Criteria for roadside safety of motorways and express roads

A proposal for road authorities in the framework of the European research project SAFESTAR, Workpackage 1.2.

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Safety standards for road design and redesign

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	NTUA	*National Technical University of Athens; Athens, GR*
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Summary

To protect occupants of vehicles that leave the road from serious injuries, safe roadsides and medians are important. This report describes the way to make safe roadsides by means of obstacle-free zones, slopes, frangible poles, crash cushions and safety barriers.

The research performed here aims to define criteria for places where safety devices are necessary. The research was carried out by means of a literature study including the national European standards. Furthermore, results from a questionnaire which was send to European institutes and ministries are described. This questionnaire contained for instance questions about national standards and/or criteria for use of safety barriers, and about accident data on motorways and express roads where safety barriers were involved.
Data from European countries, but also from the United States were analysed to prepare a proposal for standards and strategies for EU-countries.

The first issue of the report deals with the desirable width for the obstacle-free zone. Figures are presented about the only European research carried out in the Netherlands in the 1980's. Figures for motorways, single-lane highways and local single-lanes are given. Based on the questionnaires, distances of obstacle-free zones from other European countries are mentioned.

The second issue is a shoulder with safe slopes. Figures from the United States and European countries are discussed. The figures from the Netherlands are based on mathematical simulations and twelve full-scale tests on slopes with two gradients.

If fixed objects are made to yield, the third issue, they can be placed in an obstacle-free zone without safety barriers. Different solutions are mentioned, such as slip base, plastic hinges, fracture elements or a combination of these.

The fourth issue deals with crash cushions. If solitary rigid obstacles along a shoulder cannot be removed, they can be shielded with a crash cushion. Crash cushions are applied on motorways in mainly two different situations: in pointed areas at exits (often at the beginning of a safety barrier) and on shoulders to shield single objects. If crash cushions have been hit head-on, the vehicle usually remains within the shoulder so that it forms no danger for other traffic. In the case of a side impact, most types of crash cushions function like a safety barrier. Several European countries have their own, different types of crash cushions.

In the concept of a safe road side (shoulders and medians), protection with safety barriers is the least safe solution (the last issue). An effectively functioning safety barrier prevents a vehicle from leaving the roadway and striking a fixed object or terrain feature that is considered more hazardous than the barrier itself. But a collision with a safety barrier is never free from the risk of injuries for the occupants of the colliding vehicle, nor is it for other road users. Requirements, CEN standards, containment levels, differences between steel and concrete barriers, and Dutch experiences with mathematical simulations are described.

Proposals for motorway standards and strategies for EU countries are discussed. There are safety reasons for favouring wide obstacle-free zones. Based on information from many European countries a minimum width of 9 metres is recommended. Also is recommended to carry out accident investigations in different European countries to collect more data in order to take a more well-founded decision for the European situation.
Slopes may be a part of an obstacle-free zone if vehicular manoeuvres are possible. This is the case with a gradient of at least 1:5 for high slopes (> 5 m) and 1:6 for lower slopes (< 2 m). Only fixed roadside objects can be located within an obstacle-free zone, if their support poles are frangible. If solitary rigid obstacles can not be relocated, protecting them with a crash cushion is the solution.
In the report a decision model is described for determining the choice for shoulders and the median: obstacle-free or safety barriers. If a decision is made for a low containment level, steel barriers are in favour if only the installation costs are calculated. Taking into account other aspects, it depends on the local circumstances which type of barrier is to be preferred. Differences between countries are too great for a general statement.
Also for express roads and single carriageways recommendations are given for the width of obstacle-free zones and the necessity for safety barriers.

The single carriageway roads are in fact at the heart of the problem of obstacle accidents in Europe. There are many of such accidents because there are so many old roads. Unfortunately, accidents with "natural" obstacles such as trees, are widely spread so that dealing with them cannot be targeted at concentrations of dangerous locations. Apart from the erection of safety barriers, the driving speeds will have to be drastically reduced to increase the safety of such roads. Subsequently, this means that the road's function will be changed. A procedure has been described for identifying the locations and establishing priorities for those most requiring the placing of safety barriers. As a cost-benefit analysis, the "one million ECU test" of the European Commission can be applied.
A strategy developed in America to deal with these problems, appears to be applicable also in Europe. It concerns for instance better accident monitoring, research, more attention (education, spreading information, good management), and greater budgets.

Contents

1. Introduction

1.1. Objectives

To prevent occupants of vehicles that leave the road from serious injuries, safe roadsides and medians are important. Free-zones, safety barriers, and impact attenuators are effective to realise this.
The CEN standards for safety devices, that are currently being developed, ensure the effectiveness of these devices, but say nothing about the road characteristics and circumstances in which they should (or should not) be applied.
There are a number of characteristics of road and traffic environment that, in conjunction, determine whether or not a certain situation needs the protection of safety barriers. Examples of these characteristics are: average traffic speed, width of lanes and strokes, width of the emergency lane, width and material of the road shoulder, and slope of the shoulder. Also the presence of ditches near the roadside and fixed obstacles play an important part. These are based on a literature study.
The research proposed here aims to define criteria where safety devices are necessary. This is based on a general design philosophy for safe shoulders on motorways (and express roads), and based on design criteria for safety devices.
But also there is a need for criteria to chose for steel or concrete barriers, the containment level of barriers will be a part of these criteria.

The target groups of this report are the road authorities in the TERN-framework, national road authorities in the EUROPEAN countries, authorities in departments, and (technical) staff responsible for road design and/or safety devices. More uniformity concerning safe shoulders on European roads will be the final goal.

1.2. Method

The research was carried out by dividing the study in several subjects.
The characteristics of road and traffic environment have been based on a literature study. It has been provide an inventory of the relevant characteristics. This data was used to prepare a questionnaire for European institutes and ministries.
The questionnaire contained questions about national standards and/or criteria for using safety barriers, specifications of construction types, presence of safety barriers with a distinction in steel and concrete, and accidents on motorways and express roads where safety barriers were involved. There was also a request to send copies of recent research reports concerning these subjects and specially about cost-benefits.
The European accidents were complemented with data from an accident study carried out by SWOV.

1.3. Interaction between the function, criteria and standards concerning the roadside

1.3.1. *Function*

Besides the function in a technical sense (drainage, location of signs and so on), the roadside has a function to prevent errant vehicles colliding. A mistake or an emphasized manoeuvre have to be possible without resulting in a serious accident. Also, in case of troubles with the vehicle, it has to be possible to leave the carriageway.
Motorways with an emergency zone are in this case well equipped. For express roads there is at least a need for an emergency zone, hardened or not. But accident data shows that an emergency zone in many cases is too small for errant vehicles. The distance that vehicles penetrate the shoulders depends, for instance, on the velocity . The number of errant vehicles is related to the traffic volume. These two traffic characteristics are related to the type of road. Therefore, criteria and standards for the roadside should be connected with road classification.

1.3.2. *Criteria*

Creating a safe roadside the following criteria are important: safety, engineering possibilities, aesthetics, and costs. Some criteria deal with qualitatively norms, others with quantitative norms.
Safety may have a more prominent position if the immediate reason for designing a new situation (rather than a complete road) is a hazardous existing situation, like a steep slope, or a row trees at a short distance from the roadside. A safety audit can be associated with the design of large road projects. The audit ensures an independent review of the design process to guarantee that the highest possible level of safety is achieved, inclusive that of the roadside.
To determine if a roadside is safe, it is helpful to have input conditions (average traffic speed and width of lanes and strokes for instance) and criteria (acceptable vehicle manoeuvres, human tolerance).

1.3.3. *Standards*

Standards have been drawn up in order to help engineers to design the roadside. Standards are helpful on at least two levels :
- the application of expertise;
- uniformity.

McLean (1980) has added the following statements to standards: "The three major bases for the formulation of road geometric design standards were: empirical research, a consensus of good practice and a rational, or logical framework". The more the engineer is convinced that these requirements are involved, the sooner he would like to apply the standard to achieve traffic safety.

In this report an attempt is made to search for standards in the framework of the design of the roadside and with backgrounds relating to safety aspects and good practice. A procedure is described to select unsafe locations.
Results from cost-effectiveness studies can be used to determine the measures.

2. Investigation by questionnaires to European countries

2.1. The questionnaire

A questionnaire for safety barriers on motorways and express roads was made and sent to all specialist of European countries. For the exact contents see *Appendix 1*.
The following subjects were asked about:

- national standards and/or criteria for making the decision to locate safety barriers;
- containment levels of the national barrier construction types;
- presence of safety barriers with a distinction in steel and concrete (rough estimation);
- accidents on motorways and express roads where safety barriers and off-the-road accidents were involved; accident data was asked with the following characteristics: number of injury accidents and number of fatalities and injured persons;
- copies of recent research reports concerning safety barriers, and particularly the differences between steel en concrete barriers, together with aspects such as costs, accidents, cost-benefits.

About the criteria to locate safety barriers it was asked in question 3: "What is the width of the obstacle-free zone if there is no need for a safety barrier?". In this term the question is formulated owing to the difficulties O'Cinneide had found. O'Cinneide (1994) has investigated the geometric road design standards and operational regulations of EUROPEAN and EFTA countries. A part of this investigation concerns the standard cross-section dimensions for motorway. As methodology was adopted an analysis of the national standards and information from questionnaires. O'Cinneide concluded that the cross-section shoulder dimensions for similar road types differ between countries. The problem was that some countries give the dimensions inclusive the presence guard rails, and others exclusive the guard rails. O'Cinneide's project was carried out as part of the European DRIVE programme.

2.2. Response

The total answers to the questionnaires are given in *Appendix 2*.
Table 1 gives a list with countries that received a questionnaire and a summary of the response.
Questionnaires were sent to 16 European traffic safety institutes or ministries. 13 questionnaires were completed, a response of c. 80%.
In some cases when a country did not give any data on a subject, but that data was available in the literature, we have filled in the missing value in the questionnaires. In that case the literature resource is documented.

Questionnaires to	**Response**
Austria	-
Belgium Flanders Belgium Wallonia	x -
Czech Republic	x
Denmark	x
Germany	x
Greece	x
Finland	x
France	x
Italy	-
Netherlands	x
Norway	x
Portugal	x
Spain	-
Sweden	x
Switzerland	x
United Kingdom	x

Table 1. *Countries that received a questionnaire with the response.*

2.3. **Results**

In this section the items of the questionnaires will be described. Firstly the presence of standards in the different countries (*Table 2*).

National standards	Motorways	Express roads
Standards	11	9
No standards	2	2
Unknown	-	2
Total	13	13

Table 2. *Number of countries with national standard for barriers for motorways and express roads*

Most of the countries have standards both for motorways and express roads. Asked is for the width of the obstacle-free zone in the standards, if there is no need for a safety barrier. The results are given in *Table 3*.
The width differs largely for several countries. The mean value is 6 - 7 m for motorways and 4 - 5 m for express roads. Yet 4 countries have a width of 10 m or more.

Width obstacle-free zone (m)	For *motorways* the number of countries	For *express roads* the number of countries
< 4	1	3
4 - 5	3	5
6 - 7	3	2
8- 9	2	3
≥ 10	4	-
Total	13	13

Table 3. *The number of countries with a given width for the obstacle-free zone for motorways and express roads according to the standards.*

The next question concerned the containment level of barriers. The levels are according the CEN standards for testing safety barriers (see *Table 4*).
Most of the countries have a 'normal' containment level or higher for barriers.

Containment level of barriers for motorways [1]	Steel barriers	Concrete barriers
Low (T1-T3)	--	--
Normal (N1-N2)	6	3
High (H1-H3)	3	6
Own levels	2	2
Unknown	2	2
Total	13	13

[1] If in a country more levels are usual, the lowest level is chosen

Table 4. *Number of countries and the usual containment level of barriers for motorways in their country*

Also was asked for the containment level of barriers with a high class of performance (steel and concrete are summarized). The questionnaire offered the possibility to give different answers for steel and concrete; nevertheless no difference was reported. Ten countries replied with:

H1: 1 countries
H2: 5 countries
H3: 1 countries
H4: 1 countries
Own standards: 2 countries

The representatives of the countries were asked to make a rough estimation of the amount (in percentages) of the presence of steel and concrete barriers (*Table 5*).
In most of the countries the presence of steel barriers, both in the median as well as in the shoulder, is 95% or more.

Percentages steel / concrete barriers	Number of countries for the medians	Number of countries for the shoulders
40 / 60	1	
65 / 35		2
70 / 30	1	
75 / 25	1	1
80 / 20	1	
90 / 10	1	
≥95 / ≤5	8	10
Unknown	-	-
Total	13	13

Table 5. *Number of countries with a certain percentage of steel and concrete barriers for the median and shoulder of motorways (rough reported estimation).*

The next questions were I.6 and I.7 from the questionnaire, and their results are shown below.

I.6. Question: "What are the criteria to place a high performance barrier". In the table the number of countries that has marked one or more criteria. Danger for lower sited roads, a narrow median, and a high percentage of heavy traffic are the most frequent answers.

- high volume traffic	3
- percentage heavy traffic	4
- narrow median	5
- narrow cross section	1
- danger for on coming traffic (median)	2
- danger for lower sited roads, buildings (roadside)	9
- maintenance of barriers	2
- others (bridge parapet, noise protection, water area protection, rail crossing)	6

I.7. Question: "What are the criteria to place concrete barriers instead of steel ones". In the table below also the number of countries that has marked one or more criteria.

- costs	3
- environment aspects	4
- high volume traffic	4
- percentage heavy traffic	1
- narrow median	6
- narrow cross section	2
- danger for on coming traffic (median)	2
- danger for lower sited roads, buildings(road side)	1
- maintenance of barriers	7
- others (water area protection)	2
- in general: median concrete and shoulders steel	1

According to the answers to question I.7, the maintenance of barriers and narrow median are the most frequent answers.
In relation to the containment levels of barriers, we shall discuss these items in more detail in section 4.6.4.

3. Accident analyses

3.1. Injury accidents with safety barriers on motorways

Safety barriers are erected to prevent vehicles that run off the carriageway from landing in a danger zone. For double-2 lane roads, the other carriageway is seen as a danger zone, this being the reason that median crash barriers are in standard use in these situations. Another possible danger zone is the right shoulder when obstacles and steep slopes are located within short distances from the carriageway.

Erecting safety barriers is not always an absolute safe solution, however. The results from the inventory by means of questionnaires as described in the former chapter, provides figures from only some European countries. Asked is for 'injury accidents' and 'fatalities'. We are not sure that always the difference between the number of *accidents* and the number of *killed persons* is correctly understood.

Country	Injury accidents (%)	Fatalities (%)	Hospital casualties (%)
Belgium Flanders	22.7	21.2	23.3
Denmark	20.0	17.7	23.9
Germany	19.7 [1]		
France	c.18		
Netherlands	20.3	19.1	21.2

1) Including the MDO accidents (material damage only)

Table 6. *Percentages of accidents and casualties involving crash barriers related to the total number of accidents and casualties on motorways.*

This summary shows that approximately 20% of the injury accidents on motorways is the result of a collision with a safety barrier. For persons killed and victims requiring hospital treatment as a result of accidents on motorways, these figure are approximately 20% and 23%, respectively. The German figure for all accidents, including MDO accidents, is entered in the table as an indication.

Dutch figures
These accident figures include vehicles that have run off into areas that are both to the left and the right of the carriageway of motorways. Interesting is to make a comparison with a situation in which no barriers are installed at all; for instance the Dutch single-lane regional highways. Then 36% of the fatal accidents result from a vehicle leaving the carriageway; the accidents on intersections are not included. The percentage indicates the danger when no safety barriers are erected. Although the conditions on motorways differ from those on road sections of single-lane roads, we do get an indication of the effect of safety barriers.

This effect can also be seen when we compare the percentage of fatal accidents involving collisions with safety barriers as opposed to the percentage of fatalities involving collisions with other obstacles. For the safety barriers on Dutch motorways, this percentage is four times lower. The accidents on motorways involving safety barriers which occurred from 1992 -1995 were analysed in more detail. The 2,823 accidents caused 158 deaths and represent 19% of the total fatal accidents on motorways (see also *Table 6*). Fifty-six percent of the victims killed in these accidents died as a result of their vehicle colliding against the safety barrier in the primary phase of the accident. The remaining percentage of victims died as a result of their vehicle colliding against the safety barrier in the secondary phase of the accident.

Classified the primary phase accidents by type of vehicle, we get the following distribution (*Table 7*):

Vehicle type	Percentage
Passenger car	70
Trucks	8
Van	4
Motorcycle	18
Total	100

Table 7. *Distribution of vehicle types related to accidents with safety barriers in the primary phase of the accident.*

Type of crash	Percentage
Rollover	35
Stop near barrier	25
Rebound on road	23
Through barrier or over the top	17
Total	100

Table 8. *Distribution of crash type related to accidents with safety barriers in the primary phase of the accident (only cars).*

Table 8 provides the results in the primary phase of the type of crash (e.g. rollovers). In 75% of the accidents, the vehicle or the safety barrier displays an undesirable behaviour (rollover, rebound and through barrier/over the top).

Other figures show that 63% of the fatal accidents involving safety barriers take place in the median. The fact that this percentage is higher than accidents involving the right shoulder is not surprising when considering that substantially more safety barriers have been erected in the median.

Accidents with different types of safety barriers

Concerning accidents with different types of barriers, in the Chapters 5 (The difference between steel and concrete barriers) and 6 (Cost-effectiveness) many studies are described from different countries.

Unreported accidents: United States

On the basis of reported accident data in the United States, from 50 to 60% of guardrail accidents involve an injury or a fatality (Michie & Bronstad, 1994). From this highway engineers have concluded that guardrail installations are a roadside hazard. By using a more in-depth study of accident data and estimates of the frequency of unreported accidents, a more positive view of guardrail performance is projected. Assuming there are no injuries or fatalities in the unreported drive-away accidents, only 6% of all guardrail impacts involve any injury or fatality.

3.2. Characteristics

3.2.1. *Pre-crash*

From accident studies and data from the literature we know that there are a lot of causes why vehicles left the carriageway. A main division can be made in more or less *uncontrolled* and *controlled* manoeuvres.
Uncontrolled manoeuvres could be the consequence of losing the control over the vehicle, slippery manoeuvres, an accident with a other vehicle, technical failures etc.
In case of e.g. evasion manoeuvres there could be a case of a controlled manoeuvre.

The characteristics of both types of manoeuvres are:
The (more or less) uncontrolled manoeuvres

- slippery vehicle;
- relatively large exit angle of the centre of gravity of the vehicle related to the edge of the road;
- uncontrolled braking which increases the instability of the vehicle;
- uncontrolled speed reduction of the vehicle owing to slipping and rotating.

The (more or less) controlled manoeuvres

- straight trajectory;
- relatively small exit angle related to the edge of the road;
- controlled speed reduction owing to the opportunity to break effectively.

These pre-crash characteristics are the input conditions taking into account the lay out of the obstacle-free zone and for testing roadside safety accessories.

3.2.2. *Characteristics of the off-the-road vehicle*

In the crash phase of the accident, if the vehicle has left the carriageway, we had to deal with the following characteristics:

- the velocity of the vehicle;
- the rotating velocity;
- the exit angle of the vehicle (in case of a slippery vehicle, the angle of the centre of gravity of the vehicle with the edge of the road);
- braking or non-braking;
- speed reduction owing to rotating and/or braking.

The condition of the verge is also responsible for the way the vehicle crosses the shoulder.

3.2.3. *Severity of collisions with obstacles*

If obstacles are located in the shoulder, the severity of the collision with these obstacles depends on the extent of aggressiveness of the obstacle, the vehicle velocity and impact point at the vehicle, the extent of energy absorption of the vehicle, and the use and presence of restraint systems in the car.

3.2.4. *Input conditions tests safety barriers*

The above-mentioned characteristics were the basis for drawing up the input conditions for testing road restraint systems according the CEN/TC 226 standards.
The following test conditions are established for safety barriers:
- impact velocity (65 - 110 km/h);
- impact angle (8° - 20°);
- vehicle type (passenger car, bus, truck [rigid and articulated]);
- vehicle mass (900 - 38,000 kg).

The following test conditions are established for crash cushions:
- impact velocity (50 - 110 km/h);
- impact angle (0° - 15°);
- vehicle type (passenger car);
- vehicle mass (900 - 1500 kg).

Combination of impact velocity, impact angle, and vehicle mass are used providing the severity impact class to test the performance of safety devices according the CEN-standards.

In the United States other test conditions are involved (AASHTO, 1989).
First test: 1800 lb, 60 mph, 15°;
Second test: 4500 lb, 60 mph, 25°.
If tests with trucks were carried out, weights of up to 80,000 lbs are involved.

The Czech Republic has their own standards for testing and approval safety barriers. These technical specifications are based on the 1992-draft of the European Standard CEN/TC/226/WG 1 "Road Restraint Systems". The minimum testing speed is 65 km/h and the impact angle range from 15° to 25°. Performance class of safety barrier range from A1 to C1, resp. 30 to 570 kNm kinetic energy of impact (Czech Republic, 1994).

The (CEN-) tests, however, provide no definite answer as to the way in which the constructions behave under the many conceivable - as well as inconceivable - collision conditions such as slipping, braking, and steering manoeuvres. Mathematical simulations offer more possibilities in this respect. For several years in the United States it has been investigated whether the American set of test conditions reflects the real world accident characteristics. This is a critical factor in evaluation the hardware's anticipated effectiveness. An analysis of investigated injury accidents at narrow bridge sites related the actual accident impact conditions imposed in crash test matrices. As shown in the next data, a large number of these severe accidents exceeded at least one of the crash test conditions (McCarthy, 1987).

excess speed	20% (% of total investigated accidents)
excess angle	53%
braking	45%
not tracking	45%

Although the above mentioned accidents represent a small sample of injuries and fatalities (N=81), the data provides important insight into the actual dynamics of run-off-road accidents. In 70% of the reconstructed accidents, the vehicle sustained a secondary impact following a smooth redirection from the initial impact with the barrier. Such secondary impacts tend to dramatically increase the occupants risk because of: a) higher impact angles; b) the vehicle not tracking at impact; c) a collision with unprotected objects; d) vehicle rollover.

3.3. Risk and models

The risk vehicle leaving the road depends on many circumstances. Models developed in the United States include, for example, the following parameters: traffic volume, (design) velocity, alignment, distance to obstacles, rigidity of obstacles. The question is how useful these models are for the European situation. An exercise was carried out in the Netherlands by a consultancy office and SWOV (Goudappel Coffeng, 1988; Schoon, 1988). After an inventory, two models were selected for this exercise. These models were those of Hall & Mulinazzy (1978) to determine the risk index of a road section, and the model of Labadie & Barbaresso (1982) to determine the priority factor for selecting hazardous road sections.
The conclusion of this exercise was that these models were not useful in the Dutch situation for detecting hazardous road sections. If hazardous sections had to be selected on one road, the models selected only at the parameters presence of a curve, distance to obstacles, and rigidity of obstacle. No parameters were involved to select specific locations in relation with the curves. Also the values of the parameters were not appropriate for the Dutch situation.
In the report some remarks are given to improve the choice of parameter. These remarks are related to the situation that off-the-road-accidents happen especially at night:

- The traffic volume at night is more appropriate to use in a model than the daily traffic volume.
- The same fact applies to the velocity: it is more appropriate to take the percentage driving speed at night than a average for the whole day.
- The sight distance at night and under bad weather conditions.

A method for assessing the safety of roadside design by means of a software tool is described by Ray (1994). The method is used for ranking problem sites, evaluating alternative sites and allocating scarce highway improvement resources. The software tool separates the process of performing safety analysis from the details of the probablistics models. The probability of an accident with a certain severity involving a particular hazard is given by the parameters:

- probability of encroaching onto the roadside;
- probability of colliding with an object (given that an encroachment has occurred);
- probability of a severity injury (given that a collision has occurred).

Severity indices which serve as indicators of the expected injury consequences of a crash, are an integral part of the analyses of proposed roadside safety improvements (Hall, Turner & Hall, 1994). Although research since the 1960s has sought to quantify severity indices for a range of object types and impact conditions, wide variations remain in the values. The paper contents an interesting summary of severity indices found in reports and in use by different authorities of highway in the United States (*Table 9*).

Object	NCHRP 148[1]	FHWA[2]
Sign support - breakaway - rigid	 0.22 0.53	 1.7 5.3
Luminaire support - breakaway - rigid	 0.22 0.53	 2.8 5.5
Guardrail face	0 33	3.6
Tree (medium size)	0.50	5.5
Embankment - slope 6 : 1 - slope 3 : 1	 0.22 0.53	 2.6 4.0
Utility pole	0.53	5.5
Bridge pier	0.70	5.5

1) represents the portion of accidents resulting in a fatality or injury
2) represents the average severity (on a scale of 0 - 10) for 97 km/h (60 mph) design

Table 9. *Comparison of severity indices from different sources (United States. 1974, 1991)*

Although the values clearly differ, the general pattern of more severe objects remains relatively consistent. Despite continual improvements in severity indices during the past three decades, inconsistencies and difficulties remain. To clarify the current state of practice in understanding and using severity indices, a survey under national and local highway agencies was conducted. The national survey results show that the experts have greater problems with severity indices than with other aspects of roadside cost-effectiveness evaluations. Local analysts and designers found it extremely difficult selecting and justifying their choice of severity indices, accident costs, and encroachment parameters.
The findings of the project offer several opportunities for additional research: correct the deficiencies of the roadside safety evaluation methods; expand the list of severity indices to facilitate proper analysis; expanded training in the area of roadside cost-effectiveness methods; improve the quality and accuracy of severity indices. Concerning the latter issue, an optimal method for undertaking this type of study is not certain. A meaningful study based on accident and roadway data would require extensive high-quality databases and would need to account for unreported accidents.

Another study concerned approximately 1000 km French motorways between Paris and Perpignan (Martin et al., 1997b). Accident data was gathered since 1985. The accident data base is linked in this study with the database of regularly updated road infrastructure. It was found that the severity of crashes where vehicles run off the road is on average significantly higher in the absence of a safety barrier. The higher severity values are connected with vehicles which run off the road in the presence of embankments (height < 4 m) or ditches. Unfortunately in the French study, no (average) lateral distance is given from the edge of the carriageway to the embankments and obstacles.

Especially the guardrail ends give very high values of the calculated risk. The proportion rollovers as result of a collision at these ends is higher than that for a collision with safety barriers on sections (resp .21% and 8%). In order to minimize the number of safety barrier ends, regulations were made by example, that successive safety barriers had to be connected if the gap is less than 100 m.

The analyses per vehicle class does not show a noticeable difference with the exception of motorcycles. For motorcycles the risk of being injured when running of the road onto the right shoulder is approximately half when there is no safety device compared with shoulders with safety devices.

Since 1985 the presence of safety barriers in the shoulders on the motorways has increased from approx. 45% to 70%.

4. Concept of a safe roadside

4.1. Introduction

The question is: can we reduce the high percentage of injury accidents resulting from a collision with a safety barrier or an obstacle, and if so, how? Obviously, taking precautions to prevent these collisions in the pre-crash stage is needed, but these measures are not included within the framework of this report. Our point of departure, thus, is a vehicle that leaves the carriageway under any circumstances. It is the task of road authorities to assure that such an incident does not result in an accident involving seriously injured casualties. The possibilities for achieving this are:

1. a shoulder without obstacles (and without safety barriers);
2. a shoulder with safe slopes;
3. a shoulder with fixed objects that yield easily upon collision;
4. a shoulder with crash cushions;
5. a shoulder with an effectively functioning safety barrier.

This list is lined up with the strategy used in the United States called 'create forgiving roadside'. The Federal Highway Administration gives the four points creating a forgiving roadside (FHA, 1986):

- remove fixed object and provide traversable terrain features;
- else: try to relocate fixed objects;
- else: make the hazard object breakaway or crashworthy;
- else: shield the hazardous zone with guardrail.

From the list of five possible solutions the first four can be qualified as the best. They are be discussed in this chapter. The next best is the erection of safety barriers; this subject will be extensively discussed.
Owing to the systematical research carried out in Europe in relation with this list of five possible solutions, much research will be quoted from investigations carried out by SWOV under the authority of the Ministry of Transport. In addition research and data from standards from other European countries will be mentioned.

4.2. A shoulder without obstacles

The question that immediately arises when discussing an obstacle-free zone is how wide this zone should be. Every report beginning with this topic refers to American research from the 1960's and 70's. Since that time, hardly any more studies on this subject have been carried out in the United States, as far as we know Although these studies were extremely valuable and have been used as a guiding principle in many European countries, their figures are based on the American situation. Two factors in these studies which differ considerably from the current European situation are the differences of vehicle mass and driving speeds.

The only known study carried out in Europe into a desirable width for an obstacle-free zone was done in the Netherlands in the 1980's (Schoon & Bos, 1983). This study involved road sections lined with rows of trees; these rows being located at various distances from the edge of the road. What this research establishes is the relationship between the accident ratio and the distance that vehicles travel into the shoulder when an accident occurs. This ratio is the number of accidents involving trees as opposed to the number of accidents not involving trees.

This relationship was worked out for three types of road: motorways, single-lane highways, and single-lane regional highways (see the three graphs here below).

In next graphs traffic intensity (ADT) is used as a parameter; the curves are regression lines based on the given data points. In the graphs is indicated whether the regression lines are significant or not.

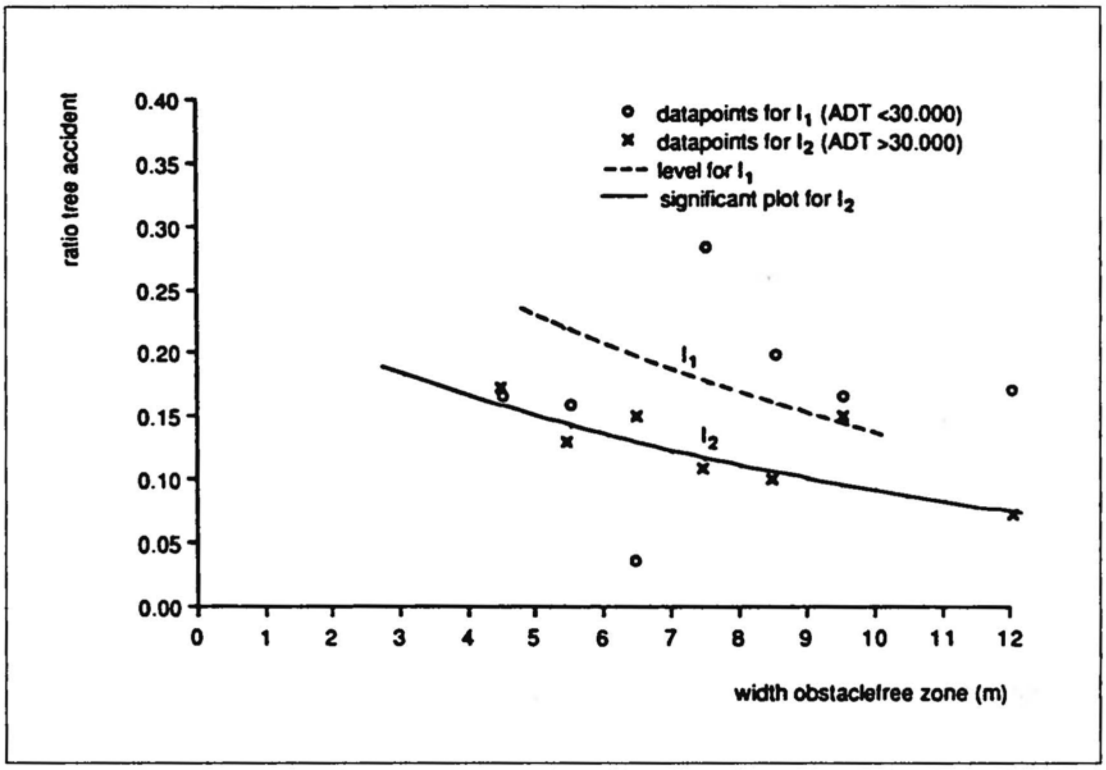

Figure 1. *The relation between the ratio of tree accidents (tree accidents v. the other accidents) and the distance that vehicles travelled into the obstacle-free zone for* ***motorways****. The regression curve for a ADT of >30.000 is significant.*

From *Figure 1* it can be seen that when trees are planted at a distance of approximately 10 metres from the road, 10 out of the 100 accidents occurring there involved trees (significant regression curve). The distances are measured from the painted marking line of the right traffic lane.

Below follows the same type of graph for single-lane federal highways (*Figure 2*).

From *Figure 2* it can be seen that when trees are planted at a distance of 7 metres from the road, 10 out of the 100 accidents occurring there involve trees. The distances are measured from the border line on the right traffic lane.

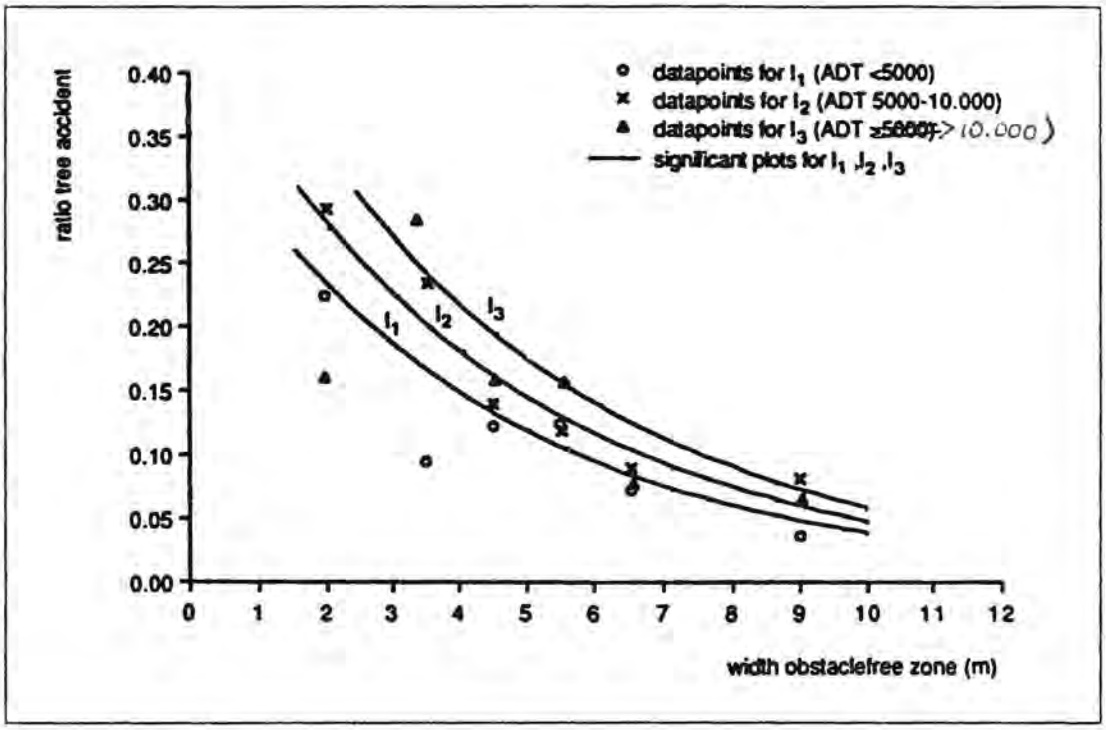

Figure 2. *The relation between the ratio of tree accidents (tree accidents v. the other accidents) and the distance that vehicles travelled into the obstacle-free zone for the* ***single-lane federal highways****. All regression curves are significant.*

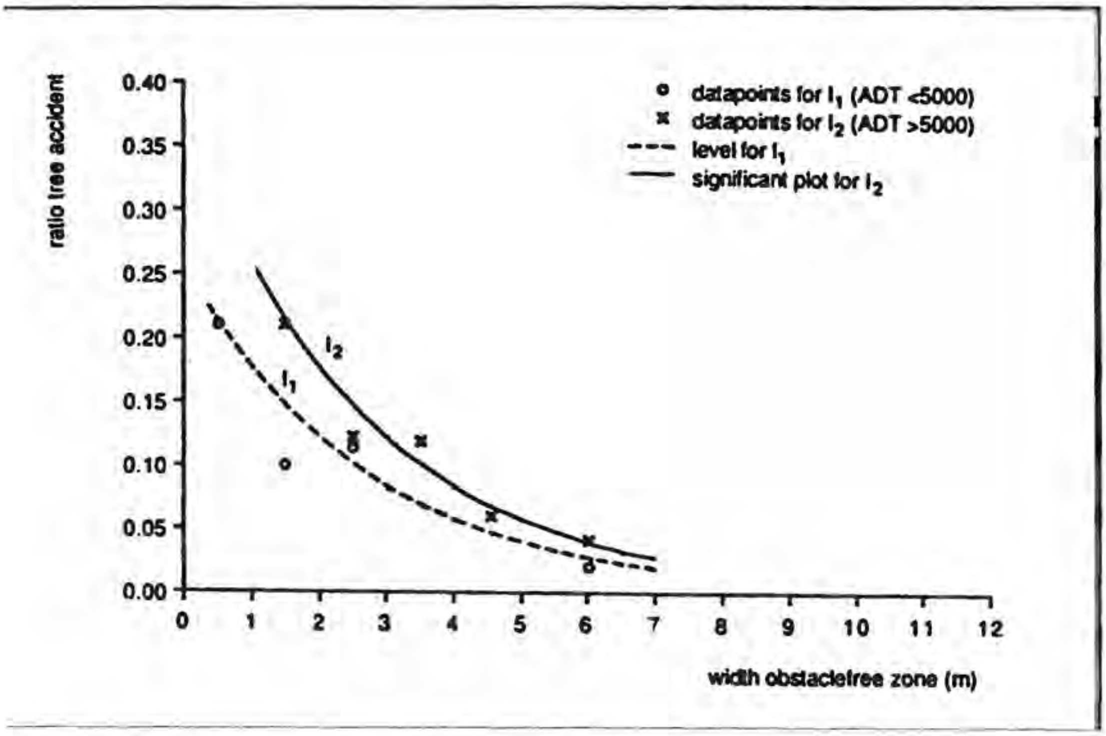

Figure 3. *The relation between the ratio of tree accidents (tree accidents v. the other accidents) and the distance that vehicles travelled into the obstacle free zone for the* ***single-lane regional highways****. The regression line for I_1 is not significant.*

Figure 3 shows the graph for single-lane regional highways. In this graph similar curves are provided for the single-lane regional highways. If we accept here also the value of 0.10 as an acceptable limit for the tree-accident ratio, we find:

- Single-lane regional highways should have an obstacle-free zone 3.5 metres wide.

The concept involving an obstacle-free shoulder should actually apply to the median as well. Due to a lack of space, however, we rarely see these types of shoulders. In comparison with the right shoulder, dealing with the median involves another two aspects that emphasise the necessity of having a median that is at least 20 metres wide:

- In most cases, no left emergency lane is available and this cannot be counted in the width of the obstacle-free zone;
- In a right shoulder, it is still acceptable for a 'slow-moving' vehicle to crash with an obstacle; in the median, however, this must always be avoided, owing to a crash with oncoming traffic.

At the same time, a physical measure must be used to prevent vehicles on the median from making U-turns.

In a recent TRB Report about standards for highways, no distance is given for the obstacle-free zone. (McGee, Hughes & Daily, 1995).
On the contrary, a graph is given with the annual average frequency of pole accidents (accidents/mile/year) as a function of pole density and lateral offset in feet to the utility pole. In *Table 10* the results for the highest pole density (>31 poles/km) set in the metric system. The figures are from accidents on two-lane and multi-lane roads in urban and rural areas. Owing to the fact that the study was carried out in 1983, the number of accidents will be lower nowadays.

Pole offset (m)	Accident frequency (accidents/km/year)
1.5	1.1
3	0.65
4.5	0.5
6	0.35
7.5	0.3

Table 10. *Pole offset versus accident frequency on two-lane and multi-lane roads in urban and rural areas.*

A method used in the State of Kentucky of the United States to determine the minimum value of a clear zone distance, is to compare the severity index of an accident with guardrail, with that of fixed objects at certain distances to the roadway (Pigman & Agent, 1991). Related to traffic volume and traffic speed, the following minimum values are found for the clear zones distance for highways:

Traffic speed	Clear zones distance
64 km/h	5 m
80 km/h	6.7 m
96 km/h	7.7 m

The values concern a traffic volume (ADT) for over the 5,000 vehicles.

Australian guidelines are related to vehicle flows and 85th percentile speed (Pak-Poy and Kneebone Pty Ltd, 1988). The guidelines concerns the 'rural roads' without a specification to type of road. Above 96 km/h and above 4000 motor vehicles (ADT), a preferable clear zone width of 9 m is found. For the European situation one can say that this value of the ADT is rather low.

The Australian NAASRA guidelines (1986) propose a doubling of the appropriate clear zones for all curves sharper than 600 m.

The widths of obstacle-free zones of the European countries are already mentioned in general in Chapter 2 "Investigation by questionnaires to European countries". The detailed data are given in *Table 11* Data must be seen in connection with the question to erect safety barriers or to provide an obstacle-free zone.

Country	**Motorway: width obstacle-free zone (m)**	**Express roads: width obstacle-free zone (m)**
Belgium Wallonia	4.5	3.75
Czech Republic	4.5	4.5
Denmark [1)]	9	3 (9 if v ≥90 km/h)
Germany	6 (10 if dangerous zone)	4.5 (7 5 if dangerous zone)
Greece	9 (19 near railway roads)	9 (19 near railway roads)
Finland	7	5.5 - 6.5
France	10	8.5
Netherlands	10 (if v=120 km/h: 13 m)	6
Norway	6 (if ADT ≥15,000)	5 (if ADT is high)
Portugal	3.5	3 5
Sweden	10 (if v =110 km/h) 9 (if v = 90 km/h) 7 (if v = 70 km/h)	10 (if v =110 km/h) 9 (if v = 90 km/h) 7 (if v = 70 km/h)
Switzerland	12 5	5
United Kingdom	4.5	4 5

1) In Denmark, the width is in discussion as a result of an audit concerning the design of the roadside as example. The intension is that the process will be based on effectiveness studies.

Table 11. *The width of the obstacle free zone based on the question in the SAFESTAR questionnaire: "what is the width of the obstacle free zone if there is no need for a safety barrier?"*

4.2.1. *Paved shoulder*

Attention has to paid to the change-over from the carriageway to the verge. If the change-over is disconnected (to a very different level), this is a potential danger for road users in the case of a controlled off-the-road manoeuvre linked with an attempt to correct the manoeuvre. If the change-over level is too large, often the result is an over-correction with unpredictable consequences.
A hardened verge -especially in case of a soft verge- and a connected level is the solution for these problems.
A paved shoulder with limited dimensions (e.g. ca. 0.5 m) is also helpful to prevent this kind of accidents. An Australian research (Ogden, 1997) determined an overall reduction in casualty accidents by 41% by shoulder paving (0.6 -0.8 m) on two-lane two-way rural highways. The break-even point (the point at which it is economically worthwhile to pave shoulders) is low: at a traffic flow of about 360 vehicles per day it is already worthwhile.

4.3. A shoulder with safe slopes

United States
Safe slopes have also been the subject of much research in the United States. Whether slopes can be considered as safe (no shielding with barriers is needed), depends on the characteristics of slopes: angle, height, rounding and the combinations. A criteria for a optimum rounding can be defined as the minimum radius a 'standard' automobile with certain encroachment conditions can negotiate without losing tyre contact.
In the United States graphs are developed with as basis that slopes with an angle of 1 : 4 and flatter are recoverable (AASHTO, 1989). Vehicles on recoverable slopes can usually be stopped or steered back to the roadway. A non-recoverable slope is defined as one that is traversable, but such that a vehicle cannot be stopped or steered back to the roadway. Embankments between 1:3 and 1:4 generally fall into this category. Slopes steeper than 1:3 are critical and are usually defined as a slope on which a vehicle is likely to overturn.
Of course there is a relationship between the slope angle and the width of the clear zone. If a slope is relatively smooth and traversable, a clear zone distance can be found in the graph. Related to embankment height, traffic volume, and traffic speed; the following minimum values are found for the clear zones distance for highways: for example: a 1 : 6 slope (downward) and a design speed of the road of 60 mph and 5000 vehicles per day gives a clear zone width of 9 m. With the same figures, a 1 : 4 slope gives 13.5 m. Of course these numbers are neither absolute nor precise.
On new constructions, smooth slopes with no significant discontinuities and with no fixed objects are desirable from a safety point of view.

In the State of Kentucky in the United States the same method is used as already described at the clear zone distance. To determine the "acceptable" values for slopes, the severity index of an accident with guardrail is used as reference.
This gives the result that all values of 1:2 and steeper are less safe than a guardrail. A slope of 1:3 has broadly the same values. Therefore, no guardrail could be warranted for a slope of 1:3 or flatter. This value is only applicable for slopes that are traversable. The embankment analyses were

carried out for highways with a driving speed of 80 km/h (Pigman & Agent, 1991).

The Netherlands

The only study of slopes ever carried out in Europe has been an investigation by SWOV. Mathematical simulations formed the basis for this research (Schoon & Van de Pol, 1987; 1988a).

The simulation results have been verified by using twelve full-scale tests on slopes with gradients of 1: 2.2 and 1:4 (see *Figure 4* next page).

From this study it was found that the radius of curvature at the top of the slope was of great importance in preventing the wheels from leaving the ground. For declining slopes, therefore, the radius of curvature may not be any smaller than 9 metres, but should preferably be 12 metres. With a gradient of 1:4, the vehicle stays in good contact with the ground, but steering manoeuvres are not helpful in gaining control. If the driver wants to be able to get the vehicle on the slope under control, a gradient of at least 1:5 is necessary for high slopes (e.g., 5 metres). For lower slopes (approx. 2 metres), a gradient of at least 1:6 is required.

Ascending slopes were also studied by SWOV by using simulations of braking and steering manoeuvres (Schoon & Van de Pol, 1988b). It was found that the radius of curvature at the foot had to be at least 4 metres and that a gradient of 1:2 or gentler would be acceptable.

United Kingdom

In United Kingdom safety fences should be installed at trunk roads where speeds of 50 mph or above are allowed, in the following situations (Department of Transport, 1985):

- on the top of an embankment with a height of 6 m or more;
- on other embankments where there is a road, railway, water hazard and others features at or near the foot of the slope;
- on the outside of curves less than 850 m radius on embankments between 3 and 6 m in height.

For dual carriageways these situation is:

- where the difference in carriageway inner channel levels exceeds 1 m and the slopes across the reserve exceeds 25%.

France

On motorways safety fences are prescribed if the height of the top is over the 4 m and 1 m if the area at foot level is dangerous with a length of at least 30 m. Fences are not necessary if the slope is 'soft', i.e. an angle of 1 : 4 or more (SETRA, 1985).

Motorways in France South must be provided with a safety fence if the slope height is between 2.5 and 4 m (Fer, 1993).

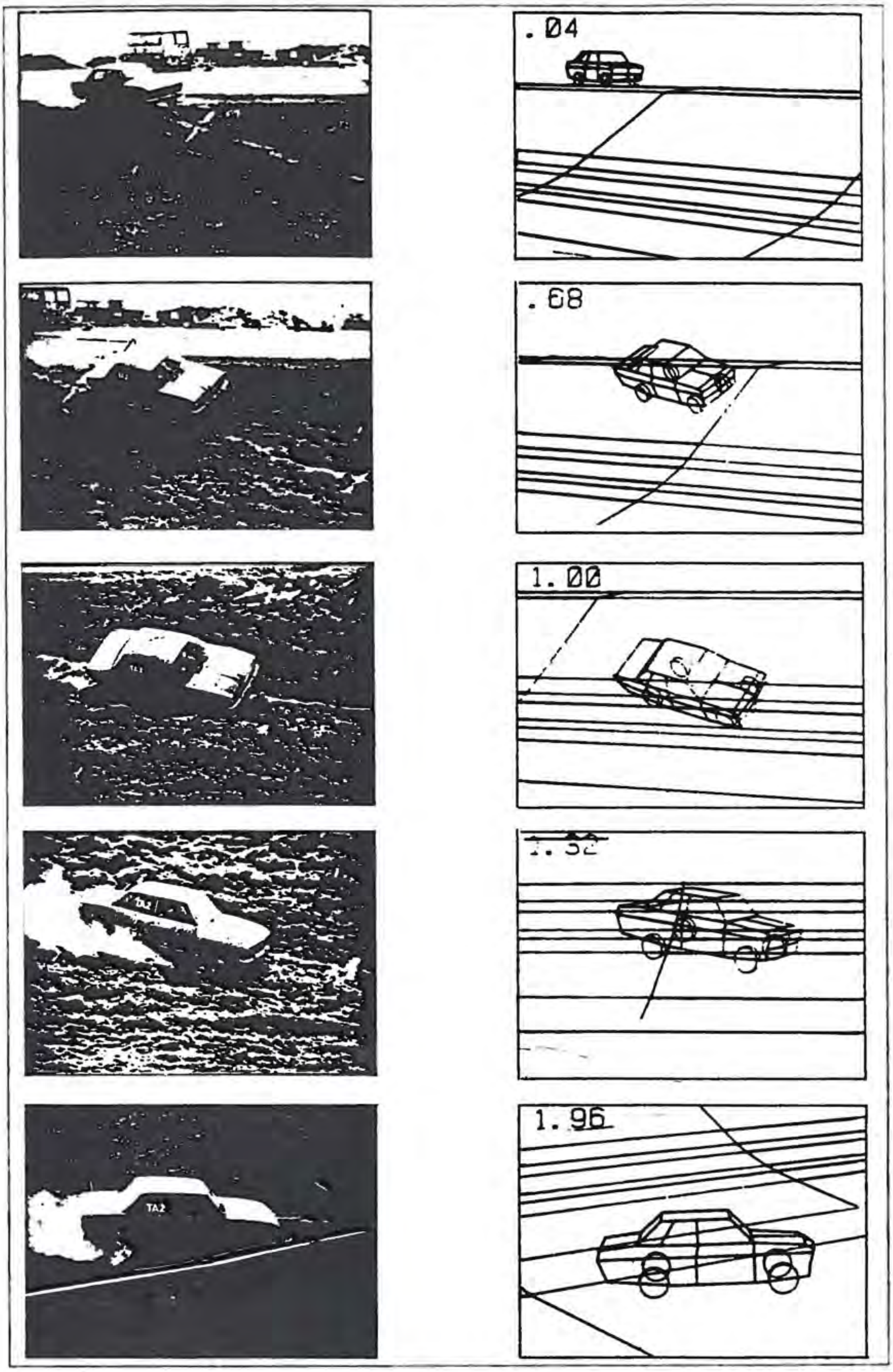

Figure 4. *A check for the matching of the results of a mathematical simulation with the results of a full scale test under the same conditions: slope 1:1,2 and velocity 75 km/h. From this comparison it was found that the vehicle movements and vehicle decelerations fit very good.*

Germany

For the German motorways a division is made into the longitudinal road radius and the distance of the slope to the edge (RPS, 1989). If the *outside radius is more than 1500 m*, safety barriers are required if:

- a slope of < 1:8 at a distance of less than 6 m (10 m);
- a slope of 1:8 to 1:5 at a distance of less than 8 m (12 m);
- a slope of > 1:5 at a distance of less than 10 m (14 m).

Data between brackets means that in the case of a very dangerous zone at the foot of the slope (by example deep water), the distance has to be increased.

If the *outside radius is less than 1500 m*, add 4 m at the given distances (and 2 m for the data between the brackets).

For the German undivided roads with an *outside radius of more than 500 m*, the dimensions, if safety barriers are required are:

- a slope of < 1:8 at a distance of 4.5 m (7.5 m);
- a slope of 1:8 to 1:5 at a distance of 6 m (9 m);
- a slope of > 1:5 at a distance of 8 m (12 m).

If the *outside radius is less than 500 m*, add 6 m at the given distances (and 4 à 5 m for the data between the brackets).

Switzerland

A graph is given with the relation between slope height and the necessity to install a safety fence. For motorways it ranges from a flat shoulder with a obstacle-free zone of 12,5 m to a slope with a height of 10 m with an obstacle-free zone of 27,5 m.

For undivided roads the range is, from a flat shoulder with a obstacle-free zone of 5 m to a slope height of 7 m with an obstacle free zone of 20 m. A slope angle in not given in the report (VSS, 1995).

Denmark

The criteria in Denmark are based on the Dutch mathematical study.

Sweden

In Sweden a slope angle of 1:5 for downwards slopes is preferred.

4.4. Shoulder with fixed objects that yield easily upon collision

If a fixed object is made to yield, it can be placed in an obstacle-free zone without safety barriers. To reduce the impact severity for cars an appropriate breakaway device can be used. Breakaway supports refers to all type of sign, luminaire, and traffic signal supports that are designed to yield when hit by a vehicle. The release mechanism may be a slip base, plastic hinges, fracture elements, or a combination of these.

In the United States criteria to determine if a support is considered as breakaway are described in "Standard Specifications for Structural Support for Highway Signs, Luminaires and Traffic Signals". Basically these criteria require that a breakaway support fail in a predictable manner when struck head-on by an 820 kg vehicle at speeds of 32 and 97 km/h. As criterion for a safe pole a limit in the change in the vehicle's speed is used. This value is 12 -16 km/h (AASHTO, 1989).

The CEN is preparing standards for testing fixed objects (Passive safety of support structures for road equipment).

Examples of collision-safe fixed objects for the Dutch (European) situation are:

- aluminum lighting poles with a length of 10 metres and smaller, and steel poles with a slipbase (Schoon & Edelman, 1978; see *Figure 5*); a deformable (patented) steel lighting pole developed in Sweden in the 1970's. In Sweden roadside safety experts are trying to change the policy to locate lighting poles on the outside of curves into inside of curves.
- a telephone box on a thin pole that bends forward and does not break off during a collision, thus preventing the pole from flying through the windscreen (Schoon, Jordaan, & Van de Pol, 1977).
- signs on thin poles that easily bend during a collision; larger direction signs on thin poles in an A-shape.
- drainage features such as culverts and ditches have to be constructed with flattened sides in such a way that these constructions are traversable.

NB. At the test carried out in the Netherlands as criterion is the ASI used (see CEN-tests) and also the deformation of the vehicle at side impacts.

Although fixed objects probably provides more of a danger for riders of motorcycles than for motorists in case of an off-the-road accident, a shoulder with solitary obstacles is much to be preferred, in terms of motorcyclist safety, over a shoulder that is completely shielded by a safety barrier.

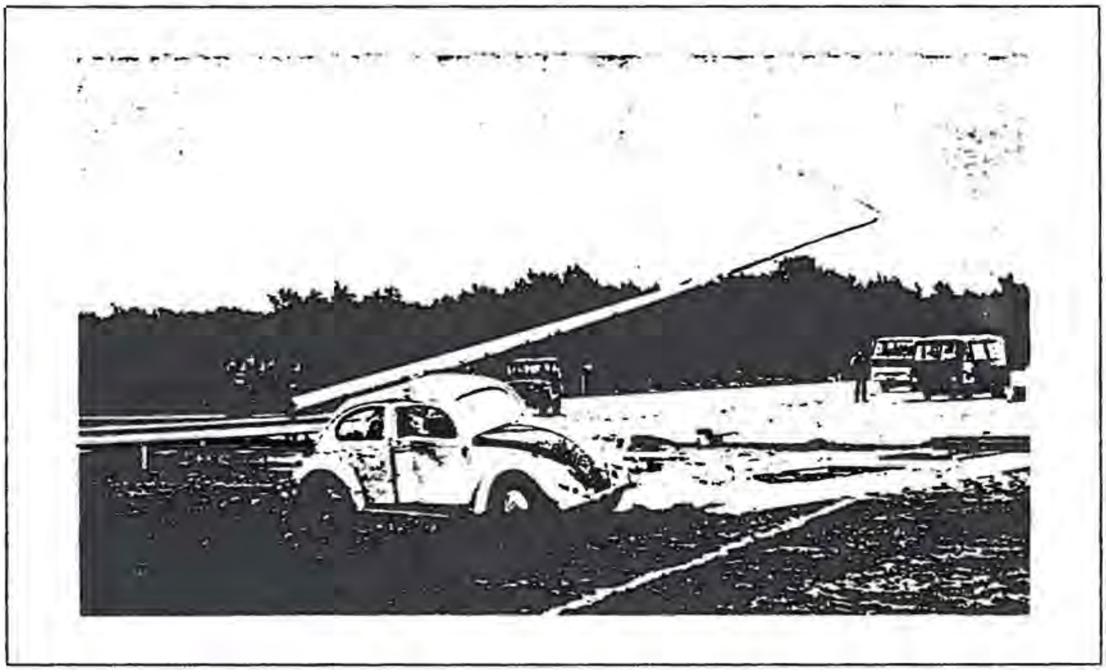

Figure 5. *This 10 m slip-design steel column hit laterally in test series at 42 km/h, gave low vehicle decelerations. It fell on the car's roof; both sideways and roof dents remained within the maxima (Schoon & Edelman, 1978).*

4.5 Shoulder with crash cushions

If solitary rigid obstacles along a shoulder cannot be removed, they can be shielded with a crash cushion. Crash cushions are applied on motorways in mainly two different situations: in gore areas at exits (often at the beginning of a safety barrier) and on shoulders to shield single objects. If crash cushion have been collided head-on, the vehicle usually remains within the shoulder so that it forms no danger for other traffic. In case of a side impact, most types of crash cushions function like a safety barrier.

Different European countries have their own type of crash cushion (Italy, United Kingdom, Germany, and the Netherlands). Most accident experience is gained in the Netherlands because the first crash cushions were located in 1982. In 1989 an evaluation study was carried out at a moment that at 170 locations crash cushions were installed. The study dealt with 97 collisions with the crash cushion. Only 6 accidents result in (slight) injuries (Schoon, 1990). At this moment over the 350 crash cushions are installed in the Netherlands.

Depending on the number of solitary rigid obstacles and the distance between them, a choice has to be made between a safety barrier or one of more crash cushion. The price also is a factor taken into account. This item will be discussed later in Chapter 6 "Cost effectiveness".

4.6. Shoulder with safety barriers

4.6.1. *Introduction*

In the concept of a safe roadside, protecting the roadside (shoulders and median) with safety barriers is the least safe solution. An effectively functioning safety barrier prevents a vehicle from leaving the roadway and striking a fixed object or terrain feature that is considered more hazardous than the barrier itself. But as shown in Chapter 3 (Accident analyses), a collision with a safety barrier is never free from the risk of injuries for the occupants of the colliding vehicle as well as for other road users.

4.6.2. *Requirements*

The requirements placed on safety barriers are:
1. The effective guiding of vehicles that have run off the carriageway.
2. This guiding function must remain after the collision.
In general, it can be said that if the first requirement is satisfied, the second one will be also.

The effectiveness of the guiding can be further qualified by the following criteria:

- Roll angle must be kept to a minimum.
- Occupants must not suffer any serious injury.
- The exit angle must be small (to avoid collisions with third parties).
- Specifically for medians and verges between the roadway and the cycle track/footpath: the construction and the vehicle (or parts of them) may not wind up on the other side of the road, putting them in the way of oncoming traffic.

4.6.3. *CEN standards*

These assessment criteria have been described quantitatively in terms of standards for testing safety barriers (CEN/TC 226, prEN 1317). These CEN tests give a good picture of the degree of safety provided by the tested safety barriers under test conditions. Both flexible steel constructions and rigid concrete constructions appear to satisfy the standards. In this sense, the tests are valuable for separating good constructions from bad ones and for enabling the comparison of one kind of construction against another.
The CEN tests, however, are based on 'straight' input conditions. Collision under conditions such as slipping, braking, and steering manoeuvres are not involved; it is also hardly to realize the many conceivable collisions. Mathematical simulations offer more possibilities in this regard. Founding tests of the CEN full scale tests with help from computer simulations with particular vehicular manoeuvres, give more insight in the scope of working of safety barriers. Verification tests must always be a part of these simulations.

4.6.4. *Containment levels*

The levels of vehicle containment within the CEN-standards is linked with the severity of impact tests that barriers should undergo. The assessment of the performance of the barrier by means of criteria of the impact severity and the working width (deflection). If the test is successful, the barrier is ranked within a class of containment level. These levels are divided in low angle containment (T1-T2), normal containment (N1 and N2), higher containment (H1 - H3) and very high containment (H4a and H4b).
The "low angle" containment level is intended to be used only for temporary safety barriers. Within the "very high" containment level tests are involved with vehicles with a mass of 30,000 and 38,000 kg.
The results of investigation by means of questionnaires (Chapter 2) give us the information about the qualification from the European countries of the safety barriers in their own country. Most of the countries qualify their safety barriers in standard situations as 'normal containment level' (N1 -N2) for steel barriers and as 'higher level' (H1 - H3) for concrete. You wonder how many countries have CEN-test results of these barriers.

The next question is very important: on which type of road had to be installed which type of barrier? Here also the questionnaires give some insight. It was asked for the criteria to place a high performance barrier. The most frequently mentioned answers were (between parentheses the number of countries of a total of 14):
- danger for lower sited roads, buildings (9);
- others (bridge parapet, noise protection, water areas, rail crossing) (6);
- narrow median (5);
- percentage heavy traffic (4).

Some European countries have made a beginning with these criteria in their standards. Switzerland's standards regulate the application of level "H2" (as the highest class) in case of the protection of hazards with large collision risk. For shielding of railroads and plants of the chemical industry a H2 level is also recommended
In Germany a concrete barrier is recommended if the risk for a collapse of the barrier is too high. As criterion for a high traffic flow is mentioned 50 000 vehicles in 24 h. Drafts are prepared with characteristics of the following

items: accident history, traffic volume, percentage of heavy truck traffic, number and width of lanes, radius of curves.

4.6.5. *Literature search into safety barriers at H4 level*

SWOV carried out a literature search on safety barriers at a very high containment level (Van de Pol, 1997). Tests done in Europe were according to the H4 level of the prEN 1317 standard; it is established that not many full-scale tests at this level have yet been carried out up till now.
In addition other tests on a similar level as H4 tests are described. These tests were carried out in Japan and the United States and deviate from the H4 tests in that they involve vehicles with a different mass and a somewhat different collision speed and/or collision angle. For inclusion, however, the collision energy was of the same level.
From the research, the following conclusions were drawn:

- Heavy vehicle safety barriers can be made of either steel or concrete. Examples of constructions made of both these materials were found that satisfy the desired H4 level.
- For constructions with small widths, concrete is to be preferred over steel constructions.
- For constructions with greater widths, steel is to be preferred over concrete constructions.
- The available heavy vehicle safety barriers are higher than current constructions. Vehicle safety barriers with a height of about 1 3 metres appear to provide good results. With a height of about 1.0 metre, vehicle roll-overs (overturning) still occur.
- Constructions that are 1.3 metres and taller have a positive effect on arresting cargoes.
- The damage suffered from collisions involving a steel construction appears to be much greater than damage suffered from collisions involving concrete safety barriers.
- The available vehicle safety barriers intended for embankments differ from those for bridges and viaducts. The safety barriers for embankments are not as massive in design as those for bridges because in the case of embankments there is a greater room for deflection.
- It appears possible that the ASI values for passenger cars during a collision with a heavy vehicle safety barrier are below the highest permitted value of 1 4 in the CEN standard.

4.6 6. *Experiences with mathematical simulations*

Mathematical simulations are very helpful to confirm the effect of construction modifications. Some examples can be shown here.
The first example is a study to the effect of the degree of flexibility of a steel safety barrier on vehicle decelerations and exit angles. SWOV has found that the exit angle at a collision against a *flexible* construction is an average of 5° smaller than at a collision against a *less flexible* construction[1] (Schoon, 1985a; see *Figure 6*).

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[1] Flexible : a deflection of 1 5 metres at a collision with a 850 kg car with a speed of 100 km/h and a impact angel of 20 degrees. Less flexible: a deflection of 0.5 metres at the same conditions.

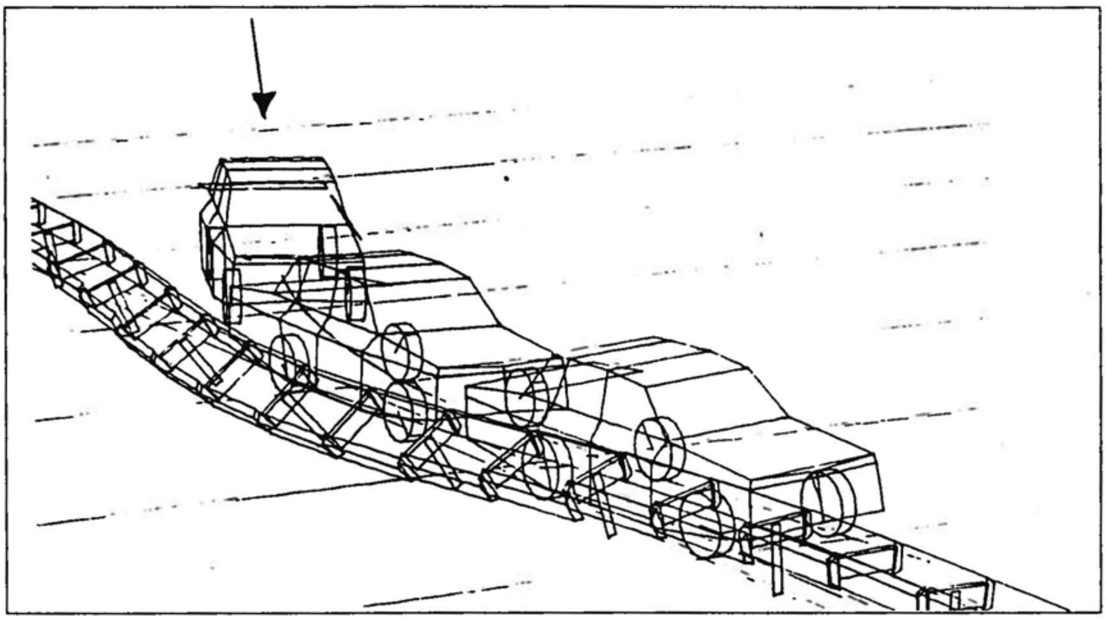

Figure 6. *An example of a mathematical simulation with a steel barrier. Velocity: 80 km/h, impact angle 20 °, vehicle mass 1245 kg. The redirection was smoothly and the vehicle deceleration acceptable (Schoon, 1985b).*

The second study of construction modification involved the coefficient of friction of the surface of the concrete New Jersey barrier. Established is the effect of these friction on the climbing height of the vehicle upon collision. It was found that a reduction in the coefficient of friction with 50%, reduces the climbing height up to c. 20 cm, and so the risk of overturning (Schoon, 1985b; see *Figure 7*).

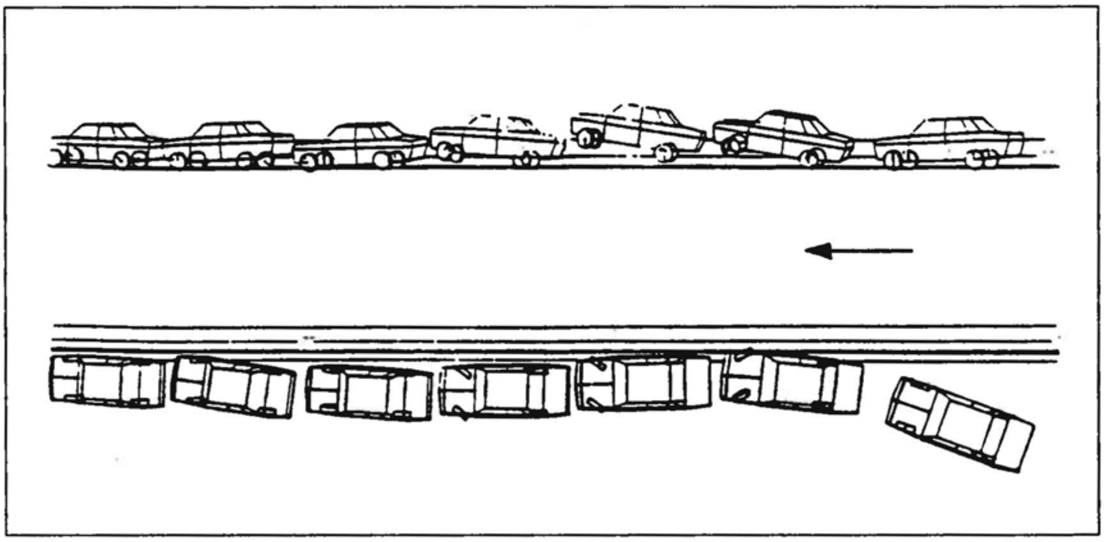

Figure 7. *An example of a mathematical simulation with a concrete barrier (New Jersey type). Velocity: 80 km/h, impact angle 20 °, vehicle mass 850 kg. Note the extremely high climbing height of the vehicle front owing to the high coefficient of friction of the barrier surface (Schoon, 1985b).*

Last years SWOV also carried out research in the field of movable barriers. With computer simulations, for example, the strength of the connections between the blocs (concrete or steel) and the movement in lateral direction under impact has been calculated.

4.6.7. *New developments*

Steeper profiles of concrete barriers

The fact that the smaller passenger cars have a greater risk for overturning has led a number of European governments (United Kingdom, the Netherlands) to abandon the New Jersey profile and to start using a steeper profile. Although the vehicle's rate of deceleration is somewhat increased, the number of cars expected to overturn is fewer.

Since, with grazing collisions, a steep profile easily leads to damages in the body of the vehicle, the latest development in the Netherlands is the 'Step barrier'. This is a barrier with a steep profile accompanied by a small upright edging on the underside. Simulations carried out by SWOV show that this edging does not unfavourably affect the course of a collision (Van de Pol & Heijer, 1993; see *Figure 8*).

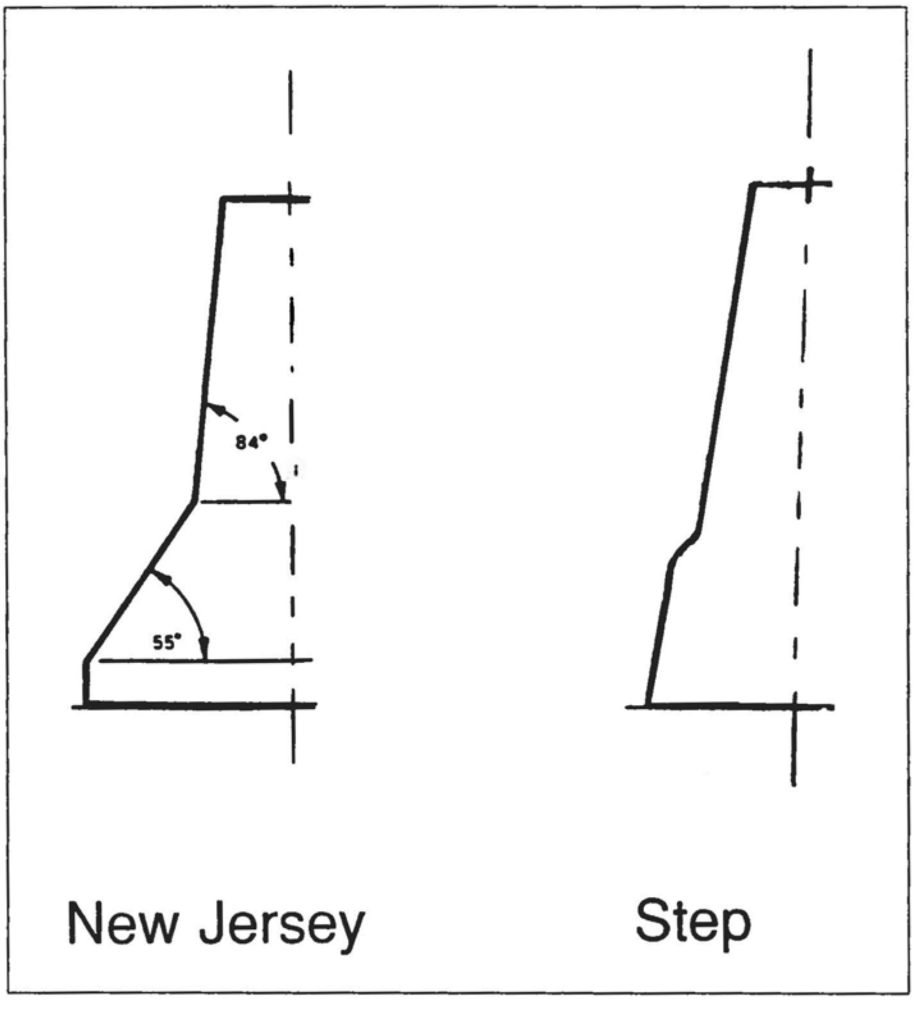

Figure 8. *Cross sections of the 'standard' type New Jersey barrier and the 'Step barrier' with a steeper profile (Van de Pol & Heijer, 1993).*

Same (older) results with steeper profiles were established in the United States. Tests with cars with a weight of 815 kg on a vertical-faced concrete wall have shown that such a barrier minimizes vehicle rotation on the longitudinal axis. The vehicle deceleration levels are greater than for concrete barriers with a specially front shape, and the exit trajectories are with a higher arc away from the barrier (McDevitt, 1984).

Need for modifying barriers

Changes in the cross sections of motorways also makes it necessary to modify safety barriers. Examples of these changes are:

- more traffic lanes for each carriageway which can result in larger crash angles;
- narrow medians that necessitate the use of narrow safety barriers;
- due to increasing traffic concentration, there is a greater need for safety barriers that are maintenance-free and are not seriously damaged during a collision;
- some countries have separated lanes for heavy traffic; a physical separation of truck traffic from other traffic with a barrier is desirable. In these cases there is a need for barriers with different collision properties on either side.
- the increase in heavy truck traffic and buses with a high centre of gravity necessitates the use of high containment construction; there are developments in the United Kingdom, Switzerland, Italy, and the USA.

Constructions for single-lane roads

Although construction modifications have the potential for favourably affecting the outcomes of accidents involving safety barriers, vehicular manoeuvres made before the collision, as well as the driver's influence on the path of the vehicle after the collision, are more important. In cooperation with industry, SWOV is now developing a safety barrier for single-lane roads that should allow the vehicle to remain close to the construction and thus avoid the danger of secondary collisions. Initial full-scale tests with a collision speed of 50 km/h provided good results.

5. The difference between steel and concrete barriers

5.1. In general

Based on the experiences with full scale tests and mathematical simulations, the following is concluded for steel and concrete barriers:

- The severity of the collision, in terms of vehicle deceleration, is greater for a concrete barrier.
- When a vehicle hits a concrete barrier with a special profile (no steep profile), the car's front end leaves the ground; especially in the case of smaller passenger cars there is the risk for overturning.
- The exit angles are larger for concrete barriers.

5.2. A French study

In a French study the severity of the first impact is compared between the impacts of vehicles with steel or concrete barriers (Martin et al., 1997a). Identified are the sections that had been changed from metal to concrete barriers. Also "control sections" were selected, that had kept their metal barriers. In all, the study covered 224 km motorways. The observation took place from 1986 to 1995.
The severity of first impacts against concrete barriers in the central reserve, (expressed by the ratio of the number vehicles with at least one casualty to the total number of damaged vehicles), increases from 10.5 to 16.2% in comparison with the old sections (provided with steel barriers). This severity index remains stable for the control sections. Taking into account the typology of the accident, the Relative Risk (RR) of being injured in a vehicle when the impact is against a concrete barrier compared with a steel barrier, is estimated at 1.9 (significantly different from 1).
An other analyses concerns the comparison of sections. At the section-level, the RR is 1.5 in favour of the steel barrier, but this value is not significant. These result take into account the possible influence of the change in the number of lane at the same time of the replacement of steel into concrete.

In an other French report concerning accidents with concrete and steel barriers on motorways, the proportions of the number of rollovers are documented (INRETS, 1993). During 1992 the accidents were monitored regarding the frequency and severity. Related to rollovers against barriers at the shoulders, no difference is found between concrete and steel barriers. More difference is found with the barriers in the median. The percentage for rollovers for concrete barriers was 20% and for steel barriers 8%.

5.3. A German study

For the medians of motorways with a high traffic flow, the type of construction (steel or concrete) is considered for the German situation (Gülich, 1996). The most important issue is to prevent the collapse of the barrier (ca. 5% of accidents with fatalities in Germany). The risk for a collision with oncoming traffic is too high. In comparison with the measures to repair the damaged steel constructions on locations where the accident risk is high, the choice for a concrete barrier gives advantages. As criterion for a high traffic flow, 50.000 vehicles in 24 h. is mentioned. Concrete barriers are recommended if the width of the median is too small for the installation of a steel barrier (< 3 m).

In other situations a decision should be made case by case for the best solution. Aspects to be taken into account are: installation costs, life span, repair costs, load for bridges, risk for a collision, difference in level between both ways, combination with a sound barrier, etcetera.

In the German article a table is given with a score for steel and concrete barriers for all these aspects. It concerns here only the medians on motorways with a high traffic flow. According the total results, the difference between steel and concrete is not large. But for specific locations, sometimes steel will be considered for installation and in other situations concrete.

In a German standard, a raised height for barriers is prescribed in case there is a danger for overriding: a height of 1.15 m instead of the normal height of 0.81 m (RPS, 1989).

Mentioned are problems with concrete barriers owing to drainage and snow removal.

Regarding the costs of the two types of barriers, in a State of Germany (data from Rheinland in 1994) the costs of concrete barriers are 4 - 5 times higher than that of steel barriers. But the costs of steel barriers had to be raised with the costs of repair after a collision (repair, management, lane closure).

5.4. An Austrian study

In Austria is stipulated that concrete barriers are at least equivalent to steel barriers (Breyer, 1988, cited in Gülich, 1996). Mentioned is that concrete barriers give almost a full protection to the collapse of the barrier in case of collisions with cars and trucks. Experiences have shown that, with the application of concrete barriers, both the number and severity of the accidents as well as the extent of material damage is decreased. The reason for the decrease of the severity is owing to the reduction of accidents as a result of the collapse of barriers. Regarding the rebound at a collision, experiences with concrete barriers are more favourable than expected.

5.5. A Dutch study

Also in the Netherlands, steel barriers were compared with concrete barriers (Rijkswaterstaat/DHV, 1990). Aspects taken into account were installation costs, costs of maintenance, and number and severity of accidents. The data of accidents were gathered from other countries owing to the little use in the Netherlands of concrete barriers in favour of steel ones.

The conclusion is that steel barriers in principle can be preferred. The total of the considered costs are higher for concrete barriers in comparison with steel barriers. Concrete barriers are recommended in situations with medians with a small space.

5.6. Results from the questionnaires

Based on the investigation results by means of questionnaires (Chapter 2), it can be concluded that road authorities already make a distinction between steel and concrete barriers in practice. In the questionnaires is asked for the criteria to place concrete barriers instead of steel ones.

The most frequently mentioned answers were (between parentheses the number of countries of a total of 14):

- maintenance of barriers (7);
- narrow median (6);
- high volume traffic (4);
- environment aspects (4).

5.7. Discussion

Both steel and concrete barriers have advantages and disadvantages. The French study gives the most detailed accident information concerning the difference between steel and concrete barriers. Mentioned is that the severity of collisions with concrete barriers is worse in comparison with collisions with steel barriers. But the amount of rollover accidents as a result of a collision with a concrete barrier, is relatively high. It is know (from the United States) that collisions with a concrete New Jersey barrier by small vehicles give a high percentages of rollovers. Rollovers are related with serious injuries, particularly if the seat belts were not used.
There are possibilities to prevent this kind of accidents by the choice for a steeper profile instead of a special profile like that of a New Jersey barrier.
It could be possible that if in the French study, the number of rollover accidents is estimated as the same for steel and concrete barriers, the difference in collision severity is approximately the same for steel and concrete barriers. An additional analyses with the accident data is recommended.
The prevention of rollovers is the reason that some countries have chosen for a more steep profile. As far we know only the United Kingdom and the Netherlands apply these profiles.

6. Cost-effectiveness

6.1. A meta-analyses

A large number of studies evaluating the effectiveness of guardrails and crash cushions in reducing traffic injury are summarized by means of a quantitative meta-analysis (Elvik, 1994). The possibilities and limitations of this kind of analysis are given. 32 evaluation studies were involved in the literature study, containing 232 numerical estimates of safety effects. The main results are: median barriers increase accident rates, but reduce accident severity. Guardrails (along the edge of the road) reduce both accident rates and accident severity. Crash cushions also reduce accident rates and accident severity, but the estimates of their effects are particularly uncertain due to methodological shortcomings of the evaluation studies.
Concerning guardrails, the report gives more specific results regarding the kind of object they protect errant vehicles from striking. The largest effects are found for protecting trees, rock sides, and utility poles.

6.2. European studies

A French study has shown the effectiveness of guardrails. During a period of 5 years, motorway sections with and without guardrails in Southern France were compared. Those accidents were analysed in which a vehicle ran off the road. Their accident severity (number of injury accidents / total number of accidents) on sections with guardrails was 16.1, and without guardrails 26.5. This data includes all types of vehicles. A further division was made using only light vehicles (no weights were mentioned). Here, the difference was much greater: 9.8 versus 24.8 (Fer, 1993).
During a period of 5 years, Fer calculated the cost-benefit ratios. Annual savings in the numbers of slightly and severely injured, and deaths, minus the material damage only accidents, amounted to a net 6.5 million FF. The extra construction costs of guardrails for these sections were 45 million FF. This means that the costs were recovered in 7 years. For a life span of guardrail is 20-25 years, this is an effective investment.

In a Finnish study the improvement of existing roads is calculated with cost-effectiveness data (Kallberg, 1994). Risk calculations were based on accident data and inventories of roadsides. Accident costs were expressed in ECU's per roadside km per year with a range from 2400 to 4400 ECU.
The costs of different types of roadside improvements vary between 1,500 and 50,000 ECU. Next step was the comparison of the investment costs and savings in accident costs (over a period of 20 years). The main conclusions of the study were:

- Changing rigid utility columns into breakaway columns is most cost-effective.
- Replacement of utility columns in the inner slope with breakaway columns or changing overhead cables into ground cables is also usually cost-effective.
- Installation of guard rails in front of rock walls could sometimes be cost-effective. Further research is needed for defining suitable locations.

- Redesign of ditches on some forest sections (e.g. less steep) could be cost-effective.

Depending on the number of solitary rigid obstacles and the distance between them, a choice has to be made between installation of a certain length of safety barrier or one of more crash cushion. A (draft) Dutch standard give arguments to make this choice. The length of the safety barrier is 60 m and that of the crash cushion 10 m. On a certain road section, the risk for an off-the-road accident on each point of the road section is equal. That means that the chance of a collision with a safety barrier is a factor 10 greater than a collision with a crash cushion. If the installation costs are the same, the choice is easy to make. But despite the installation costs of a crash cushion (approximately three times higher than that of the safety barrier with a length of 60 metres), in the Dutch standard it is recommended to site a crash cushion (Rijkswaterstaat, 1998).

The Commission of the European Communities recently (1997) set up a test criterion, the so-called "one million ECU test". This criterion means that if the costs involved to save *one* road death do not exceed 1 million ECU, then they are economically justified. This criterion in fact also includes the savings of all other accident victims (the in-patients and those less seriously injured) and material damage. This is according to particular ratios, which can differ greatly from country to country.
The "one million ECU test" is calculated within the EU on basis of the total costs of road safety. The number of road deaths within the EU is about 45,000 per annum. These figures are fairly certain, but no agreement about the costs has been reached. If the costs are estimated at 45 billion ECU, then the "one million ECU test" has been passed. There are, however, figures of the costs of 162 billion ECU (ETSC, 1997); the "one million ECU" then becomes "3.6 million ECU".

6.3. Studies in the United States

A study of the University of California (McNally & Merheb, 1991) was focussed on the effect of Jersey concrete barriers installed in the median of freeways. The results showed that cross-over accidents with fatalities were eliminated and the head-on accidents decreased significantly. Also the effect of a decreased median width as a result of installation of a New Jersey barrier, was examined. It was determined that the frequency of accidents was increased in terms of non-fatal and non-injury accidents (9.2 and 2.4% resp.) while the frequency of fatal accidents decreased by 31.3%.
If the benefits of New Jersey barriers are compared to their installation costs, it is found that, over the estimated life span of the barrier of 30 years, the cost-benefit ratio is about two-to-one in favour of the installation.

On the basis of interviews and questionnaires in connection with the effect of highway standards on safety, 44% of the respondents asked for "a step-by-step process with a built-in accident/design element relationship for conducting cost/safety trade-off analyses for design elements" (McGee, Hughes & Daily, 1995).
A procedure that can be used to select the most cost-effective roadside treatment at a location is described in the Roadside Design Guide from de U.S. It is a computer program that can be used to estimate the impacts (i.e.

run-off-road, hit fixed objects) per year, stratified by impacts with a hazard, and the average accident cost based on the average accident severity of impacts with roadside hazards. One of the major limitations with this program is that it was developed to evaluate alternative roadside designs for individual features or hazards on one side of the road. It cannot be used for designing and evaluating long highway segments like slopes.

Research plans are described with the following underlying assumptions:

1. Designers need and would use information about the relationships between design parameters.
2. Despite the limitations associated with accident research analyses, improved relationships between safety and design elements are needed and could be developed.

7. Strategies in the US for improving roadside safety

7.1. Problems and analysis

Pigman & Agent (1991) describe a procedure to identify and rank location in need of guardrail. The steps are:

1. determine whether the accident rate for a road (or road section) is abnormally high compared with an average for the same type of road;
2. list locations with critical rates of run-off-road accidents;
3. develop a hazard-index point system (relating the geometric characteristics of highway sections with their accident history);
4. conduct a field survey;
5. tabulate hazard-index points (to identify a manageable number of locations for which cost-effectiveness can be performed);
6. determine improvement costs and benefits;
7. determine the roads (or sections) with the lowest cost-benefit ratio.

Clear zone criteria have been based on limited empirical data and the collective judgement of researchers and engineers. AASHTO will seek to address these shortcomings through a NCHRP (National Cooperative Highway Research Program) project entitled "Recovery-area distance relationships for highway roadsides". A cost-effectiveness factor will be a part of the study (Ross, 1995).
At a workshop of the Transportation Research Board, a discussion group Roadside Safety Features Committee concluded that recent accident analyses indicate that vehicle rollover is a major problem. The information, available to policy makers and researchers on vehicle stability on slopes and ditches, is probably 20 years out of date and all of that particular research was done with large cars.

Also Michie (1996) mentioned problems and methods at a Roadside Safety Features Workshop of the Transportation Research Board Committee held in July and August 1995. He remarks that this TRB Committee has achieved "outstanding success in the past thirty years, but that the task to increase roadside safety is far from being accomplished". He suggests that a special committee should concentrate its efforts in three primary areas:

- define the various mechanism that cause vehicle overturns;
- trees as a hazard problem (develop a model for roadside design standards; develop a simplified method to identify the tree as critical to traffic safety; develop typical standards for shielding trees that cannot be removed);
- utility poles (a specific US problem).

Michie also noticed after consulting several experts on the field of roadside safety, that it has been disappointing to find that too often the safety features were not properly laid out and/or installed; on many occasions it has been concluded that these deviations led to performance failures and unnecessary injury and fatal accidents. Some examples have been given concerning the installation of longitudinal barrier systems.

7.2. Promotional activities

Stoughton (1996) summarized some trends that are under way with emphasis on ones road authorities should promote. The intention is that the issues will be inspire some discussion about where road authorities should put the greatest efforts. Perhaps this vision is also interesting for the European countries. Eight of the eleven points are given here.

1. pass legislation to ensure they have adequate funds and personnel for a continuous ten year period;
2. promote good management practices and hire well-qualified professionals in the field of organization and management to assist with some parts of the program;
3. pass federal legislation requiring biannual national meetings to enhance communication of good ideas;
4. coordinate long-term roadside safety goals and research;
5. encourage highway safety constituency organizations that could educate the public and lobby legislators on behalf on the highway safety community;
6. continue a multifaceted approach to solving roadside safety problems;
7. participate in a process to formulate a strategic plan for improving roadside safety that defines specific tasks and time goals; establish a communication network, if possible, by newsletter or computer; make plans for regular gathering of the broad highway safety community to report results of the assigned task and to review and update the strategic plan;
8. give higher priority to preventing roadside accidents.

A Research Results Digest has been recently (1997) published in the United States: Strategies for improving roadside safety. Emphasized is that improving roadside safety requires an integrated approach that considers the roadway, the vehicle, and the driver. A group of experts outlined the actions. Some important actions are:

- provide additional funds to upgrade highway safety programmes and roadside hardware;
- form coalitions of public agencies and private organizations;
- improve information resources for monitoring and improving roadside safety;
- make the most remedies known to be effective in improving roadside safety;
- support research to address the unanswered roadside safety questions.

7.3. Discussion

The United States have always been the leading country concerning the execution of full scale tests in the field of roadside safety. The accent of execution laid in the years 70's with tests on obstacle-free zones, slopes, frangible poles, safety barriers, and crash cushion.
Nowadays the opinion of American experts is that the problem is still great. Much of the results from years ago are out of date and renewed exertion is necessary. The catchwords related with this are: monitoring, new (research) programmes, funds providing, and legislation; they are all also subjects suitable for the European situation.

8. Proposals for standards and strategies for EU-countries

8.1. Motorways

The proposals described here, are based on Chapter 4 "Concept of a safe roadside" and concern standards for:

- shoulders: the choice for obstacle-free zones or safety barriers;
- medians: the choice for the type of safety barriers.

8.1.1. *Shoulders*

There are safety reasons for favouring wide obstacle-free zones. 6 of the 13 countries that provided information maintain a minimum width of 9 m. (see *section 4.2*). This width is recommended as a provisional minimum.
The motivation for this is:

1. When choosing whether or not to protect a shoulder, the safety barrier may not present a higher risk than the zone to be protected. Only recently has it been realised that a safety barrier is by no means risk-free. The provisional hypothesis is: a danger zone beginning at 9 m from the carriageway presents as much risk as a safety barrier directly next to the carriageway. This hypothesis needs to be verified (see insert *"research"*). It is possible that the hypothesis is incorrect and that the break-even point is lower at, for example, 7 m In that case, an obstacle-free zone of 9 m is safer than a safety barrier. But if the break-even point is higher, readjustment is necessary.
2. A distance of more than 9 m was not chosen in advance, although it is, seen absolutely, safer. But by gradually widening the width of the obstacle-free zone, the road authority will be more easily tempted to choose a safety barrier than a safer obstacle-free zone.
3. The width of 9 m for an obstacle-free zone presents no problems to about half the countries of Europe, because this distance has already been adopted in the standards.

The following decision model for determining the choice 'obstacle-free or safety barrier' can be operated:
Is there at least 9 m available --> obstacle-free zone.
The zone is available but: the zone further than 9 m is a high level dangerous zone --> safety barrier
The zone is available but: the roadside furniture is not frangible (or frangible to make), and/or the number of solitaire columns are too high for protecting them with a crash cushion --> safety barrier
NB. Slopes may be a part of an obstacle-free zone if vehicular manoeuvres are possible. This is the case with a gradient of at least 1:5 for high slopes and 1:6 for lower slopes.

If chosen for a safety barrier, then the type of barrier depends on the degree of hazardous of the protected zone. If:

- the zone behind the barrier has a high level of danger --> barrier with a high containment level,

- the zone behind the barrier has a relatively low level of danger --> barrier with a normal containment level

Research: verifying hypothesis of the 9 m obstacle-free zone
The hypothesis is as follows: a danger zone starting at 9 m from the carriageway has just as many risks involved as a safety barrier right next to the emergency lane. It is recommended that the European countries that use an obstacle-free zone of 9m or more, carry out an accident analysis. Road sections with safety barriers should be compared with road sections that have an obstacle-free zone of 9 m or more.

8.1.2. *Medians*

In terms of safety, an obstacle-free zone for off-the road vehicles in the median had to be at least 20 m. Normally this width is out of the question. As a result, a choice has to be made for the type of safety barriers.
In this case the question is: what should be the containment level of the safety barrier? The level depends on the circumstances of the cross section, the traffic volume, proportion of heavy traffic, and so on. See paragraph below, called *"opinion containment level"*.
The question 'steel or concrete barrier' had to be answered in relation to the choice for a high or low containment level. Besides the aspect of sufficient resistance, the aspect of enough height to prevent rollover to the other carriageway is also important.
If a decision is made for a high containment level, probably the difference in costs between steel and concrete barriers is not great. Taking into account other aspects as maintenance, repair problems and so on, concrete barriers are probably advantageous.
If a decision is made for a low containment level, steel barriers are in favour if only the installation costs are calculated. Taking into account other aspects, it depends on the local circumstances which type of barrier is to be preferred. Differences between countries are too great for a general opinion here. See paragraph below, called *"some reflections about the difference between steel and concrete barriers in an accident situation"*.

Opinion containment level
Some European countries have made a beginning with criteria in their standards about containment level. Also drafts are being prepared. Most of the subjects involved containment level are already known: accident history, traffic volume, percentage of heavy truck traffic, number and width of lanes, and radius of curves. The difficulty is to determine criteria related to these characteristics. The expectation is that the differences between the European countries, concerning these values, are not large. In that case an European study is recommended.

Some reflections about the difference between steel and concrete barriers in an accident situation
In section 4.6 the influence of the flexibility of barriers in collisions is summarized:

1 the rigidity of a steel barrier with a high containment level is regarding the influence of the collision on a passenger car, nearly the same as the rigidity of a concrete barrier.

2. in the case of a collision, the influence of the driver in the pre-crash, crash and post crash situation is greater than the influence of the extent of flexibility (or rigidity) of the barrier.
3. the value of the ASI-criterion in use at the CEN-tests, has to be reexamined in the future owing to: better new car standards nowadays, better crumpling zones in cars, better restraint systems (belts and airbags). For the ASI-criterion research is recommended into injury criteria directly related to the occupants instead of values related to the vehicle.

8.2. Standards for express roads

Dual carriageways
If express roads have dual carriageways, it is necessary for road safety that a safety barrier be built in the median. As far as the requirements for the safety barriers are concerned, there is not much difference with those for safety barriers on motorways. The containment level is probably lower because of the lower design speeds of the road.
Obstacle-free zones are preferred for the shoulders. For the width of these zones next to the carriageway, section 4.2 indicates that they should be about 6 m. Six of the thirteen countries who answered the SAFESTAR questionnaire use this (or a greater) width.
If there is not enough space in the shoulders, safety barriers can be placed. The fact that a physical protection is present in the median, means that there is no danger of a frontal collisions with traffic from the other carriageway.

Single carriageways
It is to be preferred that these roads with a lot of traffic have some kind of physical separation of carriageways on the road axis. This is in agreement with the (modern) ideas of separating two traffic flows in opposite directions (sustainable safety).
The shoulders are obstacle-free with a width of at least 6 m. (see above). Safety barriers such as those used on motorways do not fit this type of road because there is the danger of reflections, and therefore the chance of a frontal collision with traffic on the other lane. Special constructions are needed for this which will keep hold a car during a collision. These have, however, not yet been entirely developed (see paragraph below: *"Research"*). Standard safety barriers could be placed if there are high-risk zones (viaducts, watercourses, ravines).

Research: special safety barriers for single carriageways
Construction modifications have the potential for favourably affecting the outcomes of accidents involving safety barriers. But vehicular manoeuvres made before the collision, as well as the driver's influence on the path of the vehicle after the collision, are more important. In cooperation with industry, the SWOV is now developing a safety barrier for single-lane roads that should allow the vehicle to remain close to the construction and thus avoid the danger of secondary collisions. Initial full-scale tests with a collision speed of 50 km/h provided good results.

8.3. Strategies for attention to obstacle accidents

Renewed attention in the US
It is striking that experts in America observe that, for decennia already, attention has been paid to the problem of obstacle accidents. This problem, however, is getting bigger and bigger. Furthermore, they maintain that studies carried out in the 1970s have lost their validity since many years, partly as a result of changing cars.
The problems being signalled are mainly those of highways. The strategy developed in America to deal with these problems appear to be applicable in Europe:

- better accident monitoring;
- research on the interaction of aspects from roads, vehicles and drivers;
- give the problem fresh attention by education, spreading knowledge, good management, planning;
- greater budgets; working at fund-raising;
- traffic laws.

Increase of obstacle problems in Europe
The single carriageway roads are in fact at the heart of the problem of obstacle accidents in Europe. There are so many such accidents because there are so many old roads. Unfortunately, such accidents are widely spread so that dealing with them cannot be targeted at concentrations of dangerous locations.
The relative number of such accidents is also on the increase: the percentage of fatal off-the-road accidents, in comparison with the total number of accidents was 13% in 1971, and in 1996 this was 26 %; a doubling during a period of 25 years. This upward development applies to the Netherlands, but probably also applies to other European countries.

Identification and approach
In section. 7.1 a procedure has been described for identifying the locations and establishing priorities for those most requiring the placing of safety barriers. Seven steps are distinguished; one of which is carrying out observations of locations and a cost-benefit analysis. Owing to the application of a cost-benefit analysis, within this method also the "one million ECU test" of the European Commission can be applied (see section 6.2.).
Where (isolated) fixed objects are standing in the shoulder, there are solutions for making poles etc. frangible (see the results of a Finnish study in section 6.2.).
The "natural" obstacles such as trees present a greater problem because of a cutting down prohibition and/or because of landscape preservation. Apart from the erection of safety barriers, to increase the safety of such roads, the speeds driven will have to be drastically reduced. Subsequently this means that the road's function will be changed; from that of a through-road to one with a more local character.

8.4. Computer simulations

Computer simulations techniques can be used to expand the traditional crash testing program, with as advantages, reducing the costs and improving the range of test condition when developing or redesigning roadside hardware. At this moment the CEN standards offer no possibilities to use mathematical simulations as an instrument to support full scale results. Recommend is to discuss this item within the CEN consultations.

9. Conclusions

Standards and history

Each European country has its own views on how to design the shoulders of motorways and express roads to make them safer. There are sometimes similarities; but mostly considerable differences. Sometimes the standards are presented on which the guidelines are based; but this is usually not the case. This present study, carried out within the framework of the European Project SAFESTAR, takes the perspective "injury prevention at off-the-road incidents", and has thus made suggestions for European design norms to ensure safe shoulders. The basis for this suggestion is the "Concept of a safe roadside". Knowledge has been gathered from European and American studies, and an inventory has been made from the completed questionnaires from 13 European countries.
It appears that European standards are sometimes based on American research of the 1970s. This comes as no surprise because America carried out roadside research in a systematic way. There are, however, reservations about the application of American research to Europe: the size of American cars was (then) much larger and the speeds driven on American roads were (then) lower, than in Europe.
Research in the Netherlands forms the counterpart of the American research. This research was fundamental in the sense that it examined the important design aspects: obstacle-free zones, slopes, fixed objects, crash cushions, and safety barriers (concrete and steel). These studies, conducted in the 1980s, have been underexposed because they were not published in a language other than Dutch. The results of these and other results from America and other European countries, are discussed in this report.

Proposal for 'European standards'

In Chapter 8 of this report a strategy is described to design a safe roadside for motorways and express roads.
To summarize, it can be stated that possibilities exist to reduce the relatively high percentage of serious accidents involving obstacles and dangerous zones. The safest way is to create obstacle-free zones or safe slopes where vehicular manoeuvres are possible. The proposed values for the width of these zones are given in Chapter 8. If there is a need for road objects (for example lighting poles) the poles can be made to yield easily in case of a collision. Solitary rigid obstacles can be shielded with a crash cushion.
The use of safety barriers is the next best solution because of the fact that safety barriers are often involved accidents, in some European countries in approximately 20% of all injury accidents on motorways.
For motorcyclist safety, a shoulder with solitary obstacles is much to be preferred above a shoulder that is completely shielded by a safety barrier.

Containment level and difference between steel and concrete barriers

Tested safety barriers according to CEN-tests get a containment level ranging from low to very high. There is a need for (European) road standards to determine which level of containment is necessary on a certain road type or road section. In the before mentioned drafts concerning the desired containment level, there are some subjects related to this level: accident history,

traffic volume, percentage of heavy truck traffic, number and width of lanes, and radius of curves. Acceptable values had to be added to these subjects.
At the moment that a containment level is fixed for a road or road section, a choice can be made between steel and concrete barriers; both have advantages and disadvantages. In the report it is suggested that if the shape of a concrete barrier is steep (instead of the shape of a New Jersey barrier) the risk for a rollover is decreased and with that, the difference between steel and concrete is small in terms of accident severity. Some European countries have already modified the shape of their concrete barriers.
The ASI-test in the CEN-test has to be revised in the future owing to better new car standards nowadays, better crumpling zones in cars, better restraint systems (belts and airbags).
CEN standards offer no possibilities for the use of mathematical simulations as additional instrument to support full scale results. Advantages of these computer technics are expanding the range of test condition and reduced the costs when developing or redesigning roadside hardware. Recommended is to discuss this item within the CEN consultations.

Single carriageway roads, the greatest problem
The absolute problem of obstacle accidents is the greatest on single carriageway roads. In the Netherlands during the last 25 years, there has been a doubling of the percentage of fatal off-the-road accidents compared with the total number of accidents. Other countries probably have had a similar experience. Approaching the problem of obstacle accidents on single carriageway roads is especially difficult because the accidents are so widespread. If we do not manage to make the shoulders safer there will have to be a drastic reduction in the speeds driven and/or the road will have to perform another function; e.g. only for local traffic.

Much attention is necessary
Following up the call in America, Europe can also call attention in a structured way to the problem of obstacle accidents. The strategy adopted in America to tackle the problem seems also to apply to Europe. This was:

- better accident monitoring;
- research on the interaction of aspects concerning the road, the vehicle and the driver;
- give the problem fresh attention by education, spreading knowledge, good management, planning;
- greater budgets; working at fund-raising;
- traffic laws.

To this can be added the application of a road safety audit during the design phase of new roads. For existing roads, it is recommended to gain some experience in the application of the "one million ECU test" to the road shoulder problem. This is an easily applicable cost-benefit analysis set up by the European Commission.

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Appendix 1 Questionnaire 'safety barriers'

SAFESTAR Safety Standards for Road Design and Redesign page 1

I. Questions for safety barriers on motorways and express roads

1. Do you have standards and/or criteria for making the decision to locate safety barriers on ***motorways?***
☐ yes, please send a copy
☐ no
2. And also to locate safety barriers on ***express roads?***
☐ yes, please send a copy
☐ no

3. What is the width of the obstacle free zone if there is no need for a safety barrier?

☐ motorways: ________ m

☐ express roads: _______ m

4. What is in terms of the CEN-standards the containment level of the normal type of safety barrier:
☐ steel barriers: containment level: ___________

☐ concrete barriers: containment level: ___________

5. And what is the containment level of special high performance barriers?

☐ steel barriers: containment level: ___________

☐ concrete barriers: containment level: ___________

6. What are the criteria to place a high performance barrier
☐ high volume traffic
☐ percentage heavy traffic
☐ narrow median
☐ narrow cross section
☐ others:
☐ danger for on coming traffic (median)
☐ danger for lower sited roads, buildings (road side)
☐ maintenance of barriers

7. What are the criteria to place concrete barriers instead of steel ones
☐ costs
☐ environment aspects
☐ high volume traffic
☐ percentage heavy traffic
☐ narrow median
☐ others:
☐ narrow cross section
☐ danger for on coming traffic (median)
☐ danger for lower sited roads, buildings (road side)
☐ maintenance of barriers

II. Presence of safety barriers
Please make a (rough) estimation of the extent in % of the presence of safety barriers on motorways in your country.

Presence of safety barriers per total length of motorways	Concrete barriers %	Steel barriers %
In the median		
In the shoulders (roadside)		

III. Research reports

Please send us a copy of recent research reports concerning:
Safety barriers in your country concerning differences between steel en concrete barriers: costs, accidents, cost-benefits.

IV. Accident data

If available, please insert data:

Year: __________ (most recent)	Number of injury accidents	Fatalities	Injuries	
			Serious*	Others
1. All injury accidents on **MOTORWAYS**				
1.1. Number of off-the-road accidents				
1.1.1. Collisions with safety barriers				
1.1.1.1. Collisions with steel barriers				
1.1.1.2. Collisions with concrete barriers				
2. All the injury accidents on **EXPRESS ROADS**				
2.1. Number of off-the-road accidents express roads				
2.1.1. Collisions with safety barriers				

*) hospitalization, if you use a different definition, please put your definition here:

V. Personal data (of the person who has filled in this form):

Name:

Organization:

Post adres:

Tel.: Telefax:

E-mail:

Remarks:

Please send this form and required documents (if existing in English, otherwise in native language) to:

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Appendix 2 Answers to the questionnaire 'safety barriers'

Country	Questions from the questionnaire 'Safety Barriers'					
	I.1.+I.2 Local standards barriers - motorway - express roads	I. 3 Width obstacle-free zone (m) - motorway - express roads	I4 Containment level normal barriers - steel - concrete	I. 5 Containment level high performance barriers - steel - concrete	II Presence of barriers - steel - concrete (rough estimation) median	roadside
Belgium Flanders	no no				70%[1] 30%	75%[1] 25%
Belgium Wallonia		4,5 3,75 (MET, 1991)[3]				
Czech Republic	yes yes	4,5 4,5	N1/N2/H1/H2 N1/N2/H1/H2	H3(H4a/H4b) H3(H4a/H4b)	98% 2%	65% 35%
Denmark	yes yes	9 3	H1 H1	H2/H3 H2/H3	100% 0%	65% 35%
Germany	yes yes	6 (10) 4,5 (7,5) data between ( ): extra dangerous zones (RPS,1989)[3]	N2 H1/H2 (probably)	H4b H4b (probably)	95% 5%	95% 5%
Greece	no no	9 (19 near railw.) 9			40% 60%	100% 0%
Finland	yes yes	7 5,5/6,5	N2 H2?	 H2?	95% 5%	95% 5%
France	yes ?[2]	10 8,50	(1A) France (2B) standard	(2A) France (2A) standard	75% 25%	95% 5%
Netherlands	yes yes	10 6	H1/H2 H2	H2 H2	99% 1%	99% 1%
Norway	yes yes	6 (both depend 5 on a.d.t.+speed)	N1/N2 (not tested; H1/H2 qual. guess)	H2/H3 (not tested; H2/H3 qual. guess)	90% 10 %	95% 5%
Portugal	yes ?[2]	3,5 3,5	(1) Portuguese (1) standard	(1) Portuguese (1) standard	82% 18%	98% 2%
Sweden	yes yes	9-10 (dep. on vel.) 7-9 (dep. on vel.)	N2 N2	H2 H2	99% 1%	≈ 95% ≈ 5%
Switzerland	yes yes	12,5 5 (VSS, 1995)[3]	H1 H1/H2		98% 2%	98% 2%
United Kingdom	yes yes	4,5 4,5	N2 N2	H1/H4a H1/H4a	95% 5%	95% 5%

1) Based on an inventory of approximately 30%.
2) The country is not sure about the given data.
3) Data filled in by SWOV, based on literature mentioned.

(First part)

Question I.6. *What are the criteria to place a high performance barrier, the number of countries that has marked one ore more criteria*

- high volume traffic	3	- danger for on coming traffic (median)	2
- percentage heavy traffic	4	- danger for lower sited roads, buildings (road side)	9
- narrow median	5	- maintenance of barriers	2
- narrow cross section	1	- others (brigde parapet, noise protection, water area protection, rail crossing)	6

Question I.7. *What are the criteria to place concrete barriers instead of steel ones; the number of countries that has marked one ore more criteria*

- costs	3	- in general: in medians concrete and in shoulders steel	1
- environment aspects	4	- danger for on comming traffic (median)	1
- high volume traffic	4	- danger for lower sited roads, buildings(road side)	1
- percentage heavy traffic	1	- maintenance of barriers	7
- narrow median	6	- others (water area protection)	2
		narrow cross section	2

Appendix 2. *Response on the questions of the questionnaire 'safety barriers' sent to European countries in March 1997. (Second part).*