Roadside design in The Netherlands for enhancing safety

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Contribution to the conference 'Traffic Safety on Two Continents', Lisbon, Portugal, September 22-24, 1997

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Foreword

Safety barriers are often used on motorways. Accident figures, however, show that a safety barrier is involved in approximately 20% of all fatal accidents. This paper considers safety barriers within the context of safe designs for shoulders on motorways.
European standards for shoulders are based heavily on American research from the 1960's and 1970's. The European situation, however, differs considerably from that of the United States. Examples for this are the wide disparity in the numbers of vehicles and the difference in driving speeds.
In the 1980's, much research into the safe design of shoulders started being carried out in the Netherlands by SWOV in commission of the Ministry of Transport and Public Works, Rijkswaterstaat.
This research, in any case, is related to the European situation and has formed the basis for Dutch standards. Now that a standardisation is being considered in connection with European unity, the Dutch research results can contribute to this.

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-lane roads, the other carriageway is seen as a danger zone. This is 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 are not always a safe solution, however. An inventory recently carried out by SWOV Institute for Road Safety Research provides figures for certain European countries.

Country	Injury accidents (%)	Fatalities (%)	Hospital casualties (%)
Belgium (Flemish)	22.7	21.2	23.3
Denmark	20.0	17.7	23.9
Germany	19.7[1)]	-	-
France	appr. 18.0	-	-
Netherlands	20.3	19.1	21.2

[1)] Including the MDO-accidents (material damage only)

Table 1. *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 fatal accidents on motorways is the result of a collision with a safety barrier; for victims requiring hospital treatment as a result of accidents on motorways, this figure is approximately 23%. The German figures for all accidents, including MDO accidents, are not much different: 20%.

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 that no barriers are installed at all: for instance the Dutch single-lane regional highways. Than 36% of the fatal accidents results 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 involving safety barriers which occurred from 1992 through 1995 were analysed in more detail. These 2,823 accidents caused 158 deaths and represent 19% of the total fatal accidents on motorways. 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 to type of vehicle, we get the following distribution (*Table 2*).

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

Table 2. *Distribution of vehicle types related to accidents with safety barriers in the primary phase of the accident.*

Type of crash	Percentage
Roll over	40
Stop near barrier	25
Rebound on road	23
Through barrier/over the top	17

Table 3. *Distribution of type of crash related to accidents with safety barriers in the primary phase of the accident (only cars).*

Table 3 provides the results in the primary phase of the type of crash (e.g. roll overs). In 75% of the accidents, the vehicle or the safety barrier displays an undesirable behaviour (roll over, 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.

The question is: can we reduce the high percentage of fatal accidents resulting from a collision with a safety barrier, and if so, how? Obviously, taking precautions to prevent these collisions in the pre-crash stages is needed, but these measures are not included within the framework of this paper. 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 victims. The possibilities for achieving this are:

- a shoulder without obstacles and also without safety barriers;
- a shoulder with safe slopes;
- a shoulder with road furniture that yield easily upon collision;
- a shoulder with crash cushions;
- a shoulder with an effectively functioning safety barrier.

We will look at each of these five possibilities in more detail. In doing so, we quote from divers investigations carried out by SWOV under the authority of the Ministry of Transport and Public Works.

2. A shoulder without obstacles

The question that immediately comes up when discussing an obstacle-free zone is how wide this zone should be. Every report opened about this topic, refers to American research from the 1960's and 1970's. Since that time, no more studies on this subject have been carried out in the United States. 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 numbers of vehicles and the 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. This research establishes 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 federal highways, and single-lane regional highways. For single-lane federal highways, this relationship is provided in the next graph. Traffic intensity (ADT) is used as a parameter; the curves are regression lines based on the given data points.

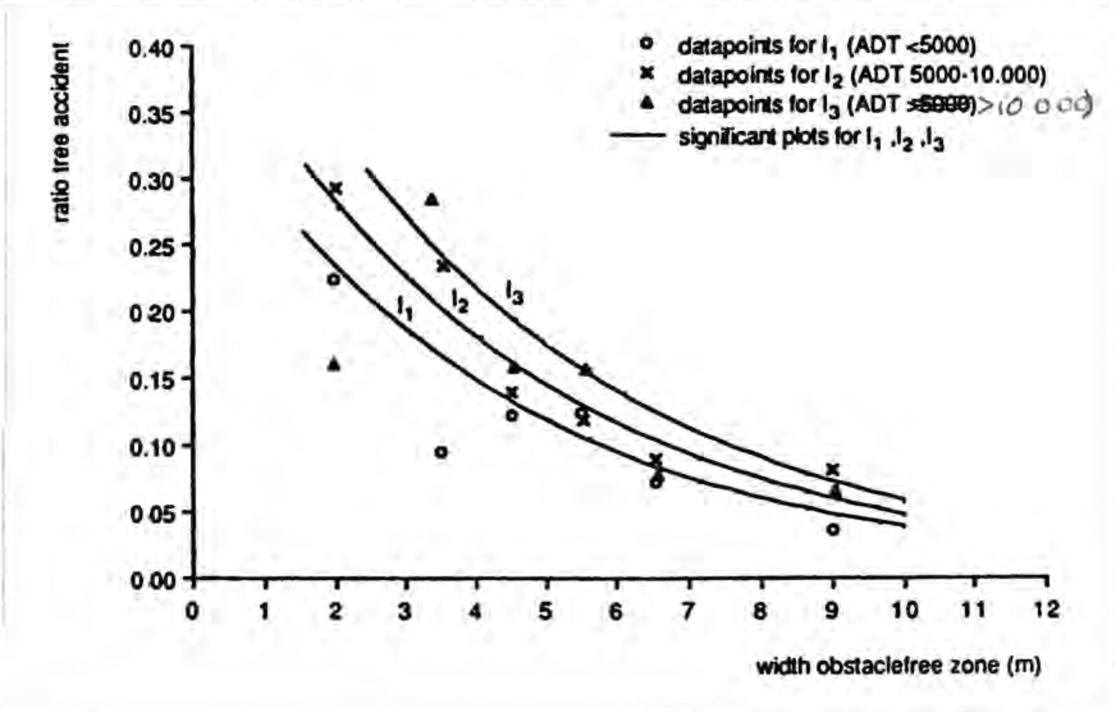

Figure 1. *The relation between the ratio of tree accidents (tree accidents vs the other accidents) and the distance that vehicles were travelled into the obstacle free zone for the single lane federal highways. All the regression curves are significant.*

From this graph it can be seen that when trees are planted at a distance of seven metres from the road, ten out of the hundred accidents occurring involve trees. The distances are measured from the border line on the right traffic lane.

In the Appendix, similar graphics are provided for motorways and single-lane regional highways. If we accept 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 that is at least 3.5 metres wide (*Figure 1.1., Appendix 1*);
- for motorways, this distance should be approximately ten metres or more (*Figure 1.2., Appendix 1*).

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 twenty 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 from making U-turns on the median.

3. A shoulder with safe slopes

Safe slopes have also been the subject of a lot of research in the United States. If 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 an optimum rounding can be defined as the minimum radius a 'standard' automobile with certain encroachment conditions can negotiate without losing tire contact.
In the United States curves are developed with as basis that slopes with an angle of 1:4 and flatter are recoverable. If such slopes are relatively smooth and traversable, a clear zone distance can be found in a graph. For example: a 1:6 slope (downwards) and a design speed of the road of 60 mph and 5,000 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 construction smooth slopes with no significant discontinuities and with no fixed objects are desirable from a safety standpoint (AASHTO, 1989).

The only study ever carried out in Europe on slopes has been the study by SWOV. Mathematical simulations formed the basis for this research (Schoon & Van de Pol, 1987; 1988a). The simulation results were verified by twelve full-scale tests on slopes with gradients of 1:2.2 and 1:4.0 (see *Figure 2.1., Appendix 2*).
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 (approximately 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.

4. Shoulder with road furniture that yields easily upon collision

If road furniture is made to yield, it can be placed in an obstacle-free zone. Examples of collision-safe road furniture are:

- aluminum lighting poles, provided they are not taller than 10 metres (Schoon & Edelman, 1978) (see *Appendix 3, Figure 3.1.-3 4*);
- 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;
- signs on thin poles that bend during a collision.

From the examples presented here, it appears that many motorcyclists are killed as a result of a collision with a safety barrier. Although road furniture provides more of a danger for riders of motorcycles than for motorists, 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.

5. Shoulder with crash cushions

If rigid obstacles that cannot be removed are located here and there along a shoulder, it is better (and often cheaper) to shield them with crash cushions. If such a crash cushion undergoes a head-on collision, the vehicle usually remains within the shoulder so that it forms no danger for other traffic. Use of the crash cushion developed in the Netherlands, known as RIMOB (see *Figure 4.1., Appendix 4*), has shown that in 97 collisions, only 6 accidents involving (slight) injuries occur (Schoon, 1990).
In 1981 and 1982 SWOV has carried out the tests with the RIMOB crash cushion. In those years there were no test conditions for crash cushions available. In accordance with some of the experiences carried out in the United States the following relevant tests have been chosen: central impacts, frontal off set impacts and side impacts.
Recently SWOV has redescribed the tests and results according to standard CEN/TC 226/WG1 (Schoon & Broertjes, 1995).
At this moment approximately 300 RIMOB crash cushions have been installed in the Netherlands

6. A shoulder with an effectively functioning safety barrier

A safety barrier can prevent a vehicle from landing in a danger zone. 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 as well.

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

a. Roll angle must be kept to a minimum.
b. Occupants must not suffer any serious injury.
c. The exit angle must be small (to avoid collisions with third parties).
d. Specifically for medians and verges between the roadway and the cycle track/footway: 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.

These assessment criteria have been described quantitatively in terms of standards for testing safety barriers (CEN/TC 226). 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, 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 in relation to manoeuvres more possibilities in this regard. One example, using the computer program known as VEDYAC that is used in Italy and the Netherlands, produced simulations involving vehicular manoeuvres for the study about slopes.

Ten years ago 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 evaluating 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 *Table 4*, a large number of these severe accidents exceeded at least one of the crash test conditions (McCarthy, 1987).

Accident characteristics	Percentage of total investigated accidents
Excess speed	20%
Excess angle	53%
Braking	45%
Not tracking	45%

Table 4. *Percentage of accidents with characteristics which exceed those of the crash test conditions.*

Although the investigated accidents represent a small sample of injuries and fatalities (N=81), the data provide 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 roll over.

VEDYAC can also be used to confirm the effect of construction modifications. One example was the testing of what effect a steel safety barrier's degree of flexibility would have on vehicle decelerations and exit angles (see *Figure 5.1., Appendix 5*). Based on mathematical simulations (Schoon, 1985), SWOV determined that the exit angle for collisions against a flexible construction (with a deflection of 1.5 metres at a collision speed of 100 km/h) is an average of 5° smaller than with a collision against a rigid construction (with a deflection of 0.5 metres at a collision speed of 100 km/h). In the Netherlands, more than half of the safety barriers are flexible. For this reason, you would expect that accident figures in the Netherlands would be more favourable than in other countries. We found with the presented Dutch figures that this is not true. Perhaps the influence of the driver in an accident situation is more important than the influence of the construction characteristics.
Another example of a construction modification, studied with VEDYAC (see *Figure 5.2., Appendix 5*), is the establishment of the effect of the concrete construction's coefficient of friction on the climbing height of the vehicle upon collision. It was established that a reduction in the coefficient of friction reduces climbing with 50% and thus the risk of overturning (SWOV, 1985).

The difference in the flexibility rate between steel and concrete safety barriers is naturally more extreme than between two steel constructions. This leads to differences in the seriousness of collision effects:
- the seriousness of the collision, in terms of vehicle deceleration, is greater for a concrete barrier;
- when a vehicle hits most kinds of concrete constructions, its front end leaves the ground; especially in the case of smaller passenger cars, this can result in overturning;
- the exit angles are larger for concrete barriers.

The fact that the smaller passenger cars have a greater risk for overturning has led a number of European federal governments (England, 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 (see *Figure 5.3., Appendix 5*). Simulations carried out by SWOV show that this edging does not unfavourably affect the course of a collision (Van de Pol & Heijer, 1993).

Many accidents with safety barriers involving seriously injured casualties are also the result of other causes. Examples are:
- the age of the construction;
- the height of the construction being made too low due to a newly constructed road surfacing;
- poor junctions between safety barriers on viaducts and bridges.

These aspects must be inspected from time to time.

New developments
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, 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.

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;
- a physical separation of truck traffic from other traffic so that safety barriers have to have different collision profiles on either side.
- the increase in heavy truck traffic and buses with a high centre of gravity is necessitating the use of high containment construction; developments are in the United Kingdom, Switzerland, Italy, USA.

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Appendices

1. *Investigation to the obstacle free zone by SWOV (1983)*
2. *Investigation to up and downwards slopes by SWOV (1987, 1988)*
3. *Investigation to road furniture: lighting poles by SWOV (1978)*
4. *Investigation to crash cushions by SWOV (1981, 1982)*
5. *Investigation to safety barrier by SWOV (full scale tests before 1975; mathematical simulations after 1985)*

Appendix 1 Investigation to the obstacle free zone by SWOV (1983)

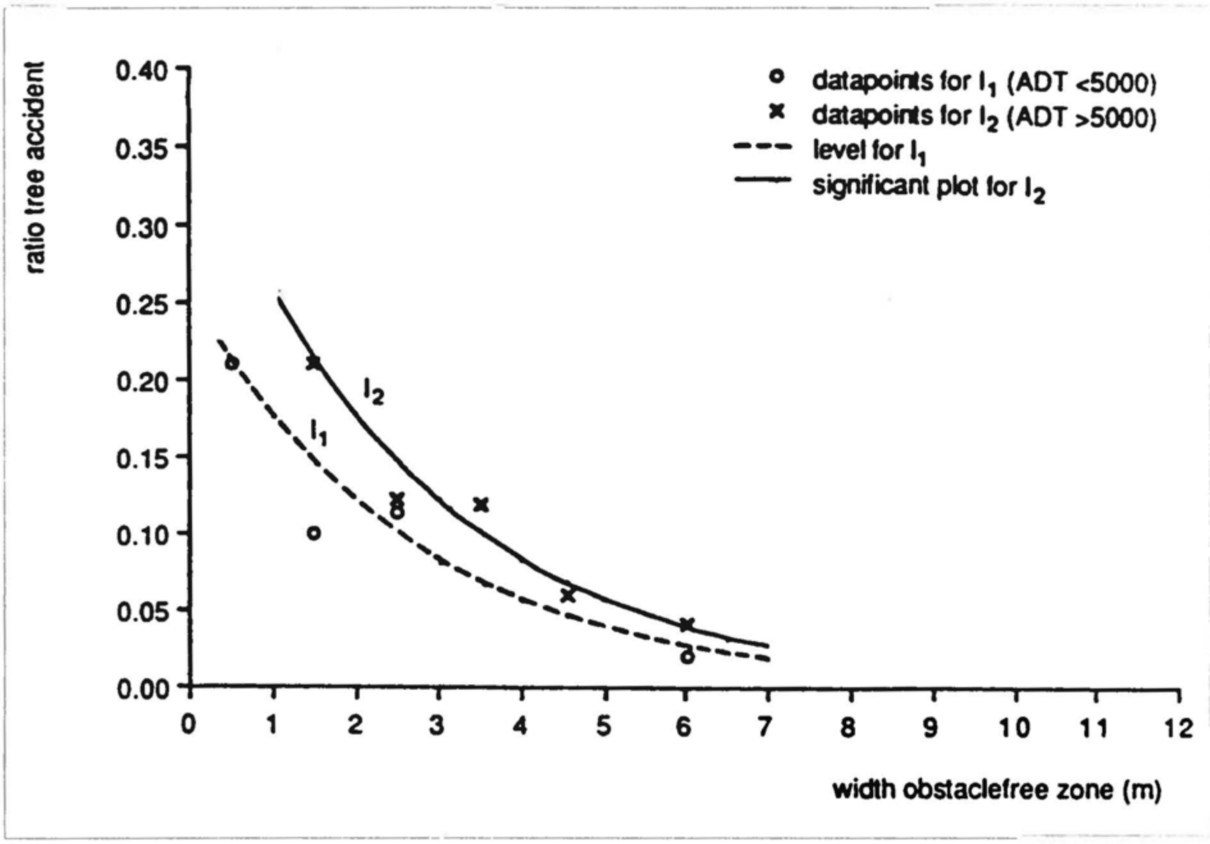

Figure 1.1. *The relation between the ratio of tree accidents (tree accidents vs the other accidents) and the distance that vehicles were traveled into the obstacle free zone for* single lane regional highways. *Only l_2 of the regression curves is significant (Source: SWOV, 1983).*

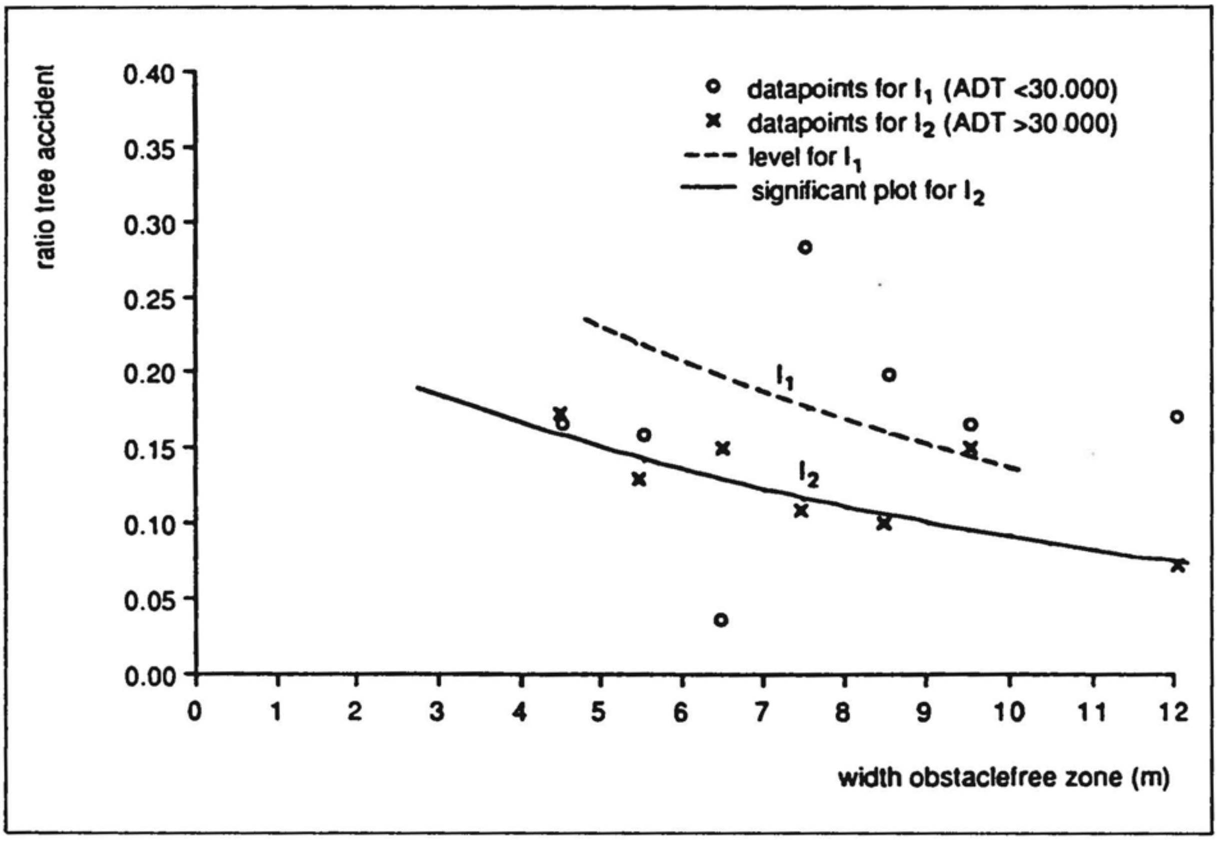

Figure 1.2. *The relation between the ratio of tree accidents (tree accidents vs the other accidents) and the distance that vehicles were traveled into the obstacle free zone for* motorways. *Only l_2 of the regression curves is significant (Source: SWOV, 1983).*

Appendix 2 Investigation to up and downwards slopes by SWOV (1987, 1988)

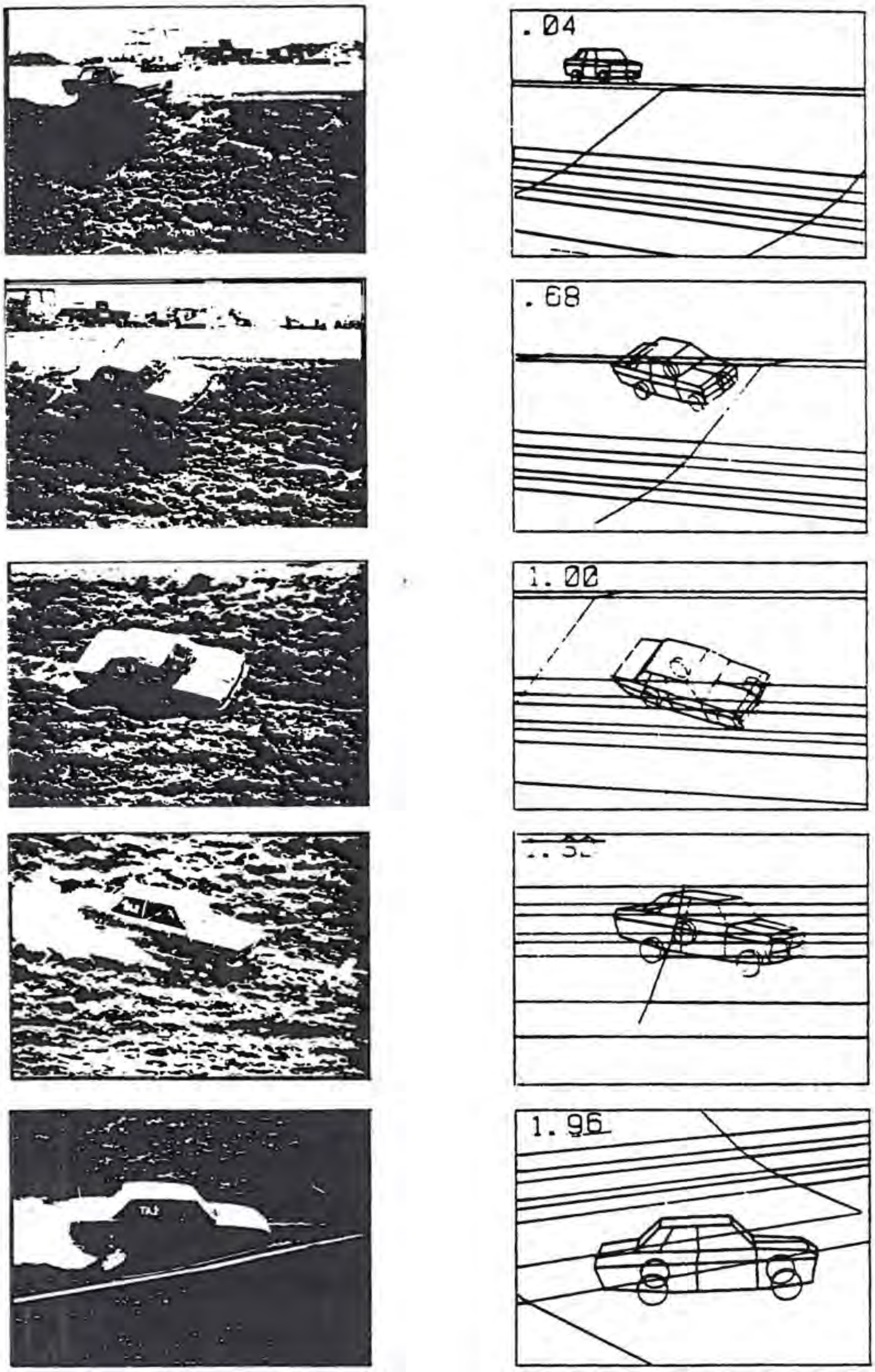

Figure 2.1 *A check for the matching of the results of a mathematical simulation with the results of a full scale test under the same conditions : slope 1 :1,2 and velocity 75 km/h. From this comparison it was found that the vehicle movements and vehicle decelerations fit very good.*

Appendix 3 Investigation to road furniture: lighting poles by SWOV (1978)

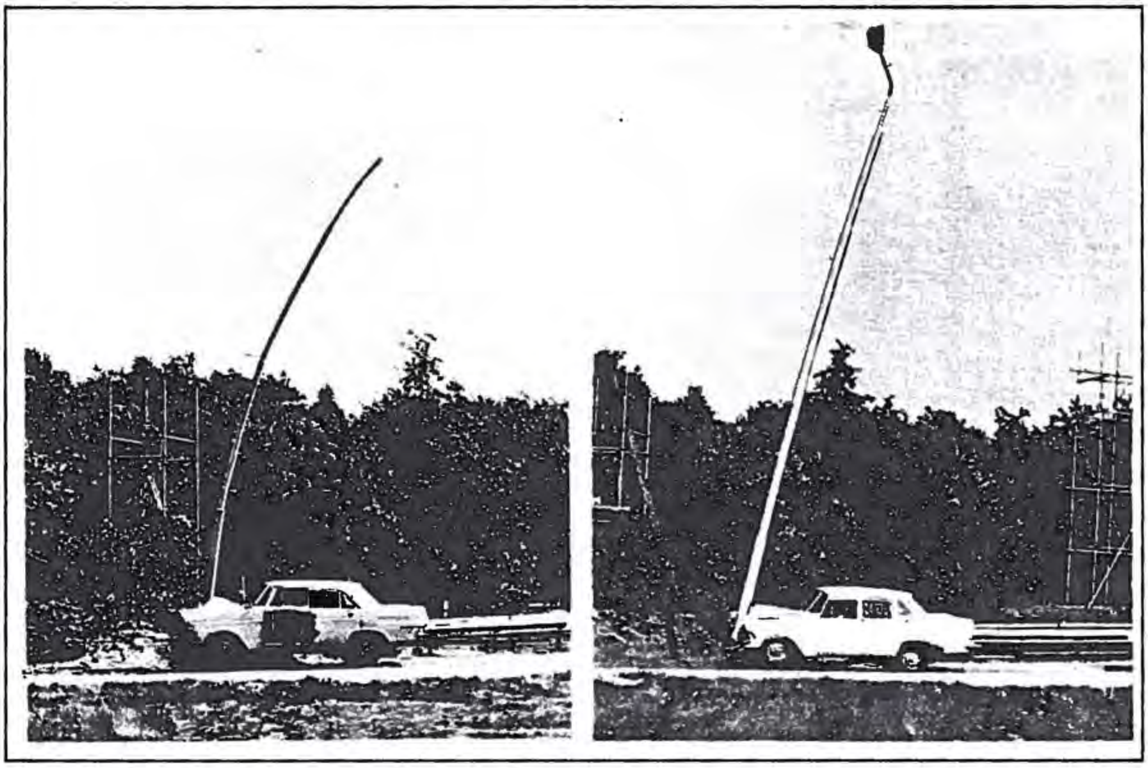

Figure 3.1. *Collision with a* steel *lighting pole (10 m) with a velocity of 82 km/h. The vehicle deceleration was too high. Only* aluminium *poles with a height of 10 m gave good results.*

Figure 3.2. *Collision with a* aluminium *lighting pole (12 m) with a velocity of 70 km/h. Owing to a high level of the vehicle deceleration, the collision was too severe.*

Figure 3.3. *This 10 m slip-design steel column hit literally 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.*

Figure 3.4. *This 10 m aluminium column hit sideways-on in test series at 30 km/h gave acceptable vehicle decelerations. But it did not break; the vehicle came to a stop against it. The dent in the vehicle's flank exceeded the maximum.*

Appendix 4 Investigation to crash cushions by SWOV (1981, 1982)

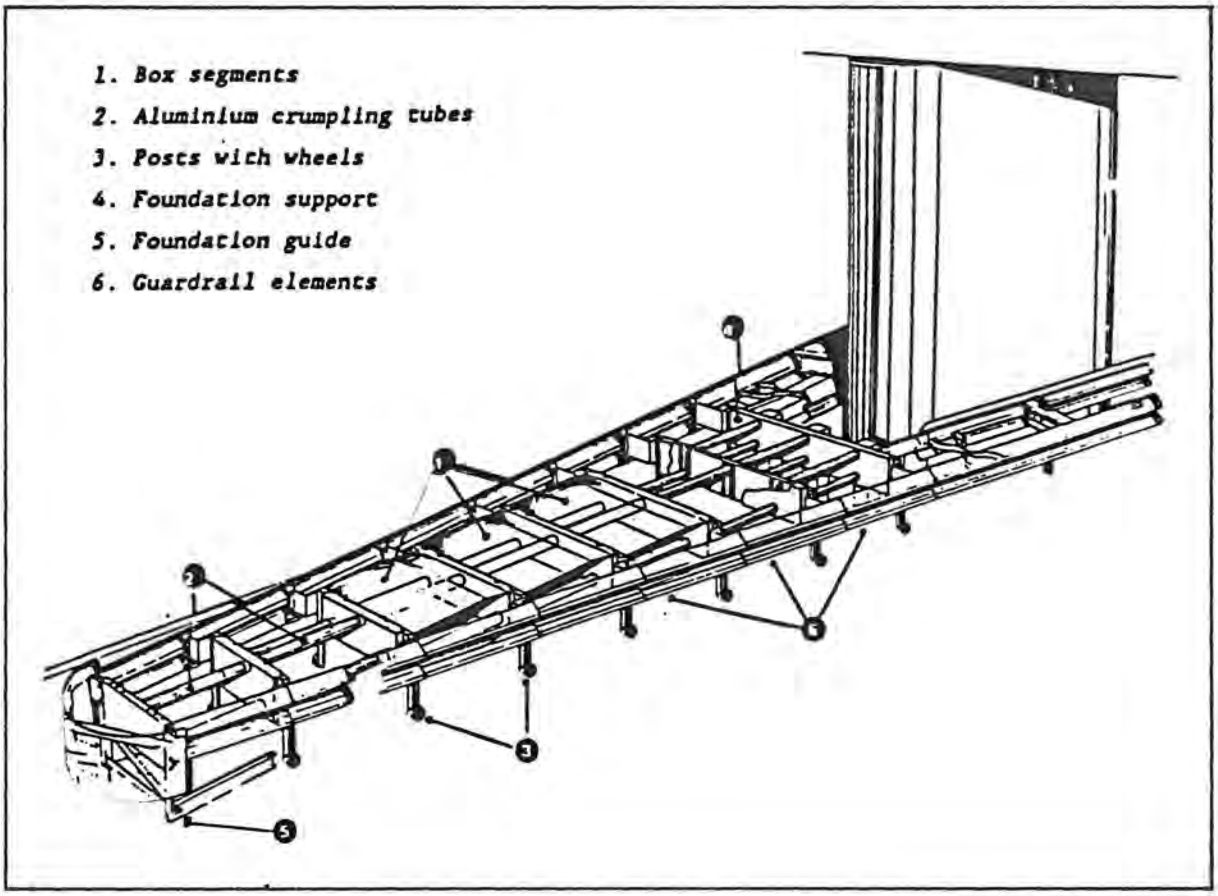

Figure 4.1 *The crash cushion RIMOB developed by SWOV in the early 1980's. At this moment approximately 300 RIMOB crash cushions have been installed in The Netherlands. The showned RIMOB has a base width of 2.70 m. Also smaller types are developed and tested.*

Appendix 5 Investigation to safety barriers by SWOV (full scale tests before 1975; mathematical simulations after 1985)

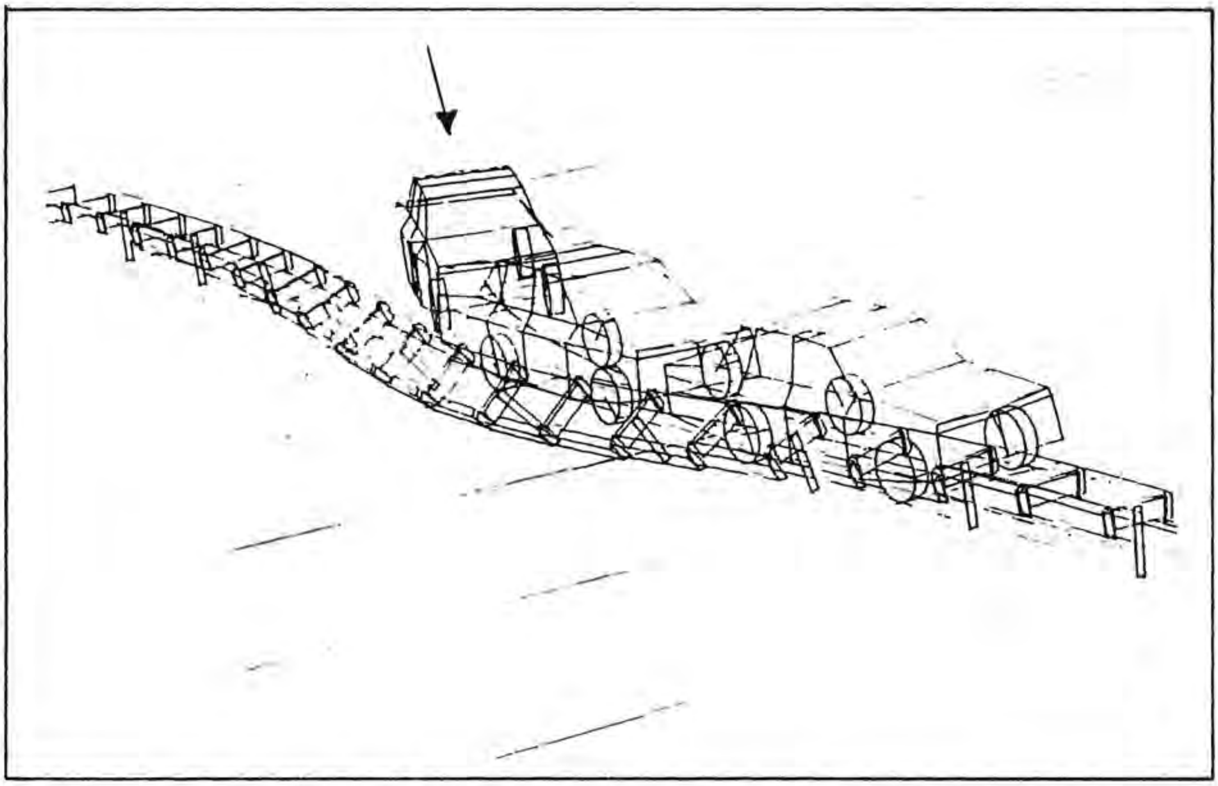

Figure 5.1 *An example of a mathematical simulation with a medium flexible steel barrier. Velocity: 80 km/h, impact angle 20 °, heavy vehicle type. The redirection was smoothly and the vehicle deceleration acceptable (SWOV, 1985).*

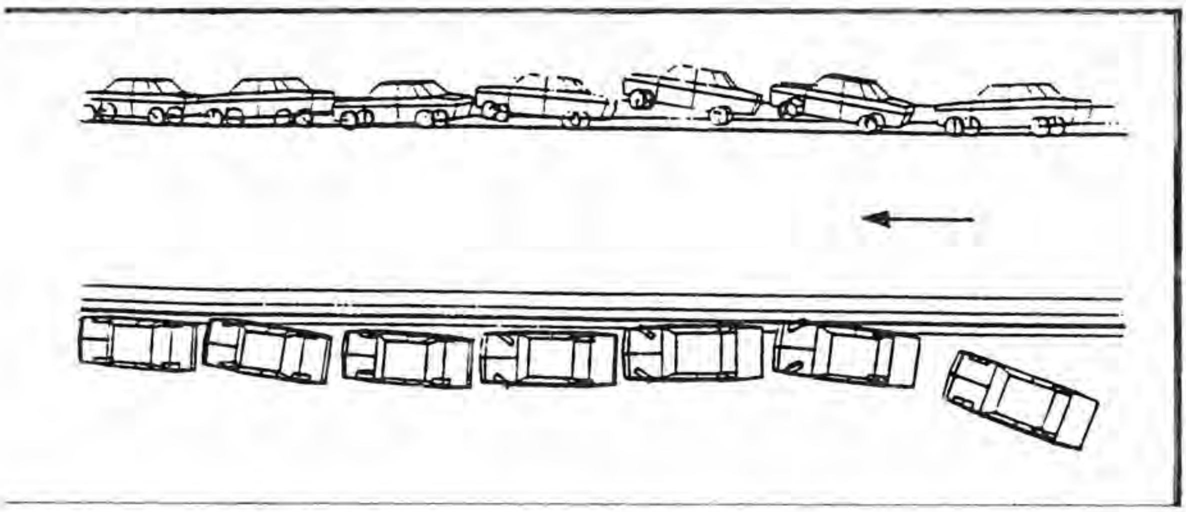

Figure 5.2 *An example of a mathematical simulation with a concrete barrier (New Jersey type). Velocity: 80 km/h, impact angle 20 °, median size vehicle type. Note the extremely high climbing height of the vehicle front. Reduction in the coefficient of friction of the barrier surface reduces climbing with 50% and thus the risk of overturning (SWOV, 1985).*

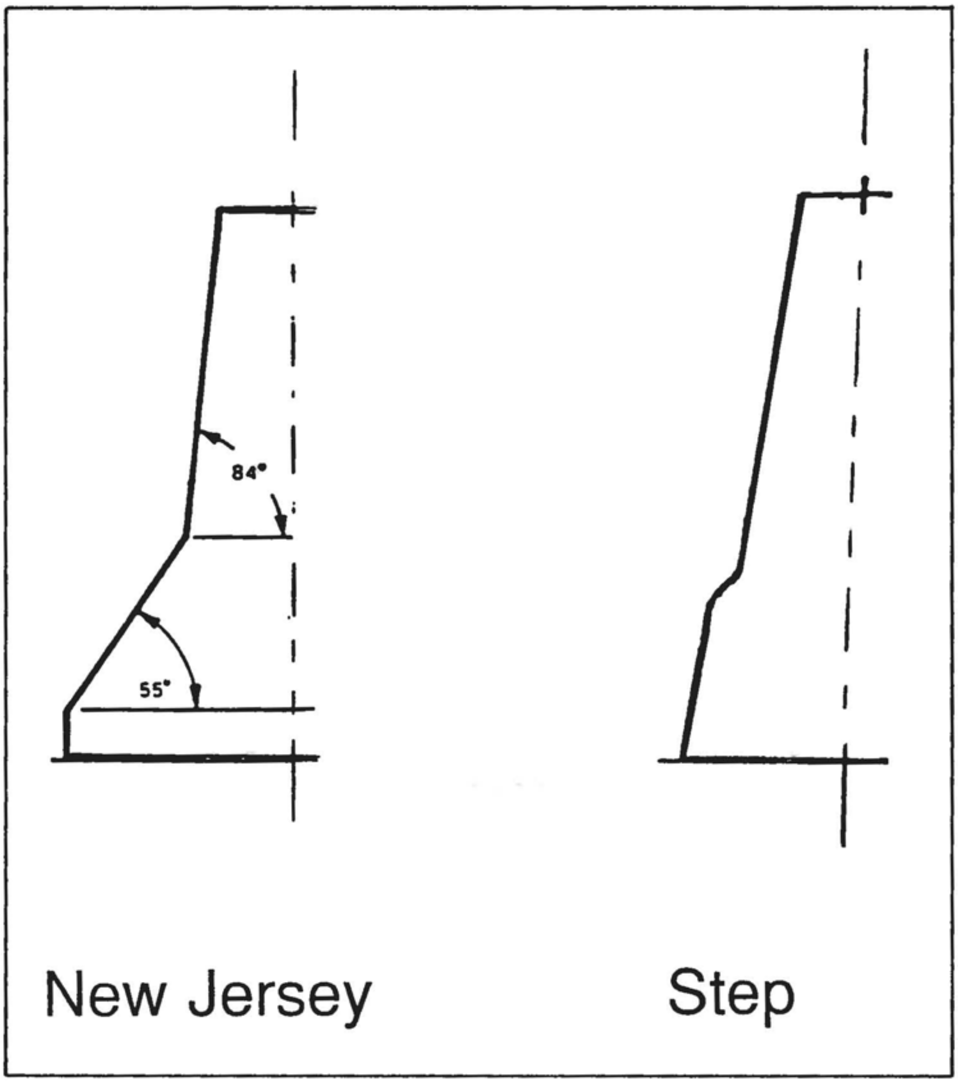

Figure 5.3. *To prevent climbing of the vehicle, SWOV has developed and tested a barrier with a new profile: the so-called 'Step barrier'. The difference with the 'standard' type New Jersey is shown. Simulations with the 'Step barrier' make clear that the steep edging does not unfavourably affect the course of a collision (SWOV, 1993).*