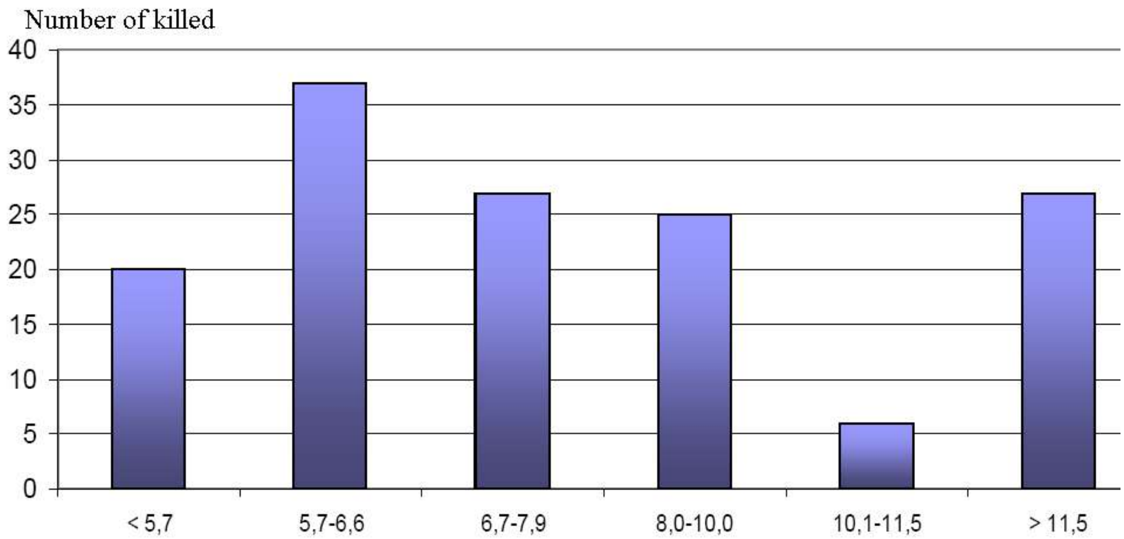


Fig.2.13 Number of killed on roads with different widths between years 2000-2003 [2]

Roadside and road furniture
44 % of all motorcycle fatal accidents studied involved a roadside object. 60 % of these accidents concerned road construction objects such as side barrier (not wire rope barrier), posts, ditches and culverts. During this study period no motorcyclist died due to collision with a wire rope central barrier. The first recorded fatal motorcycle accident involving a central wire rope barrier occurred in 2004 [6]. 30 % of the studied accidents involved collisions with trees, rock faces and the remainder 10 % involved collisions with buildings, walls or railings.

3. CRASH BARRIERS

This chapter shall look at procedure of standardising crash barriers, then will provide a brief overview of barrier types and finally will focus on wire rope barriers.

3.1 STANDARDISING CRASH BARRIERS

Crash barriers are designed to restrain and redirect uncontrolled vehicles with no harm to their occupant or other road users. Depending on the volume of traffic, available space on the road,type of roadside and vehicle type the barrier is designed to contain, different barrier types are being applied along Swedish roads. In 1990 the European Committee for Standardisation, CEN (Commité Européen de Normalisation) initiated a working group on Road Restraint Systems that resulted in producing standard EN1317.

Sweden has adopted EN 1317-1 "Terminology and general criteria for test methods" and EN1317-2 "Safety barriers-performance classes, impact test acceptance criteria and test methods". Barriers are tested at different speeds and impact angles. The speeds vary from 65 to 110km/h and the impact angles from 8 to 20 degrees. Five tests concern passenger vehicles and six tests concern heavy vehicles. Motorcycles are not taken into consideration when approving a barrier type [15].

The performance level of crash barriers is measured according to containment levels depending on impact speed, impact angle and the weight of the test vehicle. There are three main containment levels (table 3.1) [17]:

- T1-3 for low angle impacts,
- N1-2 for standard impacts,
- H1-4 for heavy vehicle impacts.

Table 3.1 Containment level for different criteria [17]

Containment level	Test	Speed (km/h)	Weight (kg)	Angle (deg)
T1	TB 21	80	1 300	8
T2	TB 22	80	1 300	15
T3	TB 21	80	1 300	8
	TB 41	70	10 000	8
N1	TB31	80	1 500	20
N2	TB 11	100	900	20
	TB 32	110	1 500	20
H1	TB 11	100	900	20
	TB 42	70	10 000	15
H2	TB 11	100	900	20
	TB 51	70	13 000	20
H3	TB 11	100	900	20
	TB 61	80	16 000	20
H4a	TB 11	100	900	20
	TB 71	65	30 000	20
H4b	TB 11	100	900	20
	TB 81	65	38 000	20

Table 3.2 Working width of crash barriers [17]

Working width	
W1	<= 0.6 m
W2	<= 0.8 m
W3	<= 1.0 m
W4	<= 1.3 m
W5	<= 1.7 m
W6	<= 2.1 m
W7	<= 2.5 m
W8	<= 3,5 m

Table 3.3 Impact severity level [17]

Impact severity level	
A	Very good
B	Good

When it comes to specifying the injury risk resulting from impact with a crash barrier, CEN specifies an Abbreviated Injury Scale (AIS) comprising of 6 levels of severity:

1. minor
2. moderate
3. serious
4. severe
5. critical
6. maximum

3.1.1 Approval institute

Swedish crash barriers are tested for approval at VTI in Linköping [17]. There are two crash tracks at VTI, an indoor and outdoor track. The 60 m indoor track enables full-scale vehicle tests as well as tests with different types of sleds. The outdoor track enables to test all types of roadside safety features.

The acceleration track is around 45 m long. The test vehicle is brought up to speed with steel wire ropes connected to two electric motors which together deliver around 3000 horse power. In theory, this results in bringing vehicles weighing 3000 kg to speeds of up to 110km/h. The present record on the outdoor track is 118 km/h and 104 km/h on the indoor track. The vehicle is not actually steered, the wheels follow a rail or a longitudinal pipe. The acceleration achieved on this 45 m track is approximately 1g which results in a final speed of 110km/h. The distance from start to impact is covered in just under 3 seconds. The collision itself lasts not more than 200 ms. Therefore, collisions are recorded on high speed film with different types of high speed cameras. VTI uses two different kinds of cameras, a video camera that can take 1000 frames per second and impact resistant cameras that take 3000 frames per second.

3.2 AN OVERVIEW OF CRASH BARRIER TYPES

Depending on the physical properties of the barrier, such as energy absorption and deflection, three main types of crash barriers can be distinguished: rigid, semi-rigid and flexible barriers [14].

3.2.1 Rigid barriers

Rigid concrete barriers have a very low energy absorption and deflection property. They are suitable for heavy vehicle impacts, low angle and low speed impacts and where there is a little space for deflection. Sweden uses concrete barriers on the central reservation of high traffic urban motorways and also temporarily during road works. The "New Jersey" barrier type (fig.3.1) is no longer used and has been replaced by vertical or convex sides. It is not a very common barrier in Sweden due to difficulties with snow clearing maintenance.

Fig.3.1 "New Jersey" concrete barrier [22].

3.2.2 Semi-rigid barriers

Semi-rigid barriers consist of supporting posts and barrier rails. The rails have to withstand axial tensile and bending stresses providing certain amount of deflection while the posts provide rigidity dependant on their spacing. There are two types of these barriers: w-beam and pipe-fence. W-beam barriers (fig.3.2) have guardrails with a "W" profile, they are the simplest and most common barrier design. Pipe-fence consists of upper and lower rails supported by 1.2 m spaced posts.

Fig.3.2 W-beam barrier [23].

3.2.3 Flexible barriers

Flexible barriers have a very high energy absorption and deflection property resulting in gradual deceleration of errant vehicles. The most common flexible barrier types used in Sweden are wire rope barriers implemented on 2+1 roads (fig.3.3). They usually comprise three or four lateral wire ropes (cables) and supporting frangible posts. The wire ropes are tensioned and fixed to the ground at both ends. They are mainly located on the central reservation but also along the edge of the road.

Fig.3.3 Wire rope barrier [17].

3.3 WIRE ROPE BARRIERS

3.3.1 Introduction

Wire rope barriers can function as a central (median) barrier, side barrier and slope barrier (fig.3.4).

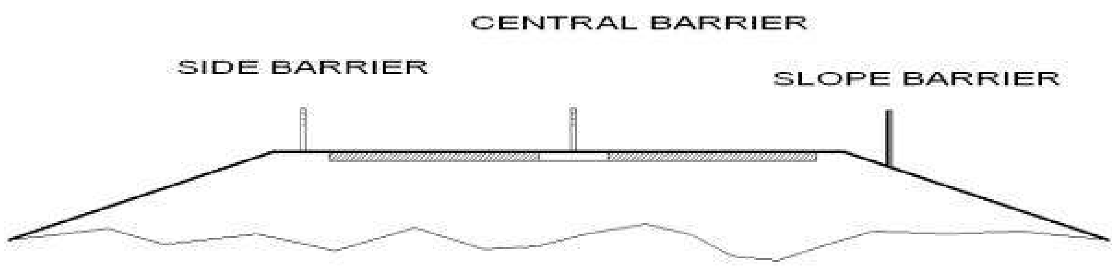


Fig.3.4 Wire rope barrier types [17]

The central barrier is intended to prevent vehicles from entering into oncoming traffic and potentially causing a head-on collision. It is either placed in the base course or in asphalt. The side barrier is used instead of an ordinary W-beam barrier preventing vehicles from run-off accidents into the roadside. The slope barriers have a similar function but are mounted further away from the carriageway, approximately 1 m, allowing vehicles to redirect themselves by giving the driver more space and time to react. The barriers' technical data varies for different manufactures [16] [17]. Generally the central barriers and side barriers have a similar construction with a top rope and 2 lower ropes on both sides whereas the slope barriers have ropes installed only on one side, facing the carriageway, and have longer posts (fig.3.5 a, b, c).

a) b) c)

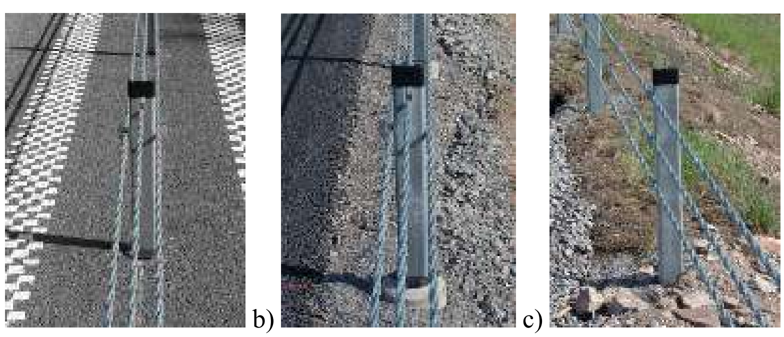


Fig.3.5 Wire rope barrier a) Central barrier b) Side barrier c) Slope barrier [16]

Wire rope barriers can have three or four ropes with a diameter of 19 mm. The ropes are tensioned by anchors at both ends and rest on breakable supporting posts generally spaced between 1 – 3.5 m. The posts can have an I, C, circular or rectangular cross section, with different types of foundations allowing adaptation to conditions on site. This structure provides high energy absorption and deflection properties. The wire ropes and breakable posts absorb some of the vehicle's kinetic energy and redirect the vehicle in a controlled mode back onto the carriageway. When compared with other barrier types vehicles bounce off the barrier instantly in a hazardous manner. There is no data available to specify the performance of wire rope barriers when it comes to motorcycles.

3.3.2 Testing of wire rope barriers

Wire rope barriers implemented on the Swedish road system have to be consistent with CEN standard requirements. The demands set by the SRA according to VU-94 are that wire rope barriers must have a containment level of N2 (table 3.1), an impact severity level A (very good, table 3.3) and a working width of W4 (less than 1.3 m, table 3.2) [16] [17].

There are two standard tests conducted on wire rope barriers:

1. TB11
2. TB32

According to table 3.1 test TB11 is carried out at an impact speed of 100km/h with a vehicle weight of 900kg and impact angle of 20 degrees. Whereas TB32 respectively: 110km/h, 1500kg and 20 degrees. Figure 3.6 shows the outcome of TB32.

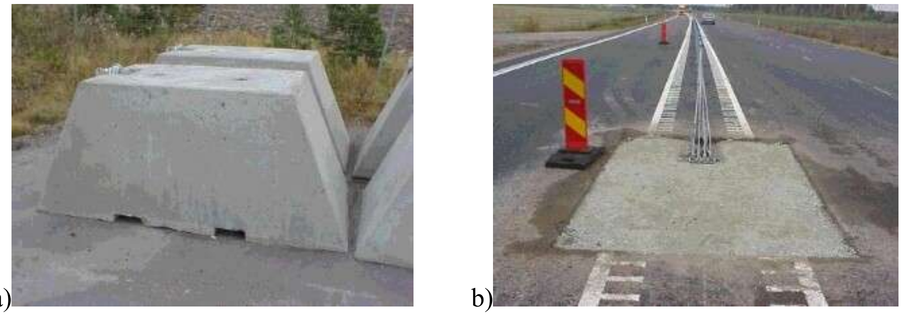
Fig.3.6 Test TB32 of slope barrier, VTI [17].

Wire rope barriers are generally not tested for heavy vehicles, but some manufactures design the barriers for containment level of H1 where test TB11 and TB42 is carried out (table 3.1). The accident data shows that standard wire rope barriers have withstood crashes with trucks at narrow angles. There are no standard tests carried out for motorcycles.

3.3.3 Installation of wire rope barriers

Depending on whether it is a central, side or slope barrier there are general installation procedures to be followed. Firstly the layout has to be planned and the start and end point set. Then the mid distances between the posts have to be precisely measured, for working class W4 the spacing is 2.5 m. If the horizontal radius is less than 300 m then spacing of posts should be enlarged to 3.5 m and intermediate anchors installed.

The construction work begins with placing the prefabricated anchors in the ground approximately 50 mm under the paving cushioned with compressible material that absorbs the forces from tensioned wire ropes (fig.3.7). The following step is to drill holes for post foundations. The posts are placed in steel cases and the rest of the hole is filled with concrete. The posts have to be adjusted in an appropriate vertical and lateral plane.



a) b)

Fig.3.7 Prefabricated anchor a) Before b) After placing into the ground [17]

Then the wire ropes have to be mounted to the end anchors. The wire ropes are delivered on barrels with an approximate wire length of 3000 m. First the wire rope needs to be attached to the front anchor, then threaded through post terminals and finally mounted to the end anchor. The wire ropes are cut into 150 m and 300 m lengths and connected by turnbuckles or rigging screw (fig.3.8). The 150 m cables are attached to the anchors on either side and the 300 m length of cable runs in between of them. Once the ropes have been attached to the end anchor they have to be tensioned.

Fig.3.8 A rigging screw [17]

The cables are tensioned to the manufacturer's specifications, generally the wire ropes are first tensioned by the nuts at the anchor and then with the turnbuckles along the route. The exact amount of tensioning depends on the ambient temperature at the time of installation. It can vary from just under 8 kN at 38 degrees Celsius to 31 kN at - 40 degrees Celsius (appendix B) [16] [17].

Depending on ground conditions, in one day approximately 700 – 1000 m of wire rope barriers can be installed.

3.3.4 Repairing wire rope barriers

Repair work is conducted under a Truck Mounted Attenuator (TMA), by closing one lane to traffic. The repairs are carried out in relatively short periods of time. The ropes usually withstand the impact, therefore when changing the damaged posts and post foundations, tensioning does not have to be reduced. Once the posts have been replaced, ropes can be put back in place.

3.3.5 Emergency performance of wire rope barriers

Wire rope barriers have quick locks established at fixed intervals along the carriageway making it possible for emergency vehicles to do U-turns. If quick locks are not present, ropes can be disassembled manually. It requires two or three people to lift the wires from the posts without having to slacken the ropes or using any tools. Then the posts are removed and the emergency vehicles or redirected traffic can pass [9][10].

If a vehicle becomes entangled in the barrier, ropes must not be cut. The cutting of the ropes will result in an immediate release of energy causing a whiplash effect that may result in fatal consequences to the rescuer and any persons in the vicinity. Wire tensioning should be released by turning rigging screws or at the anchor.

4. SWEDEN'S ROADS WITH WIRE ROPE BARRIERS

Sweden increased use of wire rope barriers in 1998 as part of the Swedish road safety programme called Vision Zero [8]. Wire rope barriers have been implemented on motorways, 2+1 semi-motorways and on 2+1, 2+2 and 1+1 cross-section ordinary roads.

Since the predominant use of wire rope barriers in Sweden is on 2+1 roads, this chapter will particularly focus on this type of road. However, other types of roads will be described in brief.

4.1 THE 2+1 ROAD

4.1.1 Background of 2+1 road design

Sweden's rural network of roads had many traffic safety problems. Nearly 100 people were killed and 300 severely injured annually [9]. Their main traffic problem concerned run-off and head-on accidents accounting for 66 % of all fatalities [9]. The head-on collisions were strongly correlated to the traffic volumes on the roads. There was a high concentration of head-on collisions on a very small percentage of roads. Figure 4.1 indicates that 80 % of fatalities that resulted from head-on collisions occurred on 15 % of the road network.

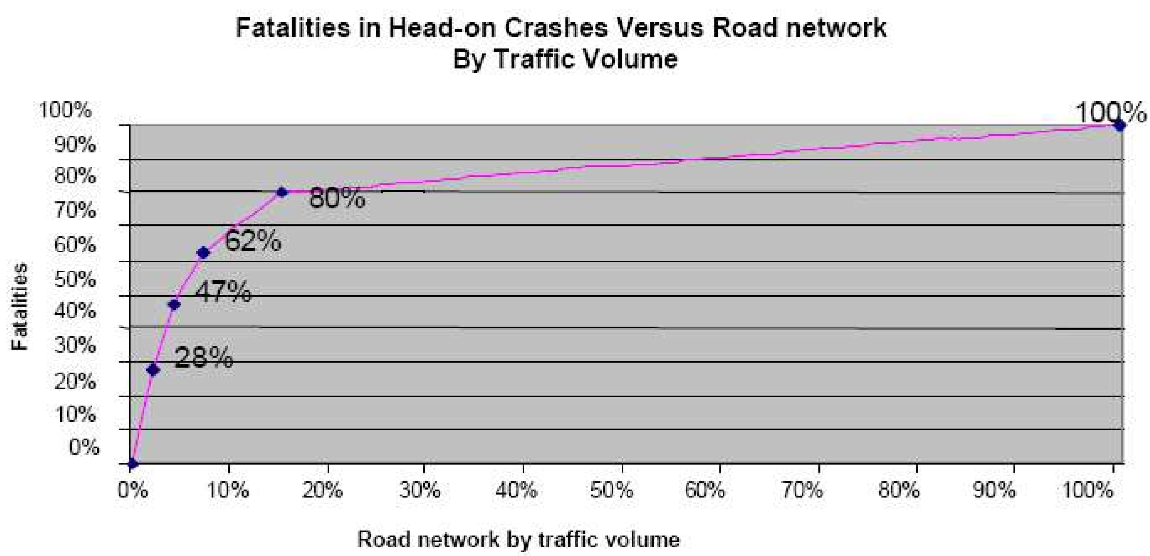


Fig.4.1 Killed in head-on collisions on Swedish national roads in 1999-2000 (motorways excluded) [9]

Similarly to head-on and run-off collisions, there is also a strong correlation between single vehicle collision and traffic volumes on roads. As figure 4.2 shows, 40 % of the road network accounted for 80 % of fatalities due to single vehicle crashes.

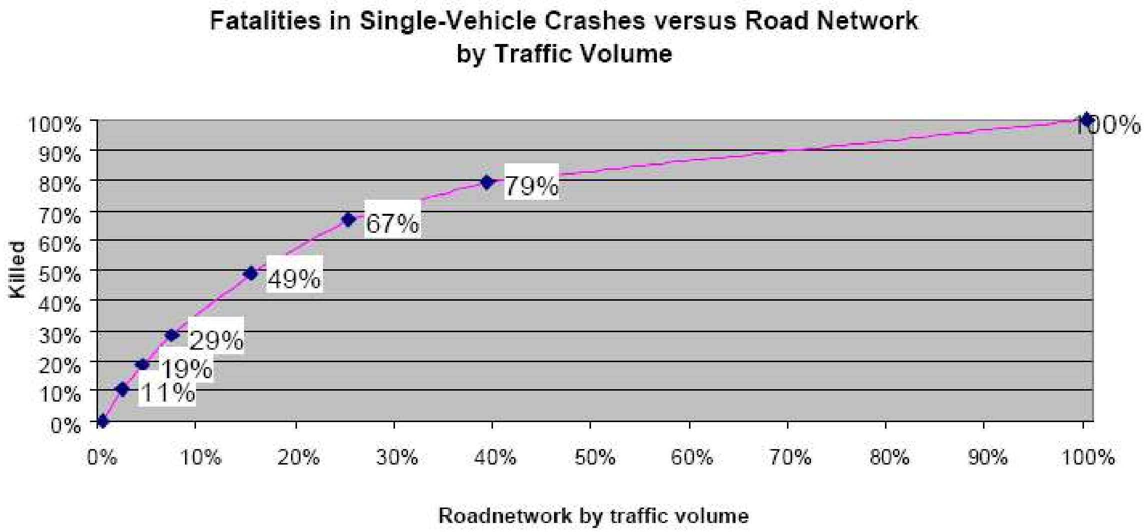


Fig.4.2 Killed in single vehicle collisions on Swedish national roads in 1999-2000 (motorways excluded) [9]

The two groups of cases mentioned above indicated which roads had to be modified in order to significantly reduce the accident toll. Therefore, the Director General of the former Swedish National Road Administration (currently called the Swedish Road Administration) decided on modifying the rural network of roads to enhance safety using low-cost measures.

These low-cost measures were to give a reasonable cost-benefit ratio meaning that the traffic safety key value would improve and the level of service would not decrease.

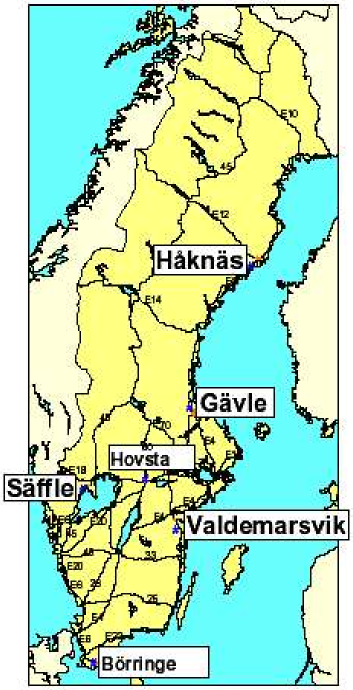
The modification consisted of introducing either the 2+1 solution or , the more costly alternative, the 2+2 road. The 2+1 solution is a continuous three-lane cross-section of road with alternating passing lanes with a separating wire rope barrier. The 2+2 solution has a four-lane cross-section and a separating wire rope barrier.

The 2+1 solution was implemented on roads with traffic flows varying from 4,000 vehicles per day (ordinary roads) to up to 20,000 veh/d (semi-motorways) [10].

Initially it was expected that this modification would yield a result of a 50 % reduction in the number of lethal and severely injured accidents. The results correspond to a reduction of 35 – 50 % in the number of killed and seriously injured, but 76 – 90 % in fatalities only [11].

Promising safety results from the first opened 2+1 road E4 Gävle-Axmartavlan encouraged SNRA to carry out further implementations of the 2+1 solutions. Further, it also led to a general replacement of the old 13m width road concept with the 2+1 or 2+2 solutions as a standard cross-section for new constructions as well as for rehabilitation of existing 13 m roads (fig.4.3 alternative 13 m development projects).

Currently there are around 960 km of 2+1 solution roads in Sweden [7] and the 13m roads are constantly being converted to 2+1 roads with a rate of 200 km per year [8]. About twothirds of 2+1 roads are semi-motorways with restricted access for pedestrians, cyclists and farm vehicles and the rest are ordinary roads with direct access. Most of the existing 2+1 roads were constructed on the basis of previous 13 m ordinary road design; only a few were of brand new construction.



Road	Object	Measure	AADT	Constr. years[2)]	Km [1)]	Million SEK[1)]
E65	Börringe-Skurup	15,75:2+2cb	9500	00-01	10	100
Rv60	Hovsta-Lilla Mon	15,75:2+2cb	10000	00-01	20	124
E4	Håknäs-Stöcksjö	13:2+1cb	5300	00-01	33	90
E4	Gävle-Axmartavlan	13:2+1cb	7000	98-00	33	32
Rv45	Åmål-Säffle	13:2+1cb	6000	00-01	19	34
E22	Valdemarsv.-Söderköping	13:2+1cb	5500	01-02	35	60

1) Name, planned opening year, length and investment cost according to the SNRA proposal on National investment scheme for 1998-2007
2) Forecasts December 1999
3) cb=cable barrier

Fig.4.3 Alternative 13m development projects [8]

4.1.2 Technical data of 2+1 road solution

The 2+1 solution has a separating wire rope barrier between one continuous lane in each direction and one middle lane alternating the permitted direction of travel at intervals of 1.5-2.5 km (fig.4.4a). The length of the interval depends on road alignment and locations of intersections. On ordinary 2+1 roads intersections are located in the transition area between alternating passing lanes (fig.4.4b).

a) b)

Fig.4.4 a) 2+1 road with transition area b) Intersection on 2+1 road [10]

Cross-section

As mentioned previously, Sweden rehabilitates the existing 13m roads or builds 2+1 roads as new constructions. For rehabilitation, it is advised to keep the existing road width of 13m or widen to 14m, whereas for new constructions the recommended width is 14m.

The cross-section for the existing 2+1 13 m roads is as following (fig.3.5):

- 1.25 m central reservation with a continuous wire rope barrier
- 3.25 m wide traffic lanes in the two-lane direction and 3.75 m wide lane in the one-lane direction
- 0.75 m outer hard shoulders, to accommodate any low volumes of pedestrians and cyclists
- 1.0 m strip of road with full bearing capacity but without an overlay can be added on the side of the one-lane sections for emergencies if necessary.

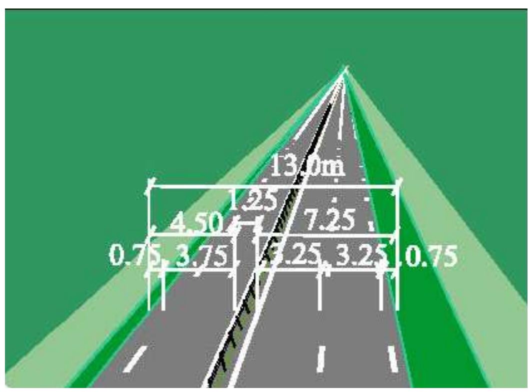


Fig.4.5 Cross-section of existing 13 m 2+1 road [8].

The recommended cross-section for 13 m semi-motorways differs from 13 m roads by being 1.75 m wider and having a narrower outer hard shoulder of 0.5 m where pedestrian and cycle traffic is prohibited. The cross-section for 14 m roads differs from the 13 m roads in the width of central reserve and the outer hard shoulder varies on different road types.

Transition zones

Depending on alignment and location of intersections, transition zones are located at intervals of 1.5 to 2.5 km. Transition zones from two lanes to one are 150 m long and from one to two lanes are 100 m long. Warning signs to alert drivers of approaching lane-closure are placed on both sides of the road 400 m in advance. In transition zones the barrier delineator post spacing is decreased from the typical 100 m spacing to 10 m. There are arrows painted on the roadway indicating motorists to merge right (fig.4.6) [10].

Marking and signing

The signing and marking concerning the transition zones involves road markings and visual devices placed on barriers. All along the 2+1 roads there is an embedded, noise producing line, painted on either side of the wire rope barrier. The delineators are located every one hundred meter along the stretch [10].

Capacity

On average, the capacity in one direction on 90 km/h roads is about 1,550 veh/h and 1,500veh/h on 110 km/h roads. Compared with unmodified 13 m roads, the capacity of modified roads is 400-450 veh/h less. The transition zones have performed well in terms of traffic operations [9].

Roadside

For rehabilitation projects, SRA recommends to remove all solid objects from the roadside or implement side wire rope barriers at dangerous locations such as right bends, rock faces and on all embankments within the clear zone.

Emergency

Emergency openings in the wire rope barriers along the carriageway are usually situated every 3-5 km enabling the emergency services to carry out U-turns. Otherwise, emergency services can use quick locks or dismount the barriers manually (section 3.3.5).

Maintenance

The maintenance standard involves: bridge inspections, overlay repairs, delineator post washing and snow clearance. Snow is removed in the first 0.4 m of the central reserve so that the pavement marking is visible. Maintenance, if possible, takes place during low traffic volume conditions.

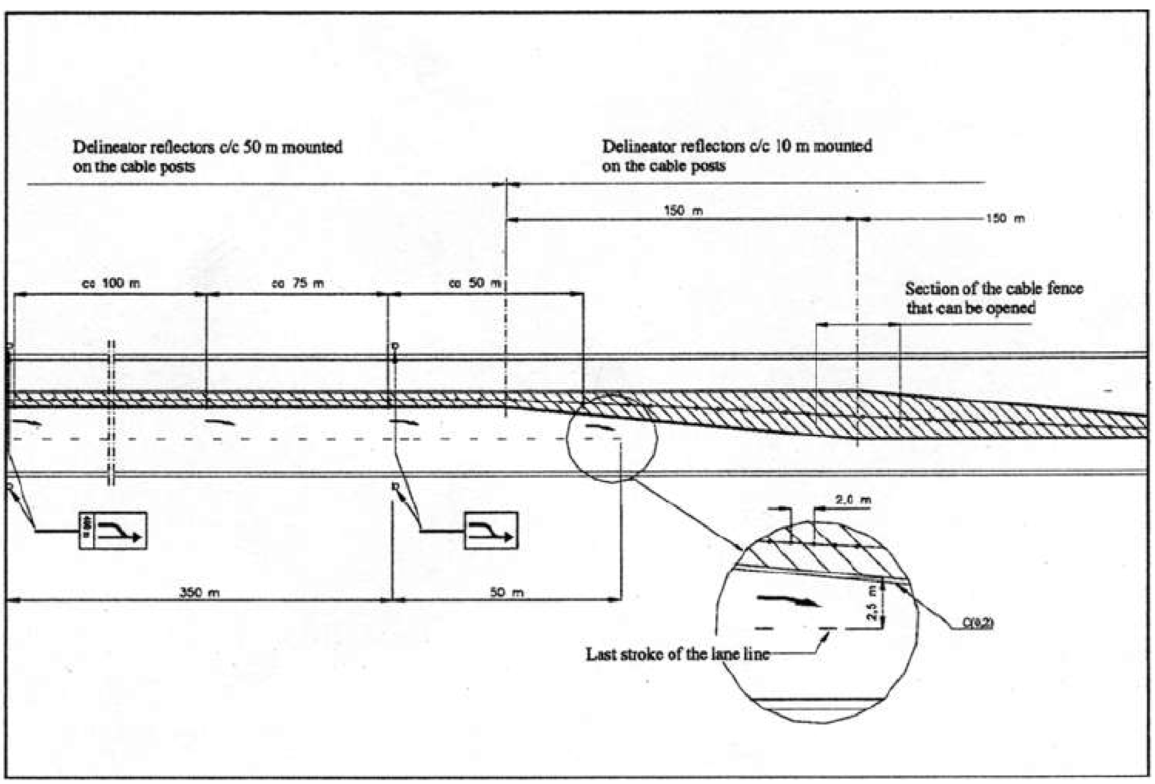


Fig.4.6 Transition zone design principles [10]

4.1.3 Types of 2+1 roads

Below are the different types of 2+1 roads denoted by their Swedish name and will be referred to in such way later on in the thesis.

MML 110

This is a semi-motorway (from Swedish *motortrafikled*) with a speed limit of 110 km/h. The cross-section widths are 13 or 14 m.

The roadside area can have three classes:
A – a side barrier or flat slopes
B – clearing and smoothing
C – no special measures

By July 2004 there were around 270 km of such roads with traffic mileage of 2100 million vehicle-axle pairs in kilometres (Mapkm) [6].

MML 90

This semi-motorway has a speed limit of 90 km/h. The cross-section widths are 13 or 14 m. The roadside area can be of the following classes: A, B and C. By July 2004 there were around 165 km of such roads with 1970 Mapkm [6].

MLV 110

This is the ordinary 13 m 2+1 road but with some stretches of a 14 m width. The *MLV* notation comes from Swedish *mötesfri landsväg*. The speed limit is 110 km/h. The roadside area can be of the following classes: A, B or C. By July 2004 there were around 120 km of such roads with 330 Mapkm [6].

MLV 90

This is the ordinary 13 m 2+1 road with some stretches of 14 m width. The speed limit is 90km/h. The roadside area can be of the following classes: A, B or C. By July 2004 there were around 405 km of such roads with 1485 Mapkm [6].

2+1 målat 90

This is a 2+1 road with a speed limit of 90 km/h without wire rope barriers. Lanes are divided only by road markings (*målat* in Swedish), the roadside and the pavement area have been modified in recent years. By September 2003 there were five stretches of such roads accounting for around 60 km in total, with vehicle mileage of 450 Mapkm [6]. By July 2004 three of these had wire rope barriers installed.

Information on the location of the above mentioned road types can be found in appendix C.

4.1.4 Costs of 2+1 roads

The cost of rehabilitation of an existing ordinary 13 m road to a 2+1 ordinary road varies from SEK 5,000 to SEK 15,000 per meter. For upgrading to a 2+1 semi-motorway the cost in SEK/m varies from 1,000 to 3,000. Brand new construction is estimated to be between

SEK/m 20,000 to 25,000 [11]. The construction of the wire rope barriers is approximately SEK/m 200 [17]. The repair cost is SEK/m 17 (including SEK/m 10 of depreciation of wire rope barriers) [7].

4.1.5 Public acceptance

Two surveys were conducted on drivers' opinion of the first 2+1 road in Sweden E4 Gävle-Axmartavlan in the autumns of 1998 and 1999 [8] [9]. The first survey's results showed that 2+1 roads with road markings only were preferred to ordinary roads and only 1 % stated that they preferred 2+1 roads with wire rope barriers most. However, the second survey showed that 40 % of drivers surveyed preferred 2+1 roads with wire rope barriers and only 30 % preferred 2+1 roads with road markings only.

Changes in attitude were greatest among passenger vehicle drivers that represented non-local traffic. However, on the whole drivers' opinion was positive also among local traffic users who struggle with a potential barrier effect caused by the wire rope barrier itself (barrier limiting access to local road networks).

Motorcyclists' opinion was not stated in the literature.

4.2 AN OVERVIEW OF OTHER ROAD'S WITH WIRE ROPE BARRIERS

4.2.1 The 2+2 roads

A 2+2 road design means that two or more lanes operate in each direction and are separated by a wire rope barrier placed either along the road centre or directly on the pavement. The design of 2+2 is implemented on sections with high volumes of traffic to improve traffic performance. Some parts of 2+1 roads are widened to 2+2 in order to avoid one-lane sections on road inclines. This allows light traffic to overtake heavy vehicles easily.

There are two types of 2+2 roads: 2+2 90 and Alt 4 F 110.

2+2 90 (MLV)

This is a modified 13 m road broadened to the width of 15.75 m. The speed limit is 90 km/h. The roadside area can be of the following classes: A, B and C. By July 2004 there were two stretches of such roads with a total length of 22.5 km and 250 Mapkm [6].

Alt 4 F 110

This is a 2+2 road with a width of 18.5 m. By July 2004 there were four stretches of such roads with a total length of 62.5 km and 760 Mapkm [6].

4.2.2 1+1 roads

A 1+1 design is a road with only a single lane in each direction separated by a wire rope barrier. This design is meant to be used on long bridges that can be quite expensive to widen, and on sections of road with numerous access points. This design is also suitable for areas that have a heavy flow of pedestrians and cyclists, and where creating a separate path would be too costly or impossible [9].

4.2.3 Motorways

Motorways usually have at least two lanes in one direction and are separated by a central reservation with crash barriers. Installed barrier types vary from normal beam barriers to wire rope barriers. Currently motorway barriers are successively being changed to wire rope barriers where it is assumed to be more applicable. The new design of the E4 motorway between Eket and Ringarp has wire rope barriers as side barriers and the central barrier (fig.4.7).

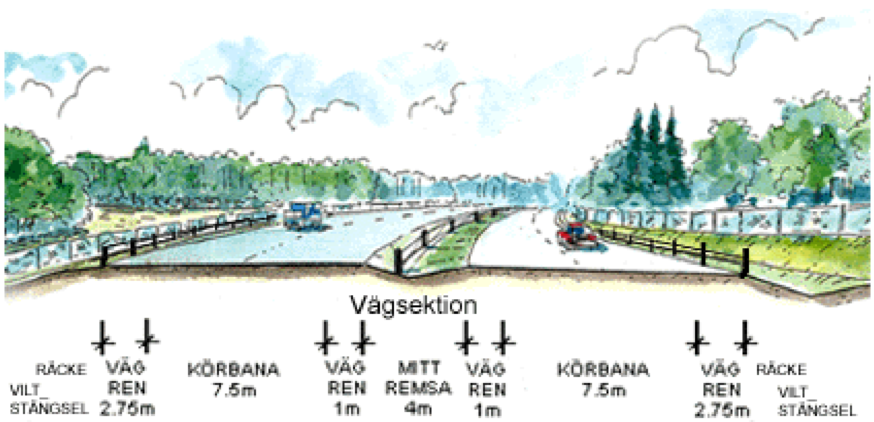


Fig.4.7 New design standard for Swedish motorways [18]

The roadside area, as for semi-motorways, can be of the following classes: A, B and C. Access to motorways is restricted. It is only possible to enter at junctions by slip-roads. The total length of motorways in Sweden in 2004 was around 1,600 km with vehicle mileage of 12,000 Mapkm [12]. Motorways account for 1.6% of total road network.

4.3 SAFETY PERFORMANCE OF ROADS WITH WIRE ROPE BARRIERS

This section will focus mainly on the safety performance of 2+1 and 2+2 roads as a result of the predominant use of wire rope barriers. Motorways will not be included due to the fact that there was not sufficient data available for motorways with wire rope barriers. However, a brief description of safety performance on motorways will be provided. The analysed types of roads are divided in accordance with sections 4.1.3 and 4.2.1 relying on data up to July 2004. The safety performance only focuses on general safety of wire rope barriers, motorcycle accidents are analysed in chapter 6.

4.3.1 Introduction

The implementation of wire rope barriers and roadside measures was intended to eliminate head-on collisions and reduce the consequences of run-off collisions. This combination of measures was expected to reduce the number of severe injuries and fatalities at most by 50 % [11]. So far, on 2+1 semi-motorways the reduction in the number of severely injured or killed in all accident types accounts for 45-50 %, but for up to an incredible 90 % when considering lethal accidents alone [11]. For ordinary 13 m 2+1 roads the results correspond to a reduction of 35-50 % in the number of killed or severely injured in all accident types and up to 76 % for lethal accidents alone [11].

The SNRA safety prediction model [11], used in the cost-benefit calculation program for investment planning, was used to calculate the expected accident outcome for ordinary semi-motorways. Table 4.1 shows the comparison between the number of predicted and observed accidents.

Table 4.1 Comparison of predicted and observed accidents for 2+1 roads until 1 January 2001 [11]

Number of:	Predicted	Observed
Accidents	195	253
Injuries	124	102
Severe injury and fatality (DSS)	37.3	16
Fatalities (D)	9.6	1

The observed number of severe and fatal injuries indicates a significant reduction of 57 % to the predicted number. The most significant difference is the number of fatalities alone, where 1 was observed but 9.6 predicted.

However, the scope of this data is only until the end of year 2000. By July 2004, 12 people had died in the vicinity of 2+2 or 2+1 roads (excluding 4 fatalities that occurred at the *2+1 målat 90* where there are no wire rope barriers) [6]. This is due to the fact that there are currently more roads with wire rope barriers than there were at the end of year 2000 [7]. Accidents will happen no matter what measures are implemented. If we approach it from a different point of view, when no measures had been implemented, the outcome would have been significantly worse. For instance, the analysis of accidents that occurred on E4 Gävle – Axmartavlan before 1999 show that if a barrier had been installed it could have reduced the severity of consequences by up to 70 % [11]. The same analysis conducted on E18 Västerås indicated an 80 % potential reduction [11].

Inevitably wire rope barriers are a successful road safety measure judging by the reduction and potential prevention from fatal and severely injured accidents. However, collisions with barriers are more frequent than expected, around 1 crash per week [10]. Normally barrier crashes cause damage to the vehicles (passenger or heavy) only. Around 65 % of crashes occur in the one-lane section, only 8 % occur in the transition from two lanes to one (considering that the proportion of length of two to one lane transition zones to the total length of road is 10 %) [10]. Drivers seem to use the transition zones in a cautious and responsible manner [9]. The barrier ends do not seem to cause safety problems, they also do not cause any ramping effect. Barrier crashes tend to be a winter problem as about 55 % of accidents occur during the winter (between December and March) when the annual distance travelled accounts for just 25 % of the total travelled in one year [9]. These accidents are usually caused by skidding, flat tyres and loss of control or driver's concentration [9].

There has been a concern with wire rope barriers' extent of deflection when struck by an errant vehicle [10]. Namely, the errant vehicle should not get "trapped" by the barrier on the opposing travel lane causing potential hazard for vehicles travelling along that lane. Wire rope barriers were designed for a working width of W4, around 1.3 m, which the SNRA assumed as a safe deflection amount assuming that vehicles are redirected and not "trapped". So far there has been no such case. Moreover, wire rope barriers are not designed for truck crashes but they have withstood heavy vehicle crashes at narrow angles.

4.3.2 Motorways

It has been estimated that if an ordinary 13 m road was replaced by a motorway it would result in a 65 % reduction in severely injured and killed [11]. A motorway with a median barrier and roadside area C, until the end of year 2000, had a rate of killed or severely injured (DSS, from Swedish "Dödade och Svårt Skadade") of 0.0149 Mapkm [11]. This was 17 % lower than the DSS rate for 2+1 roads. On motorways with a median barrier and roadside area A, the DSS rate was 0.0119 Mapkm, which was 34 % lower than for 2+1 roads [11].

In the 1990's the SNRA conducted a traffic safety investigation on motorways with a speed limit of 110 km/h. The DSS rate, depending on the roadside measures, varied between 0.014 – 0.02 Mapkm which is the current average rate for all 2+1 roads [11].

4.3.3 MML roads

MML 110

On *MML 110* roads by July 2004, 6 people died (D), 43 were severely injured (SS) and 241 had minor injuries (LS), all of which accidents occurred along a stretch of road apart from 2 that occurred at an intersection. The rate of injured along the stretch of road accounts for 0.137 Mapkm giving a 5 % reduction when compared to unmodified roads with a speed limit of 110 km/h (*ML 110*) with an injury rate of 0.145 Mapkm [6].

The rate of killed or severely injured (DSS) along the stretch was 0.0233 Mapkm, which implies the following results when compared with *ML 110*:

- 48 % reduction (0.0452 Mapkm), *ML 110* roadside area C
- 43 % reduction (0.0407 Mapkm), *ML 110* roadside area B

Accident types for DSS were as follows:

- Single vehicle type: 1 D and 28 SS with a rate of 0.0138 Mapkm (slightly more when compared with accident data from 1994-1998)
- Overtaking: 2 SS with ratio 0.0009 Mapkm
- Tailgating: 3 D and 13 SS with a rate of 0.0076 (three times as more when compared with accident data from 1994-1998)
- Vulnerable road users: 2 D with a rate of 0.0009 Mapkm

MML 90

Until July 2004 on *MML 90* roads, 1 person died (D), 34 were severely injured (SS) of which 5 accidents occurred at an intersection (1 accident involving a motorcyclist). Moreover, 245 had minor injuries (LS) of which 23 accidents occurred at an intersection. This resulted in overall injury rate of 0.142 Mapkm which is the same as for unmodified roads with a speed limit of 90 km/h (*ML 90*). However, when compared with the injury rate along a stretch of road (rather than intersection) with *ML 90* there has been a reduction of 4% [6].

The rate of killed or severely injured (DSS) along the stretch was 0.0152 Mapkm, which implies the following results when compared with *ML 90*:

- 60 % reduction (0.0383 Mapkm), *ML 90* roadside area C
- 56 % reduction (0.0345 Mapkm), *ML 90* roadside area B

Accident types for DSS were as follows:

- Head-on: 1 SS with a rate of 0.0005 Mapkm, a passenger vehicle entered the long lane on a 2+1 road
- Single vehicle: 16 SS with a rate of 0.0081 Mapkm (less than for *MML 110* and 40 % less when compared with accident data from 1994-1998)
- Overtaking: 3 SS with a rate of 0.0015 Mapkm
- Tailgating: 8 SS with a rate of 0.0041 Mapkm (45 % less than for *MML 110* but four times more when compared with accident data from 1994-1998)
- Various: 1 SS with a rate of 0.0005 Mapkm
- Vulnerable road users: 1 D with a rate of 0.0005 Mapkm
- Intersection: 5 SS with a rate of 0.0025 Mapkm

Comparison of MML roads

Both *MML 110* and *MML 90* have a good safety performance improvement when compared to unmodified *ML* roads with corresponding speeds by 48 % and 60 %. When comparing *MML* roads with each other as table 4.2 shows, the rate of DSS and D per Mapkm is significantly lower for *MML 90* roads.

Table 4.2 The rate of killed (D), killed and severely injured (DSS) per vehicle mileage per Mapkm on MML roads [6].

MML roads	DSS rate per Mapkm	D rate per Mapkm
110	0.0233	0.0029
90	0.0152	0.0005

On *MML 110* roads the proportion of accidents with severe consequences is much higher than on *MML 90* roads. Single vehicle and tailgating accidents that occurred along the stretch on *MML 90* account for 80 % of all DSS accidents which is 40-45 % less to *MML 110*.

4.3.4 MLV roads

MLV 110

Vehicle mileage on *MML 110* roads of 330 Mapkm is too low for reliable accident data analysis. Nonetheless, until July 2004, no one died, 12 people were severely injured (SS), of which 4 accidents occurred at an intersection and 45 accidents resulted in minor injuries

(LS). The rate of injured along stretches of road accounted for 0.161 Mapkm, which is 18 % higher to unmodified 13 m roads with a speed limit of 110 km/h, where injury ratio accounts for 0.136.The rate of killed or severely injured (DSS) along the stretch was 0.0242 Mapkm, which implies a 52 % reduction to unmodified 110 km/h 13 m roads (0.0511 Mapkm). The worst performance of *MLV 110* roads was noted on the E4 Håknäs – Stöcksjö, where 8 people were severely injured in single, overtaking, tailgating accidents and other 4 at an intersection. This resulted in an appalling DSS ratio of 0.063 Mapkm [6].

MLV 90

The *MLV 90* roads have a much higher vehicle mileage than *MLV 110* roads, of 1,485 Mapkm. Until July 2004 on *MLV 90* roads, 2 people died (D), 25 were severely injured (SS) of which 8 accidents occurred at an intersection (4 at roundabouts and 4 at a crossing). Moreover, 159 had minor injuries (LS) of which 26 accidents occurred at an intersection. This resulted in overall injury rate of 0.125 Mapkm, which compared with unmodified 90km/h 13 m roads is 18 % lower, with an injury ratio of 0.173 Mapkm. When compared with injury rate along the stretch with unmodified 90km/h 13 m roads, there has been a reduction of 30 % [6].

The rate of killed or severely injured (DSS) along the stretch was 0.0128 Mapkm, which is less than on *MML 90* roads. This DSS ratio implies a reduction of 70 % when compared with unmodified 90km/h 13 m roads with roadside area C (0.0423 Mapkm).

Accident types for DSS were as follows:

- Single vehicle: 2 D and 16 SS with a rate of 0.0081 Mapkm (less than for *MML 90* and 60 % less when compared with accident data from 1994-1998)
- Overtaking: 6 SS with a rate of 0.004 Mapkm (more than for *MML 90* and the same when compared with accident data from 1994-1998)
- Tailgating: 1 SS with a rate of 0.0007 Mapkm
- Various: 3 SS with a rate of 0.002 Mapkm (less when compared with accident data from 1994-1998)
- Turning off: 1 SS with a rate of 0.0007 Mapkm
- Intersection: 8 SS with a rate of 0.0054 Mapkm

Comparison of MLV roads

It is difficult to compare both roads due to the fact, that *MLV 110* has a relatively low vehicle mileage. Nonetheless, both *MLV 110* and *MML 90* have a good safety performance when compared to unmodified 13 m roads with a reduction in accidents by, respectively, 52 % and 70 %. When comparing *MLV* roads with each other, as table 4.3 shows, the rate of DSS per Mapkm is lower for *MLV 90* roads.

Table 4.3 The rate of killed (D), killed and severely injured (DSS) per vehicle mileage per Mapkm on MLV roads [6].

MLV roads	DSS rate per Mapkm	D rate per Mapkm
110	0.0242	0
90	0.0128	0.00135

The proportion of overtaking accidents is clearly higher on *MLV 90* roads whereas single vehicle and tailgating type accidents is lower.

4.3.5 2+2 roads

2+2 90

Until July 2004, no one died, 8 people were severely injured (SS) and 32 had minor injuries (LS) on 2+2 90 roads. Six of those accidents occurred at an intersection with 4 SS and 11 LS. The overall injury rate accounted for 0.16 Mapkm, which is clearly higher to 2+1 *MLV* roads. The injury rate along the stretch of 0.1 Mapkm was the same as for *MLV 90* roads. The overall DSS rate accounts for 0.032 Mapkm, which is around 75 % higher than MLV 90 roads. The DSS rate along the stretch was 0.0161 Mapkm, which is higher than 2+1 *MLV* roads [6].

It has to be noted that vehicle mileage of 250 Mapkm is too low to draw any significant conclusions.

Alt 4F 110

On *Alt 4F 110* roads until July 2004, 3 people died (D), 15 were severely injured (SS) and 92 had minor injuries (LS). All of these accidents occurred along the stretch. The injury rate along the stretch accounts for 0.145 Mapkm, which is 5 % higher than on *MML 110* roads. The DSS rate along the stretch was 0.0237 Mapkm, which is slightly higher than *MML 110* roads. However, one must bear in mind that vehicle mileage of *Alt 4F 110* accounts for 35 % of *MML 110's* total vehicle mileage [6].

Accident types for DSS were as following:

- Single vehicle type: 10 SS with a rate of 0.0132 Mapkm (exactly the same when compared with accident data from 1994-1998 for *ML 110*)
- Overtaking: 1 SS with a rate of 0.0013 Mapkm
- Tailgating: 1 D and 2 SS with a rate of 0.0076 Mapkm (about 5 % higher when compared with accident data from 1994-1998)
- Crossing course: 1 D and 2 SS with a rate of 0.0009 Mapkm
- Various: 1 D with a rate of 0.0013 Mapkm

Single vehicle and tailgating accidents account for over 70 % of all DSS accidents. If "crossing course" accidents were excluded, single vehicle and tailgating accidents would account for 87 %, which is the same result as for *MML 110* roads. Statistically, *Alt 4F 110* roads are similar to *MML 110* roads.

Comparison of 2+2 roads

It is difficult to compare *2+2 90* roads with *Alt 4F 110* due to the fact that vehicle mileage on *Alt 4F 110* is three times higher and also the roads are of a higher standard (with a different width). Nonetheless, *Alt 4F 110,* according to table 4.4, has DSS rate along the stretch of 47 % higher than on *2+2 90* and no one has died on a *2+2 90* road.

Table 4.4 The rate of killed (D), killed and severely injured (DSS) per vehicle mileage per Mapkm on 2+2 roads [6].

2+2 roads	DSS rate per Mapkm	D rate per Mapkm
2+2 90	0.0161	0
Alt 4F 110	0.0237	0.0039

4.3.6 2+1 målat 90 (2+1 road without wire rope barriers)

This type of road is currently being converted into 2+1 roads with wire rope barriers. Until July 2004, 4 people died, 7 people were severely injured (SS), out of which 2 accidents occurred at an intersection, and 40 had minor injuries (LS. The DSS rate along the stretch was 0.02 Mapkm, which is about 30 % higher than *MML 90* roads. Two fatal accidents were of unusual character, and if those were excluded, the DSS rate would have been 0.0155 Mapkm. This would mean a 60 % reduction in accident rate when compared with *ML* roads [6].

4.3.7 Comparison of safety performance on roads with wire rope barriers

Table 4.5 sums up the safety performance of all of the above mentioned road types. Values of overall DSS rate and DSS along the stretch per Mapkm are used as a comparison factor between these roads. The fifth column shows the reduction of DSS rate along the stretch when compared with unmodified roads corresponding to each road type (e.g. the reduction of DSS rate between *MML 110* and *ML 110*).

Table 4.5 The comparison of wire rope barrier roads' safety performance [6]

Road type	Vehicle mileage in Mapkm	Overall DSS rate per Mapkm	DSS rate per Mapkm along the stretch	DSS stretch Reduction (%)
MML 110	2,100	0.023	0.0233	48
MML 90	1,970	0.017	0.0152	60
MLV 110	330	0.036	0.0242	53
MLV 90	1,485	0.018	0.0128	70
2+2 90 (MLV)	250	0.032	0.0161	62
Alt 4F 110	760	0.024	0.0237	48
2+1 målat 90	450	0.022	0.0180	53

The safety performance is the best for all roads when a 90 km/h speed limit is compared with a 110 km/h speed limit for the equivalent road. The best safety performance out of all roads is by the *MLV 90* with the lowest DSS rate along the stretch and the largest DSS reduction when compared with an unmodified 13 m 90 km/h road. The worst performance is by both *Alt 4F 110* and *MLV 110* with an overall DSS rate of nearly 50 % higher than the equivalent *MLV 90*. *MML 90* roads have a slightly better overall DSS rate but it is worse along the stretch. Out of all 90 km/h roads, the worst safety performance is by *2+1 målat 90* and *2+2 90 roads*. It is worth noting that the *2+2 90* roads had a worse outcome than the 2+1 90 km/h roads.

Prediction model

Figure 4.8 presents a prediction of safety performance of the above mentioned roads compared with motorways (*motorväg*, denoted *MV*) based on the software "EVA". The compared roads have a speed limit of 110 km/h and two different cross-section widths: 21.5 m (*MV 21.5 110*) and 26.5 m (*MV 26.5 110*). The accident prediction data for *MV 21.5 110* is based on the difference between the *Alt 4F 110* data and the empirical data for *MV 26.5 110*. Whereas prediction data for *MV 26.5 110* is based on the difference between the empirical data of roads with a roadside class A and C (from "EVA" model) [6].

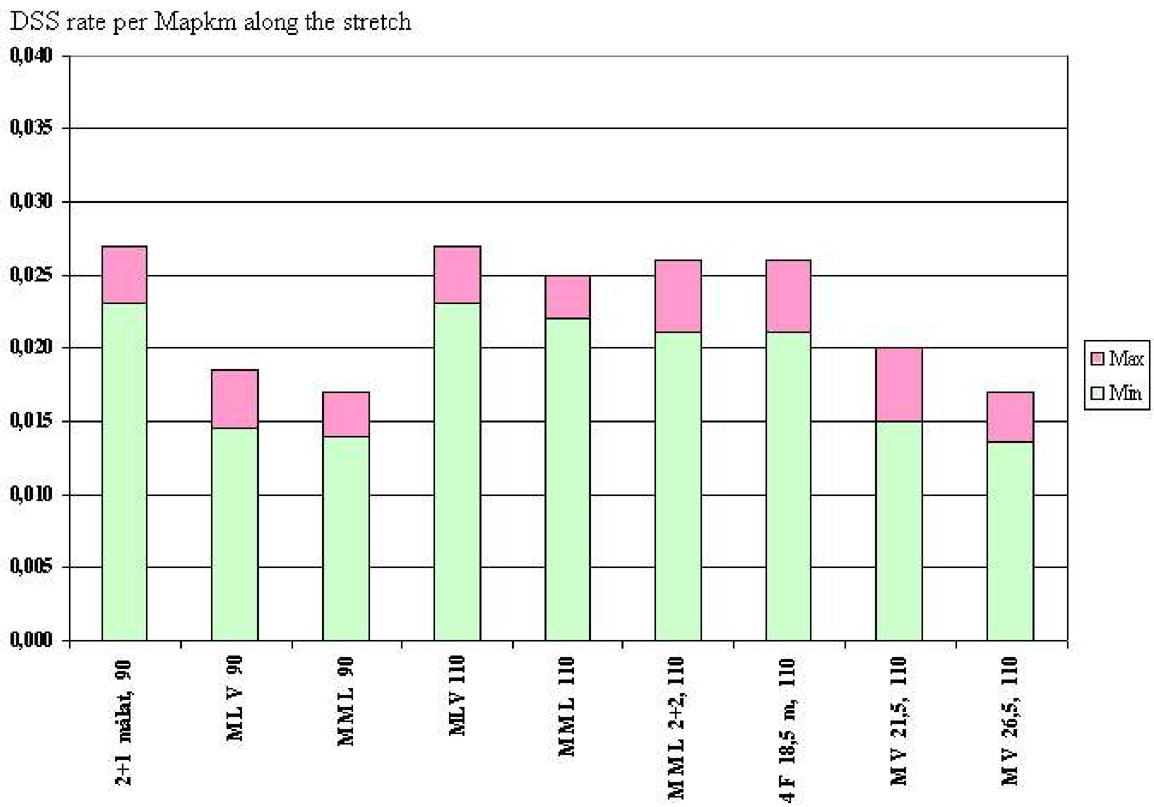


Fig.4.8 Predicted dead or severely injured rate (DDS) along the stretch for 90 km/h and 110 km/h 2+1 and 2+2 roads compared with motorways of 110 km/h [6].

This diagram shows that:

- *MV 26.5 110*'s predicted safety performance is the same as for *MML 90*
- *MV 21.5 110*'s predicted performance is almost equal to *MLV* 90's, which is between 10 – 20 % worse than *MV 26.5 110.*
- *MLV 110'*s performance is predicted to be slightly worse than *MML 100*, similar performance is expected for *2+1 målat 90* .
- Both 2+2 roads have a similar expectancy.

4.3.8 Collisions with barriers

Passenger vehicle collisions with barriers happen very frequently, as mentioned before, they happen more often than expected. Fortunately, in most cases they do not affect the occupant

of the vehicle. On the contrary, motorcycle barrier collisions are not very frequent but have severe consequences when they do occur.
By the end of year 2003 there have been 1,853 barrier collisions with an overall crash rate of 0.51 Mapkm [7]. The rate differs on different types of roads and their location. Wire rope barrier collisions are most frequent on *MML* roads with the overall rate of 0.53 Mapkm [6]. *MLV* roads have a rate of 0.44 Mapkm [6]. 2+2 roads have a much better result. The frequency of crashing into the barrier on *Alt 4F 110* is 0.28 Mapkm [6]. *2+2 90* roads have a higher rate, of 0.36 Mapkm, but this is 20 % lower than *MLV* roads [6].

Barrier collisions. as mentioned before (3.3.1), are predominantly a winter problem [9]. Table 4.6 shows barrier crash rates per Mapkm on *MML* and *MLV* roads for south and north regions of Sweden, where winter conditions differ.

Table 4.6 Barrier collision rate on MML and MLV roads per Mapkm [6]

Road type	Region	110 km/h	90 km/h	110+90
MML	North	0.61	0.48	0.56
	South	0.36	0.53	0.48
	Whole of Sweden	0.55	0.51	0.53
MLV	North	0.57	0.49	0.54
	South	–	0.33	0.33
	Whole of Sweden	0.57	0.37	0.44
MML+MLV	North	0.60	0.48	0.56
	South	0.36	0.46	0.43
	Whole of Sweden	0.56	0.47	0.51

Table 4.6 shows that there is a strong correlation between winter conditions, speed and barrier collision rate. The rate of barrier crashes in the north being more frequent than in the south of Sweden implies that winter conditions are a key factor. The barrier crash rate on *MML* roads is about 15 % lower in the south of Sweden. The same correlation can be observed on *MLV* roads. Speed has also a clear influence on the barrier crash rate, especially when combined with winter conditions. *MML 90* roads have around an 8 % lower barrier crash rate than *MML 110* roads. Northern *MML 90* roads have a 25 % lower rate than northern MML 110 roads. Moreover, this rate is also lower when compared to MML 90 in the south. A similar correlation can be observed for MLV roads, with barrier crash rates varying by 15 % between 110 km/h and 90 km/h roads [6].

There is also correlation between road cross-section widths and barrier crash rates [6]. 14 m wide roads in the south of Sweden have a rate of 0.25 Mapkm compared to 0.51 Mapkm on 13 m wide roads [6]. The extra metre gives the driver more distance and time to react in case of loss of concentration. However, there is no difference between rates on the northern roads, neither on 90 km/h or 110 km/h roads. This implies that in winter conditions, the extra metre is not sufficient enough for the driver to change the direction of travel of the vehicle.

Traffic volumes also have an impact on barrier collision rates. Most 2+1 roads with a rate of 0.6 Mapkm have an average annual daily traffic of 9,000 axle pairs per day. The reason for high crash rates on heavy traffic loaded roads is that on the two-lane segments most of the vehicles drive on the overtaking lane. According to Berdica, Bergh and Carlsson's findings [11], the number of overtakings is proportional to the squared number of traffic volume. This implies that the number of vehicles causing barrier crashes on the overtaking lane is proportional to the total traffic flow.

4.4 SPEED PERFORMANCE ON ROADS WITH WIRE ROPE BARRIERS

Speed performance is not influenced by the existence of wire rope barriers on motorways. Therefore, this section will only focus on 2+1 roads.

4.4.1 Introduction

The SNRA had to face criticism for traffic operation before implementing the 2+1 roads with wire rope barriers. The main concern were the narrow one-lane sections, without the overtaking sections of lengths of up to 2.5 km, that could potentially cause capacity reductions and lower average speeds. 2+1 roads were expected to reduce the speed on average by 2 to 4 km/h [10]. However, the average speed has increased by 1.5 km/h when compared to unmodified 13 m roads at one-directional flows of up to 1400 veh/h [9].

4.4.2 Speed performance findings

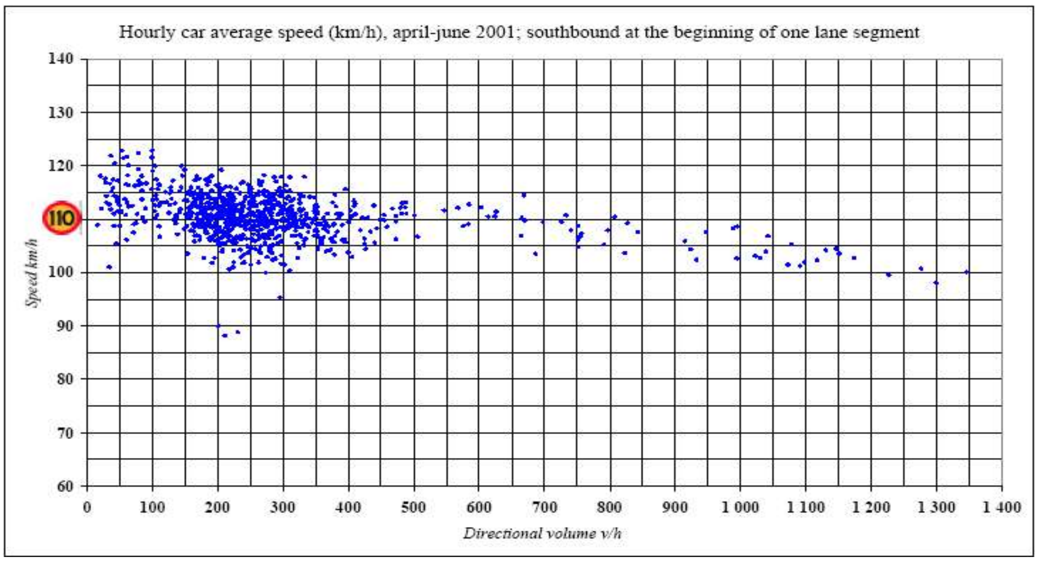
An evaluation of speed performance [13] was conducted on E4 Gävle-Axmartavlan, the first 2+1 road with a central wire rope barrier in Sweden, 1.5 year after opening to traffic (until year 2000). Several techniques were used to carry out this evaluation. Before and after spot measurements were compared with a controlled section on an adjacent 13 m road. Continuous lane based spot speeds were measured at the start of the 1-lane section for the southbound and at the end of a 2-lane section for the northbound. Furthermore snow ploughing and emergency operations were investigated.

Findings of this evaluation [10] [13] state that the speed performance was better than expected. The average travel speeds for passenger vehicles increased by about 2 km/h on 90km/h roads and by about 4 km/h on 2-lane sections when compared with unmodified 13 m roads [10]. The average spot speeds of passenger vehicles were 101 km/h and 107 km/h respectively for 90 km/h and 110 km/h roads [10].

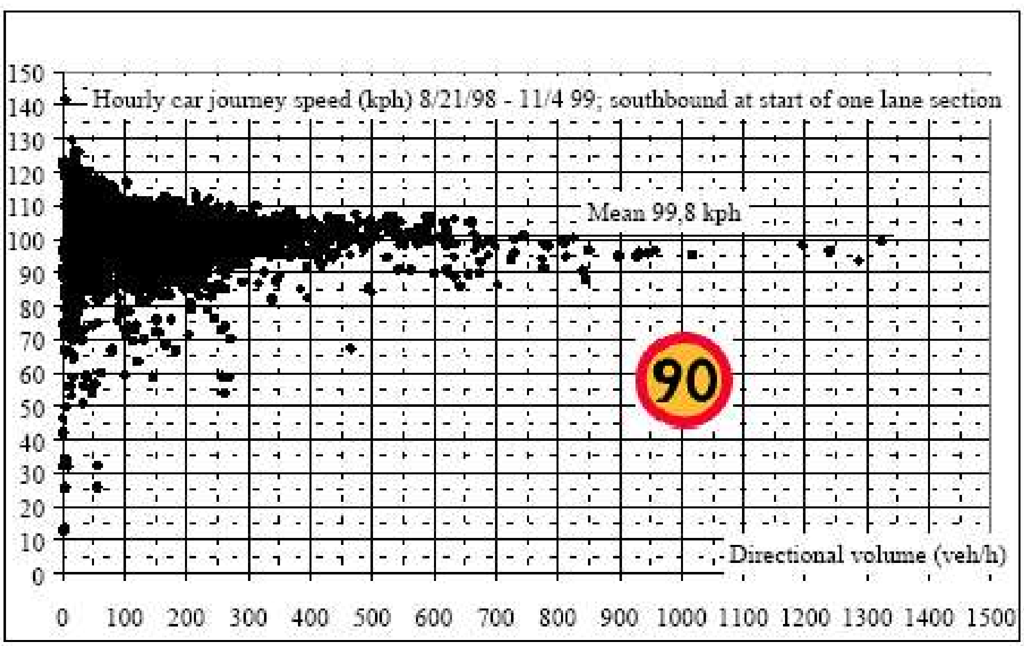
Transition zones performed well in terms of the speed performance [9]. Spot speeds at the beginning of 1-lane sections ranged from 93 km/h to 100 km/h on traffic flows of between 1200-1350 veh/h [10]. The overtaking lane's spot speeds in the 2-lane section went far beyond the speed limit of 90 km/h, ranging between 110 km/h and 120 km/h [10]. The average speeds for 2-lane sections were about 5 km/h higher than for 1-lane sections [10].

The spot speeds on 2-lane sections were slightly higher on 2+1 roads without a central barrier than on a 2+1 road with a central barrier. The evaluation showed that side wire rope barriers located more than 1 m away from the carriageway did not affect the speeds.

Bergh and Carlsson's findings [13] show that the speeds on 2+1 roads were mostly influenced by maintenance and emergency operations than by flow. As figure 4.9a and b shows there was no impact to flows below 700 veh/h on 90 km/h and 110 km/h roads. However, for volumes of above 900 veh/h in one direction, the speeds varied in different segments of the road. 5 % of the hourly speeds were below 90 km/h on roads with a speed limit of 90 km/h.



a)



b)

Fig.4.9 Hourly car speeds versus total flow at the start of 1-lane section
a) on 110 km/h roads [8]
b) on 90 km/h roads [13]

5. METHOD

5.1 MOTORCYCLISTS' SAFETY ASSESSMENT ON WIRE ROPE BARRIER ROADS

The objective of this study is not to assess the safety of Swedish wire rope barrier roads with respect to motorcyclists, but to highlight the magnitude of this issue. The assessment is to be conducted in two ways. The first will rely on literature data, mainly from Arne Carlsson's first half year 2004 report [6] and general motorcycle data flow statistics [20] used for dead or severely injured (DSS) rate calculations. The second approach will depend on motorcycle accident data for all main rural roads in years 1998-2002 [20]. The latter approach is meant for a general comparison of 2+1 roads with other main rural roads.

5.1.1 Literature review of 2+1 roads motorcycle accidents

This method looks at all 2+1 roads motorcycle accidents that have been mentioned in half year reports. The circumstances are being analysed and the barrier involvement. Then DSS rate is being calculated based on the accident data from literature [6] and general data flows of motorcycle traffic [20].

Delimitations and assumptions

The literature does not provide specific information on accident circumstances. There is no data available on motorcycle mileage. Therefore, the mileage has been assumed as 1 % of total traffic on all rural roads regardless of the road type. This value is statistically correct for motorcycle participation in rural traffic [20].

5.1.2 Motorcycle accident data analysis

This method compares types of accidents occurring on 2+1 roads with other road types.

Scope of data

The scope of motorcycle accident data coming from SRA's accident database [20] is as follows:

- years 1998-2002
- total length of roads is 15400 km
- total annual vehicle mileage is 31,000 Mapkm
- motorcycle mileage accounts for 1 % (310 Mapkm)
- around 800 km of roads with wire rope barriers at the end of 2002
- with average traffic flow of 8,000 vehicles per day of which 80 are motorcycles
- Type of roads:

1. motorways,
2. semi-motorways
3. 2+1 semi-motorways
4. 4 lane roads
5. ordinary roads
6. ordinary 2+1, 2+2, 1+1 roads

- Accident types:

1. head-on
2. tailgating
3. turn off
4. crossing
5. overtaking
6. collisions with pedestrians
7. collisions with cyclists
8. various
9. with game

- Occurrence of accidents:

1. hitting road furniture: barriers (with a distinction between wire rope and ordinary barrier), signs etc.
2. hitting roadside objects: trees, rock faces etc.
3. hitting another vehicle
4. falling onto the road surface

- Outcome of accident: fatal, severely injured, with minor injuries - all summed up together

Detailed data can be found in appendix D.

Delimitations and assumptions

In the data there is no distinction between roads with or without wire rope barriers e.g. motorways and 4 lane roads. The assumption used is, that all 2+1 roads mentioned in database had wire rope barriers. The vehicle mileage is not known for all types of roads. Motorcycle mileage has been assumed as 1 % of total traffic on all rural roads regardless of the road type. The outcome of accidents is not distinguished (fatal, severely injured and with minor injuries accidents are all summed up together).

5.2 THE INFLUENCE OF WIRE ROPE BARRIERS ON MOTORCYCLISTS

In order to fully investigate the influence of wire rope barriers the following methods have been used.

First, motorcycle traffic flow and speeds have been analysed on the data stored on the SRA's database [21]. Traffic flow data has been used to find out what possible travelling patterns motorcyclists opt to take and if wire rope barrier roads are being avoided and alternative routes chosen instead. Then the speed data from SRA's database has been used for determining the correlation between speeds and road types where wire rope barriers were or were not present. Moreover, differences in motorcycle traffic volumes and speeds have been investigated on the same roads before and after the implementation of the barriers.

Secondly, an internet questionnaire has been conducted among motorcyclists. Its purpose was to obtain information on how they reacted to wire rope barriers in terms of speed, distance, feeling of security, choice of alternative roads and general opinion on the issue, according to age, gender, motorcycle type and engine size.

One randomly chosen motorcyclist was interviewed on wire rope barriers. This approach was meant to provide information from a "live source" on the opinion and attitude to wire rope barriers by means of casual conversation.

Finally, a site study was conducted. Speeds of motorcycle vehicles was measured on different types of roads, with and without wire rope barriers and also at different sections of 2+1 roads. The main purpose of these measurements was to determine how the existence of wire rope barriers in the road environment affects motorcyclists' speeds. But also the aspect of riding distance from the barrier has been studied.

5.2.1 Motorcycle traffic flow and speed data from SRA's data base

Traffic flow and speed data from the SRA's database is collected at certain points along the stretch of the road (fig.5.1a). The frequency of measurements depend on the level of importance of a particular road. European roads are measured every 1-2 years, national roads between 2-4 years and other roads, depending on importance, between 4-8 years. At every measure point the traffic volume and speed data is collected with accordance to: the type of vehicle, direction (north and/or south bound), and time of day (fig.5.1b).

a) 

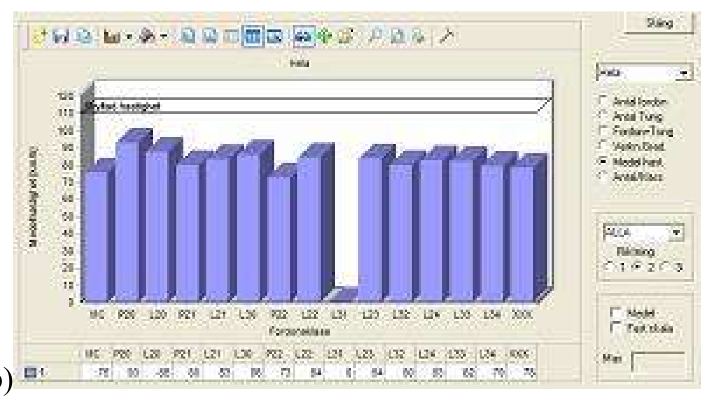
b) 

Fig.5.1a) Measure points (marked green) [18] b) Data from a measure point [21]

Scope of collected data

Data used in this method comes from only two regions of Sweden: Västerbotten (denoted as AC) and Norrbotten (denoted BD). Data is not stored in general statistics, therefore it had to be obtained manually from particular points. The measure points have been selected in key points needed for particular evaluation.

The following wire rope barrier roads have been studied (table 5.1):

Table 5.1 Wire rope barrier roads in the region of Västerbotten (AC) and Norrbotten (BD) by the end of 2004 [7]

Road	Stretch	Road type	Date of construction	Region
E4	Persön - Råneå	MML	9/2004	BD
E4	Gäddvik – Rutvik Rutvik - Ängesbyn	MML MLV	10/2002	BD
E4	Antnäs - Gäddvik	Alt 4 F	10/2002	BD
E4	Antnäs - Ersnäs	Alt 4 F	10/2002	BD
E4	Ersnäs – Norr Rosvik	MLV	10/2003	BD
E4	Kåge - Byske	Alt 4 F	End of 2004	AC
E4	Yttervik - Tjärn	MLV	10/2003	AC
E4	Håknäs - Stöcksjö 14 km Håknäs - Stöcksjö 19 km	MLV	10/2000 10/2001	AC
E4	Nordmaling - Håknäs	MLV	10/2003	AC

Delimitations
The main delimitation in the analysis is the year in which the data was collected. In many cases the data is before the construction of wire ropes. The other limitation is the scope of considered roads, only two regions of Sweden are being evaluated considering that the study concerns the whole of country. On one hand, motorcycle traffic is much lower in these regions than in the south of Sweden. On the other hand, motorcycle traffic is proportional to the total traffic and this proportion is assumed to be equal in each region.

"Motorcycle travelling patterns and choice of alternative routes" method
This method was used to find out if a motorcyclist travelling from one point to another that has two roads of a similar length between them, for instance from Måttsund to Luleå (fig.5.2a, b), uses the road 581 then E4, where wire rope barriers are installed, or the alternative road 580.

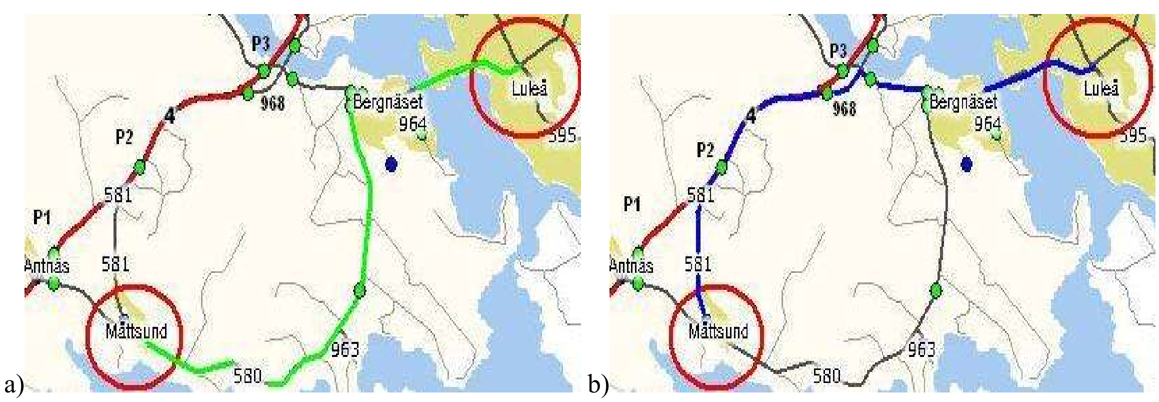


Fig.5.2 a) Alternative rout b) Primary rout between Måttsund and Luleå [18]

Initially, this evaluation was going to be carried out by comparing traffic volumes at measure points along the alternative and the primary road. However, both roads are of different importance and the periods the data was collected are too far apart. For the above mentioned example, last measurements on road 580 were taken in the year 2000 and for E4 in 2003.

Therefore, this method has been abandoned and only one example has been studied based on a similar principle. It will be discussed below and not included in the general results as this method, which relies solely on this provided data does not allow any constructive conclusions to be drawn.

On the 6 August 2003 traffic flow calculations were carried out on E4 Antnäs – Gäddvik, covering the distance between Måttsund and Luleå. At the first measure point south to the junction E4-581 (point P1, fig 5.2a,b) there were 28 motorcycles travelling northbound, at the next measure point just after the junction (point P2, fig 5.2a,b) the flow was 33 motorcycles, meaning that 5 motorcycles from Måttsund entered E4 to travel north. At the third point (point P3, fig 6.2a,b), which is located just after the first direct turn off from E4 to Luleå (junction E4-968) there were 15 motorcycles still travelling north. Out of those 33 motorcycles travelling north after the junction connecting Måttsund and E4, 18 motorcycles turned off to road 968 in Luleå's direction. There is a possibility that in those 18 there were some of the 5 motorcycles that entered E4 by road 581. However, it is quite possible that all of them continued travelling north.

Delimitations of the method
No matter what results were obtained, they do not necessarily mean that motorcyclists chooses certain routes due to the existence of the barriers. There could be several factors that determine their choice, such as the traffic load, beauty of the surroundings, etc.

"Before and after" study method
This method was used to find out how motorcycle traffic and speeds were affected in the same sections after the installation of wire rope barriers. Motorcycle volumes are related to the total traffic volume. The speeds are being compared with the speed limits and the average speeds of traffic at that time. The other aspect investigated is, whether motorcycles were the vehicle type with top speeds or not. North and south road directions are analysed separately.

Delimitations of the method
Most of the measurements were taken before the installation of wire rope barriers. This was the predominant factor that limited the analysis. The analysis of the data relies only on one day of measurements that could have been affected by temporary factors.

"Comparison of equivalent roads" method
This method will give an overview on how the speed and flow data may vary on equivalent roads. Equivalent roads are roads with the same speed limits, similar traffic volumes and importance in the communication network. The obtained results for traffic flow comparison may answer the question if wire rope barrier roads are being avoided or not by motorcyclists. However, the question if alternative roads are being chosen instead cannot be answered as the destinations of analysed roads are different. The real comparison cannot be conducted due to the fact that all of the data has not been included. The roads have been analysed in the following way:

- "110" roads without wire rope barriers
- National "90" roads

Delimitations of the method
The selection of roads within the analysed groups was chosen in a random manner and therefore may not reflect reality.

5.2.2 Internet questionnaire

A questionnaire was put up on The Swedish Motorcyclists Association's website, SMC (Sveriges Motorcyklisters Centralorganisation) [4] between 5 April 2005 and 8 May 2005 (fig.5.3).

Fig.5.3 Questionnaire put up on the SMC's website [4]

Its main objective was to obtain information directly from motorcyclists regarding the way they were being influenced by the existence of wire rope barriers. The data was collected separately for every individual answer. This allowed finding possible correlations between the reaction to wire rope barriers according to age, gender, type and engine size of motorcycle.

Scope of the study
Due to the fact that the questionnaire was put up on the web page, the scope is only limited by the access of the motorcyclists to the internet and their will to fill it in. The questionnaire was in Swedish for the users' convenience and to limit the possibility of foreign motorcyclists answering the questionnaire. This was decided to obtain a national view on the issue. The questionnaire asked motorcyclist for the following information:

1. age
2. gender
3. motorcycle type, consistent with the FEMA categorisation [3], section 2.1.1
4. motorcycle engine size
5. whether involved in an incident or not
6. reaction in terms of the speed when noticing wire rope barriers and the distance from the barrier
7. feeling of security (in the questionnaire referred to security as "safety" for better understanding of the question)
8. attitude to the wire rope barriers
9. whether they chose alternative roads and if yes, why
10. any comments

Apart form the 10th question all choices for answers were provided with a possibility of choosing only one answer for each question. This was intended to avoid logical errors (for example selecting gender, both male and female at the same time). The original and translated version of the questionnaire can be found in the appendix E.

Delimitations
The questionnaire was put up on the web page and excluded all the motorcyclists that did not use the internet or visited the SMC's home website. Those who filled in the questionnaire were not identified, therefore there could be a possibility that the same person filled in the questionnaire more than once. Some of the questions gave a limited number of options to answer not giving an option of leaving out the question or giving an alternative answer. The obvious delimitation is that the answers could be dishonest or not consistent with the reality, meaning that one might think he or she is reacting in a certain way but in reality it could be different.

5.2.3 Interview

A randomly chosen motorcyclist was interviewed while having a brake at a petrol station in Persön on the 1 May 2005 (fig.5.4). The motorcyclist was asked generally on the issue of wire rope barriers, what were the advantages and disadvantages and about preferences of the road environment. The interview had a character of a casual conversation. The interviewed motorcyclist asked to be anonymous.

Delimitations
More than one motorcyclist should have been interviewed. Similar to the questionnaire, the answers may not always be honest or consistent with the reality.

Fig.5.4 The petrol station in Persön, where the motorcyclist was interviewed.

5.2.4 Speed and distance measurements on site

The site study was conducted on the weekend (when motorcycle traffic flow is the largest during the week) [4] on the 30 April and 1 May 2005. This study had several objectives. The main, was to determine at what speeds motorcyclists ride when wire rope barriers are present in the road environment and when they are not. The other approach was to determine how the speeds are being affected by the transition from the section of a 2+1 road with wire rope barriers to the section without and the other way round. Moreover, the riding distances from the barrier were studied and the distances from the centre of the road when wire rope barriers were not present.

Scope of the study

The measurements were conducted in the following 6 different places (table 5.2)

Table 5.2 Measuring points of the site study 30/4/-1/5/2005

Road/junction	Type of road	Time range	Date
Luleå, E4 - 97	2+1 “110”	11.50-13.00	30/4
Luleå, E4 - 968	2+1 “110”	13.20-14.30	30/4
Luleå, along 968	Ordinary “70”	14.50-15.50	30/4
Persön, E4 - 596	1+1	9.30-10.00 12.15-13.20	1/5
Persön, along E4	2+1 “110”	10.15-11.00	1/5
Jämtön, E4 - 691	Ordinary 13 m “110”	14.00-14.50	1/5

“Speed measuring” method

The measurements were conducted with laser speed-measurement equipment (fig.5.5) from inconspicuous places to riders, usually from bridges hidden behind railings. The riders’ speeds were usually measured from behind. When measurements were not taken from the bridge they were taken from behind of piers, trees or embankments.


Fig.5.5 Laser speed-measurement equipment

Delimitations of the method

The measurements were taken at random times and places. This means that the measurements are not representative of the whole of traffic on a particular road. There is no assurance that the riders did not notice that their speed of travelling was being measured. The speed-measuring equipment could have shown the measurements incorrectly, or the measurements might have been conducted in inappropriate way.

"Distance measuring" method

This method was used to determine how motorcyclists react in terms of riding distance from the barrier. This was assessed by observation and divided into 3 categories: closer to the barrier (denoted in the results as L) in the middle of the lane (denoted as M) and closer to the edge of the lane (denoted as R). For comparison, the distances have also been observed on roads without wire rope barriers. The example of judging the distance category is shown on figure 5.6, where the distance has been categorised as M.


Fig.5.6 Distance category "middle" (denoted "M"), Persön

Delimitations of the method

The main delimitation might be that riding distance of motorcyclists' along the wire rope barriers is independent from the barriers themselves. The other delimitation is the accuracy of the eye.

"Speed and distance change" method

This objective of this method was to determine how motorcyclists react in terms of distance and speed at transition sections from a road with wire rope barriers to one without and vice versa (fig.5.7). This method comprises visual observations and speed measurements. The visual observations were used for both speed and distance assessment. For transition from the road without barriers to with barriers brake lights were being observed, indicating whether the motorcyclist slows down just before the barriers. No visual observations were carried out to assess acceleration. The assessment of distance was conducted in the same way as the "distance measurement" method.

Fig.5.7 Transition from the stretch of road with and without wire rope barriers, Persön

The speeds with laser speed-measuring equipment were taken some distance before the stretch with wire rope barriers and respectively for the stretch without wire rope barriers. Compared to visual observations, this part of the method intended to investigate the long term effect, assuming that the rider might change the speed after some time of realisation of presence or lack of wire rope barriers.

Delimitations of the method

Apart from the delimitations mentioned in the "speed measuring" and "distance measuring" methods the prime delimitation is that the motorcyclist might change the speed for independent reasons from the existence of the barrier in the road environment. The speed measurements along the stretch might be too conspicuous to the riders due to lack of bridges and places for the observer to hide behind.

Area description of measure points

The location of the six measure points is shown on figure 5.8. The points' notation tells at which road or junction the measurement took place.

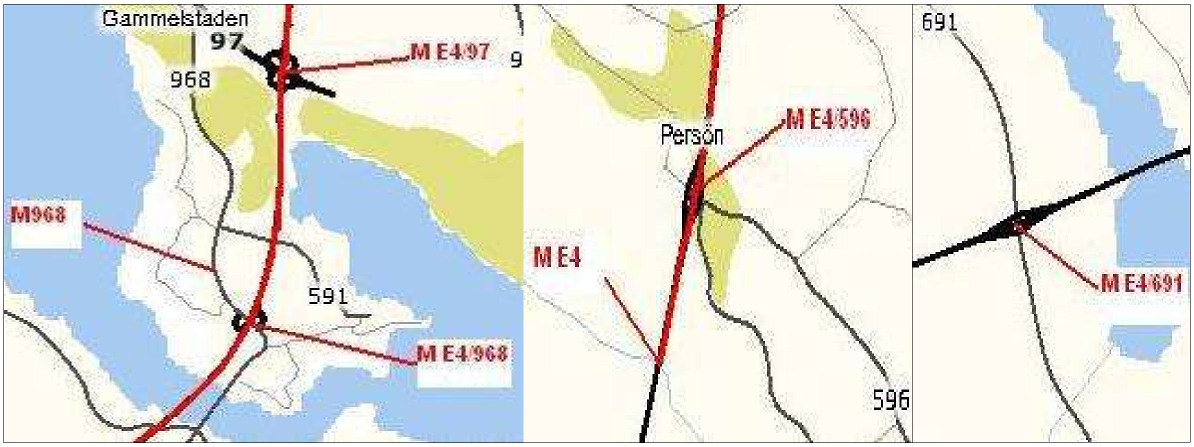


Fig.5.8 Location of site study measure points [18], scale not adjusted.

Luleå, E4 – 97, measure point denoted as M E4/97

This is a junction between two main roads of Luleå's rural road infrastructure (fig.5.8 and fig.5.9a). At this junction E4 is a 2+1 road where one of the lines is a turn off line from the southbound. The speed limit is 110 km/h. There is only a central wire rope barrier and an ordinary barrier protecting the piers. The measurements were taken from behind a pier on the southbound due to high level of traffic on the bridge of road 97 (fig.5.6b). In this location speed and riding distances from the barrier were studied.

a) b)

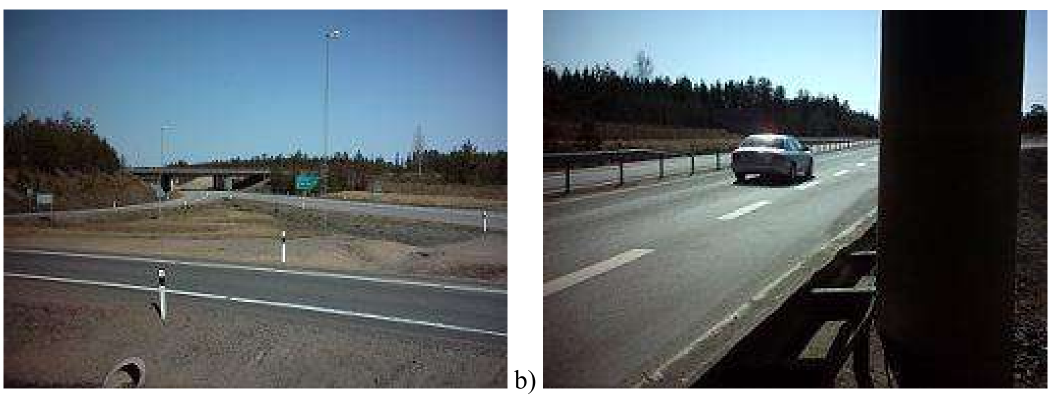


Fig.5.9a) Junction E4-97 b) View from measure point M E4/97

Luleå, E4 – 968, measure point denoted as M E4/968

This junction is between E4, 2+1 road (under the bridge 2+2 with turn off lines in both directions) with a central wire rope barrier and ordinary barriers protecting the piers, and ordinary road 968 (fig.5.8 and fig.5.10a). The speed limit on E4 is 110 km/h. The measurements of speeds and distances were taken from behind the bridge's railings (fig.5.10b). The riders' speeds were measured from the front or behind.

a)  b) 

Fig.5.10 a) Junction E4-968 b) View from measure point M E4/968

Luleå, along the stretch of 968, denoted as M 968

Road 968 is an ordinary rural (suburban) road with a speed limit of 70 km/h (fig.5.8 and fig.5.11a). The speed and distance measurements were carried out on the straight sections of the road. The measure point was located behind the trees (fig.5.11b). The measurements were taken from the front or behind.

a)  b) 

Fig.5.11 a) Stretch of road 968 b) View from measure point M 968

Persön, E4 – 596, measure point denoted as M E4/596

The E4 at this junction has a long section of a 1+1 design with a central and side wire rope barrier on both bounds (fig.5.8 and fig.5.12a). The speed limit is 110 km/h. The measure point was located on the bridge of road 596, behind the bridge's railings (fig.5.12b). The measurements of speeds and distances were taken from the front or behind.

a)  b)

Fig.5.12 a) Junction E4-596 b) View from measure point M E4/596

Persön, along E4, measure point denoted as M E4

Within 1 km south from the junction E4-596 there is a transition from the 2+1 road with wire rope barriers to without on the southbound (fig.5.8 and fig.5.13a), with a central barrier only. The measure point was located on both sides of the road behind an embankment (fig.5.13b). “The speed and distance” method was conducted at this measure point.

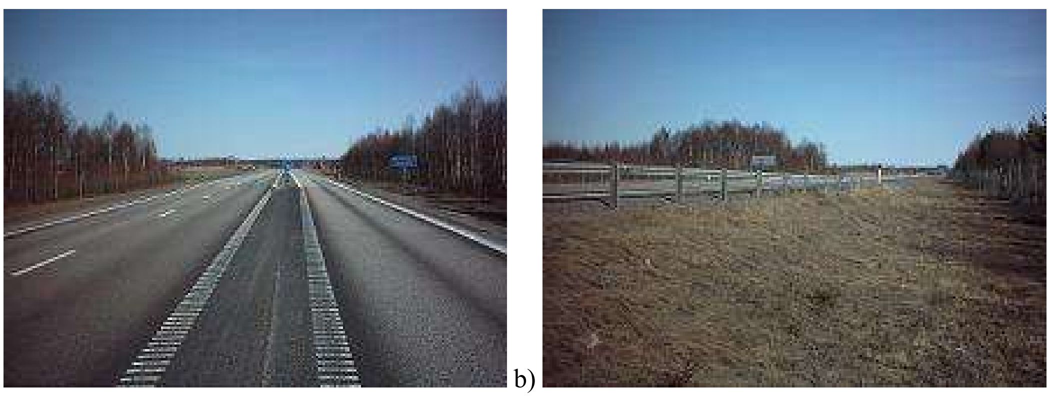
a)  b)

Fig.5.13 a) Transition from stretch with and without wire rope barriers b) View at the measure point M E4

Jämtön, E4 - 691, measure point denoted as M E4/691

The speed and distance measurements were conducted on E4 that has a cross-section of an ordinary 13 m road with wide lanes and where the speed limit is 110 km/h (fig.5.8 and fig.5.14a). The measure point was located on the bridge of road 691, behind the railings (fig.5.14b). The measurements were taken from the front and behind.

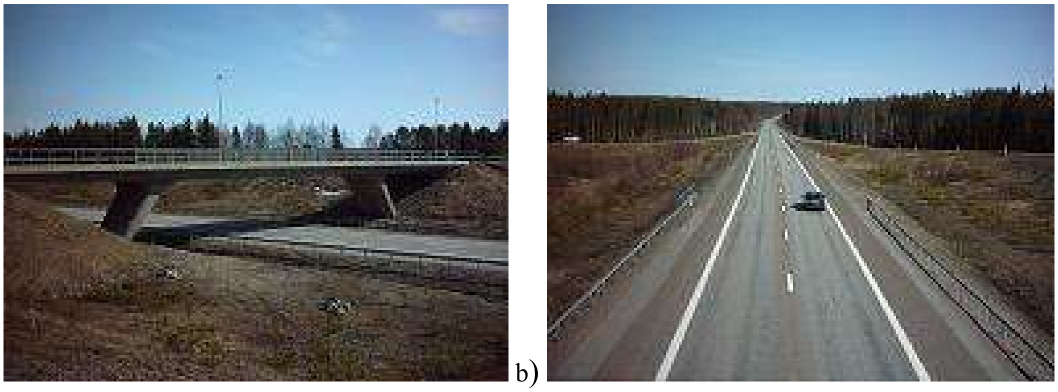
a) b)


Fig.5.14 a) Junction E4-691 b) View from measure point M E4/691

6. RESULTS

6.1 MOTORCYCLISTS' SAFETY ON WIRE ROPE BARRIER ROADS

6.1.1 Literature review of 2+1 roads motorcycle accidents

MML roads

The first half of year 2004 was very unfortunate for motorcyclists on *MML* roads, during which 7 out of all 15 accidents took place for the period studied. Just in those 6 months, 2 riders died, 4 had severe and 2 minor injuries. Four accidents were single vehicle, 2 tailgating and 1 overtaking accident. Throughout the whole accident history of *MML* roads, as stated above, 15 motorcycle accidents occurred, which involved 2 motorcyclists being killed, 7 severely injured and 7 with minor injuries. 11 of those accidents were single vehicle, 2 overtaking and 2 tailgating accidents [6].

Most of the severely injured and fatal accidents occurred along the stretch of the road. Nonetheless, 3 of the single vehicle accidents occurred at an intersection where 1 person was severely injured and 2 had minor injuries. The accidents that occurred along the stretch of the road are described below:

- 1 motorcyclist died and 1 passenger was severely injured after skidding and impacting the central wire rope barrier on E18 Köping-Västjädra.
- 1 motorcyclist was severely injured after impacting with the central wire rope barrier at low speed on the same road (E18 Köping-Västjädra).
- 1 motorcyclist died due to impacting from behind into a heavy vehicle that had an engine failure on E22 Trensum-Björketorp.
- 1 motorcyclist was severely injured after impacting into the central wire rope barrier when riding with 2 other motorcycles side by side. This accident occurred on E20 Gröndal-Eskilstuna.
- 1 motorcyclist was severely injured after impacting into a heavy vehicle’s tire while overtaking on E18 Stolpen-Övre Kvarn.
- 1 motorcyclist was severely injured after using a handbrake and riding into the central wire rope barrier. This accident occurred on Rv 44/45 Överby-Båberg.
- 1 motorcyclist was severely injured after impacting with the central wire rope barrier due to strong gust of wind. This accident took place on E4 Deltavägen.

Five of the seven above mentioned accidents occurred on *MML 110* roads. There were four single and one overtaking accident that resulted in minor injuries, in two cases the central wire rope barrier was involved.

The outcome of motorcycle accident data for *MML* roads is as following:

- 11 single vehicle accidents with 1 D, 5 SS and 6 LS, of which 1 SS and 2 LS at an intersection.
- 2 running into 1 D and 1 SS.
- 2 overtaking with 1 SS and 1 LS.

- Wire rope barriers were involved in 7 out of all 15 accidents with 1 D, 5 SS and 2 LS.

***MLV* roads**
There was only one motorcycle accident in total on *MLV* roads, which occurred on E4 Håknäs-Stöcksjö. Two motorcyclists were severely injured after riding into a vehicle that slowed down in order to turn off [6].

2+2 roads
The literature does not mention motorcyclists being involved in 2+2 road accidents.

2+1 målat (no wire rope barriers installed)
The literature states that one accident with a severe outcome occurred at an intersection, with a motorcycle falling onto the road surface.

Comparison of 2+1 (2+2) roads and accident analysis
Motorcycle accident data of 2+1 roads with wire rope barriers is shown in table 6.1. The table provides general information on total vehicle mileage and motorcycle mileage calculated on the basis of general motorcycle traffic data. On average 1 % of rural traffic comprises of motorcycles [20]. The following information concerns the number of casualties on specific road types. Figures marked with a question mark mean that no information was given in the analysed literature on motorcycle accident occurrence on a particular road type. The "casualties" column is just for information and is not meant for comparison as it is the ratio of the number of casualties to the volume of traffic, which is a reasonable measure of comparison. The "total number of dead rate" in overall traffic (D) and "total number of dead or severely injured rate" in overall traffic (DSS) and the corresponding motorcycle D and DSS rates were calculated. The last two columns of the table show the ratio of motorcycle D and DSS rates (denoted as MC D and MC DSS) correspondingly to the overall traffic D and DSS rates. These values are a measure of comparison between the level of safety for motorcyclists related to the overall level of safety on a particular road type.

MML roads have the worst motorcycle safety performance amongst all wire rope barrier roads. The motorcycle D rate is 28 times larger than the overall D rate on the *MML* road type. However, it is important to note that until the end of year 2003 no motorcyclist was killed in the vicinity of *MML* roads (or any other 2+1 roads). The first half of year 2004 was very unfortunate for motorcycle safety performance of *MML* roads. In that period, two motorcyclists were killed, four out of seven motorcyclists were severely injured and another two out of seven had minor injuries [6]. Moreover, central wire rope barriers were substantially involved in motorcycle accidents on *MML* roads. They were involved in seven out of all fifteen *MML* motorcycle accidents causing one out of two fatal accidents, five of seven severely injured accidents and two out of seven of minor injuries [6]. There are no details in literature of how exactly wire rope barriers were involved in these accidents. . Although *MLV* roads have a twice as small vehicle mileage to *MML* roads, they have a correspondingly much better safety performance. There were no fatal motorcycle accidents on a *MLV* road and the sole accident that resulted in two severely injured motorcyclists was not caused directly by the geometry or the design of the 2+1 road (tailgating accident type).

A point to note is that *2+1 målat 90* road, that has no wire rope barriers had a higher DSS rate (0.222) than *MML* road type (0.221) despite the ratio of the motorcycle DSS to the overall was in favour of *2+1 målat 90* roads. This is due to the low overall safety level of *2+1 målat 90* roads when compared to the overall *MML* safety performance. However, no constructive conclusions can be drawn as vehicle mileage of *2+1 målat 90* roads is very low.

No motorcycle accidents occurred on 2+2 roads. This could imply that they are safer than 2+1 roads, which could be due to the fact that the carriageway is wider and there is a lack of transition zones. However, it is difficult to compare both roads as the literature does not state exactly on what sections of 2+1 roads the accidents occurred. Another point to note is that vehicle mileage of 2+2 roads is considerably lower than *MML* or *MLV*'s.

This comparison was intended to provide the magnitude of wire rope barrier safety performance with respect to motorcyclists. Due to lack of general details on motorcycles, motorcycle mileage, accident circumstances and other unforeseen factors in the calculation method this assessment should not be taken as a fully reliable safety assessment.

Table 6.1 Comparison of wire rope barrier roads' safety performance for motorcycles.

Road type	Vehicle mileage in Mapkm	Casualties			D per Mapkm	DSS per Mapkm	MC D / overall D	MC DSS / overall DSS
		D	SS	LS				
MML 110	2100	6	43	241	0.003	0.023		
MML 90	1970	1	34	245	0.001	0.018		
MML 90 and 110	4070	7	77	486	0.002	0.021		
MC on MML	**40.7**	**2**	**7**	**7**	**0.049**	**0.221**	**28.57**	**10.71**
MLV 110	330	0	12	45	0	0.036		
MLV 90	1485	2	25	159	0.0013	0.018		
MLV 90 and 110	1815	2	37	204	0.0011	0.021		
MC on MLV	**18.15**	**0**	**2**	**0?**	**0**	**0.110**	**0**	**5.13**
2+2 90 (MLV)	250	0	8	32	0	0.032		
MC on 2+2 90	**2.5**	**0?**	**0?**	**0?**	**0?**	**0?**	**0?**	**0?**
Alt 4F 110	760	3	15	92	0.004	0.024		
MC on Alt 4F 110	**7.6**	**0?**	**0?**	**0?**	**0?**	**0?**	**0?**	**0?**
2+1 malat 90	450	4	7	40	0.009	0.024		
MC on 2+1 malat 90	**4.5**	**0?**	**1**	**0?**	**0**	**0.222**	**0**	**9.09**

6.1.2 Motorcycle accident data analysis

Motorways

Between years 1998-2002 on average 76 motorcycle accidents resulting in injuries occurred on motorways annually. The distribution of those accidents is shown on the pie-chart below (fig.6.1).

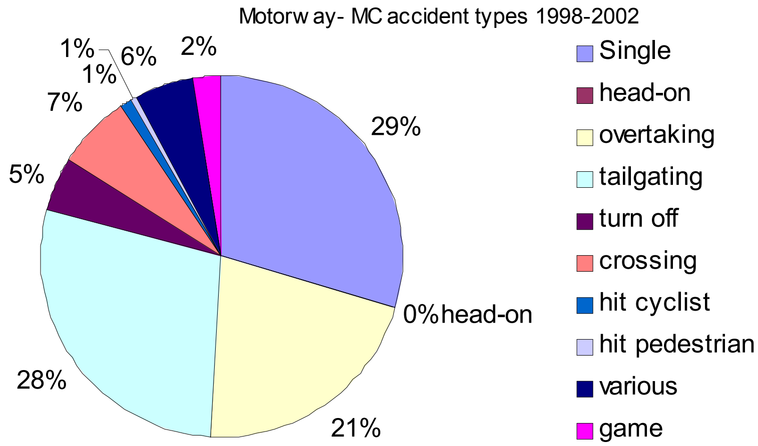


Fig.6.1 Motorcycle accidents that occurred on motorways according to type in years 1998-2002.

Most of the accidents were single vehicle accidents and tailgating. A surprisingly high number comprised accidents involving pedestrians and cyclists for whom access to the motorways is restricted, accounting for 2 % of the total. There were 2 single vehicle accidents during this study period, between 2002 and 2003, which involved a wire rope barrier. On average 2 accidents per year involved an ordinary crash barrier. However, the majority of accidents involved motorcycles colliding or being run into by another vehicle, on average 27 accidents per year.

Semi-motorways

On average there were 5 accidents per year during the study period (23 in total).The distribution of accidents for semi-motorways (without wire rope barriers) is shown on the pie-chart below (fig.6.2):

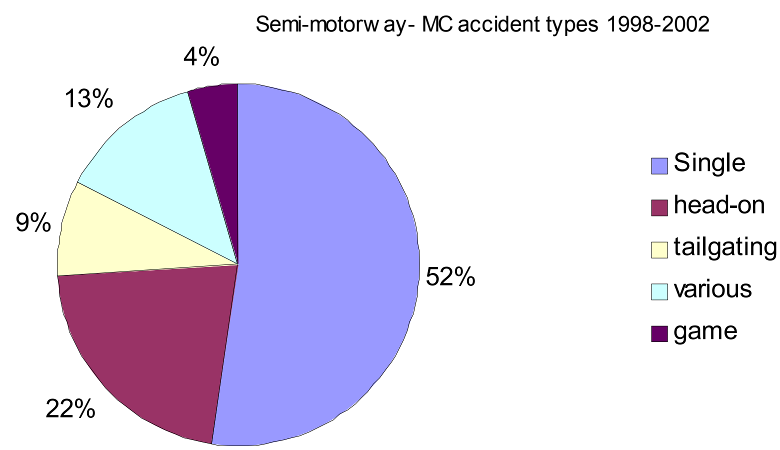


Fig.6.2 Motorcycle accidents that occurred on semi-motorways according to type in years 1998-2002.

More than half of motorcycle accidents on semi-motorways were single vehicle accidents. However, more than one fifth accounted for head-on collisions. No pedestrians or cyclists were involved. There are no wire rope barriers on this type of road but one accident occurred with a motorcycle hitting an ordinary barrier. Two most frequent accident occurrences were either skidding and falling onto the carriageway or colliding with another vehicle.

2+1 semi-motorways

The data for 2+1 semi-motorways has been merged to 4 years, from 1999 to 2002, when the first wire rope barrier roads started to be implemented. 12 motorcycle accidents took place during that period of time. The accidents were of two types: single vehicle and crossing accidents. The distribution is as follows (fig.6.3):

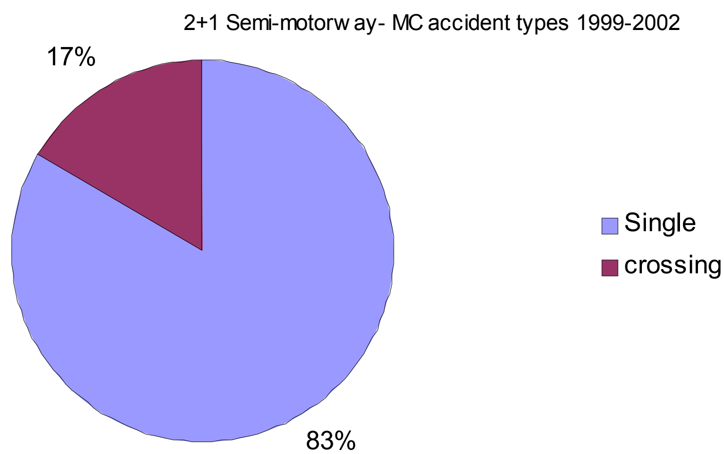


Fig.6.3 Motorcycle accidents that occurred on 2+1 semi-motorways according to type in years 1999-2002.

Over 80 % of the accidents were single vehicle accidents. One single vehicle accident involved a motorcyclist crashing into a wire rope barrier, another with a post and the rest were mainly run-off accidents. Two accidents occurred at an intersection involving a motorcycle colliding with a different vehicle.

4-lane roads

There were 81 accidents on 4 lane roads between 1998 and 2002, their distribution is as follows (fig.6.4):

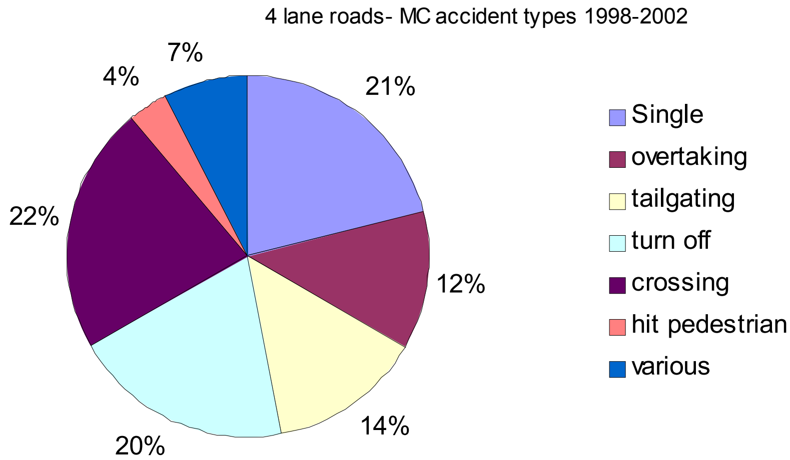


Fig.6.4 Motorcycle accidents that occurred on 4 lane roads according to type in years 1998-2002.

The most common types of motorcycle accidents on 4 lane roads during the study period were ones that occurred at an intersection, crossing and turn off type accidents. Together they accounted for 42 % of the total. Single vehicle accidents accounted for more than one fifth. Most accidents involved colliding with another vehicle. Among single vehicle accidents two involved a crash barrier and the rest mainly run-off accidents.

Ordinary roads

These roads have the highest amount of vehicle mileage and therefore the number of accidents is much higher when compared with other roads. On average 240 accidents per year occurred during those 5 years of study. The distribution is as follows (fig.6.5):

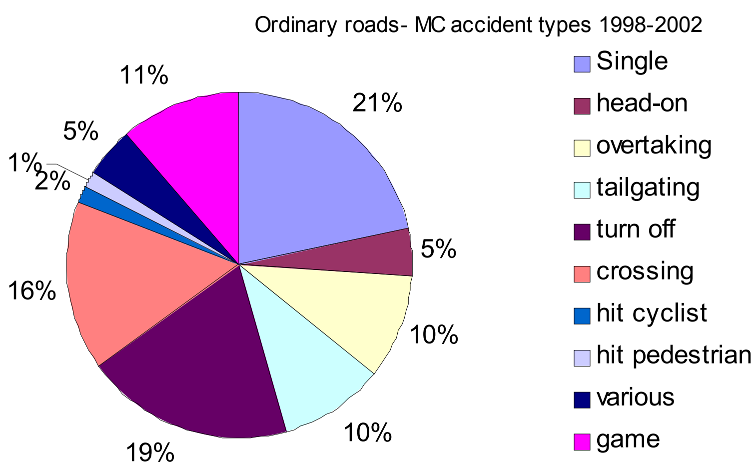


Fig.6.5 Motorcycle accidents that occurred on ordinary roads according to type in years 1998-2002.

Accidents occurring at an intersection account for 35 % with turn off accidents being the dominant type. Single vehicle accidents, as in other road types, account for more than 20 %. Wild animals contributed substantially to the types of accidents, accounting for 11 %. Head-on collisions accounted for a considerable low proportion, being only 5 %. Among single vehicle accidents many involved roadside objects such as stones, rock faces and trees. However, road furniture played also a substantial role, 17 accidents throughout the study period involved a crash barrier.

Ordinary 2+1, 2+2 and 1+1 roads

The data for 2+1 semi-motorways has been merged to 4 years for the same reason as for 2+1 semi-motorways. Since 1999 until 2002, 7 motorcycle accidents took place, of which 2 occurred at an intersection as a crossing accident and 5 of "various" type. In those 5, 1 involved a wire rope barrier, 2 concerned overtaking and the remaining 2, skidding and run-off accidents. The distribution of accidents is shown below (fig.6.6)

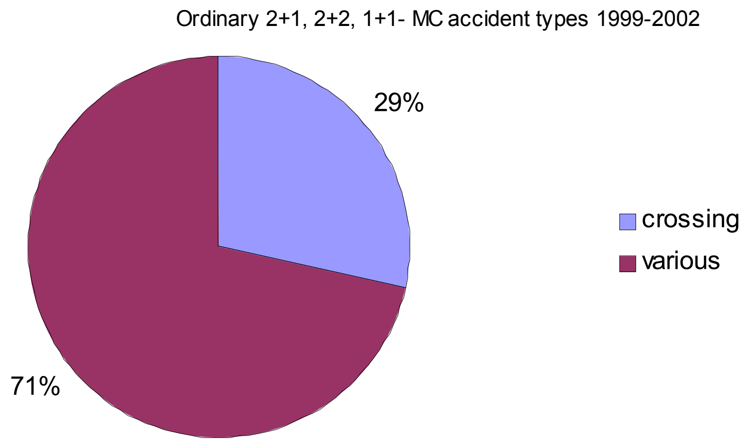


Fig.6.6 Motorcycle accidents that occurred on ordinary 2+1 roads according to type in years 1999-2002.

Comparison of different road types with respect to motorcyclists

It is rather difficult to evaluate a fair comparison of road types not knowing what is the real motorcycle volume and mileage for each of the roads. Nonetheless, the distribution of types of accidents gives a magnitude of the issue.

Motorways due to their geometrical design do not allow head-on collisions to occur. Therefore, it could be anticipated that other accident types would dominate. Surprisingly 2 % of accidents involved pedestrians and cyclists, road users with restricted access to motorways. On the contrary, semi-motorways had a very high number of head-on collisions, accounting for 22 %. 2+1 semi-motorways managed to eliminate this accident type due to the central wire rope barrier. Roads with more direct access to the carriageway had a very high accident rate at intersections. This also applies to ordinary 2+1 roads where 2 crossing accidents occurred. There were not too many head-on collisions on ordinary roads but many accidents involved game, this might have been prevented by a side barrier.

6.2 THE INFLUENCE OF WIRE ROPE BARRIERS ON MOTORCYCLISTS

As assumed in section 6.1, the risk of getting killed or severely injured on 2+1 roads with wire rope barriers is at the least not higher than on 2+1 roads without wire rope barriers. However, this may not be due to the merits of the physical prevention of wire rope barriers but the reaction of motorcyclists to the barriers. The reaction may be in the form of enhanced concentration, reduction of speed or more thoughtful riding. Moreover, motorcyclists may avoid roads with wire rope barriers choosing alternative routes. This could give an illusion that wire rope barrier roads are safe to motorcyclists due to the lack of motorcycle traffic. But in fact this would mean that motorcycle accidents happen among just few riders resulting in a very high accident rate.

Apart from learning how motorcyclists react in terms of the speed and distance to the wire rope barrier it is also crucial to find out what is their opinion and how they adapt to these controversial barriers. This section will attempt to answer the above questions.

The results will be presented according to the methods used. They are revised below.

6.2.1 Results of motorcycle traffic flow and speed data analysis

The method "Motorcycle travelling patterns and choice of alternative routes" has been excluded from general results due to many limitations it had. The result of one approach was discussed in the method description in 5.2.1.

All of the analysed data comes from the SRA's database [21].

Results of "Before and after" method

Only data from 3 measuring points fulfilled the objective of this method. However, one more point was included in the analysis, which concerns data only when wire rope barriers were already installed. Previous data for the same point could not be obtained. An example of another measure point was also included, which shows how the speed and traffic volume data changed before the road was converted to a 2+1 road.

The results are presented in order as described above, first the actual comparison at 3 points, then the sole example when wire rope barriers were installed and finally the variation of speed and flow data on the road before it was modified.

Measure point number 24140012 on E4 Antnäs – Gäddvik (constructed 10/2002)

The measurements from 1996 and 2003 are analysed separately respectively in tables 6.2a and 6.2b. The comparison of speed and flow data from each year is evaluated in figure 6.7a for speeds and 6.7b for motorcycle volumes.

Table 6.2a Before installation of wire rope barriers

Measurement date: 1996-06-07	North	South	N and S
Speed limit	110	110	110
Average MC speed	100	69	99
Below/above limit	-10	-41	-11
Average traffic speed	99	100	99
Below/above average traffic speed	1	-31	0
Vehicle with top speed	not mc	not mc	not mc
MC volume	50	2	52
Total volume	6953	5038	11991
MC volume %	0,7	0,0	0,4

Table 6.2b After installation of wire rope barriers

Measurement date: 2003-08-06	North	South	N and S
Speed limit	110	110	110
Average MC speed	108	91	106
Below/above limit	-2	-19	-4
Average traffic speed	104	103	103
Below/above average traffic speed	4	-12	3
Vehicle with top speed	MC	not mc	not mc
MC volume	33	4	37
Total volume	3001	2031	5032
MC volume %	1,1	0,2	0,7

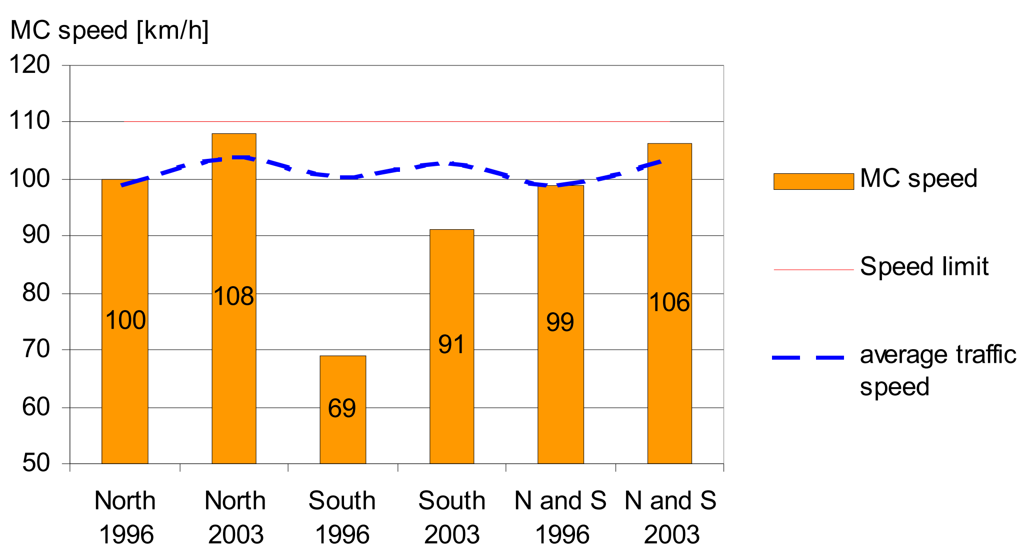


Fig.6.7 a) Speed comparison in years 1996-2003 at E4 Antnäs – Gäddvik, point # 24140012

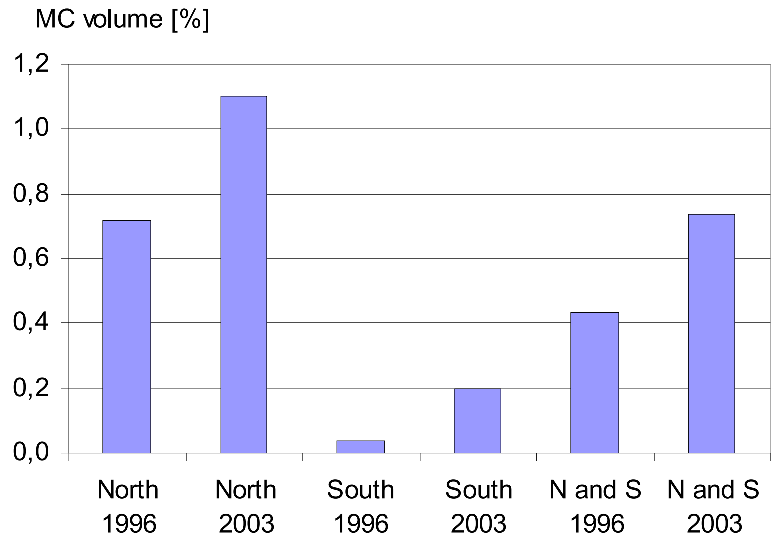


Fig.6.7 b) Volume comparison in years 1996-2003 at E4 Antnäs – Gäddvik, point # 24140012

Judging by the outcome shown on figures 6.7a and b, and tables 6.2a and b, an increase in motorcycle speeds can be observed between 1996 and 2003. In both cases motorcycle speeds did not exceed the speed limit. On the whole, in 1996, the speeds were close to the average speeds of all traffic. In contrast, in 2003 motorcycle speeds were higher than average. The ratio of motorcycle traffic increased due to substantial reduction of total traffic. However, actual motorcycle traffic flow dropped from 52 to 37.

Measure point number 20010008 on E4 Håknäs - Stöcksjö (constructed 10/2000)
The comparison is evaluated between the years 1996 and 2003. Both years are first analysed separately in tables 6.3a and b. The actual comparison is shown on figures 6.8a and b.

Table 6.3a Before installation of wire rope barriers

Measurement date: 1996-08-22	North	South	N and S
Speed limit	110	110	110
Average MC speed	118	94	115
Below/above limit	8	-16	5
Average traffic speed	102	102	102
below/above average traffic speed	16	-8	13
vehicle with top speed	MC	not mc	MC
MC volume	17	2	19
Total volume	2669	2185	4854
MC volume %	0,6	0,1	0,4

Table 6.3b After installation of wire rope barriers

Measurement date: 2003-06-24	North	South	N and S
Speed limit	110	110	110
Average MC speed	107	104	105
Below/above limit	-3	-6	-5
Average traffic speed	103	99	101
Below/above average traffic speed	4	5	5
Vehicle with top speed	not mc	MC	not mc
MC volume	24	25	49
Total volume	1257	1564	2821
MC volume %	1,9	1,6	1,7

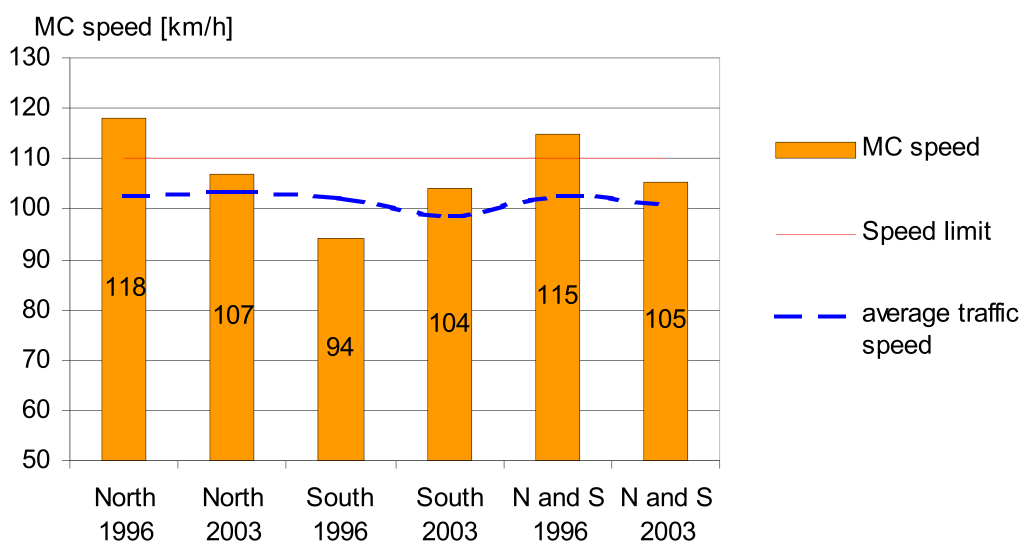


Fig.6.8 a) Speed comparison in years 1996-2003 at E4 Håknäs – Stöcksjö, point # 20010008

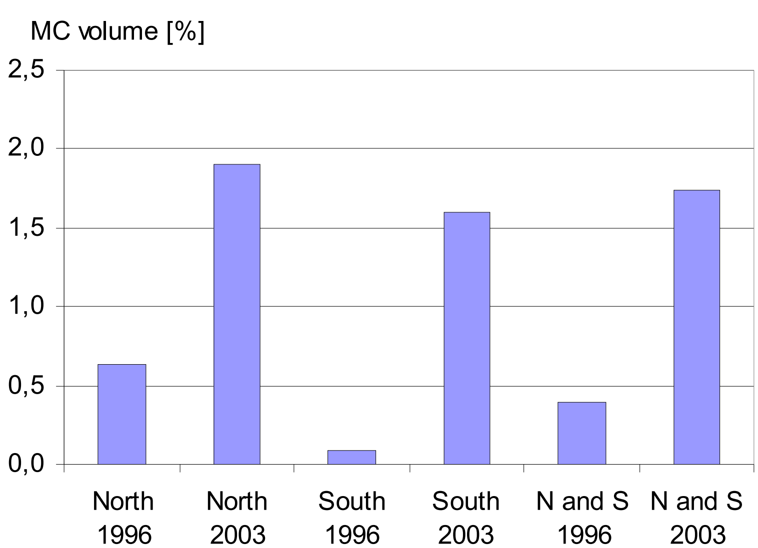


Fig.6.8 b) Volume comparison in years 1996-2003 at E4 Håknäs – Stöcksjö, point # 20010008

Between 1996 and 2003 motorcycle traffic volumes, when related to the total traffic volumes, increased by more that 4 times, in numbers from 19 to 49. However, the total traffic volumes decreased by nearly a half. In both cases the speeds were above the average speeds. However, in 1996 the motorcycle was the fastest travelling vehicle exceeding the speed limit on average by 8 km/h on northbound roads and by 5 km/h on average. In contrast, in 2003 the speeds were always above the average but did not exceed the speed limit.

Measure point number 20010002 on E4 Håknäs - Stöcksjö (constructed 10/2000)
Same principles apply for presenting the results as for the two examples discussed above. The results are revised in table 6.4a and b and on figures 6.9a and b.

Table 6.4a Before installation of wire rope barriers

Measurement date: 1996-08-22	North	South	N and S
Speed limit	90	90	90
Average MC speed	111	106	109
Below/above limit	21	16	19
Average traffic speed	97	97	97
Below/above average traffic speed	14	9	12
Vehicle with top speed	MC	MC	MC
MC volume	29	17	46
Total volume	3352	3207	6559
MC volume %	0,9	0,5	0,7

Table 6.4b After installation of wire rope barriers, NOTE: the speed limit changed to 110 km/h

Measurement date: 2003-06-24	North	South	N and S
Speed limit	110	110	110
Average MC speed	110	95	109
Below/above limit	0	-15	-1
Average traffic speed	104	103	104
Below/above average traffic speed	6	-8	6
Vehicle with top speed	MC	not mc	MC
MC volume	48	3	51
Total volume	2515	1306	3821
MC volume %	1,9	0,2	1,3

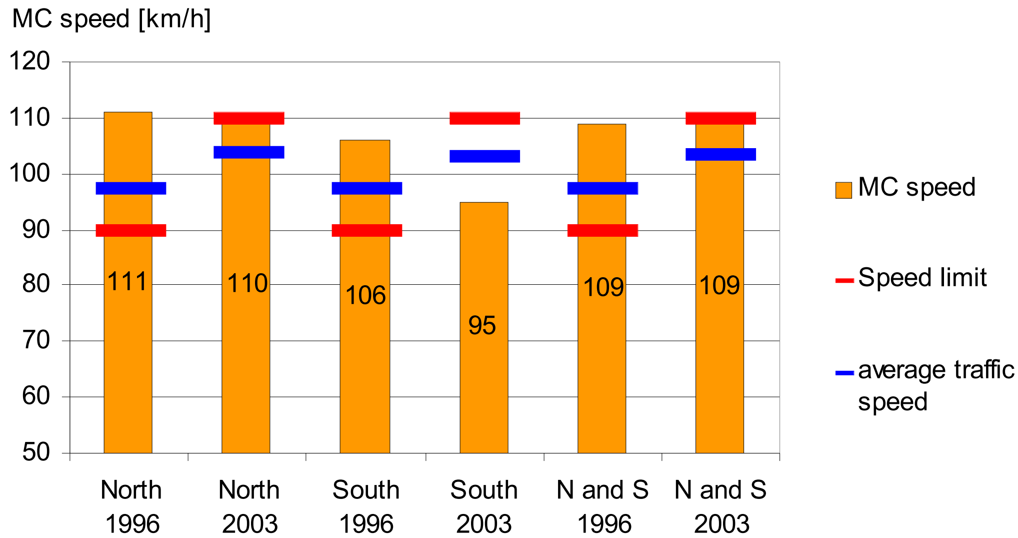


Fig.6.9 a) Speed comparison in years 1996-2003 at E4 Nordmaling – Håknäs, point # 20920012

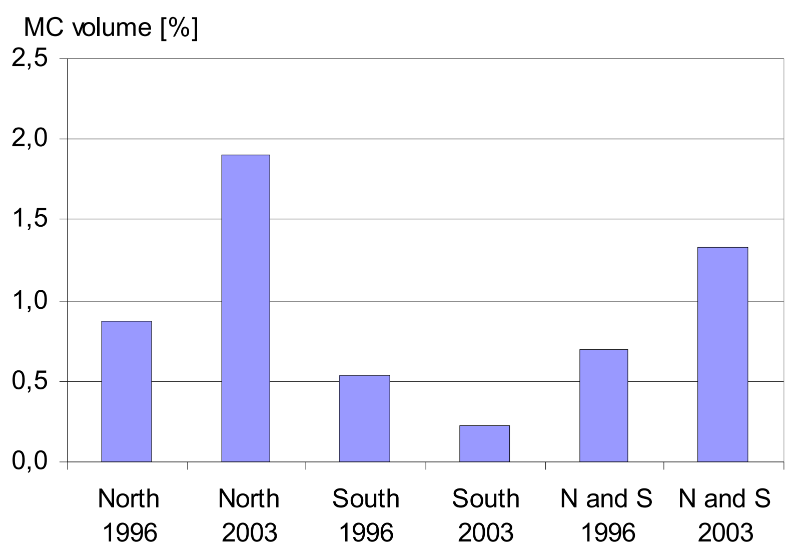


Fig.6.9 b) Volume comparison in years 1996-2003 at E4 Nordmaling – Håknäs, point # 20920012

Motorcycles were the fastest travelling vehicles in traffic in both years. When the road was modified to a 2+1 design the speed limit was raised from 90 km/h to 110 km/h. In 1996 on the northbound stretch the speed limit was exceeded on average by 21 km/h and on the whole by 19 km/h. On the 2+1 road with wire rope barriers (in 2003) the speeds were on the whole higher than average but lower or equal to the speed limit. The proportion of motorcycle traffic to the total traffic has doubled due to the reduction of total traffic volumes, but in addition there was been a slight increase in the number of motorcyclists (from 46 to 51).

Measure point number 24140236 on E4 Antnäs – Gäddvik (constructed 10/2002)
The results for only "after" study were obtained. The results are presented in table 6.5 and the speed performance visualised on figure 6.10.

Table 6.5 After installation of wire rope barriers

Measurement date: 2003-08-06	North	South	N and S
Speed limit	110	110	110
Average MC speed	107	116	110
Below/above limit	-3	6	0
Average traffic speed	101	107	103
Below/above average traffic speed	6	9	7
Vehicle with top speed	MC	MC	MC
MC volume	28	17	45
Total volume	2951	2017	4968
MC volume %	0,9	0,8	0,9

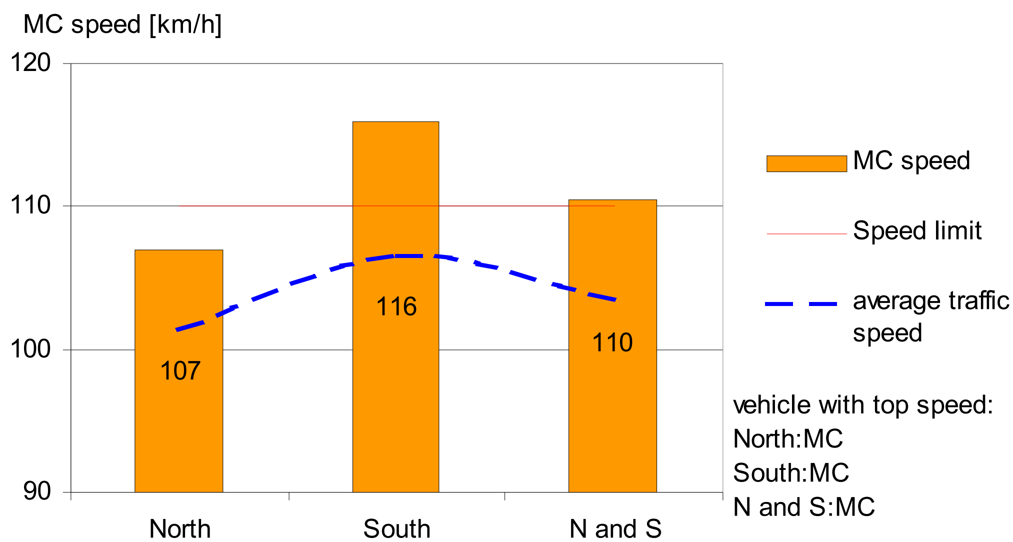


Fig.6.10 Motorcycle speeds on roads with wire rope barriers, example from 2003-08-06 at E4 Antnäs – Gäddvik, point # 24140236.

At the analysed measure point the speeds of motorcyclists were always above the average speeds of the whole traffic. Moreover, the motorcycle in both directions was the fastest travelling vehicle. The speed limit was exceeded by 6 km/h on southbound roads. Motorcycle traffic volume accounted for just under 1 % of total traffic on that cross-section of road.

Measure point number 20920012 on E4 Nordmaling - Håknäs (constructed 10/2003)
The results are analysed for years 1996, 1998 and 2003. The values are presented separately in tables 6.6a,b and c and the comparison has been illustrated on figure 6.11.

Table 6.6a Before the installation of wire rope barriers

Measurement date: 1996-08-22	North	South	N and S
Speed limit	110	110	110
Average MC speed	110	121	118
Below/above limit	0	11	8
Average traffic speed	99	103	101
Below/above average traffic speed	11	18	17
Vehicle with top speed	MC	MC	MC
MC volume	8	20	28
Total volume	2503	2679	5182
MC volume %	0,3	0,7	0,5

Table 6.6b Before the installation of wire rope barriers, NOTE: the speed limit changed to 90 km/h

Measurement date: 1998-08-24	North	South	N and S
Speed limit	90	90	90
Average MC speed	68	71	69
Below/above limit	-22	-19	-21
Average traffic speed	102	98	100
Below/above average traffic speed	-34	-27	-31
Vehicle with top speed	not mc	not mc	not mc
MC volume	7	3	10
Total volume	3221	3038	6259
MC volume %	0,2	0,1	0,2

Table 6.6c Before the installation of wire rope barriers

Measurement date: 2003-06-24	North	South	N and S
Speed limit	90	90	90
Average MC speed	104	97	101
Below/above limit	14	7	11
Average traffic speed	99	96	98
Below/above average traffic speed	5	1	3
Vehicle with top speed	MC	not mc	not mc
MC volume	32	16	48
Total volume	1565	1669	3234
MC volume %	2,0	1,0	1,5

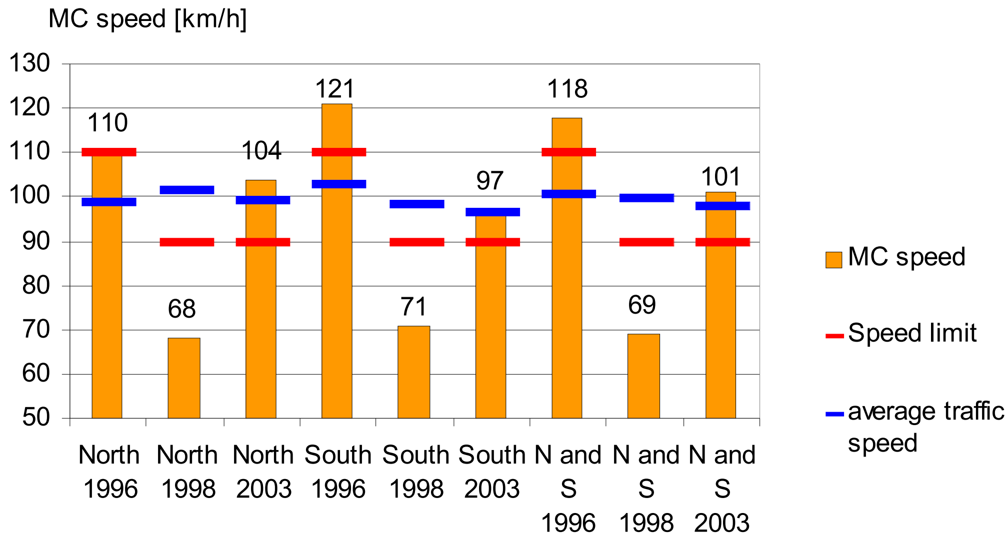


Fig.6.11 a) Speed comparison in years 1996-1998-2003 at E4 Nordmaling – Håknäs, point # 20920012

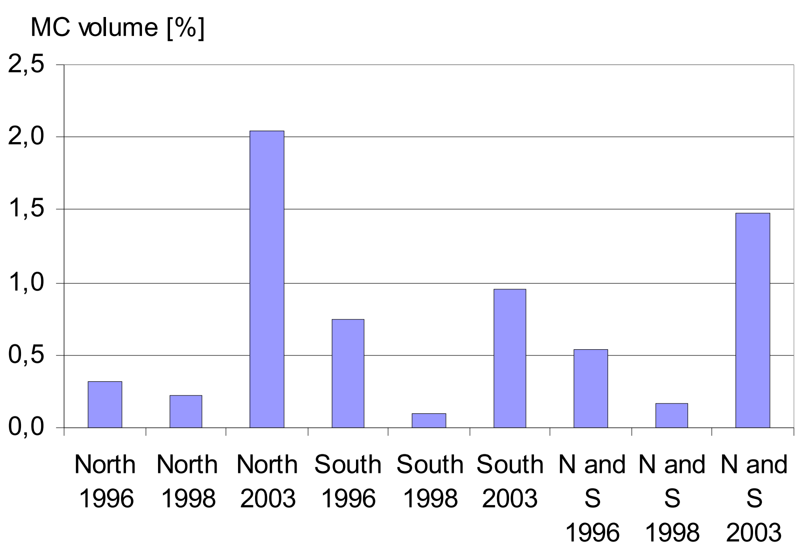


Fig.6.11 b) Volume comparison in years 1996-1998-2003 at E4 Nordmaling – Håknäs, point # 20920012

In 1996, when E4 on analysed stretches of the road had a speed limit of 110 km/h, motorcycles were the fastest travelling vehicles with speeds exceeding the speed limit on average by 11 km/h on the southbound stretches and on the whole by 8 km/h. In 1998, when the speed limit was already changed to 90 km/h, motorcycle speeds were much lower than the speed limit, 21 km/h and even lower than the average speed of traffic, 30 km/h. However, motorcycle traffic was very low on that day which might indicate that the weather conditions or other factors influenced the speed performance. In 2003 motorcyclists always rode above the speed limit but only slightly above the average speed level and were generally not the fastest travelling vehicle type. The ratio of motorcyclists to the total traffic has substantially increased between 1996 and 2003, when it accounted on average for 1.5 % of traffic in 1996. However, the total traffic volumes decreased almost by half (from 6,259 in

1998 to 3,234 in 2003) but motorcycle traffic increased by nearly a half (from 28 in 1996 to 48 in 2003).

Results of "Comparison of equivalent roads" method
Speed and flow data for both equivalent types of roads ("110" and "90") has been assembled in tables of results. The results are presented in order according to the total traffic volumes, from largest to lowest and are followed by a commentary within each group.

"110" roads without wire rope barriers
The results for the equivalent "110" roads are presented in tables from 6.7a to 6.7e.

Table 6.7a E4 Råneå-Töre measure point number 25120028

Measurement date: 2002-06-12	North	South	N and S
Speed limit	110	110	110
Average MC speed	101	105	102
Below/above limit	-9	-5	-8
Average traffic speed	100	101	101
Below/above average traffic speed	1	4	1
Vehicle with top speed	not mc	MC	not mc
MC volume	39	13	52
Total volume	2606	2548	5154
MC volume %	1,5	0,5	1,0

Table 6.7b E4 Töre- Kalix measure point number 25230016

Measurement date: 2002-06-12	North	South	N and S
Speed limit	110	110	110
Average MC speed	111	96	110
Below/above limit	1	-14	0
Average traffic speed	101	101	101
Below/above average traffic speed	10	-5	9
Vehicle with top speed	MC	not mc	MC
MC volume	24	2	26
Total volume	1893	1872	3765
MC volume %	1,3	0,1	0,7

Table 6.7c E4- Umeå-Sävar measure point number 20040010

Measurement date: 2003-06-26	North	South	N and S
Speed limit	110	110	110
Average MC speed	99	121	102
Below/above limit	-11	11	-8
Average traffic speed	101	104	103
Below/above average traffic speed	-2	17	-1
Vehicle with top speed	not mc	MC	not mc
MC volume	12	2	14
Total volume	934	1499	2433
MC volume %	1,3	0,1	0,6

Table 6.7d E10 Töre-Morjärv measure point number 25230003

Measurement date: 2002-05-23	North	South	N and S
Speed limit	110	110	110
Average MC speed	86	92	90
Below/above limit	-24	-18	-20
Average traffic speed	105	101	103
Below/above average traffic speed	-19	-9	-13
Vehicle with top speed	not mc	not mc	not mc
MC volume	5	8	13
Total volume	789	852	1641
MC volume %	0,6	0,9	0,8

Table 6.7e E4- Jävre-Byske measure point number 23130007

Measurement date: 2002-05-30	North	South	N and S
Speed limit	110	110	110
Average MC speed	118	93	109
Below/above limit	8	-17	-1
Average traffic speed	106	102	104
Below/above average traffic speed	12	-9	5
Vehicle with top speed	MC	not mc	not mc
MC volume	7	4	11
Total volume	549	491	1040
MC volume %	1,3	0,8	1,1

On the above reviewed “110” roads it is difficult to find a pattern within total traffic volumes. The speeds varied from 24 km/h below the speed limit and 19 km/h below average speeds to 11 km/h above the speed limit and 17 km/h above the average. When compared with roads with wire rope barriers in the examples analysed in the “Before and after” method the values were on the whole more concentrated. However, the extreme values for the 2+1 roads with a speed limit were: 116 km/h and 91 km/h. Motorcycle traffic volumes account on the whole for under 1 % of all traffic. The actual numbers are on the whole slightly lower than on 2+1 roads with wire rope barriers.

“90” roads without wire rope barriers

The results for the equivalent “90” roads are presented in tables from 6.8a to 6.8e.

Table 6.8a Road 97- Luleå-Boden

Measurement date: 2002-06-01	North	South	N and S
Speed limit	90	90	90
Average MC speed	94	86	90
Below/above limit	4	-4	0
Average traffic speed	89	85	87
Below/above average traffic speed	5	1	3
Vehicle with top speed	MC	not mc	MC
MC volume	49	38	87
Total volume	2342	2437	4779
MC volume %	2,1	1,6	1,8

Table 6.8b Road 363 Umeå-Hissjö

Measurement date: 2001-06-21	North	South	N and S
Speed limit	90	90	90
Average MC speed	102	98	99
Below/above limit	12	8	9
Average traffic speed	92	95	93
Below/above average traffic speed	10	3	6
Vehicle with top speed	MC	MC	MC
MC volume	20	31	51
Total volume	2076	1749	3825
MC volume %	1,0	1,8	1,3

Table 6.8c Road 373-Piteå-Arvidsjaur

Measurement date: 2001-07-26	North	South	N and S
Speed limit	90	90	90
Average MC speed	91	84	87
Below/above limit	1	-6	-3
Average traffic speed	91	91	91
Below/above average traffic speed	0	-7	-4
Vehicle with top speed	not mc	not mc	not mc
MC volume	20	36	56
Total volume	1953	1762	3715
MC volume %	1,0	2,0	1,5

Table 6.8d E12 Umeå- Holmsund

Measurement date: 2003-06-26	North	South	N and S
Speed limit	90	90	90
Average MC speed	86	100	89
Below/above limit	-4	10	-1
Average traffic speed	86	89	87
Below/above average traffic speed	0	11	2
Vehicle with top speed	not mc	MC	MC
MC volume	37	10	47
Total volume	1382	915	2297
MC volume %	2,7	1,1	2,0

Table 6.8e E12 Umeå-Vännäsby

Measurement date: 2003-06-24	North	South	N and S
Speed limit	90	90	90
Average MC speed	92	102	96
Below/above limit	2	12	6
Average traffic speed	87	89	87
Below/above average traffic speed	5	13	9
Vehicle with top speed	MC	MC	MC
MC volume	10	8	18
Total volume	810	1248	2058
MC volume %	1,2	0,6	0,9

Similar to “110” roads without wire rope barriers, judging by the above mentioned examples, the speed determining factor cannot be found. The speeds vary from 12 km/h above the speed limit and 13 km/h above average to 6 km/h below the speed limit and 7km/h below the average traffic speed. When compared with “110” roads without wire rope barriers the data is more consistent in “90” roads but the top extreme values are similar. These roads cannot be compared with 2+1 roads with wire rope barriers because 2+1 “90” roads were not analysed in the “Before and after” method. Nonetheless, the extreme top values are larger on “90” roads without wire rope barriers. Motorcycle traffic volume ratio varies between 1 % and 2 %. The actual numbers are on the whole larger than on 2+1 roads with wire rope barriers.

Summary of results of motorcycle traffic flow and speed data analysis
According to the “Before and After” method results before wire rope barriers were installed motorcycle speeds were either substantially above the speed limit and average speeds or below. Whereas after the modification into 2+1 roads the speeds were generally above the average but below the speed limit (apart form the southbound stretch in measure point *24140236*). Traffic volume ratio in 'before' period was substantially lower than in “after” period.

The ”Comparison of Equivalent Roads” method results show that speeds on both “90” and “110” equivalent roads are more spread out than on 2+1 roads with wire rope barriers. The speed limit is more likely to be exceeded on the equivalent roads. Motorcycle traffic is slightly higher on “90” roads (without wire rope barriers) than on the wire rope barrier roads.

6.2.2 Results of the questionnaire

346 persons responded to the internet questionnaire. The results are first analysed generally, then within the following groups: age, gender, motorcycle type and the engine size. In order to see how representative the results were, the answers were related to the actual statistics in Sweden (apart from motorcycle type), as shown in section 2.1.3 [19], [2]. They are presented below in the following order: age (fig.6.12), gender (fig.6.13), motorcycle type (fig.6.14) and engine size of motorcycle (fig.6.15).

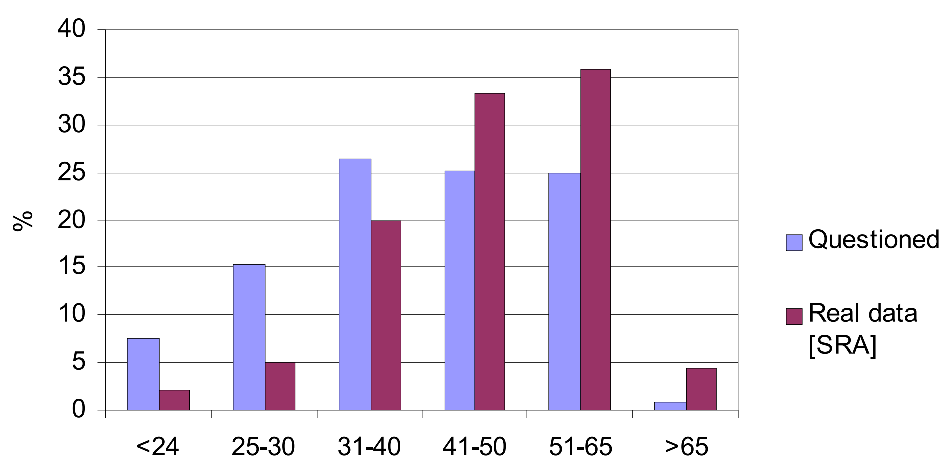


Fig.6.12 Age distribution.

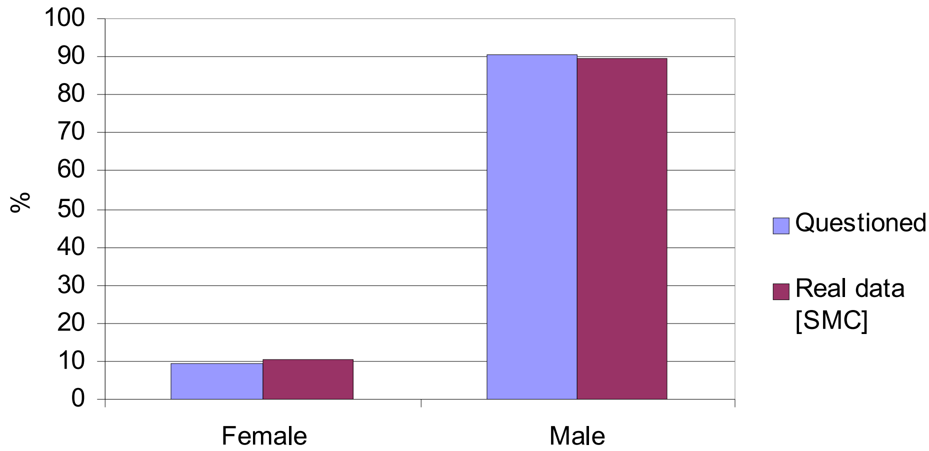


Fig.6.13 Gender distribution.

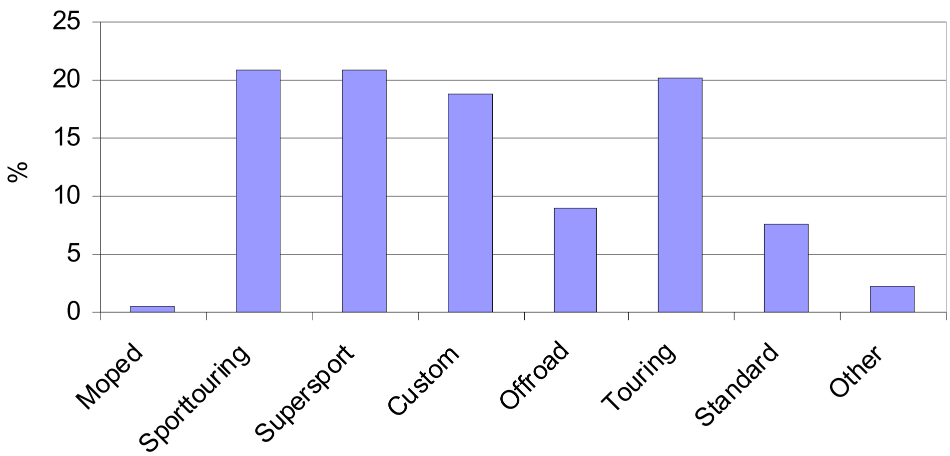


Fig.6.14 Motorcycle type distribution

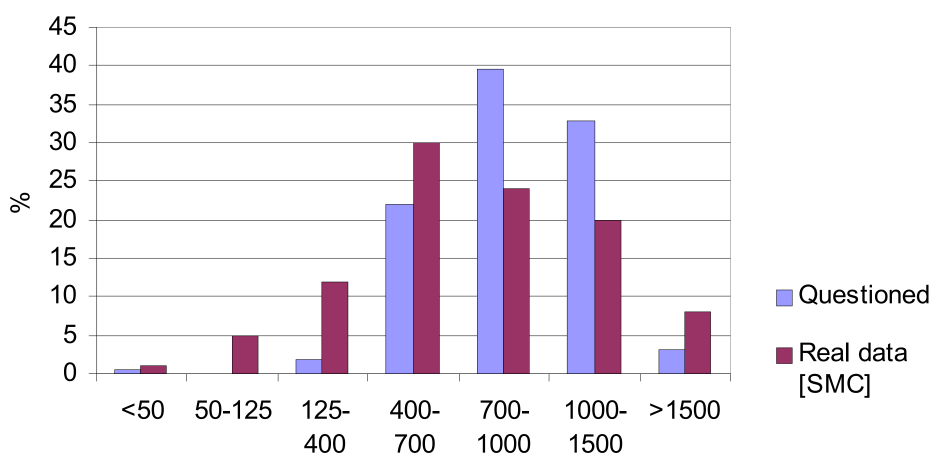


Fig.6.15 Motorcycle engine size distribution.

On the whole the questionnaire data is quite well distributed. The younger generation is quite overrepresented and the 40-65 age group is greatly under-represented. Gender is distributed very well with only a 1 % difference in favour of male riders. The custom motorcycle type is underestimated, as in reality it is the most popular motorcycle in Sweden [19]. The large engine sizes are overrepresented in the questionnaire by about 30 % in engine size range 700-1500.

General results

The answers are presented in the order consistent with the questionnaire (appendix E) on figures from 6.16a to 6.16f.

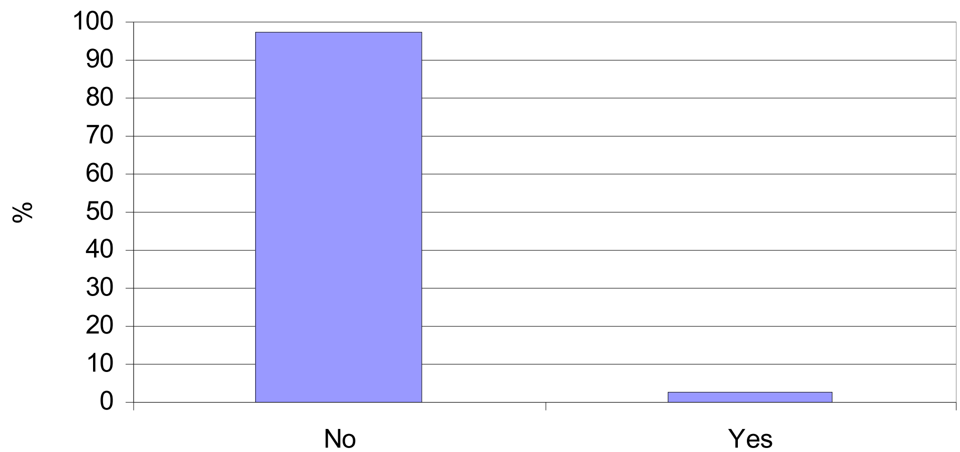


Fig.6.16a. Motorcyclists involved in incidents with wire rope barriers.

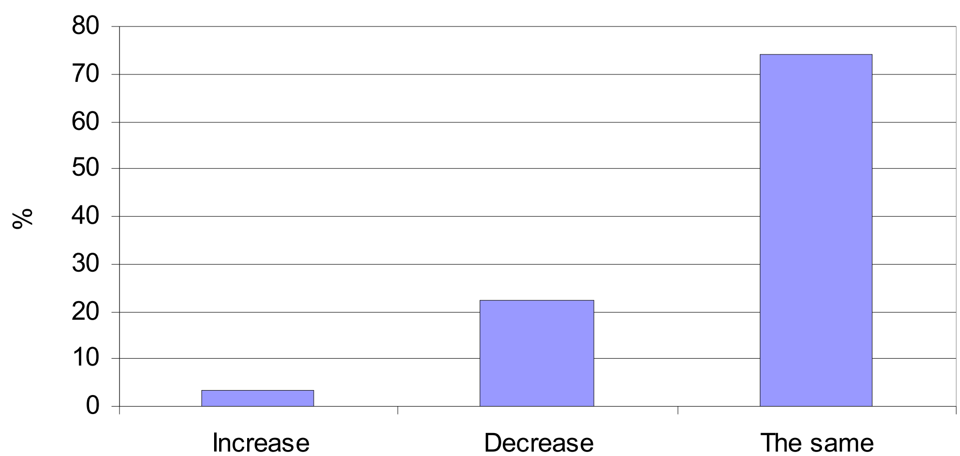


Fig.6.16b. Motorcyclists’ speed adjustment when noticing wire rope barriers.

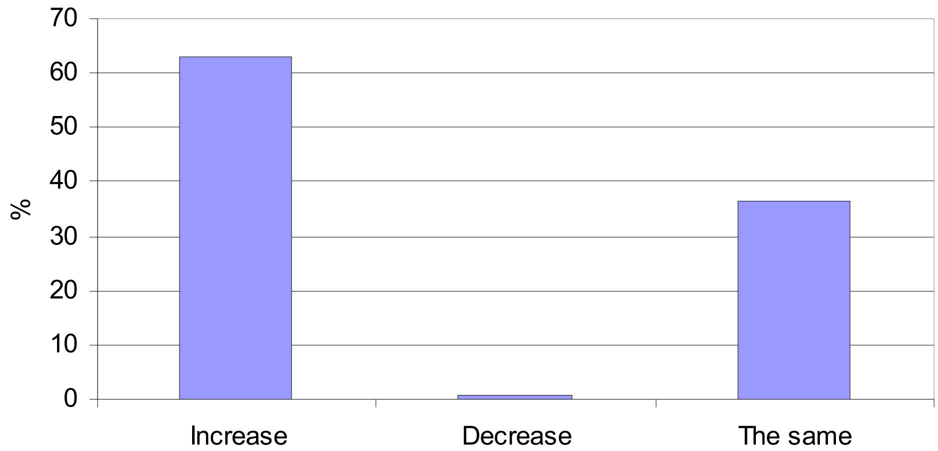


Fig.6.16c. Motorcyclists' distance adjustment when noticing wire rope barriers.

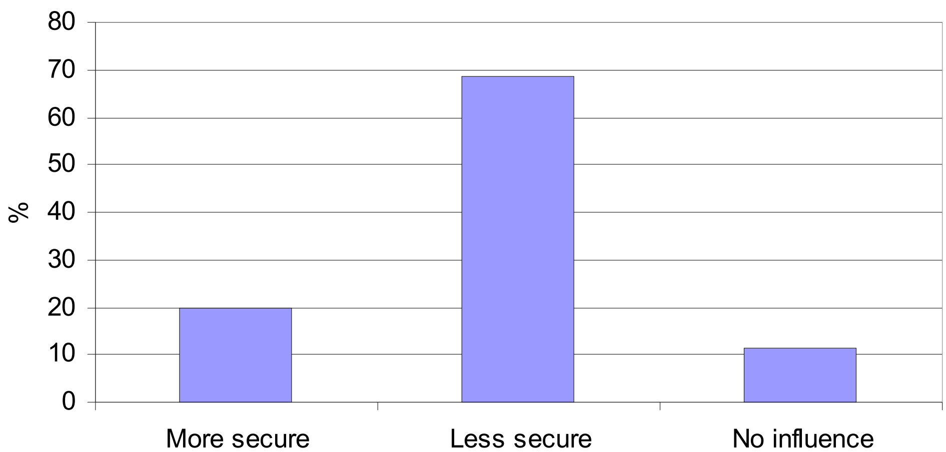


Fig.6.16d. Motorcyclists' feeling of security when riding along wire rope barriers.

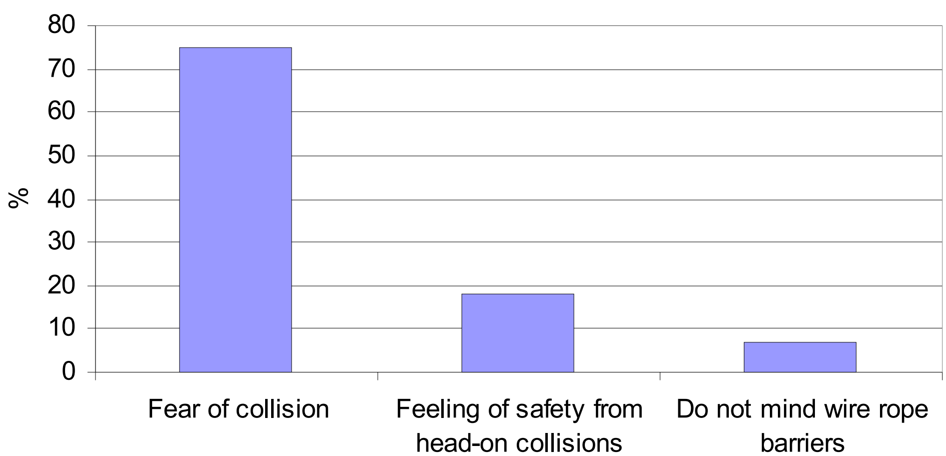


Fig.6.16e. Motorcyclists' thoughts on wire rope barriers when riding along them.

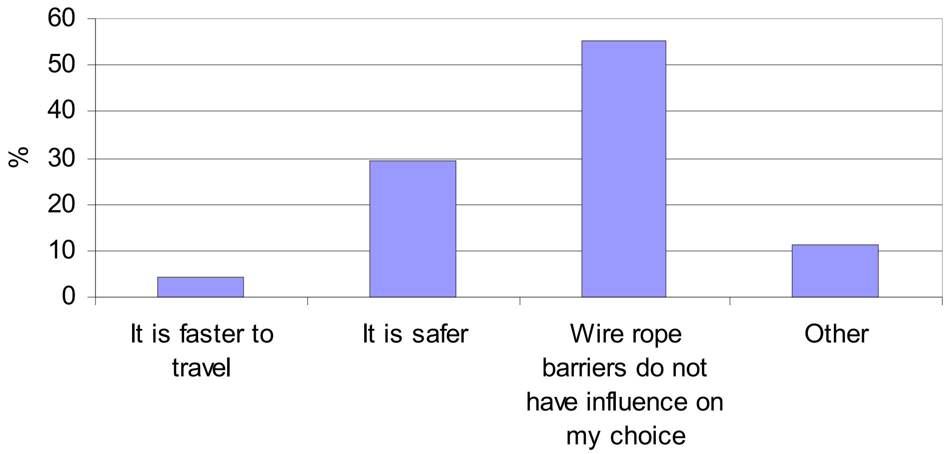


Fig.6.16f. Reason for choosing roads without wire rope barriers.

Most of the respondents had not been involved in incidents, out of those who were (10) only 2 described what had happened. One person fell off the motorcycle, slid across the road and found himself under the wire rope barrier, fortunately the accident ended in property damage only. The other person's motorcycle crashed into the barrier but he managed to stay on the carriageway on the side of the road. 74 % of respondents believe that their speed is not influenced by the barrier and keep the same speed before and after entering a stretch with wire rope barriers. However, 22 % answered that they decreased their speed. 63 % of the riders increase the distance from the barrier, 36 % keep the same distance and those 2 people who decrease their distance are believed to have chosen this option accidentally (considering that one person stated to be involved in an incident). 69 % felt less secure when riding along the barrier, 20 % felt more secure, and the remaining 11 % said the wire rope barrier had no influence on them in terms of security. 75 % were afraid of collision with the barrier but 18 % were convinced of the barrier protecting them from head-on collisions and the remaining 7 % did not mind the barrier. In 55 % cases the wire rope barriers did not influence the choice of travelling rout, 29 % though that roads without wire rope barriers were safer and only 4 % that they were faster.

Results according to age

Within the female group most of the respondents were 31-40 years old. In the male group the interval age of 31-65 dominated accounting for 80 % of all male respondents. "Supersport" motorcycle type dominated in the age group 31-40 and 25-30. "Sporttouring" dominated also in the 31-40 age group. "Custom" and "touring" dominated in the 41-65 age interval. The engine sizes between 700-1000 cc were mainly owned by 31-40 year olds, above 1000 cc mainly belonged to riders aged between 51-65. The answers to the questionnaire were as follows (fig.6.17a-f):

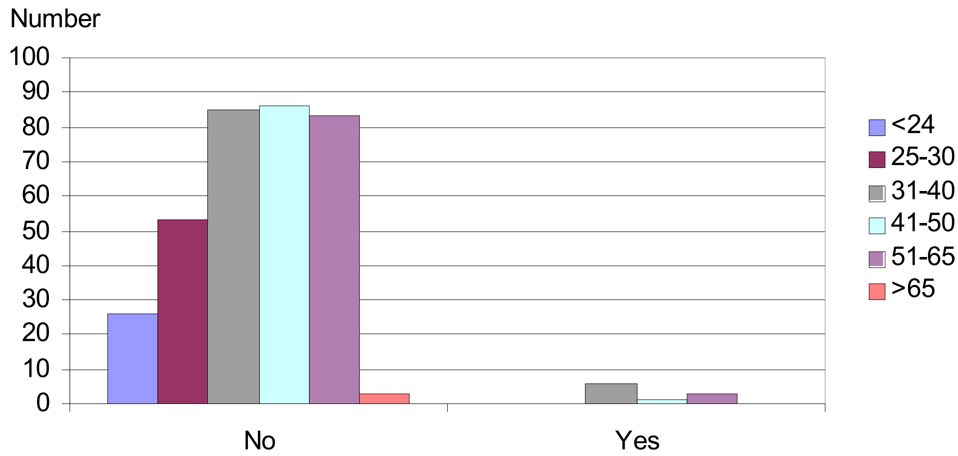


Fig.6.17a. Motorcyclists involved in incidents with wire rope barriers. According to age.

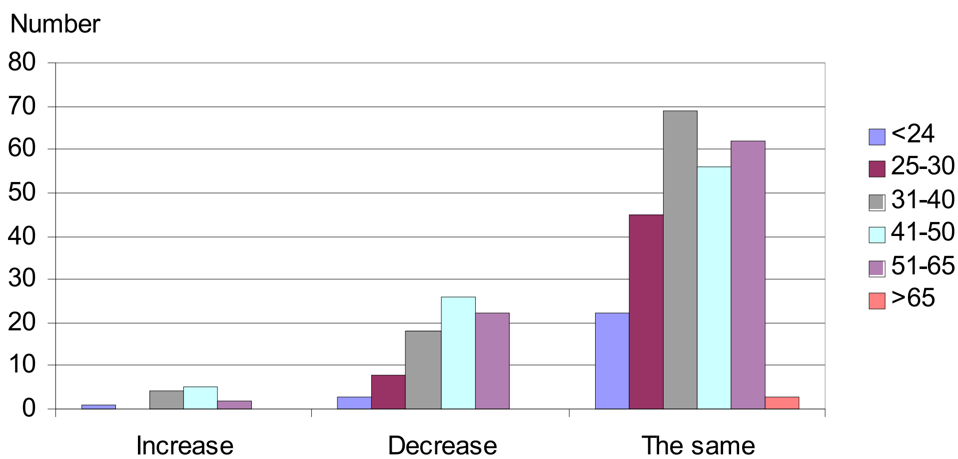


Fig.6.17b. Motorcyclists' speed adjustment when noticing wire rope barriers. According to age.

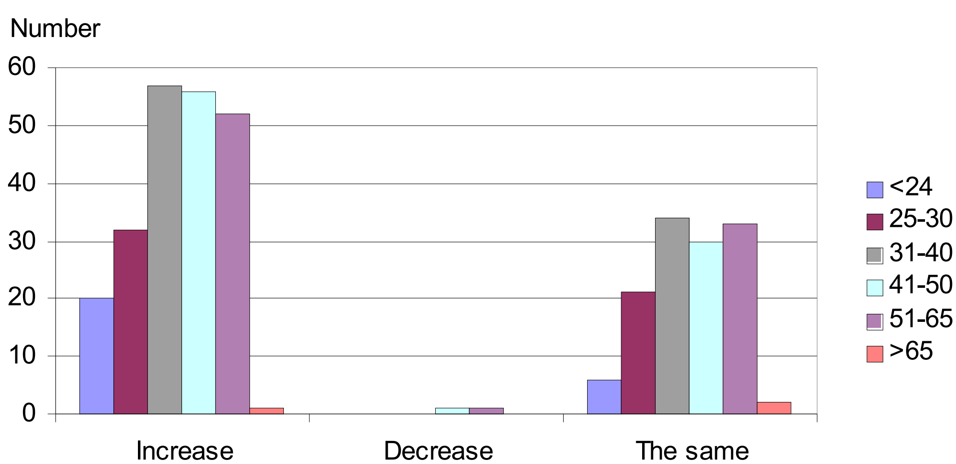


Fig.6.17c. Motorcyclists' distance adjustment when noticing wire rope barriers. According to age.

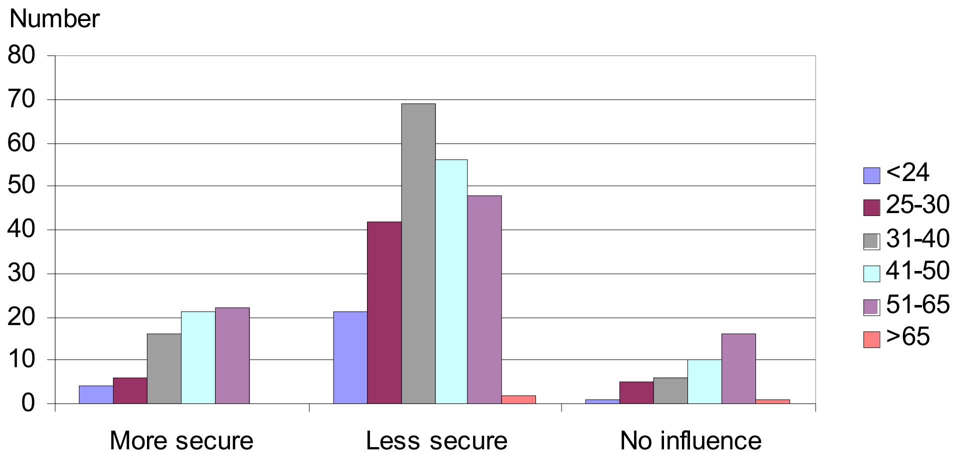


Fig.6.17d. Motorcyclists' feeling of security when riding along wire rope barriers. According to age.

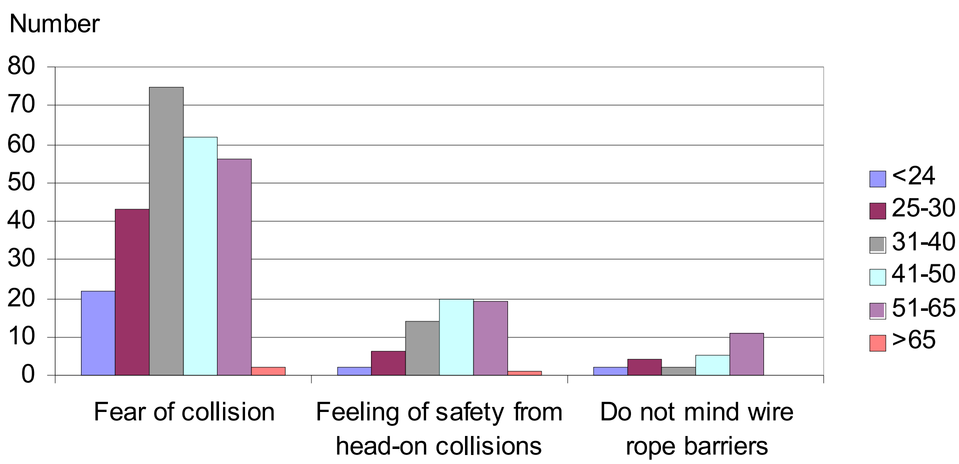


Fig.6.17e. Motorcyclists' thoughts on wire rope barriers when riding along them. According to age.

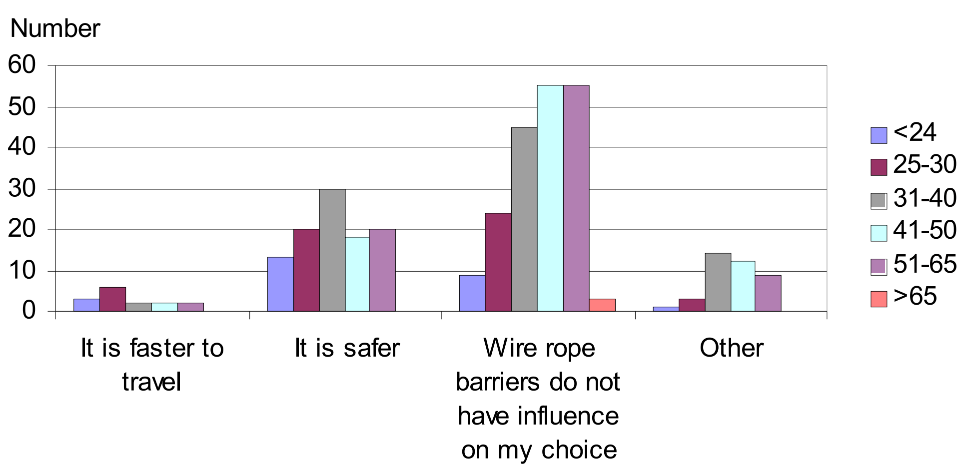


Fig.6.17f. Reason for choosing roads without wire rope barriers. According to age.

All of those who believed to have an incident were aged above 31 and 60 % of them were aged between 31-40. Most of those who kept the same speed regardless of the presence of wire rope barriers were riders aged between 31-40 and those who slowed down on seeing the barrier were mainly aged between 41-50. The proportion of increasing the distance or keeping the same distance from the barrier was the same for all age groups. The dominant age group that felt the least secure was between 31-40 and those who felt more secure was 41-50. However, the ratio of those who felt more and less secure is the largest in the 25-30 group where 7 times more people responded that they were less secure. Similar relation can be observed for motives of fear or feeling of safety. The dominant age group that answered that it was faster to travel by alternative routes was 25-30. The most positive comments on wire rope barriers were from riders aged 41-65 and most negative among younger riders.

Results according to gender

32 women and 314 men responded to the questionnaire. Among women “custom”, “supersport” and “sporttouring” types of motorcycle were the most common. For men, apart form the same ones as mentioned for women, “touring” was also popular. As well as for men as for women the engine size 700-1000 was the most common. The rest of results are presented below (fig.6.18a-f)

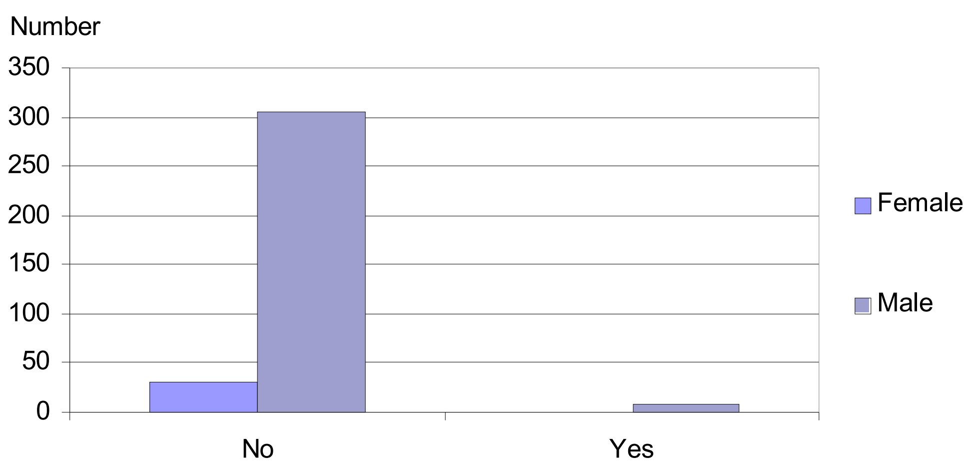


Fig.6.18a. Motorcyclists involved in incidents with wire rope barriers. According to gender.

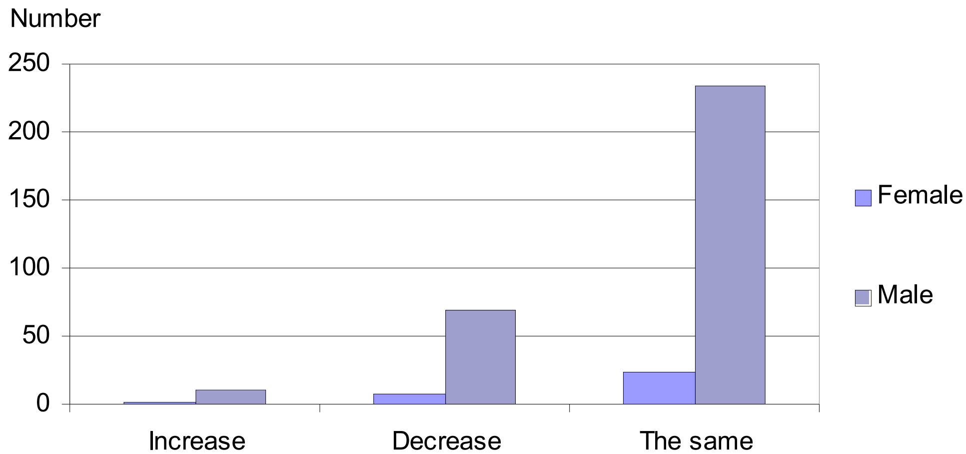


Fig.6.18b. Motorcyclists' speed adjustment when noticing wire rope barriers. According to gender.

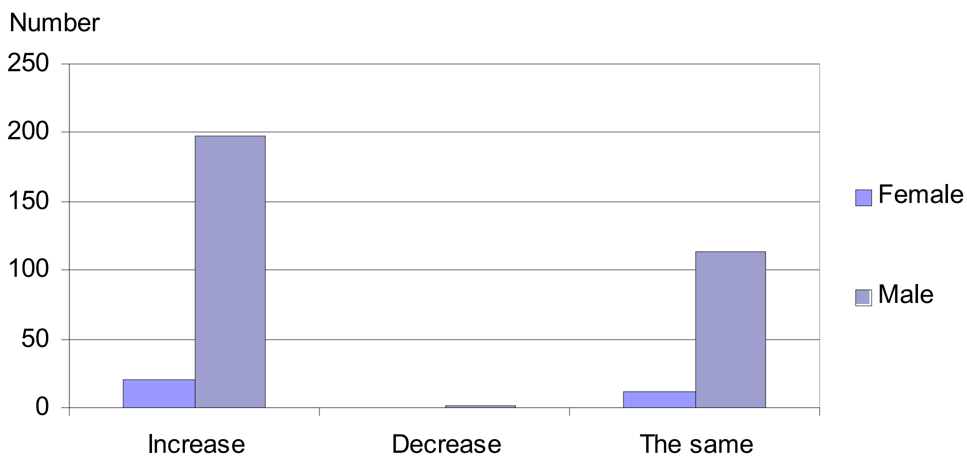


Fig.6.18c. Motorcyclists' distance adjustment when noticing wire rope barriers. According to gender.

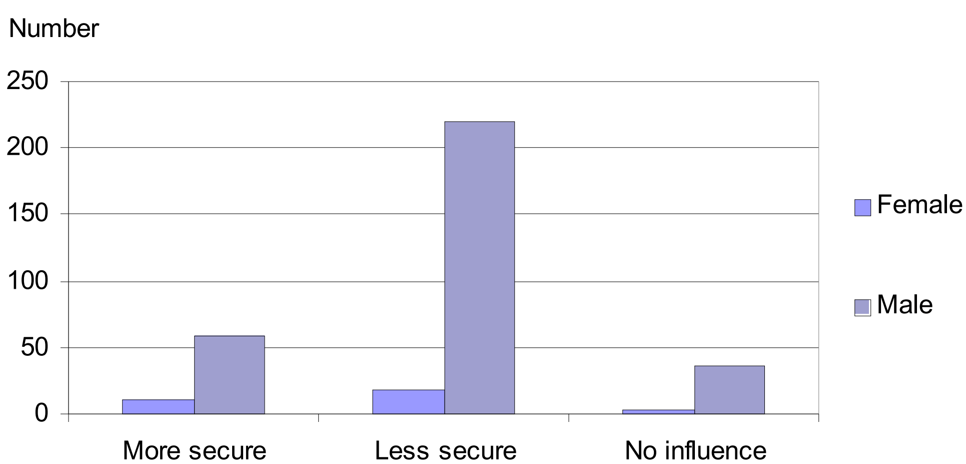


Fig.6.18d. Motorcyclists' feeling of security when riding along wire rope barriers. According to gender.

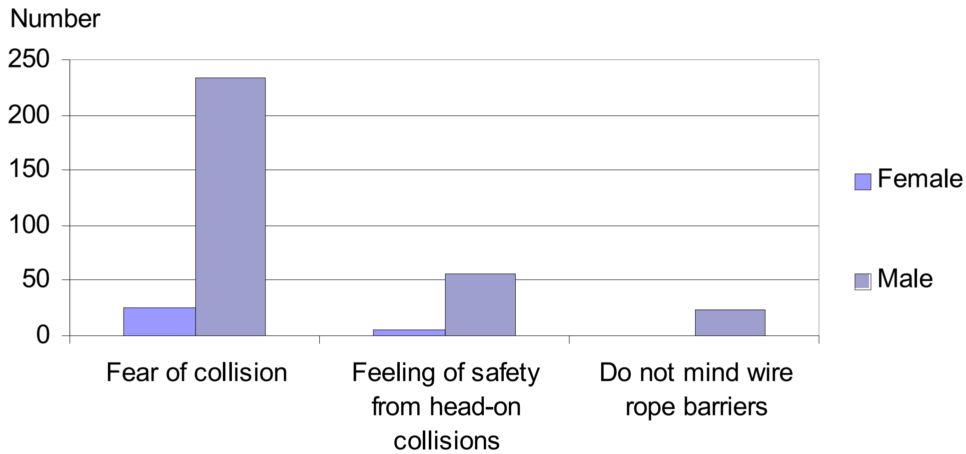


Fig.6.18e. Motorcyclists' thoughts on wire rope barriers when riding along them. According to gender.

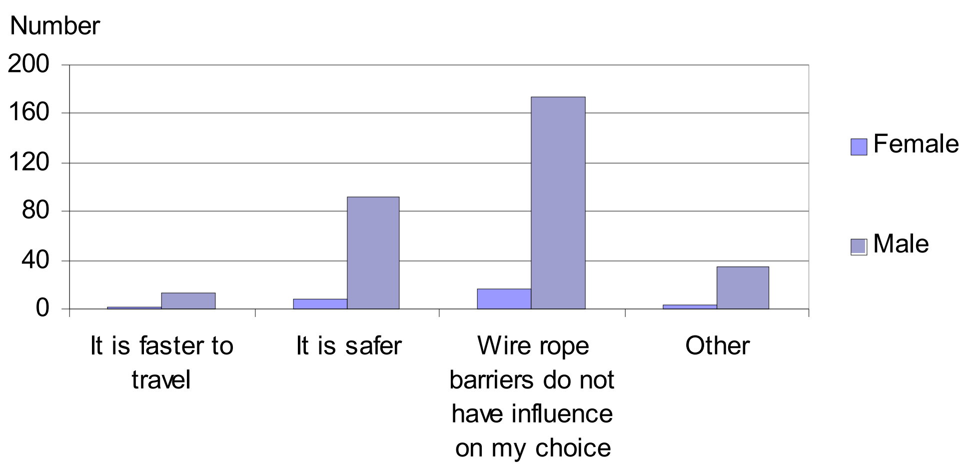


Fig.6.18f. Reason for choosing roads without wire rope barriers. According to gender.

90 % of those who believed to have an incident with wire rope barriers were men. The same ratio of answers was given to the question on speed and distance performance. Almost every third woman answered that she felt more secure when riding along wire rope barriers compared to every 6th man. However, the vast majority of men and women were afraid of colliding with the barrier. The distribution of answers to the question about alternative roads was quite similar for male and female riders. Men were more critical of the barriers.

Results according to motorcycle type

Most of those who answered owned not only either "sporttouring" or "supersoport" motorcycles but also touring and custom (fig.6.14). The largest engine sizes had respectively "touring" and "custom" motorcycles of over 1000 cc. "Supersport" and respectively "sporttouring" dominated in the 700-1000 cc interval. Here are the results according to the motorcycle type (fig.6.19a-f):

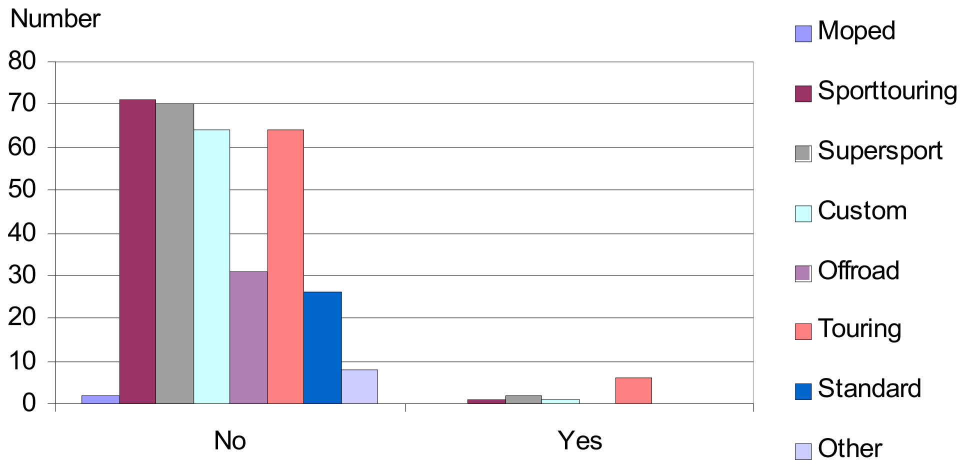


Fig.6.19a. Motorcyclists involved in incidents with wire rope barriers. According to motorcycle type.

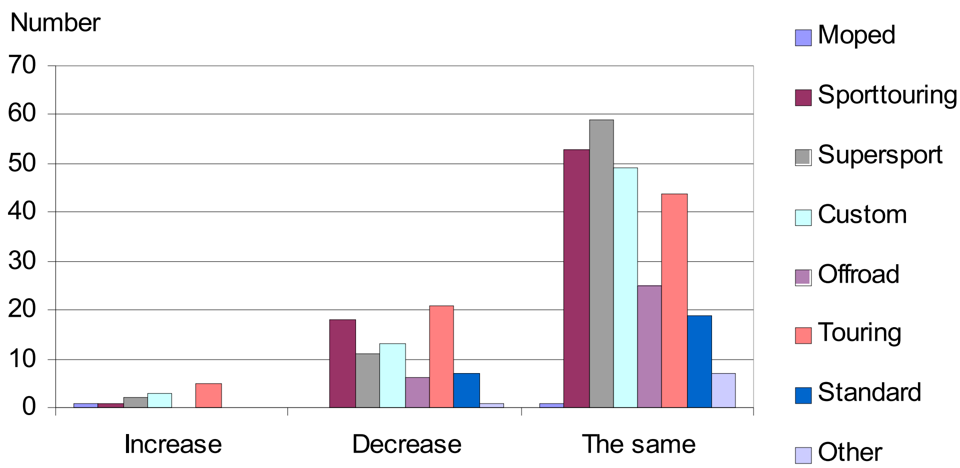


Fig.6.19b. Motorcyclists' speed adjustment when noticing wire rope barriers. According to motorcycle type.

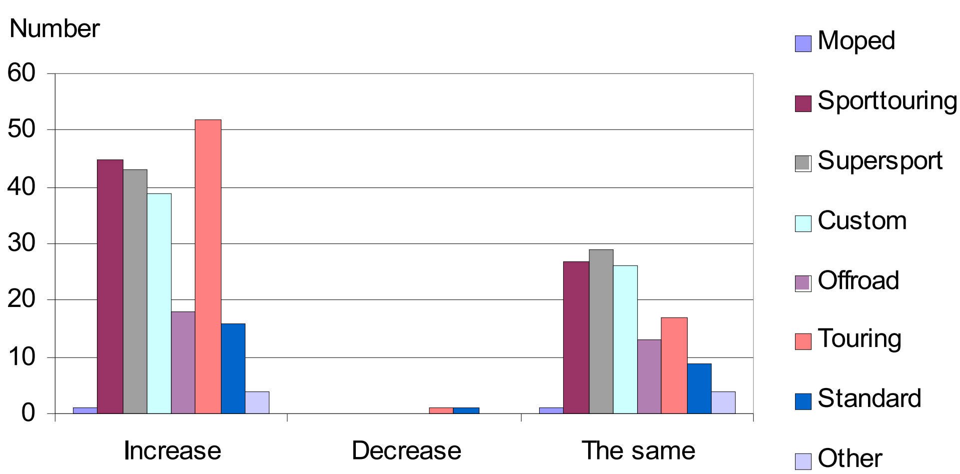


Fig.6.19c. Motorcyclists' distance adjustment when noticing wire rope barriers. According to motorcycle type.

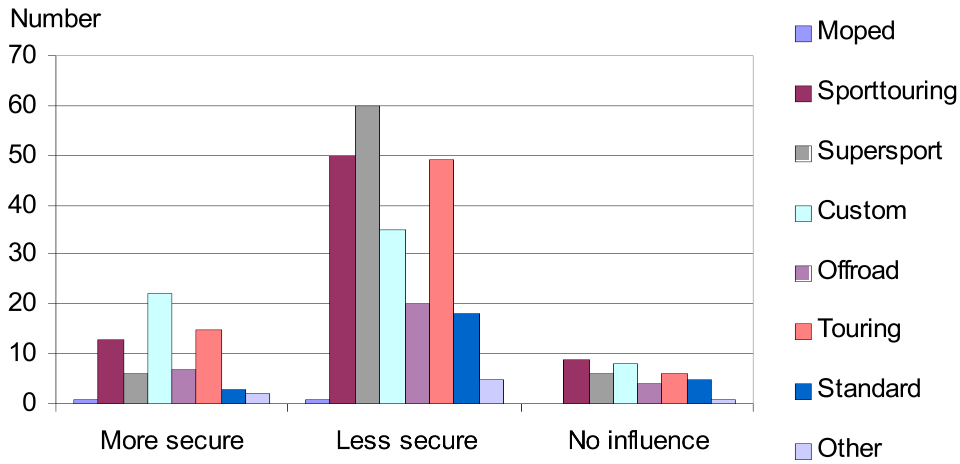


Fig.6.19d. Motorcyclists' feeling of security when riding along wire rope barriers. According to motorcycle type.

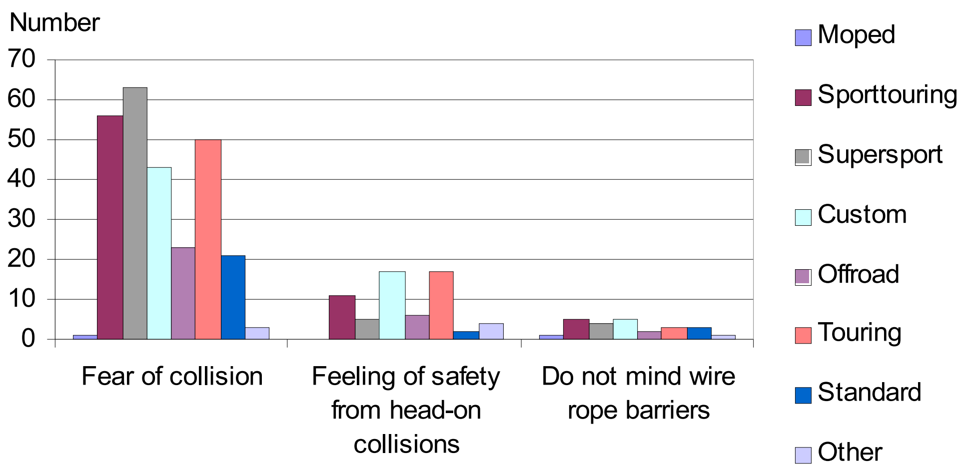


Fig.6.19e. Motorcyclists' thoughts on wire rope barriers when riding along them. According to motorcycle type.

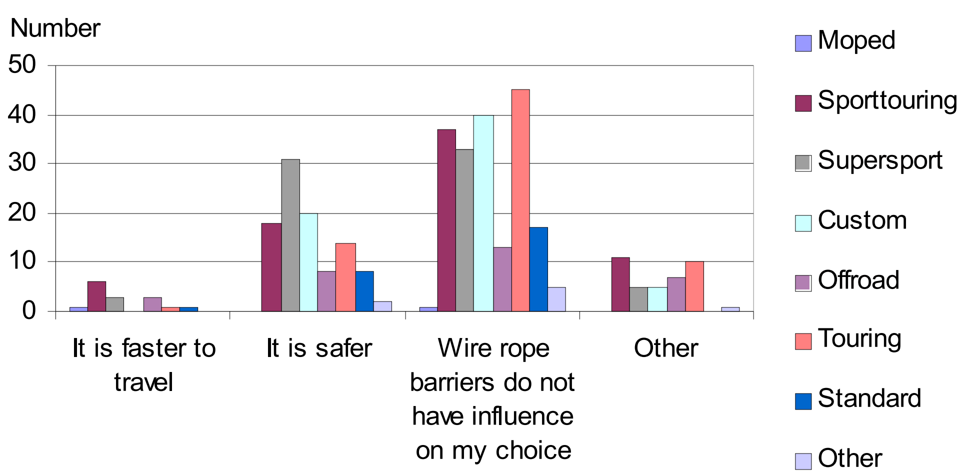


Fig.6.19f. Reason for choosing roads without wire rope barriers. According to motorcycle type.

60 % of those riders who believed to be involved in an incident were "touring" motorcycle owners. Those two riders who mentioned their incident owned "touring" and "sporttouring" motorcycles. Almost 30 % of "touring" motorcycle owners declared that they reduced the speed on noticing wire rope barriers. 6 out of 7 "supersport" motorcyclists kept the same speed. Most of those who increased the distance from the barrier were "touring" motorcycles. The majority of those who felt less secure and feared colliding with the barrier owned a "supersport" motorcycle. "Sporttouring" owners dominated at stating that alternative roads were faster. "Supersport", "sporttouring" and "touring" owners were most critical of the barriers.

Results according to the motorcycle engine size

Most of the engine sizes were in the interval of 700-1000 cc and more than 1000 cc. There were no answers from motorcycle owners with engine size between 50-125 cc (fig.6.15). The results to answers within this group were as follows (fig.6.20a-f):

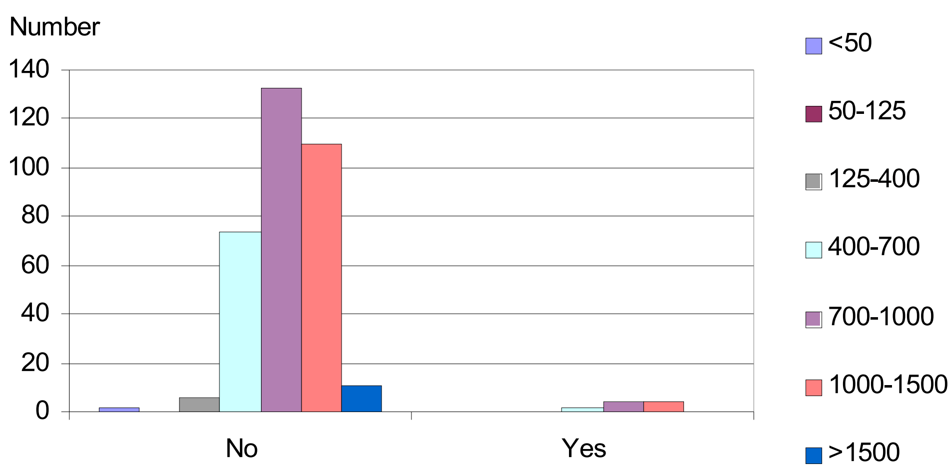


Fig.6.20a. Motorcyclists involved in incidents with wire rope barriers. According to engine sizes.

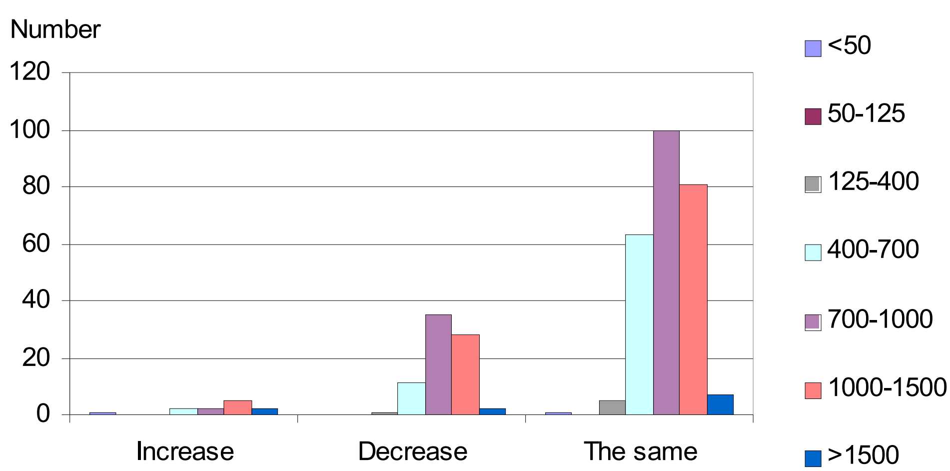


Fig.6.20b. Motorcyclists' speed adjustment when noticing wire rope barriers. According to engine sizes.

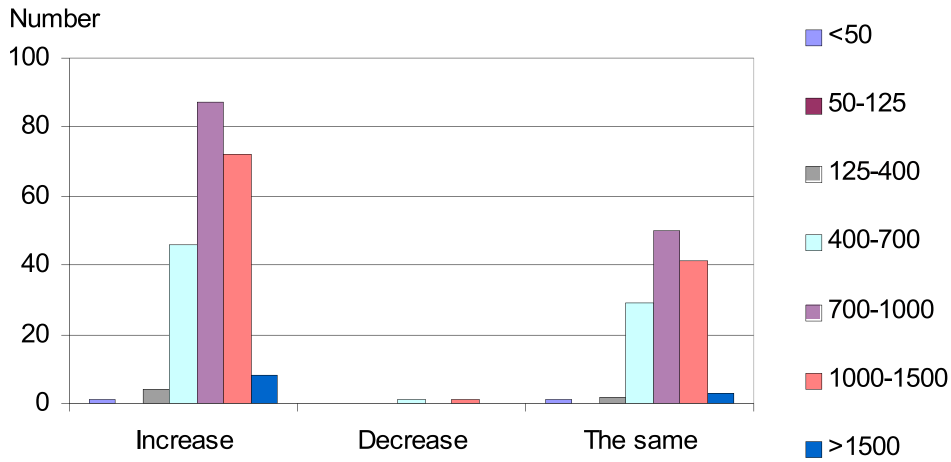


Fig.6.20c. Motorcyclists' distance adjustment when noticing wire rope barriers. According to engine sizes.

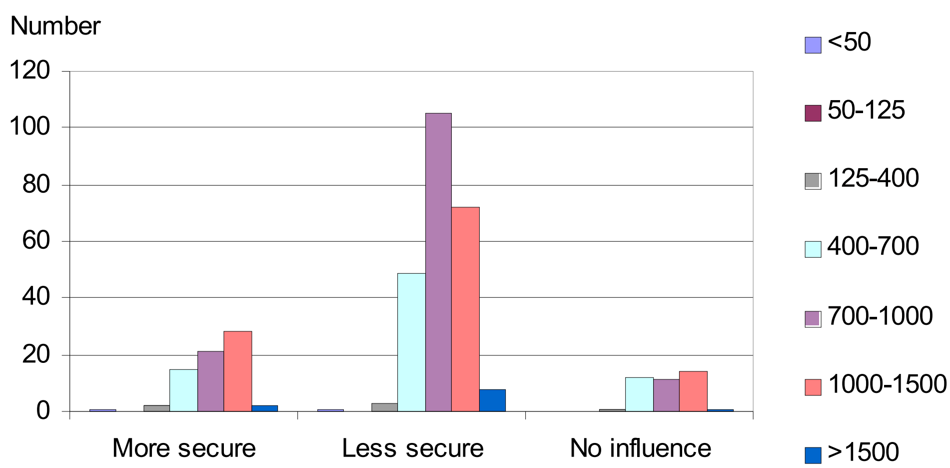


Fig.6.20d. Motorcyclists' feeling of security when riding along wire rope barriers. According to engine sizes.

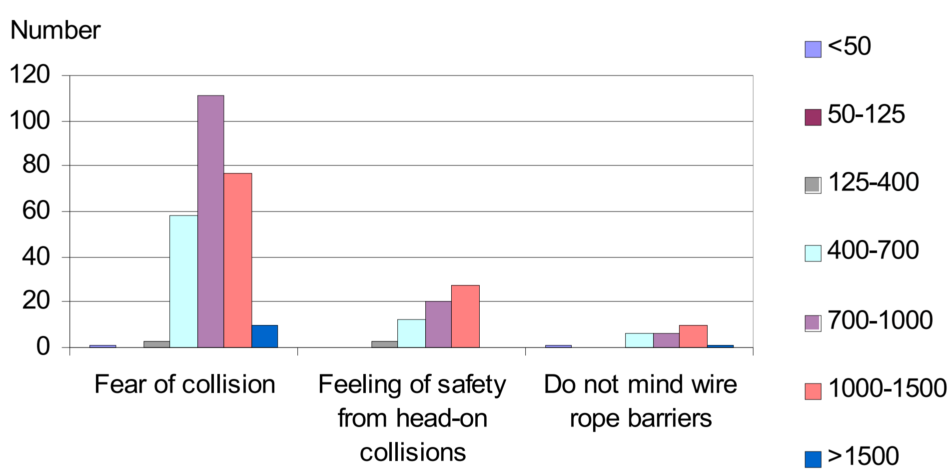


Fig.6.20e. Motorcyclists' thoughts on wire rope barriers when riding along them. According to engine sizes.

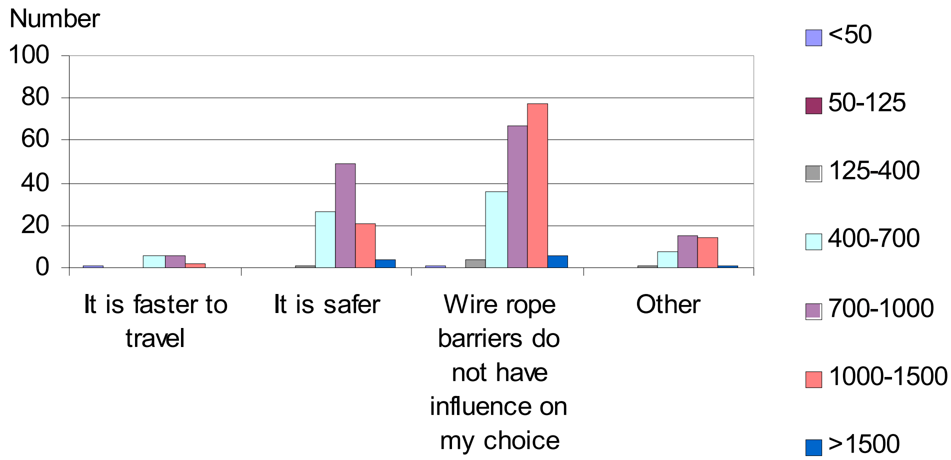


Fig.6.20f. Reason for choosing roads without wire rope barriers. According to engine sizes.

80 % of those who stated that they were involved in an incident, owned motorcycles with engine sizes between 700-1500 cc. The largest disproportion in terms of the speed adjustment was among motorcycles with engine sizes between 400-700 cc, where every seventh rider declared to decrease the speed. The distance adjustment was proportional for each group. 700-1000 cc motorcycle owners were the majority to state that they felt less secure when riding along the barriers and feared of colliding with the barriers. Those who felt more secure owned motorcycles with engine sizes 1000-1500 cc. Substantial majority of those who thought that alternative roads were safer were 700-1000 cc motorcycle owners. They also were the most critical about wire rope barriers.

Summary of results of the internet questionnaire

The results of the questionnaire show that more than 97 % of respondents were not involved in an incident with wire rope barriers. Those who were involved in incidents were male owners of “touring” motorcycles with engine sizes between 1000-1500 cc. More than 74 % declared to keep the same speed regardless of the existence of wire rope barriers in the road environment. The largest disproportion between to keeping the same speed and decreasing was among riders aged below 24, owning a “supersport” motorcycle with an engine size of 400-700 cc. 63 % of riders stated that they increased their distance from the barrier upon noticing it. About 69 % felt less secure when riding along wire rope barriers but the majority were among men aged 25-30 owning a “supersport” motorcycle with an engine size of 700-1000 cc. However, 30 % of women declared to feel more secure. More than 75 % feared colliding with the barrier in contrast to 18 % of those who felt protected from head-on collisions. Those who feared colliding the most were male riders aged between 31-40, owning a “supersport” motorcycle with an engine size of 700-1000 cc. Those who felt that wire rope barriers protected them from head-on collisions than pose danger of collision were mainly riders aged between 41-65, owning a custom or touring motorcycle with an engine size of 1000-1500 cc. More than 55 % of answers indicated that wire rope barriers had no influence on their choice of travel routes. The minority stated that it was faster to travel using the alternative roads. Those who chose that option were mainly “spotrttouring” motorcycle owners aged between 25-30. Those who stated that roads without wire rope barriers were safer were mainly “supersport” motorcycle owners aged between 31-40. Those who were most critical about wire rope barriers were male “supersport” motorcycle owners aged under 40. The criticisms mainly concerned the narrow 1-lane sections of the roads limited by wire rope barriers from both sides. The riders did not like to ride during times with high levels of traffic volumes especially with heavy vehicles that generally have a longer braking distance. Moreover, the exposure to collision with wire rope barrier independent from human factors was mentioned, for example: strong wind, slippery surface.

6.2.3 Interview results

The interviewed motorcyclist was a “supersport” motorcycle owner with an engine size of 999 cc. The motorcyclist was a 50 year old man.

He said that he did not like the barriers on 2+1 roads as they limited the possibilities of overtaking slow moving vehicles especially during heavy traffic. He did not mind the type of barrier, he said that any kind of barrier is an obstacle in that case. The presence of barriers did not determine his way of travelling, namely he did not seek alternative roads. The safest and best solution according to him was the motorway. The big disadvantage of the barrier was that they were inconspicuous during night time and bad weather conditions. Moreover, roads with wire rope barriers on both sides of the lanes (central and side) do not give enough space for safe riding since a motorcycle is considerably lighter than a passenger vehicle, it is more exposed to barrier crashes due to strong winds.

6.2.4 Results of the speed and distance measurements on site

The results for “Speed measuring” and “Distance measuring” methods are presented together in tables and are followed by a commentary. The same principle applies to the analysis of results obtained from “Speed difference” method.

Notations

Few notations have been used to make the results more legible:

Type of road:
2+1* - means that the outer lane is a turn-off lane

The direction of travel referred to as “manoeuvre”:
TF – the motorcycle was turning off the 2+1 road.
TN - the motorcycle was turning onto the 2+1 road.
S - the motorcycle was travelling straight.

Distance from the barrier referred as to “position”:
L - closer to the left side of the lane.
M - in the middle of the lane.
R – closer to the right side of the lane.

NFV – NOT FREE VEHICLE, motorcycle that had to accustom its speed to the vehicle in front.

~60 – visually assessed motorcycle speeds. NOTE: not included in speed analysis.
128 – speeds exceeding the limit are marked in bold.
Range – is the distance for which a certain speed was measured.

"Speed measuring" and "Distance measuring" method results

The results are presented according to the time when they were conducted at. When the measurements were taken the motorcycles were always on the main lane (this also applies to those who were either turning off or onto the 2+1 road). The results for this method are presented in tables 6.9 – 6.13.

Table 6.9 Speed and distance performance on a road with wire rope barriers.

Location of measure point:				speed limit:	weather conditions:		
Luleå, Intersection: E4 - 97				**110**	no wind, dry, about 10 C, sunny		
date:		time range:	road no.:	road type:	wire rope barriers:		
30-04-2005		11.50-13.00	E4	2+1*	central		
SOUTH		To:	Piteå				
#	time	speed km/h	range m	manoeuvre TF, TN, S	position L, M, R	MC-type	passenger 1-no 2-yes
1	12.02	82	317,4	S	R	TOURING	2
2	12.36	66	76,2	TN	R	TOURING	1
3	12.45	78	302,9	S	M	CUSTOM	1
	average:	75					

Note: No motorcycle traffic on northbound.

Table 6.10 Speed and distance performance on a road with wire rope barriers.

Location of measure point:				speed limit:	weather conditions:		
Luleå, Intersection: E4 - 968				**110**	no wind, dry, about 10 C, sunny		
date:		time range:	road no.:	road type:	wire rope barriers:		
30-04-2005		13.20-14.30	E4	2+2*	central		
SOUTH		To:	Piteå				
#	time	speed km/h	range m	manoeuvre TF, TN, S	position L, M, R	MC-type	passenger 1-no 2-yes
1	**13.25**	**118**	**267,7**	**S**	**M**	**SUPERSPORT**	**1**
	average:	118					
NORTH		To:	Kalix				
2	13.31	62	240,2	S	M	CUSTOM	1
3	13.55	75	27,7	TF	R	SUPERSPORT	2
4	13.58	79	375,5	TN	R	TOURING	1
5	14.03	64	32,2	TF	R	CUSTOM	1
6	14.10	77	202,2	S	R	SCOOTER	1
7	14.10	NFV		S	R	TOURING	1
8	**14.16**	**114**	**316,4**	**S**	**R**	**CUSTOM**	**1**
9	*14.18*	*~60*	*S A*	*TF*	*R*	*TOURING*	*1*
10	*14.20*	*~60*	*S A*	*TF*	*R*	*CUSTOM*	*1*
	average:	79	NOTE: speed assumptions are not considered				

Table 6.11 Speed and distance performance on a road with wire rope barriers.

Location of measure point:				speed limit:	weather conditions:		
Persön, Intersection: E4 - 596				**110**	mild wind, dry, about 10 C, sunny		
date:		time range:	road no.:	road type:	wire rope barriers:		
1-05-2005		9.30-10.00	E4	1+1	central and side		
		12.15-13.20					
SOUTH		To:	Piteå				
#	time	speed km/h	range m	manoeuvre TF, TN, S	position L, M, R	MC-type	passenger 1-no 2-yes
1	9.41	68	121,2	S	M	STANDARD	2
2	12.56	91	110,9	S	L	TOURING	1
3	13.20	80	131	S	M	CUSTOM	1
	average:	80					

Note: No motorcycle traffic on northbound.

Table 6.12 Speed and distance performance on a road without wire rope barriers.

Location of measure point:				speed limit:	weather conditions:		
Jämtön, Intersection: E4 - 691				**110**	no wind, dry, about 10 C, sunny		
date:		time range:	road no.:	road type:	wire rope barriers:		
1-05-2005		14.00-14.50	E4	13 m ordinary	lack		
SOUTH		To:	Piteå				
#	time	speed km/h	range m	manoeuvre TF, TN, S	position L, M, R	MC-type	passenger 1-no 2-yes
1	14.18	95	132,9	S	L	CUSTOM	2
4	**14.29**	**113**	**553,6**	**S**	**L**	**STANDARD**	**1**
	average:	104					
NORTH		To:	Kalix				
2	**14.22**	**119**	**437,8**	**S**	**L**	**CUSTOM**	**1**
3	14.22	NFV		S	L	CUSTOM	1
5	14.43	91	153,9	S	M	TOURING	1
6	14.42	NFV		S	M	TOURING	1
	average:	105					

Table 6.13 Speed and distance performance on a road without wire rope barriers.

Location of measure point:				speed limit:	weather conditions:		
Luleå, along the stretch between 591 and E4				**70**	no wind, dry, about 10 C, sunny		
date:		time range:	road no.:	road type:	wire rope barriers:		
30-04-2005		14.50-15.50	968	ordinary	lack		
NORTH		To:	N. Gäddvik				
#	time	speed km/h	range m	manoeuvre TF, TN, S	position L, M, R	MC-type	passenger 1-no 2-yes
1	14.51	52	56,2	S	M	MOPED	1
2	14.56	41	64,1	S	M	MOPED	1
3	15.03	63	59,7	S	M	CUSTOM	1
4	15.03	NFV		S	M	CUSTOM	1
5	*15.05*	*~60*	*S A*	*S*	*M*	*CUSTOM*	*1*
6	**15.13**	**72**	**72,2**	**S**	**M**	**SCOOTER**	**1**
7	15.13	NFV		S	M	SCOOTER	1
8	15.16	61	79	S	M	TOURING	1
9	15.34	62	63,2	S	M	TOURING	2
10	*15.35*	*~60*	*S A*	*S*	*M*	*TOURING*	*1*
11	*15.50*	*~55*	*S A*	*S*	*M*	*SCOOTER*	*1*
	Average:	59	NOTE: speed assumptions are not considered				

Note: No motorcycle traffic on southbound.

The speeds on roads with wire rope barriers, on average, were considerably lower than the speed limit. This is mainly due to the fact that measurements were taken on junctions and many motorcyclists were slowing down before turning off. However, among those who continued to go along the 2+1 roads were 2 riders who exceeded the speed limit by 4 km/h and 8 km/h. On the 13 m road with wide lanes 3 out of 6 measured motorcycles exceeded the speed limit, 1 by 3 km/h and other 2 by 9 km/h (assuming that the motorcycle going behind “NOT FREE VEHICLE” was travelling at the same speed as the one in front). On the ordinary “70” road the average speed was 59 km/h and only 2 out of those measured exceeded the speed limit by 2 km/h. The distance from the barrier was as anticipated. Where there was only central wire rope barrier, motorcyclists were riding closer to the edge of the line, when the wire rope barriers were on both sides, 2 out of 3 analysed motorcyclists were riding in the middle. On the roads without wire rope barriers it differed according to the type. 4 out of 6 motorcyclists travelling on the 13 m road with wide lanes rode closer to the middle of the road (to the left of the line). The observations from the ordinary “70” road show that all motorcyclists were riding in the middle of the lane. What is worth noticing is that motorcycle traffic volumes on the “70” road were higher than on 2+1 roads. However, this road is part of the local network and cannot be considered as an alternative road to the 2+1 roads.

"Speed and Distance change" method results

The results for this method are revised in table 6.14. Few new notations have been introduced. They are explained after the table.

Table 6.14 Speed and distance performance in transition from stretch with and without wire rope barriers.

Location of measure point:							weather conditions:		speed limit:	
Persön, along the stretch E4, the transition between with and without WRB							mild wind, dry, about 10 C, sunny		**110**	
date:		time range:	road no.:	road type:	wire rope barriers:					
1-05-2005		10.15-11.00	E4	2+1	central					
SOUTH (to Luleå)		transition from:	with Wire Rope Barriers (WRB) to without					no. of lanes:		2
#	time	1st speed km/h	range m	2nd speed km/h	range m	position L, M, R	comment	MC-type	P	Lane
1	10.17	80	182,2	N/D	N/D	R/M		S	1	1
3	10.28	105	134,5	N/D	N/D	R/M		C	2	1
4	10.28	NFV		N/D	N/D	R/M		C	2	1
5	10.32	102	107,5	N/D	N/D	R/M		T	1	1
6	10.38			N/D	N/D	R/M		S	1	1
8	**10.42**	**120**	**70,5**	**N/D**	**N/D**	**R/M**		**S**	**1**	**1**
9	10.47	100	132,9	107	802,6	R/M	7	S	1	1
10	10.49	99	246,6	N/D	N/D	R/M		C	1	1
11	10.49	NFV		N/D	N/D	R/M		C	2	1
12	10.52	95	128,5	N/D	N/D	R/M		C	1	1
13	10.52	NFV		N/D	N/D	R/M		C	2	1
14	10.53	100	135,1	99	592,2	R/M	-1	C	2	1
15	10.53	NFV		N/D	N/D	R/M		C	1	1
16	10.53	NFV		N/D	N/D	R/M		C	2	1
17	10.57	85	303,3	N/D	N/D	R/M		S	1	1
	average:	98		103						
NORTH (to Kalix)				transition from:		without WRB to with			1 lane	
2	10.25	N/D	N/D	100	121,2	R/R	NL	S	1	-
7	10.40	N/D	N/D	104	142,3	R/R	NL	S	1	-
	average:			102						

Additional notations used:

P – passenger,
1 - no,
2 - yes

Comment:
NL – no light, no brake light observed
N/D – no data

Motorcycle type:
C – custom
S – standard
T – touring

Only 2 out of 17 measurements fulfilled the objective of the method. That is, to observe how motorcyclists react in terms of speed when noticing the barrier or its disappearance. Those two cases concerned motorcyclists leaving the stretch of 2+1 road with wire rope barriers.

One of them increased the speed by 7 km/h once being on the stretch without wire rope barriers and the other one decreased the speed by 1 km/h. No conclusions can be drawn from this scarce data. Two motorcycles were travelling on the northbound lane, where there is a transition from no wire rope barriers to them suddenly appearing. Their speeds before entering the transition were not measured. However, no braking lights were observed indicating that the riders did not decrease their speed. Only one motorcyclist out of those 17 exceeded the speed limit by 10 km/h. It was measured on the stretch with wire rope barriers. The average motorcycle speeds on the southbound lane ranged between 98 km/h on the stretch with wire rope barriers and 103 km/h without. However, the scope of data for the latter concerns only 2 motorcyclists. As for the distance performance the results indicate significant correlation between the barrier and the distance from it. When the motorcyclists were leaving the stretch of road with wire rope barriers they in all of the above mentioned cases rode from the edge of the road to the middle of the road. In the other direction both motorcyclists rode closer to the edge of the road. It is worth noticing that in the 2-lane section the outer lane was always used. However there was no heavy traffic, therefore there was no need to use the inner lane.

Summary of results of the site study

No significant conclusions can be drawn on speed performance. However, general patterns could be observed. The speeds on 2+1 roads with wire rope barriers are on the whole lower than the speed limit. However, there were a few riders who exceeded the speed limit by up to 10 km/h. In contrast, on the 13 m road with wide lanes, the speeds on average were lower than the speed limit but considerably higher than on 2+1 roads with wire rope barriers. Moreover, in 3 out of 6 cases the speed limit was exceeded by up to 9 km/h. There was no correlation observed with regards to the number of occupants of the motorcycle; the speeds with passengers varied between 68-105 km/h on 2+1 roads. There is not enough data to state how wire rope barriers influence the motorcyclists' speeds in the transition sections from with to without wire rope barriers. However, there is a clear influence on the riding distance from the barrier. Motorcycles tend to ride away from the barrier but ride closer to the left or middle of the lane when there is no barrier.

7. CONCLUSIONS AND DISCUSSION

7.1 CONCLUSIONS ON QUALITY OF DATA

7.1.1 Accident data

Motorcycle 2+1 roads accident data obtained from SRA [20] contained many details on the accident circumstances. However, details essential for this study were unavailable or uncertain. There was lack of information on whether wire rope barriers were installed on particular road types or not. This especially regarded motorways and 4 lane roads as in the assessment it was assumed that all 2+1 roads had wire rope barriers installed. Moreover, vehicle mileage was not available for specific modes of transport on specific road types, which is an essential piece of information for accident rate calculations. These aspects should be considered when updating the database.

7.1.2 Traffic flow and speed data

Traffic flow and speed data collected by SRA [21] was abundant in information. However, it was difficult to obtain collective data on particular types of vehicles, in this case on motorcycles. Instead all of the data had to be obtained manually by looking up separate measure points. Therefore, organised collection of all data for the database is essential.

The data itself was very useful. Traffic volumes of separate modes of transport and their speeds helped in the motorcycle speed performance analysis. However, the speed data only revealed the average speeds. There was lack of information on individual speeds of vehicles or 90 percentile speed of traffic within the vehicle type. The average speed could lead to wrong conclusions. Suppose the average speed was around the speed limit. One may say that all vehicles were travelling at the speed limit speed but it could also mean that half were speeding and the other half were travelling below the speed limit. Therefore, the magnitude of speeds is essential for speed performance analysis.

As for the *"Motorcycle travelling patterns and choice of alternative routes"* method traffic flow, the data was insufficient. In order to succeed the measure points should identify each motorcycle, for example by plate numbers. This would give the information to the next measure point and show whether a particular motorcycle chose a particular road, providing that the measurements were conducted on both the alternative and the primary road at the same time.

7.1.3 Questionnaire

The internet questionnaire was a very good source of information providing a vast number of opinions on the issue. However, the questionnaire was meant to give a representation of views of the majority of motorcyclists and not just those who had access to the internet. This result could only be obtained by personally visiting all registered motorcyclists at their place of residence. This of course would have been a very inconvenient process for both the interviewer and those interviewed.

The localisation of the questionnaire on SMC's website was good but it also should have been put up on other websites that attract motorcyclists. The questionnaire could have had an identification requirement, for instance the plate number of the motorcycle, but this could have discouraged from filling in the questionnaire. Any other form of identification could also discourage from filling in the questionnaire. Providing identification however, would have limited the possibility of filling out the form more than once.

Another aspect is that the questionnaire could have had more questions but this may have also resulted in discouragement.

Above all, some knowledge of social and psychological behaviours are needed when creating a questionnaire.

7.1.4 Interview

The interview provided crucial information on the issue of wire rope barriers. The interview gave the motorcyclist the possibility to exactly express his opinion. Only one person was interviewed; for better more reliable results more people should have been interviewed.

In general, the interview should include psychological and social aspects, based on science in this area, in order to obtain answers closer to reality. Practical tests could also be conducted to obtain the actual reaction. However, persons that are aware of being tested may tend to react in a different way than they do on a regular bases.

7.1.5 Site study

The site study brought the most detailed information as it was actually conducted at the source. However, due to technical difficulties the obtained data was limited. For the results to be reliable the measurements should be taken constantly over considerably long periods of time and in an inconspicuous way. Fixed speed cameras could be a solution.

The distance performance tests could be done by installing monitoring cameras or sensors on the cables measuring the traffic volume that would register the distance from the barriers or roadside.

In order to investigate the reaction in terms of the change in speed when motorcyclists notice wire rope barriers speed measuring equipment could be introduced that would allow to measure the change in speed of the rider.

7.2 CONCLUSIONS ON WIRE ROPE BARRIER ROADS' SAFETY WITH RESPECT TO MOTORCYCLISTS

The results of motorcycle safety on wire rope barrier roads assessment are different for particular 2+1 road types. The risk of getting killed or severely injured for a motorcyclist (when motorcycle mileage is assumed to be 1 % of the total [20]) was ten times higher than for an average road user on *MML* roads but only five times higher on *MLV* roads. However, the highest DSS rate of all 2+1 roads was on *2+1 målat 90* roads where there are no wire rope barriers.

The analysis of motorcycle accidents from years 1998-2002 shows that only in two out of all nineteen motorcycle accidents occurring on 2+1 roads, wire rope barriers were involved [20]. The analysis has also confirmed the total elimination of head-on collisions. However, this does not mean that wire rope barriers themselves are not hazardous to motorcyclists' health.

The first half of year 2004 was very unfortunate for safety performance of 2+1 roads with respect to motorcyclists. *MML* roads begun to be built in years 1998-2003 and there were fewer accidents during that period than there were only in the first half of 2004. It is in 2004 that the first ever two motorcyclists on 2+1 roads were killed and one of them died due to an impact with a wire rope barrier [6]. On *MML* roads seven out of all fifteen accidents involved wire rope barriers, causing (details of accident occurrence not revealed) one death, five severe injuries and two minor injuries [6]. One must bear in mind that barrier collisions are very frequent on the whole resulting in property damage only but for similar accident circumstances the outcome for motorcyclists might be much more severe. Nonetheless, the safety outcome is still in favour of 2+1 roads with wire rope barriers, despite the unfortunate safety outcome in the first half of year 2004, when compared to 2+1 roads without wire rope barriers (although due to low vehicle mileage of this road type no fair comparison can be conducted). Furthermore, the risk of getting killed calculated for *MLV* roads was zero and the risk of getting killed or severely injured was five times larger than for an average *MLV* road user. These values could be set against the risk values given by VTI [1], stating that the risk of a motorcyclist being killed is eight times higher than of a passenger vehicle driver. It must be stated that if the average motorcycle mileage was lower than assumed (1 % [20]) the risk of being injured would correspondingly be higher.

7.3 CONCLUSIONS ON INFLUENCE OF WIRE ROPE BARRIERS ON MOTORCYCLISTS' CHOICE OF TRAVELLING ROUTE

It is rather difficult to assess how wire rope barriers affect motorcyclists in terms of their choice of travel when they have an alternative road without wire rope barriers to choose from. The attempted method which had this objective in mind could not be used for conclusions due to many limitations. Nonetheless, 2 other sources, the questionnaire and the interview, indicate that wire rope barrier roads are not being avoided but are not appealing either. More than 55 % of respondents did not consider wire rope barriers as a decisive factor in their choice of travel. Despite that fact, 75 % declared to fear colliding with the barrier than feeling of being protected by it from head-on collisions. The "Before and after" method results show that motorcycle volumes have actually increased on the same sections of roads after installation of wire rope barriers. Not only the ratio increased, considering that the total traffic volumes decreased, but also the actual number of motorcycles increased. This may have been caused by an increase of motorcycles in traffic, which was greater than the increase in other modes of transport. Nevertheless, motorcycle traffic volumes have not been influenced by the implementation of wire rope barrier roads. This might imply that wire rope barriers have gained motorcyclists acceptance despite their general criticism.

7.4 CONCLUSIONS ON INFLUENCE OF WIRE ROPE BARRIERS ON MOTORCYCLISTS' SPEED AND PERFORMANCE

Judging by the results obtained from statistical data and the site study wire rope barriers have a tendency to influence the speed of motorcycles. The statistical data analysis shows that motorcycle speeds were rather concentrated and usually above the average speed of total traffic but below the speed limit (apart from one example). Whereas the "equivalent roads" analysis shows that the speeds are rather spread out and in many cases the speed of travel is either substantially higher or lower than the speed limit, and sometimes even lower than the average speed of the whole traffic. The latter case is believed to be determined by local factors such as the weather or surface conditions. The site study did not indicate significant patterns. However, on the whole the speeds were higher on roads without wire rope barriers, although the extreme values were recorded on the stretches with wire ropes.

Based on the results obtained from the questionnaire, 74 % of respondents stated that wire rope barriers had no influence on their speed but 22 % stated that they decreased their speed on noticing the barriers. 4 % of those who responded to the questionnaire stated that they chose roads without wire rope barriers because it was faster to travel. The interviewed motorcyclist was not fond of wire rope barriers because they restricted, as he stated, safe overtaking. One must bear in mind that there is the subjective and objective feeling of safety and this also applies to the reaction to different factors. What one may think how he or she reacts does not necessarily mean that they act in the same way in the reality.
It cannot be significantly stated that wire rope barriers are the physical speed measure factor, but it seems to indicate so. Wire rope barriers installed on both sides of the lane, especially on 1-lane sections, considerably narrow the perspective and therefore influence not only the riders but other road users to reduce the speeds. Nonetheless, wire rope barriers have a different purpose and should not be considered as physical speed measure factor.

As for the distance performance there is a clear correlation between the existence of barriers in the road environment and the riding distance form the central reservation. All of the site study results indicate that motorcyclists ride away from the barrier but ride in the middle of the lane or closer to the median if the barrier is not present. The site study also showed that on the 1+1 road with wire rope barriers installed on both sides the motorcyclists rode equally distanced from the barriers. However, the questionnaire indicated that only 63 % of riders increased the distance from the barrier and 36 % stated that the barrier had no influence on the distance performance. Once again, one may not notice his or hers reactions.

Riders prefer to ride closer to the roadside rather than closer to the barrier. However, the roadside may be in some cases more hazardous than the barrier itself. This is an aspect to be considered when designing roadside furniture or crash barriers.

8. FURTHER RESEARCH

This chapter will concentrate on what actions ought to be taken in the future. First, the wire rope barriers shall be looked at in terms of safety improvements with respect to motorcyclists. Then, the influence of wire rope barriers on motorcyclists will be discussed.

8.1 REASEARCH AND IMPROVEMENT IN WIRE ROPE BARRIER'S SAFETY WITH RESPECT TO MOTORCYCLISTS

An in-depth study of wire rope barrier safety with respect to motorcyclists is needed. So far no such study has been conducted. Those accidents that occurred, involving wire rope barriers and motorcycles, ought to be analysed in detail. Barrier crashes among passenger vehicles are very common, around 1 per week. Considering that motorcycle traffic [19] and wire rope barrier implementation [9] is increasing, further research is required. Moreover, actions should be taken to make the barriers more motorcycle-friendly, at least sharp edges ought to be covered and longitudinal redirection provided.

There is no information on how the barriers themselves perform the function of containment and redirection. It is considered necessary for the CEN to include motorcycle safety in regulations for standardisation of crash barriers; current EN 1317 does not mention motorcycle safety.

8.1.1 Possibilities for general improvements to roadside and crash barriers for motorcycle safety

The main concern regarding crash barrier safety with respect to motorcyclists is that barriers may not fulfil their function of containment and redirection. Sharp edges of supporting posts are recognised as the most hazardous. Here are some of the examples mentioned in literature of how to provide a more motorcycle-friendly road environment [9] [14] [15]:

- Reducing impact energy to the level that a human body can resist by coating road furniture with highly energy absorbent materials, this especially applies to crash barrier posts.

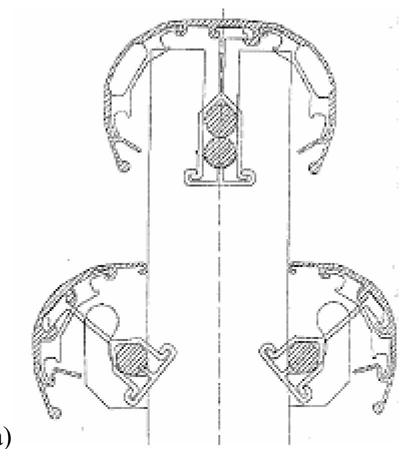
- Clearing roadside obstacles and possibly smoothening them with soft materials such as LECA marbles, used in Grand Prix motorcycle races.

- Providing longitudinal redirection of the rider by adding additional beams.

- Avoidance of any sharp edges, especially the I-shaped posts.

8.1.2 Possibilities for improvements of wire rope barriers

There is no evidence that wire rope barriers cause a so called "cheese cutter" effect [9]. However, there has been an attempt to exclude such possibility by introducing padding on upper and lower rope system [14] (fig.8.1a). This device has been tested for motorcycle performance with an initial velocity of 100 km/h and impact angle of 20 deg. The results of the test showed that the motorcycle along with the rider was redirected in a longitudinal direction. The padding protected the rider's body parts when sliding along it. Neither the rider nor the motorcycle was cut by the barrier. However, this device does not cover sharp edges of supporting posts. The "Mototub" system manufactures believe that (fig.8.1b) their motorcycle device can be fitted to wire rope barriers and fully protect exposed sharp edges. There is no information in the literature of how this system performed in practice. Further research, crash tests and computer simulations are essential for improvements of roadside safety barriers. More on motorcycle-friendly devices and examples of computer simulations can be found in appendix F.

a) 

b) 

Fig.8.1a) Wire rope padding b) "Motortub" system [15]

8.2 FURTHER REASEARCH ON THE INFLUENCE OF WIRE ROPE BARRIERS ON MOTORCYCLISTS

This study did not have sufficient sources to determine whether motorcyclists opted to travel using alternative roads or not. Detailed exposure study relying on updated traffic volume data ought to be conducted. Motorcycle (or other types of vehicles) volume data should be obtained collectively in order to ease the evaluation.

The speed performance is still very unclear. On one hand the site study and scarce statistical data tends to show that roads with wire rope barriers (2+1 roads) influence motorcycle speed but on the other a vast majority of questionnaire respondents believe that these barriers have no influence on their speed. "Before and after" study on a broader scale should be conducted involving all roads that were converted to 2+1 roads with wire rope barriers. This also applies to the "Comparison of equivalent roads" method. However, the criterion of fair comparison needs to be investigated.

Narrow 1-lane sections limited by wire rope barriers on both sides of 2+1 roads raised discussion among the respondents. The concerns were that it poses risk of collision independent from the rider, namely strong wind, slippery or uneven surface. This should also be investigated and given thought.

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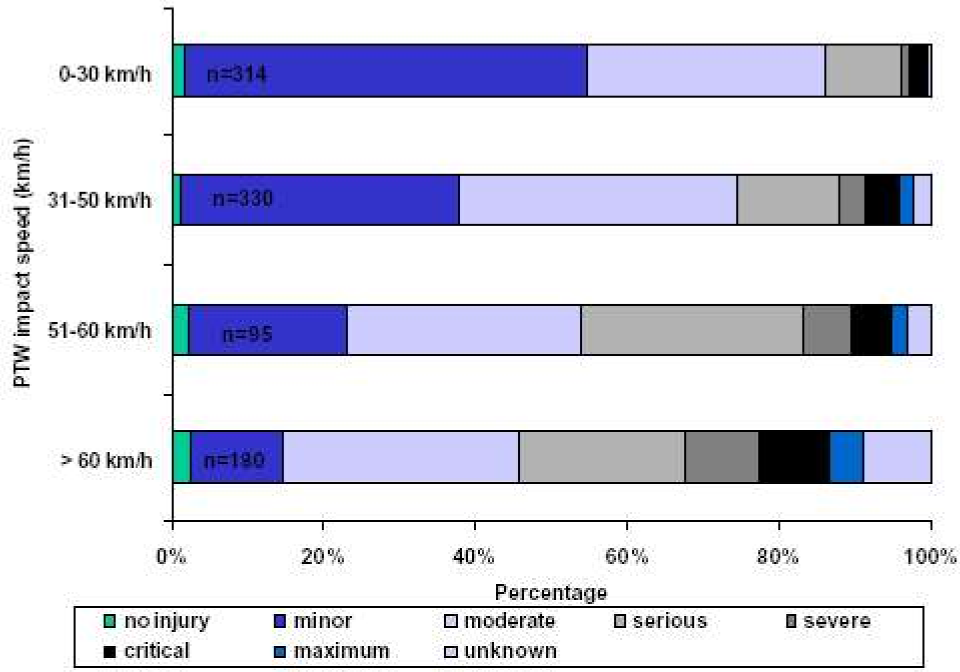
APPENDIX A: MOTORCYCLISTS' SAFETY

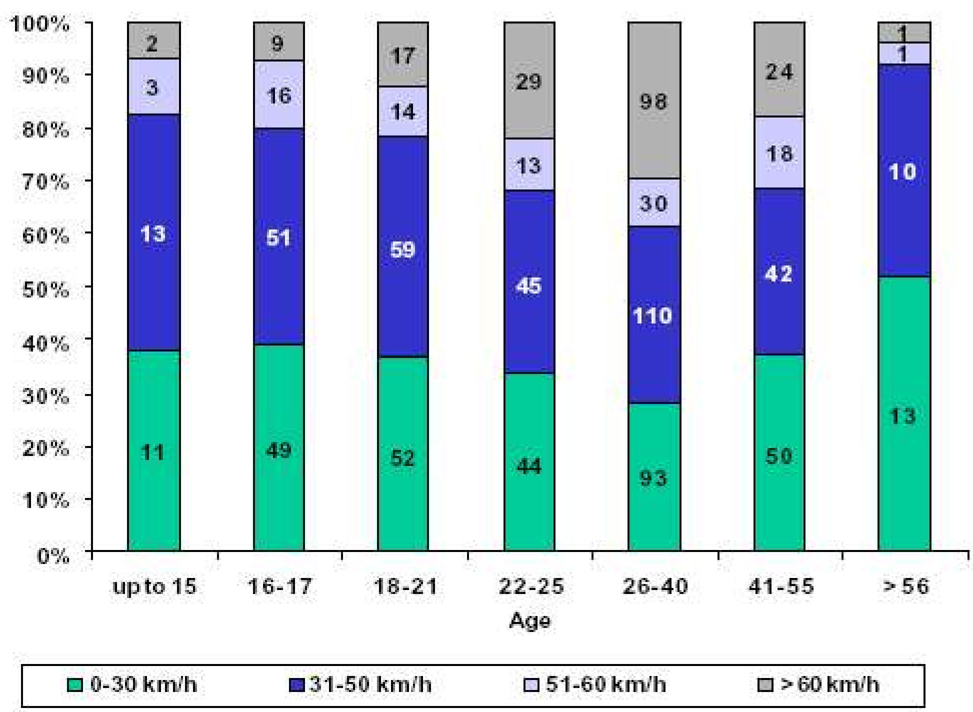
Courtesy of: Association of European Motorcycle Manufacturers (ACEM) [24]

NOTE: the data comes from an extensive in-depth study of motorcycle and moped accidents during the period 1999-2000 in five sampling areas located in France, Germany, Netherlands, Spain and Italy.

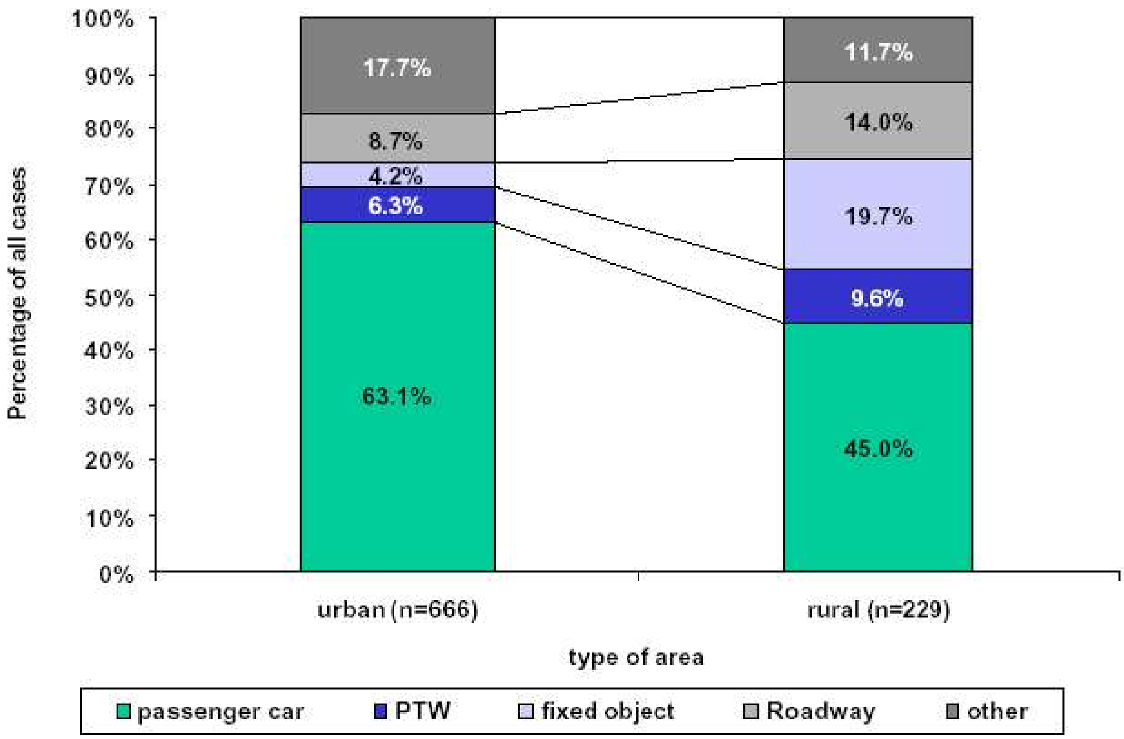
Cross-tabulation of rider by motorcycle impact speed



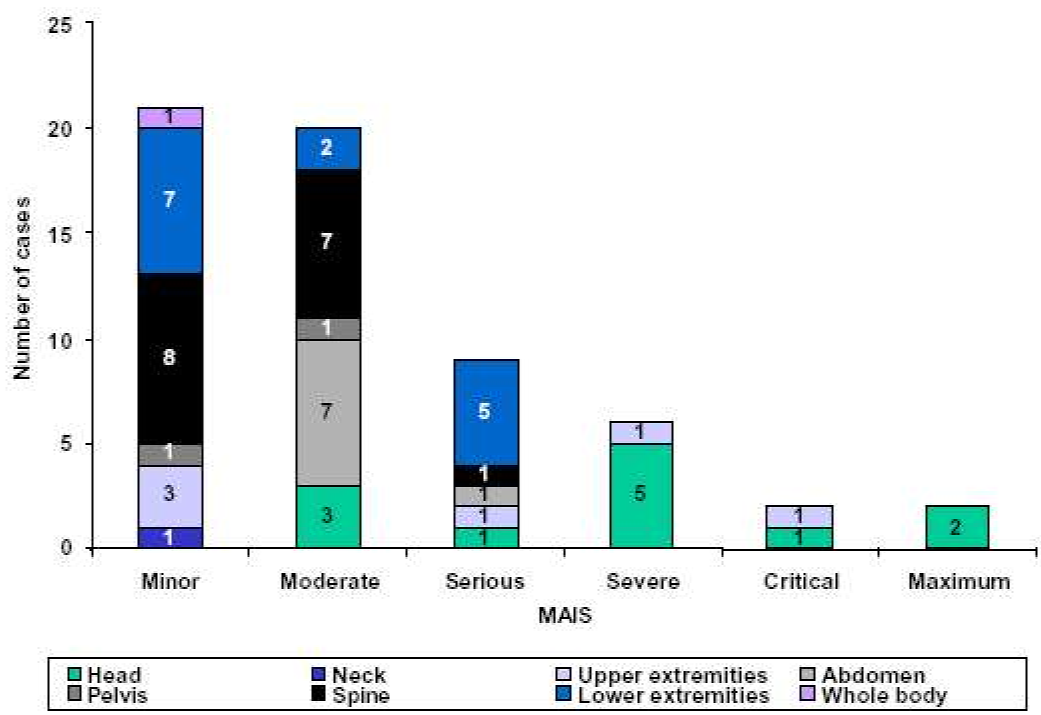
Motorcycle impact speed by rider's age



Motorcycle collision partner by type of area.



Roadside barrier injury



Motorcycle accidents occurring on different road types.

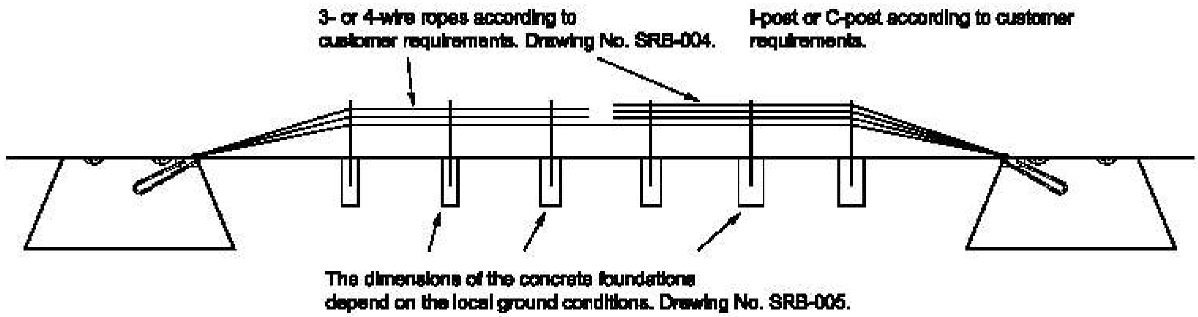
	Frequency	Percent
Motorway	39	4.2
Major arterial	192	20.9
Minor arterial	475	51.6
Non-arterial, sub-arterial	126	13.8
Parking lot, parking area	4	0.4
Driveway	3	0.3
Round about or traffic circle	6	0.7
Overpass	2	0.2
Underpass	5	0.5
Dedicated bicycle or moped path separated from traffic roadway	51	5.5
Dedicated bicycle or moped path not separated from traffic roadway	3	0.3
Other	14	1.5
Unknown	1	0.1
Total	921	100.0

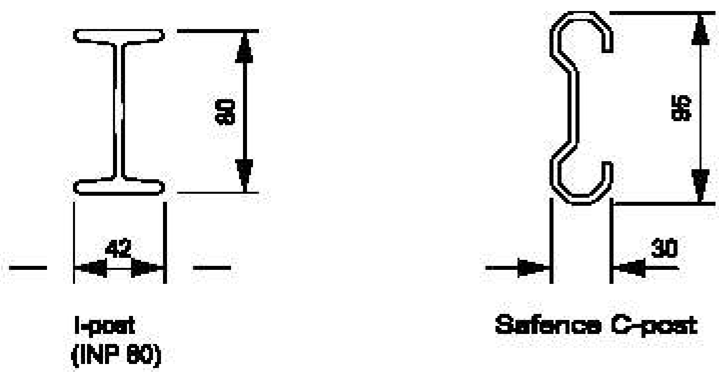
Engine displacement

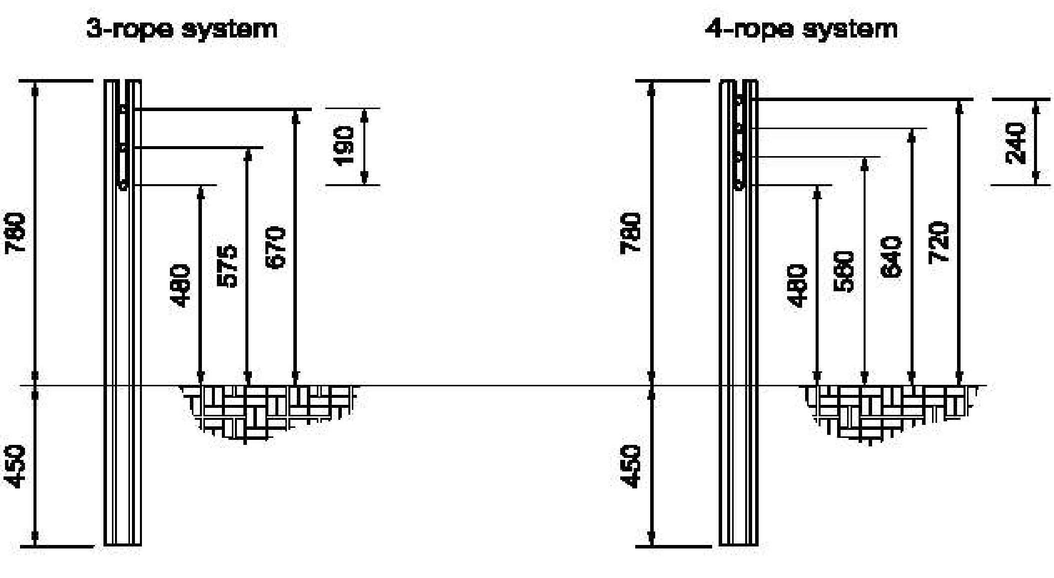
	Accident data		Exposure data	
	Frequency	Percent	Frequency	Percent
up to 50 cc	394	42.7	367	39.8
51 to 125 cc	89	9.7	86	9.3
126 to 250 cc	37	4.0	32	3.5
251 to 500 cc	56	6.1	50	5.4
501 to 750 cc	206	22.4	193	20.9
751 to 1000 cc	80	8.7	107	11.6
1001 or more	58	6.3	88	9.5
Unknown	1	0.1	0.0	0.0
Total	921	100.0	923	100.0

APPENDIX B: WIRE ROPE BARRIERS

Courtesy of: BLUE SYSTEMS AB [17]



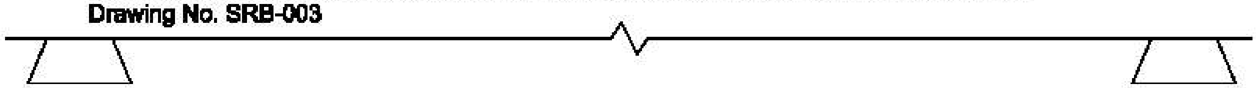




Installation guide

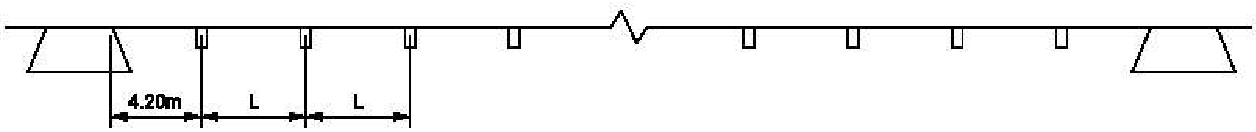
1. End anchors

Install the pre-fabricated or cast-on-site anchors at the beginning and end of each stretch.
Drawing No. SRB-003



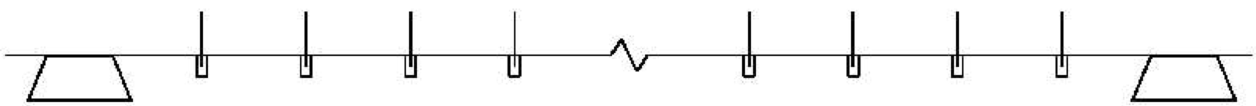
2. Post footings

Install the pre-fabricated or cast-on-site footings. Drawing No. SRB-004 + SRB-005



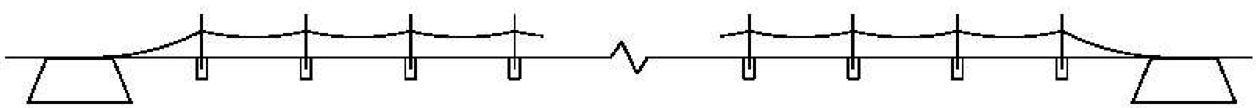
3. Posts, plastic dust covers

Assemble all posts with plastic joint and stand in footing. Drawing No. SRB-006



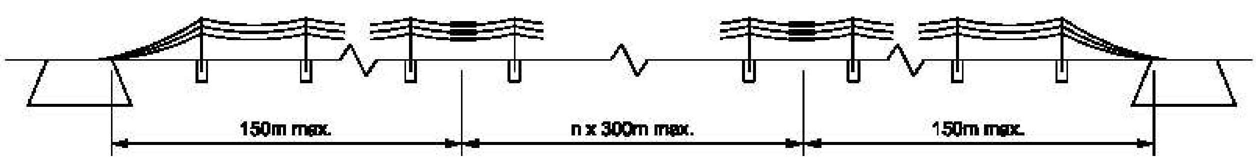
4. Installation of wire rope.

Run out the wire rope. Drawing No. SRB-006



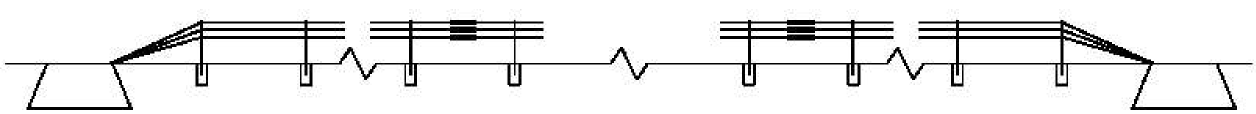
5. End fitting, swage fitting, rigging screw

Mount end fitting, swage fitting and rigging screw. Drawing No. SRB-007

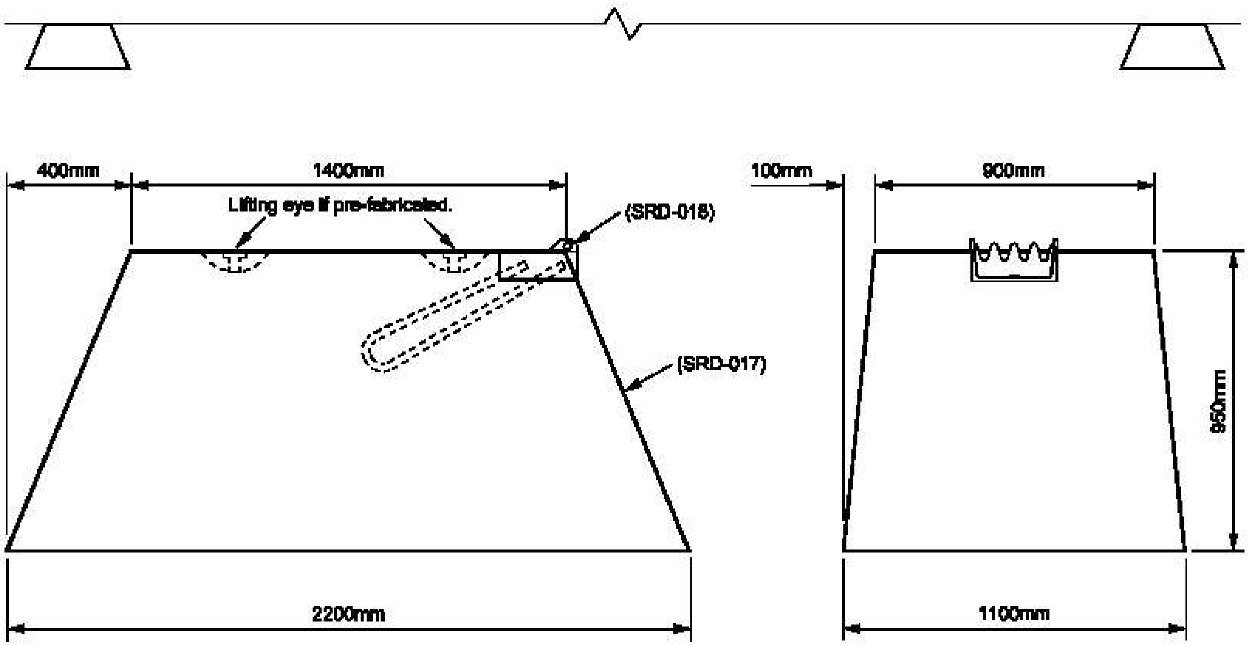


6. Tensioning

Tension the ropes to the right force. Drawing No. SRB-007

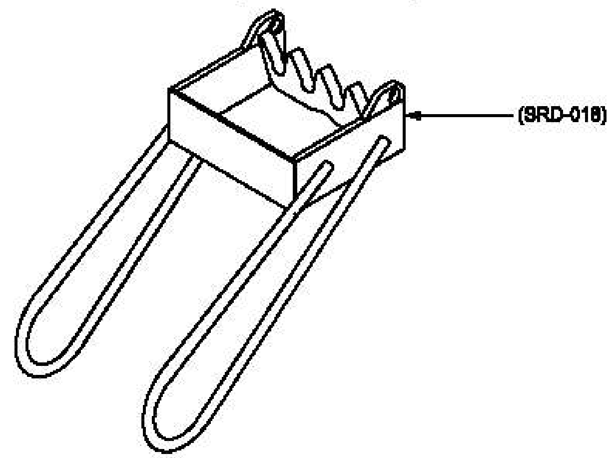


End anchors

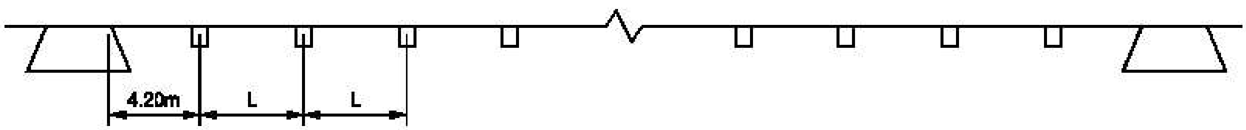


-The concrete anchors can be cast or pre-fabricated.
-Ensure that the anchor is in line with the wire rope safety fence.
-The embedded wire anchor fitting is to be at ground level and follow the slope of the ground.
-Afterwards the hollow space around the anchor is filled with friction facing that is to be vibrated.

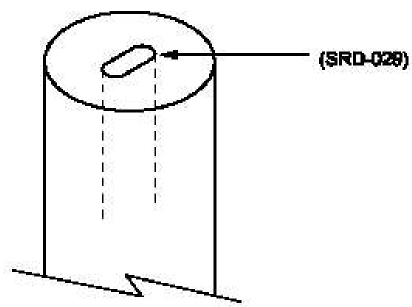
Embedded wire anchor fitting 3- or 4- ropes.



Post footings



-The post footings are to be installed in a compacted material.
-The upper edges of the post footings are to be at ground level
 or max. 4 cm. belov ground level.
-If the post footings are cast-on-site a plastic mould can be used.



-The wire rope safety barrier is to follow the contours and line of the road
 without any visible horizontal or vertical deviations.

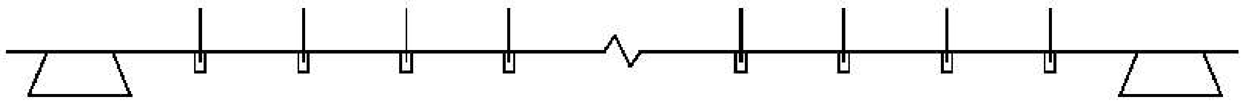
Distance between the posts (post footings)

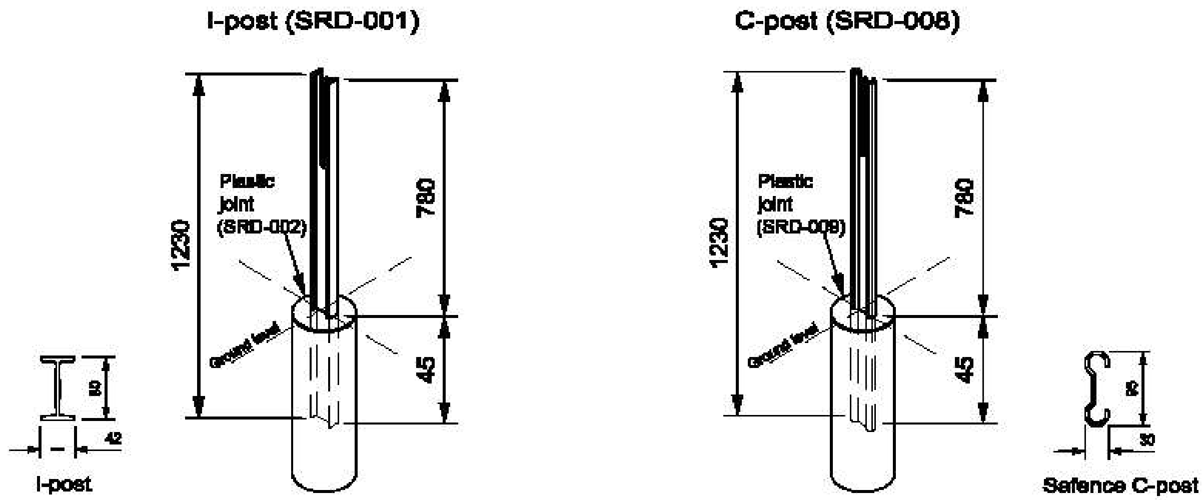
Containment level N2 SAFENCE 3RI, 3RC, 4RI, 4RC		
Post distance	Working width	CEN class
1,0m	0,8m	W2
1,5m	0,9m	W3
2,0m	1,0m	W3
2,5m	1,3m	W4
3,0m	1,7m	W5

Containment level H1 SAFENCE 4RI, 4RC		
Post distance	Working width	CEN class
1,0m	1,0m	W3
1,5m	1,1m	W4
2,0m	1,3m	W4
2,5m	1,5m	W5
3,0m	1,8m	W6

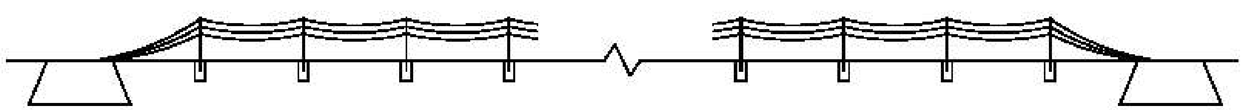
Post distances 1,0 and 1,5 metres should only be used when passing bridges or other obstacles.

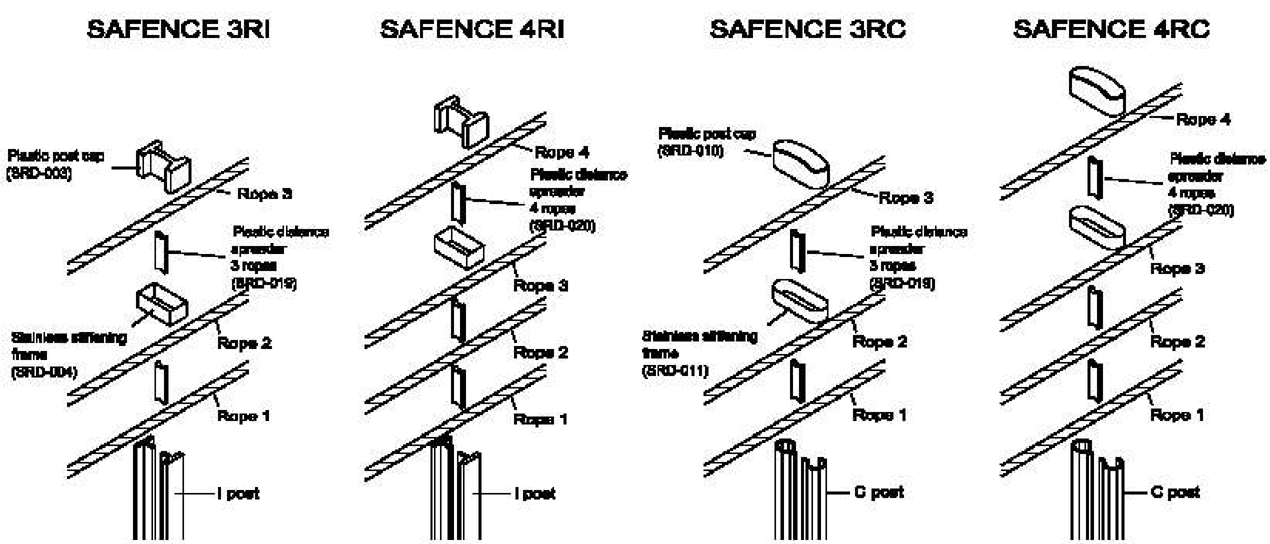
Post - plastic joint



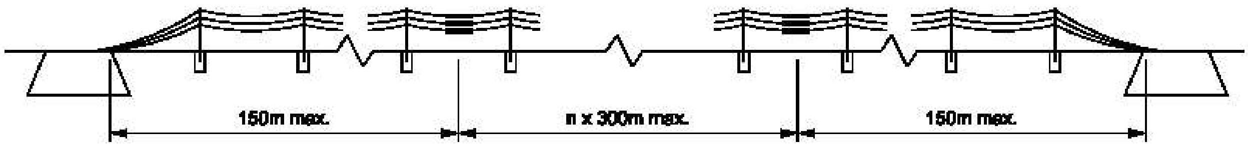


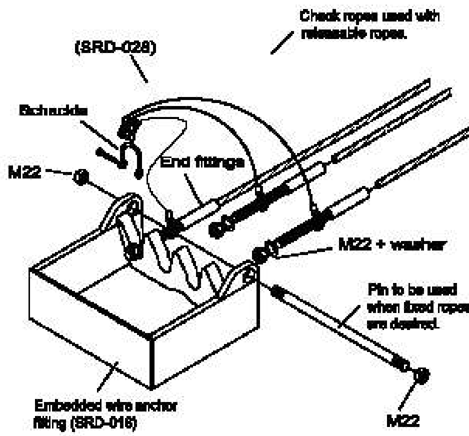
Wire ropes - installation





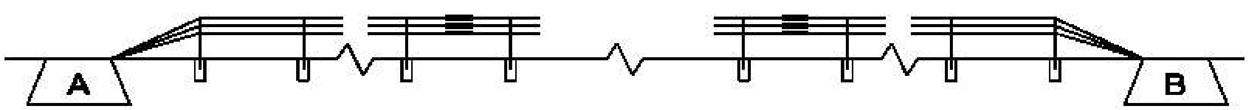
End fittings - Rigging screws





1. Swage end fittings onto all wire ropes with the swaging machine. Mount end fitting in end anchor A.
2. Tension the wire ropes by hand to the first rigging screw, max. 150m (tension panel)
3. Swage the fittings in the swaging machine and mount the rigging screw between the 2 posts.
4. Tension the wire ropes by hand to the next tension panel, max. 300 m. Mount the rigging screw between the 2 posts and so forth.
5. Finish by mounting the end fitting in anchor B.

Tensioning



1. Tension the wire ropes with the nuts at anchor A and B.
2. Tension the wire to the right tensioning force at each rigging screw (see table). Start on the middle of the stretch and work by turns towards anchor A and B.

Note: Should the length of the rigging screw not be sufficient to obtain the right tensioning force, tension to half of the length of the rigging screw. Then adjust the rigging screws so they all have the right tensioning force.

Tensioning force

Temperature C°	Kp
-40	3.200
-30	2.900
-20	2.600
-10	2.300
0	2.000
+10	1.700
+20	1.400
+30	1.100
+40	800

APPENDIX C: 2+1 ROADS

List of 2+1 roads (2+2, 1+1) in Sweden by July 2004 [7].

Väg	Objekt och längd (km)	Vägtyp	Datum	Anmärkning
E4	Ljungby–Toftanäs 31 km	MML	6/11-00	
E4	Gävle–Axmartavlan 32 km	MML	Juni 98	I utv.program, **14** m
E4	Axmartavlan–Noran 14 km	MLV	Okt 02	
E4	Noran–Söderhamn, etapp 1 10 km	MLV	Okt 03	Etapp 2 15km i okt 04
E4	Timrå–Torsboda (Deltavägen) 11 km	MML	7/9-01	1+1 öster om Midlanda tpl i 2,7 km
E4	Överdal–Gallsäter (Höga Kusten-bron) 32 km	MML	1/10-01	1+1 över Höga Kusten-bron, 5,5 km
E4	Hammering–Kongberget 16 km	Räfflat	Okt 03	13 m målat, **delvis mitträfflor**, Räcke 2004
E4	Skule–Skulnäs (Skulebackar) 10,6 km	MLV	Dec 03	2+1 i långa stign.fält
E4	Överhörnäs–Tvillingsta 4,3 km	MLV	Dec 03	
E4	Husum–Lämsgräns AC 12 km	MLV	Dec 03	
E4	Nordmaling–Håknäs 6,1 km	MLV	29/10-03	
E4	Håknäs–Stöcksjö 14 km Håknäs–Stöcksjö 19 km	MLV	Okt 00 23/10-01	Etapp 1 utv.progr. **14** m Etapp 2 utv.progr. **14** m
E4	Yttervik–Tjärn 15 km	MLV	3/10-03	
E4	Norr Rosvik–Ersnäs 11 km	MLV	Okt 03	
E4	Gäddvik–Rutvik 10,5 km Rutvik–Ängesbyn 9 km	MML MLV	1/10-02 1/10-02	
E14	Torvalla–Lugnvik 13 km	MML	1/10-01	
E18	Västerås–Sagån 12,5 km	MML	1/11-00	
E18	Enköping 1 km	MML	höst-00	1+1, utvärderas ej
E18	Köping–Västjädra 23,5 km Västjädra–Västerås 6 km	MML	1/7-01 1/7-01	
E18	Skattkär–Väse 13 km	MML	1/11-01	
E18	Stolpen–Övre Kvarn 10 km Övre Kvarn–Bodalen 10,5 km Bodalen–Kojängen-Karlskoga 10 km	MLV MLV MLV	15/12-02 April 04	3 km med MML
E18	Rosenkälla–Söderhall 18,5 km	MML	1/1-03	
E20	Lyrestad–Fagerlid 7km	MLV	9/12-03	
E20	Ledfallet–Lgr Örebro 2,5 km Lgr V:a Götaland–Finnerödja 6,8 km	MLV	26/11-03	
E20	Laxå–Sandstubbetorp 8,3 km	MLV	28/10-03	
E20	Gröndal–Eskilstuna 7,5 km	MML	1/11-01	

Väg	Objekt och längd (km)	Vägtyp	Datum	Anmärkning
E22	Söderåkra–Hossmo 28 km	MML	1/12-00	Nybyggd, **14** m
E22	Förbi Lindsdal 5 km	MML	26/7-02	Utvärderas ej
E22	Ålem–Mönsterås 7 km	MLV	30/11-02	
E22	Emån–Oskarshamn 14 km	MLV	Okt 03	
E22	Förbi Oskarshamn 9 km	MML	2/12-02	
E22	Verkebäck–Västervik 6 km	MLV	22/11-02	
E22	Valdemarsvik–Söderköping 27 km	MLV	Okt-03	I utv.program. **14,5** m
E65	Börringe–Skurup 9 km	MLV	1/2-02	2+2 i utv.progr. **16** m
E65	Skurup–Rydsgård 7 km	MLV	1/2-02	2+1
E65	Rydsgård–Ystad Etapp 1 13 km Etapp 2 2 km	MLV	Dec 02 Juni 03	
Rv 11	Burlöv 0,6 km	MML		2+2, utvärderas ej
Rv 11	Malmö–Kyrkheddinge 11 km	MLV	30/12-00	
Rv 21	Förbi Åstorp 2 km	MML	23/11-00	2+1, ansluter till väg med 4 kf, utvärderas ej
Rv 21	Perstorp–Tyringe 6,7 km Tyringe–Finja 2,5 km Finja–Ignaberga (Hässleholm) 14 km	MLV MLV MML	6/2-02 6/2-02 22/12-00	
Rv 23	Hässleholm–Östanå 14,5 km Almaån–Rävninge 3 km	MLV	30/12-00 ej klar	Etapp 1+2 Fortsätter Etapp 3 norr Östanå
Rv 23	Östanå–Osby Etapp 1 4,8 km Etapp 2 4,0 km Etapp 3 2,3 km	MLV	Dec 02 Juni 03 9/12-03	Fortsätter som Osby-Länsgränsen
Rv 23	Osby–länsgränsen (Loshult) 13 km Loshult–Älmhult 3 km	MLV	1/2-01 1/6-01	
Rv 25	Förbi Smedby 4 km	MLV	31/10-02	Utvärderas ej
Rv 26	Oskarström–Brandshult 1,4 km Brandshult–Spenshult 4,7 km	MLV	9/12-03 Dec 02	Utvärderas ej
Rv 26	Nyebro–Torup 2,3 km Torup–Rydöbruk 3,6 km	MLV	Dec 03 Dec 02	Utvärderas ej
Rv 27	Värnamo–Kärda 11 km	MLV	30/10-03	
Rv 31	Nässjö–Öggestorp, 21 km	MLV	1/10-02	
Rv 36	Sjögestad–Tift 8 km	MML	30/12-02	1,3 km med MLV
Rv 36	Motala–Ervasteby 4 km	MLV	15/11-02	13,75 m. Utvärderas ej
Rv 40	Göteborgsbacken 3 km Nissastigen–Hedestorp 13 km	MML MLV	juni 01 1/10-02	2+2, utvärderas ej 2+1
Rv 40	Länsgräns O–Nissastigen 9,3 km	MLV	3/11-03	
Rv 40	Ulricehamn–Lgr Jönköping 27 km	MLV	3/12-03	
Rv 41	Varberg–Derome Etapp 1 4,2 km	MLV	Nov 2003	Utvärderas ej
Rv 44	Trollhättan–Håsten 10,5 km	MLV	22/12-00	Nollvisionsstr., **14** m
Rv 44/45 Lv 2026	Överby–Skogsbo–Båberg 4,1 km Skogsbo–Korseberg 2,3 km	MML MML	Dec 01	
Rv 45	Båberg–Norr Vänersborg 7,5 km	MLV	Juni 03	
Rv 45	Åmål–Säffle 14 km	MLV	Nov 01	I utv.program, **14** m
Rv 50	Motala–Nykyrka 8 km	MLV	Nov 03	
Rv 50	Lillån–Axbergshammar 13 km	MLV	1/11-01	2+2 i utv.progr. **16** m
Rv 50	Åsbro–Brändåsen 7,1 km	MLV	4/7-03	
Rv 53	Gröndal–Kvicksund 6 km	MML	15/11-02	
Rv 55	Åby–Simonstorp 13,1 km	MLV	1/12-02	Målat sedan 1/12-01
Rv 70	Säter–Solvarbo 6 km	MML	19/10-01	Etapp 1
Rv 70	Solvarbo–Borlänge 11,5 km	MML	Okt 02	Etapp 2, delvis MLV

Väg	Objekt och längd (km)	Vägtyp	Datum	Anmärkning
Rv 80	Förbi Sandviken 1,5 km	MML	Nov 02	Utvärderas ej.
Rv 80	Hillsta–Tegelbruket 13 km	MML	Nov 03	Forts. på 4 F
Lv 100	Höllviken–Vellinge 5 km	MML	30/12-00	2+1 målad i okt. 99
Lv 103	Prästberga–Flackarp 2,2 km	MLV	Dec 02	Fortsätter som Lv 108
Lv 108	Klörup–Aggarp 5 km (syd Svedala)	MLV	Dec 03	
Lv 108	Flackarp–Furulund 9 km	MLV	20/12-01	
Lv 158	Särö–Brottkärr 9 km	MML	10/10-01	
Lv 161	Rotvik–Holma 4,2 km Holma–Torp 2,8 km	MLV	2/12-00 15/10-03	Etapp 1 Etapp 2
Lv 222	Insjön–Mölnvik 6,5 km	MML	1/11-00	
Lv 267	Stäket–Rotebro 6 km	MLV	1/3-01	1+1 betongbar. 70 km/h
E4	Söderhamn–Enånger 27,7 km	4 F	10/20-99	Alt 4 F, 18,5 m
E4	Ersnäs–Antnäs 4 km	4 F	1/10-02	2 km med 2+1, 13 m 2 km Alt 4 F, 18,5 m
E4	Antnäs–Gäddvik 9 km	4 F	10/10-02	Alt 4 F, 18,5 m
E6	Gläborg–Rabbalshede 20,7 km	4 F	11/11-00	Alt 4 F, 18,5 m
E22	Gårdstånga–Hurva 6,5 km	4 F	1/10 01	Alt 4 F, 18,5 m
Rv 80	Sandviken V–Hillsta 3,2 km	4 F	Nov 03	Alt 4 F, 18,5 m

APPENDIX D: MOTORCYCLE ACCIDENT DATA

Motorcycle accident data from major roads in Sweden between 1998-2002

20050407, Östen J   Vägverket VITS

Svårhetsgr	ad		Dödl.per Svår per Lindr.pe	ssk. ssk. rssk	
Väghållare	vid ol.	tillf.	Staten		Riksvägar Dvs endast större vägar på landsbygd plus någon genomfart
Trafikelem	enttyp		Tung mc Lätt mc		

2 . År   1998

Olyckstyp	Singel	Möte	Omkörning:	Upphhinna:	Avsväng	Korsande	Cykel/mop:	Fotgängare:	Varia :	Klövvilt	SUMMA :
Vägtyp vid ol.ti Händelse(förl	llf. opp)	head-on	overtaking	catching-u	turning acc	intersecting accident		pedestrian	various	hitting a wild animal	
Motorväg	**Single**	**head-on**	**overtaking**	**catching u**	**turn off**	**crossing**	**hit cyclist**	**hit pedestr**	**various**	**game**	**sum**
Påk kantsten	1										1
Påk vägräcke	4								1		5
1:a sammanst			2	10	2	2			2	2	20
2:a sammanst				2							2
Filbyte			3					18.79			3
Man p/t vägb	4		1	1					1		7
Avk fr vägb.	10										10
Omkull på vb	10		3	2							15
Vält utf väg	1										1
SUMMA	30		9	15	2	2	0	0	4	2	64
Motorled											
1:a sammanst									2		2
Omkörning									1		1
Man p/t vägb	2										2
Omkull på vb	2										2
SUMMA	4	0	0	0	0	0	0	0	3	0	7
Motorled 2+1											
SUMMA	0	0	0	0	0	0	0	0	0	0	0
väg 4 körfält tätort											
Påk vägräcke	1										1
1:a sammanst			2	2	2						6
2:a sammanst				2							2
Filbyte			1								1
Man p/t vägb	1										1
Avk fr vägb.	2										2
Omkull på vb	1										1
Vält utf väg	1										1
SUMMA	6	0	3	4	2	0	0	0	0	0	15
Vanlig väg											
Påk bergvägg	1										1
Påk kantsten	1										1
Påk staket	1										1
Påk sten							1				1
Påk träd										1	1
Påk vägmärke	1										1
Påk vägräcke	2			1							3
Påk brunn	1										1
Påk övrigt	3										3
1:a sammanst		2	10	20	30	12	6	2	10	10	102
2:a sammanst			4	6	2				4		16
3:e sammanst									2		2
Omkörning			7		2	1	2				12
Filbyte			1								1
Man p/t vägb	5		4	1	5		2	1	1	1	20
Avk fr vägb.	17		3	1	2		1			3	27
Omkull på vb	11		3	2	3	2		1		3	25
Vält utf väg	3		1	1			1				6
SUMMA	46	2	33	32	44	15	13	4	17	18	224
Vanlig 2+1, 2+2 eller 1+1											
SUMMA	0	0	0	0	0	0	0	0	0	0	0

2 . År 1999

Olyckstyp	Singel	: Möte	Omkörning : Upp	: hinnande	Avsväng :	: Cyk Korsande	el/moped : Fo	: tgängare	Varia :	: Klövvilt	SUMMA :
Vägtyp vid ol.tillf. Händelse(förlopp)											
Motorväg											
Påk vägräcke			1								1
Påk bar.elem			1								1
Påk viltst:l	1										1
1:a sammanst			10	8		2			2		22
2:a sammanst			2	2		2					6
3:e sammanst				2							2
4:e sammanst				2							2
5:e sammanst				2							2
6:e sammanst				2							2
7:e sammanst				2							2
8:e sammanst				2							2
Omkörning			5								5
Filbyte			3								3
Man p/t vägb	4		4								8
Avk fr vägb.	5		2								7
Omkull på vb	5		2	2							9
Vält utf väg	2										2
SUMMA	17	0	30	24	0	4	0	0	2	0	77
Motorled											
Man p/t vägb	1										1
Avk fr vägb.	1										1
Omkull på vb	2										2
SUMMA	4	0	0	0	0	0	0	0	0	0	4
ML 2+1											
Påk vägmärke	1										1
Man p/t vägb	1										1
Avk fr vägb.	1										1
SUMMA	3	0	0	0	0	0	0	0	0	0	3
4 körfält tätort											
Påk kantsten	1										1
Påk vägmärke	1										1
1:a sammanst			2			2					4
Filbyte			1								1
Man p/t vägb	1							1			2
Avk fr vägb.								1			1
Vält utf väg	1							1			2
SUMMA	4	0	3	0	0	2	0	3	0	0	12
Vanlig											
Påk kantsten	1										1
Påk staket	1										1
Påk stolpe	2										2
Påk träd										1	1
Påk vägräcke										1	1
1:a sammanst		4	6	12	36	36	2	2	12	32	142
2:a sammanst					10						10
3:e sammanst					2						2
4:e sammanst					2						2
Omkörning			6		4		2				12
Man p/t vägb	13	4	5	2	4			1		1	30
Avk fr vägb.	15	3	6		4	1			1	5	35
Omkull på vb	11		1	2	4	1				1	20
Vält utf väg	4	1	1							1	7
SUMMA	47	12	25	16	66	38	4	3	13	42	266
Vanlig 2+1, 2+2, 1+1 -8											
1:a sammanst						2					2
SUMMA	0	0	0	0	0	2	0	0	0	0	2

2 . År 2000 0

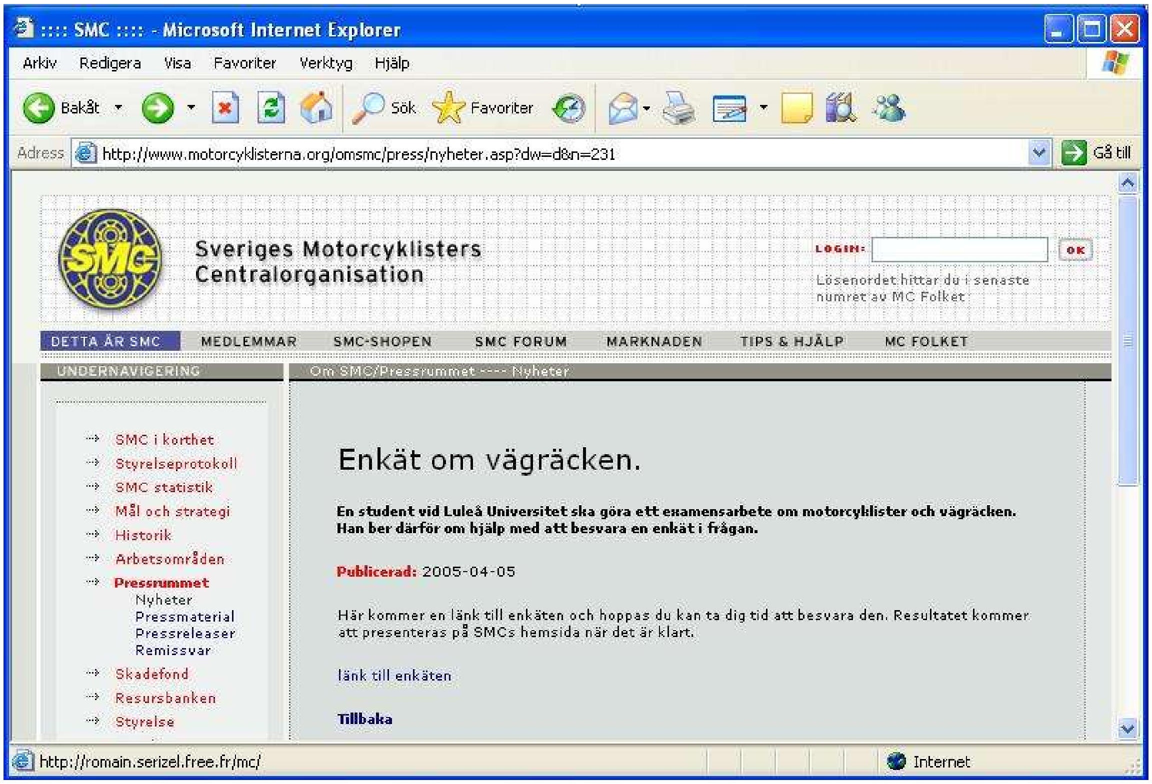
Olyc	kstyp Singel	: O Möte	mkörning : Upp	: hinnande	Avsväng :	: Cyk Korsande	el/moped : Fo	: tgångare	Varia :	: Klövvilt	SUMMA :
Vägtyp vid ol.ti llf. Händelse(förl opp)											
Motorväg											
Påk vägräcke	3										3
Påk bar.elem			1								1
1:a sammanst			4	14	6	4			2		30
Omkörning			2								2
Filbyte			4			1			1		6
Man p/t vägb	4		1	4					1		10
Avk fr vägb.	4		1								5
Omkull på vb	5		2	1	1				2		11
Vält utf väg	2										2
SUMMA	18	0	15	19	7	5	0	0	6	0	70
Motorled											
Omkull på vb										1	1
SUMMA	0	0	0	0	0	0	0	0	0	1	1
Motorled 2+1											
Påk stolpe	1										1
Avk fr vägb.	1										1
Omkull på vb	1										1
SUMMA	3	0	0	0	0	0	0	0	0	0	3
4 körfärlt i tätort											
Påk vägräcke	1										1
1:a sammanst				2	2	4					8
Man p/t vägb	1					2					3
Omkull på vb	1				1	1					3
SUMMA	3	0	0	2	3	7	0	0	0	0	15
Vanlig											
Påk staket	1										1
Påk vägräcke	4		1		1						6
1:a sammanst		4	8	14	30	36		2	4	20	118
2:a sammanst			2		2						4
Omkörning		2	8		3	1			1		15
Filbyte					1						1
Man p/t vägb	4	1	2		6	3		1			17
Avk fr vägb.	17		6	2	4	4				2	35
Omkull på vb	17		2		4	4				3	30
Vält utf väg	4									1	5
SUMMA	47	7	29	16	51	48	0	3	5	26	232

										2001	
Motroväg											
Påk viadukt	1										1
Påk kantsten	1										1
Påk stolpe	1										1
Påk vägräcke	1		1								2
Påk linräcke	1										1
1:a sammanst			2	16				2		6	26
2:a sammanst				2							2
3:e sammanst				2							2
4:e sammanst				2							2
5:e sammanst				2							2
6:e sammanst				2							2
7:e sammanst				2							2
Omkörning			2								2
Man p/t vägb	3		1	1							5
Avk fr vägb.	5		1								6
Omkull på vb	7			3						1	11
SUMMA	20	0	7	32	0	0	0	2	0	7	68
Motroled											
Påk vägräcke	1										1
Man p/t vägb	1										1
Avk fr vägb.	1										1
Omkull på vb	1										1
SUMMA	4	0	0	0	0	0	0	0	0	0	4
Motorled 2+1											
1:a sammanst						2					2
SUMMA	0	0	0	0	0	2	0	0	0	0	2
4 körfält i tätort											
1:a sammanst				2	2	4					8
Man p/t vägb	1										1
Omkull på vb	1					2					3
SUMMA	2	0	0	2	2	6	0	0	0	0	12
Vanlig väg											
Påk bergvägg	1										1
Påk kantsten	2		1								3
Påk staket	1										1
Påk stolpe	1										1
Påk vägräcke	3	1				1					5
Påk övrigt	2										2
1:a sammanst		6	2	20	32	42			6	14	122
2:a sammanst		2	2	2	4					2	12
3:e sammanst		2									2
Omkörning		1	4		4				1		10
Filbyte			2		1						3
Man p/t vägb	15		3	2	4	6					30
Avk fr vägb.	22	1	2	1	1				1	2	30
Över mittrem	1										1
Omkull på vb	9	1	3	3	2	4			1	1	24
Vält utf väg	7		1			1			1	1	11
SUMMA	64	14	20	28	48	54	0	0	10	20	258
Vanlig väg 2+1, 2+2, 1+1											
Påk linräcke									1		1
Omkörning									2		2
Man p/t vägb									1		1
Avk fr vägb.									1		1
SUMMA	0	0	0	0	0	0	0	0	5	0	5

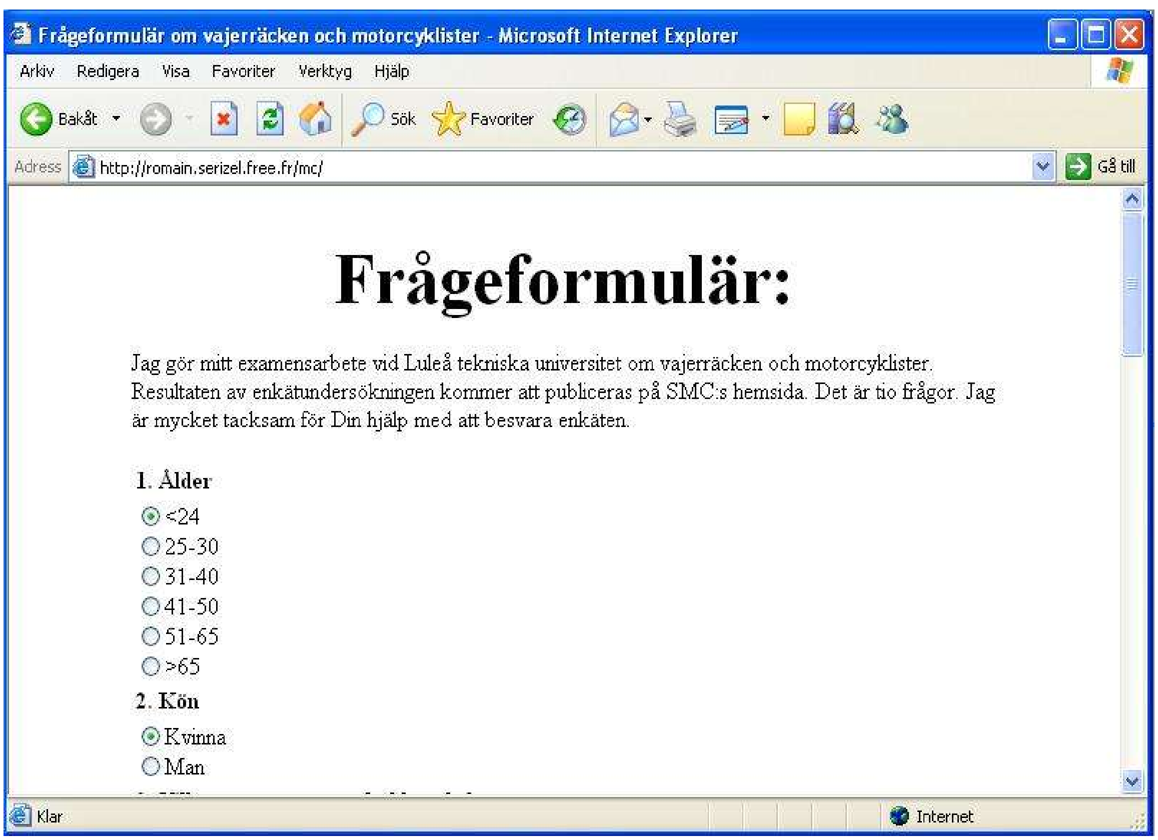
								2002			
Motorväg											
Påk vägräcke	2					1					3
Påk linräcke	1										1
1:a sammanst			6	10	6	8	2		2		34
2:a sammanst				2					2		4
Backning									1		1
Omkörning			3				1				4
Filbyte	1		4								5
Man p/t vägb	4		2	1		1			1		9
Avk fr vägb.	5		1	2		1			2		11
Omkull på vb	13		3	3	3	3	1				26
Vält utf väg	2								1		3
SUMMA	28		19	18	9	14	4	0	9	0	101
	22.6	0	16	21.6	3.6	5	0.8	0.4	4.2	1.8	76
Motorled											
1:a sammanst		2		2							4
2:a sammanst		2									2
Omkull på vb		1									1
SUMMA	0	5	0	2	0	0	0	0	0	0	7
	2.4	1	0	0.4	0	0	0	0	0.6	0.2	4.6
Motorled 2+1											
Påk linräcke	1										1
Man p/t vägb	2										2
Omkull på vb	1										1
SUMMA	4	0	0	0	0	0	0	0	0	0	4
	2.5	0	0	0	0	0.5	0	0	0	0	3
4 körfält i tätort											
-4											
Påk kantsten									1		1
Påk vägmärke									1		1
1:a sammanst			2	2	4	2			2		12
Omkörning			1		1						2
Filbyte									1		1
Man p/t vägb	1				1						2
Avk fr vägb.					1						1
Omkull på vb	1		1	1	2	1			1		7
SUMMA	2	0	4	3	9	3	0	0	6	0	27
	3.4	0	2	2.2	3.2	3.6	0	0.6	1.2	0	16.2
Vanlig väg											
Påk kantsten	2										2
Påk sten	1										1
Påk stolpe	2										2
Påk vägräcke	1			1							2
Påk viltst:l	1										1
1:a sammanst		8	2	14	16	22	4	2	8	24	100
2:a sammanst		2		4				2	2	2	12
Omkörning			3		2				1		6
Filbyte						1					1
Man p/t vägb	8	5		1	2	4		1			21
Avk fr vägb.	20	1	2	2	1				2	2	30
Omkull på vb	10	3		5		8				3	29
Vält utf väg	10	1	1		2						14
SUMMA	55	20	8	27	23	35	4	5	13	31	221
	51.8	11	23	23.8	46.4	38	4.2	3	11.6	27.4	240.2
Vanlig 2+1, 2+2 eller 1+1											
SUMMA	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0.5	0	0	1.25	0	7

APPENDIX E: INTERNET QUESTIONNAIRE

The questionnaire put up on SMC's website.



The questionnaire's website.



Original Swedish version of the internet questionnaire:

Frågeformulär:

Jag gör mitt examensarbete vid Luleå tekniska universitet om vajerräcken och motorcyklister. Resultaten av enkätundersökningen kommer att publiceras på SMC:s hemsida. Det är tio frågor. Jag är mycket tacksam för Din hjälp med att besvara enkäten.

1. Ålder

◉<24
○25-30
○31-40
○41-50
○51-65
○>65

2. Kön

◉Kvinna
○Man

3. Vilket typ av motorcykel kör du?

◉ Moped
○ Sporttouring
○ Supersport
○ Custom
○ Off road
○ Touring
○ Standard
○ Annat

4. Motorstorlek på din motorcykel

◉<50cc
○50-125cc
○125-400cc
○400-700cc
○700-1000cc
○1000cc – 1500 cc
○>1500 cc

5. Har du haft någon incident med vajerräcken?

◉Nej
○Ja

6.Vad är din reaktion när du ser vajerräcke?

A

◉Ökar hastigheten
○Sänker hastigheten
○Behåller samma hastighet

B

◉ Ökar avståndet till vajerräcket
○ Kör närmare vajerräcket
○ Behåller samma avstånd

7. Hur känner du dig när du kör på en väg som har vajerräcke?

◉ Mer säker
○ Mindre säker
○ Vajerräcket har ingen betydelse

8. Hur uppfattar du känslomässigt att färdas på en väg som har vajerräcke?

◉ Jag är rädd för att kollidera med vajerräcket
○ Det känns säkrare för att vajerräcket förhindrar frontalkrockar
○ Jag bryr mig inte om vajerräcket

9. Om du bestämmer dig för att åka alternativa resvägar, där det inte finns vajerräcken, vad är anledningen till detta ?

◉ Det går fortare på vägar utan vajerräcken
○ Det är säkrare på vägar utan vajerräcken
○ Jag väljer aldrig väg utifrån om de har vajerräcken eller inte
○ Annat :

10. Kommentarer i övrigt om frågorna eller om motorcyklister och vajerräcken rent generellt:

The questionnaire in English:

1. Age

○<24
○25-30
○31-40
○41-50
○51-65
○>65

2. Gender

○Female
○Male

3. Your motorcycle type:

○ Moped
○ Sporttouring
○ Supersport
○ Custom
○ Off road
○ Touring
○ Standard
○ Other

4. Engine size of your motorcycle:

○<50cc
○50-125cc
○125-400cc
○400-700cc
○700-1000cc
○1000cc – 1500 cc
○>1500 cc

5. Have you had any incidents with wire rope barriers?

○No
○Yes

6.What is your reaction when you encounter wire rope barriers?

A

○Increase speed
○Reduce speed
○Keep the same speed

B

○Increase distance from the barrier
○Decrease distance from the barrier
○Keep the same distance

7. Do you feel safer or less safe when ridging along the barriers?

○Safer
○Less safe
○Wire rope barriers have no influence on my feeling of safety

8. What do you feel when ridging along the barriers?

○ I am afraid of colliding with the barrier
○ I feel safer because the barrier prevents from head-on accidents
○ I do not care if the barriers are there or not.

9. If you decide to travel using alternative routes without wire rope barriers is it because:

◉ It is faster to travel on roads without wire rope barriers
○ It is safer to travel on roads without wire rope barriers
○ Wire rope barriers do not influence my choice of travel routes
○ Other :

10. Comments on the issue of motorcyclists and wire rope barriers

General results of the questionnaire:

1. Age

<24	25-30	31-40	41-50	51-65	>65
26	53	91	87	86	3

2. Gender

Female	Male
32	314

3. Motorcycle type

Moped	Supertouring	Supersport	Custom	Off Road	Touring	Standard	Annat
2	72	72	65	31	70	26	8

4. Engine size

<50	50-125	125-400	400-700	700-1000	1000-1500	>1500
2	0	6	76	137	114	11

5. Incidents:

No	Yes
336	10

6.Reaction

A

Increase speed	Decrease speed	Same speed
12	77	257

B

Increase distance	Decrease distance	Same distance
218	2	126

7. Feeling of security

More secure	Less secure	Barriers have no influence
69	238	39

8. Feeling when riding along wire rope barriers

Fear of collision with the barrier	Feeling of security because of the prevention from head-on collisions	No opinion
260	62	24

9. Choice of alternative routes without wire rope barriers

Alternative routes are faster	Alternative routes are safer	Wire rope barriers have no influence on choice of routes	Other
15	101	191	39

Comments of those who answered that had an incident with wire rope barriers:

Som bilist tycker jag om vajerräcken, men som mc-förare är jag skraj. Var med om en olycka sommaren-04 på just vajerväg. Jag kanade självk på asfalten längs med vajerräcket, men MC:n for som en vante och snurrade runt kring stolparna. Vill inte tänk på vad som hade hänt om jag själv hade farit in i dessa.

Känner mig instängd på väg med vajerräcken, många gånger sitter det på båda sidorna vilket gör att jag inte har någon flyktväg om det skulle ske något.

Livsfarligt med trängande bilister och taskiga avstånd. Nästan omöjligt att sänka farten vid behov för rädsla att bli påkörd bakifrån.

Pga. ren bonntur så kan jag säga att jag inte blev ett offer för dessa räcken då jag gled ikull på en av våra fruktasnvärt dåligt underhållna vägar. Framhjuls släpp i låg fart och pang i backen. Cykeln in i räcket och totalskrot, jag liggandes på mage mellan stolpar och under vajjern. Det gick bra för mig men när kommer den första dödsolyckan? Allt snack om nollvisionen och sedan ställer vi ut dödsfällor på och brevid vägarna. Men visst, det är en fördel att slippa möten på fel väghalva, men dock den enda.

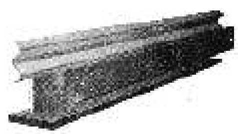
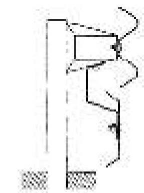
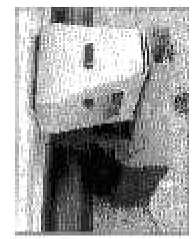
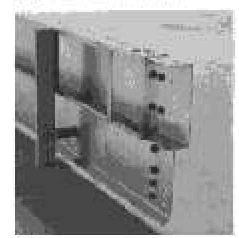
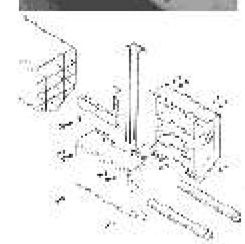
Att alltid köra mitt i körbanan (ta plats) när det finns vajer för att inte bli tryckt av vägen och in i vajern som ibland finns på kanten av vägen.

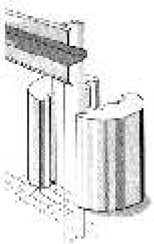
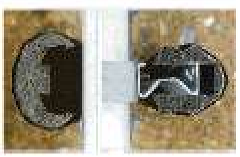
MC-åkare offras av ekomomiska skäl på vajerräcks altaret på grund av den rådande politiska trafikreligionen, där inga protester är tillåtna. Ve den politiker eller samhällsdebatör som har andra åsikter än den som trafikreligionen föreskriver, han eller hon är "totalt ute" och får naturligtsvis inget utrymme i masmedia.

All results are available at: http://romain.serizel.free.fr/mc/results/

APPENDIX F: MOTORCYCLE-FRIENDLY DEVICES

Source: [25]

Motorcycle-friendly Roadsides: BARRIERS	Company Model	Costs (july 99)	Type	Details	Address & Contact details	
	Sec Envel Ecran Motard	Material 12 €/m Fitting 3 €/m	Adaptable to existing rail	Cheapest «secondary rail» approach	SEC Envel 18 rue Pasteur F-77250 Veneux les Sablons T: +33 160709393 F: +33 160709999	
	Sodirel Mototub	Material 21 €/m Fitting 2 €/m	Adaptable to existing rail	Made up of 70% recycled material	Sodirel Route d'Orange F-84100 Uchaux T: +33 490111600 F: +33 490516240	
	Solosar Motorail	Material 38 €/m Fitting 6 €/m	«All in one» solution	Integrated solution: Cost of metal barrier included (estimated cost of metal barrier without metal shield: 18,3 €/m)	Solosar 3 rue G.Schoettke ZI Parc d'activités du Grand Bois F-57200 Sarreguemines T: +33 387985604 F: +33 387955593	
	Sodilor Railplast	Material 23 €/m Fitting 4 €/m	Adaptable to existing rail	Joining the advantages of the «secondary rail» and the «impact protector»	Sodilor Rue du champ de Mars BP 40739 F- 57207 Sarreguemines cedex T: +33 387982588 F: +33 387984656	

Motorcycle-friendly roadsides: **POST PROTECTOR**	**Company** **Model**	**Costs (july 99)**	**Description**	*Recommendation of use depends on the profile of crash barrier post. Contact Company directly for best advice.*	**Details**
	ADV SPU	Material 10,5 € Fitting ?	2 (½) shells	Adaptable to existing rail	Firma ADV Postfach 110067 D-63434 Hanau T: +49 6181661748 F: +49 6181499276
	Salzer Formtech Rectangular CBP	Material 4,6 € Fitting ?	1 single ¾ shell	Adaptable to existing rail	Salzer Formtech Stattersdorferstrasse 50 A-3100 St Poelten T: +43 2742290313 F: +43 2742290333
	Volkman & Rossbach SPU Crash Absorber	Material nc Fitting ?		2 (½) shells clipping together	Volkman & Rossbach Hohe Strasse 11-19 D-56401 Montabaur T: +49 26021350 F: +49 26021349

Posts are usually located every 2 meter or every 4 meter.

Motorcycle-friendly roadsides: ALTERNATIVE SOLUTIONS FOR NEW INSTALLATIONS	Type	Costs	+	-	Remarks	Details
	Concrete Walls	38 €/m	Lower maintenance costs Prevents truck crossover	No impact absorbtion property Not recommended in nordic countries	Motorcycle "friendliness" depends largely on the profile used «All in one» solution	Costs valid only for large quantities
	Obstacle free roadsides	Variable	Benefits all categories of road users Increases visibility at road junctions		Feasibility depends on road layout and location	
	Shrub planted roadsides	Variable	Benefits all categories of road users Can reduce glare on central reservation of motorway	Requires some leeway area where shrubs can grow	Complementary to the «obstacle free» roadside approach	

Computer simulations