# AFTER SEVEN YEARS RIMOB IN PRACTICE

An evaluation of the Dutch impact attenuator RIMOB

R-90-49
C.C. Schoon
Leidschendam, 1990
SWOV Institute for Road Safety Research, The Netherlands

CONTENTS

PREFACE

Since 1982 about 170 RIMOB impact attenuators have been installed on the medians and shoulders of motorways in the Netherlands. The Dutch RIMOB is an impact attenuator with crumpling tubes to absorb the collision energy. This report is an evaluation study of this type of attenuator.

There were three reasons to develop a specific impact attenuator for the Netherlands (European) market:

1. The wish of road authorities to apply a construction, capable to safely stop light and heavy cars.
2. The need of V-shaped constructions to be applied in gore areas at motorway exits.
3. A low price to make the attenuator widely applicable.

The development led to RIMOB tested in experiments (Schoon, 1982, Quack & Schoon, 1982). Because RIMOB has been used for 7 years now an evaluation study could be made.

The accidents and practical data have been collected by DHV Raadgevend Ingenieursbureau BV (DHV, 1989). In this report the inventory data have been summarized. SWOV Institute for Road Safety Research analyzed the data.

The research was commissioned by the Transportation and Traffic Research Division (DVK) of the Public Works Department (RWS) of the Ministry for Transport and Public Works.

On behalf of DHV, we thank the Directorates of RWS, Department of Bridges and the RIMOB manufacturer (Prins NV) for the provision of the research material used for this evaluation study.

## 1. INTRODUCTION

RIMOB is applied on motorways in three different situations: in gore areas at exits often at the beginning of the guide-rail construction (Figure 1), on outer separators (Figure 2), and on shoulders to shield single objects standing alone (Figure 3).

RIMOB consists of a composition of box-like segments which are compressed in a head-on collision. The segments, which are each one metre long, contain aluminum tubes lying in an axial direction. These are crushed in a violent head-on collision to about 20% of their original length. RIMOB is protected at the side by overlapping 2-metre guide-rail elements, for which a standard profile is used. In a collision with the side of RIMOB they function in the same way as normal barrier constructions.

The impact which RIMOB can absorb can be programmed. It can be adjusted by changing in the number of segments, the number of crumpling tubes per segment, the diameter of the tubes and the thickness of the tube walls. RIMOB is attached to the ground at only two points. The advantages hereof are simple foundations and easy erection. Standard barriers can be connected to RIMOB.

Three standard types of RIMOB are used in the Netherlands (Figure 7):
V-270, a V-shape with a basic width of 2.70 metre and 7 segments with a total length of 7.50 metre;
V-185, a V-shape with a basic width of 1.85 metre and 6 segments with a total length of 6.50 metre;
P-110, a parallel-shape with a basic width of 1.10 metre and 4 segments with a total length of 4.50 metre.
Other variations are possible. The relationship between length and width is important for the stability of RIMOB in a collision sideways on the nose (Schoon, 1984).

## 2. RESEARCH DESIGN AND EXECUTION

### 2.1. Research design

For the execution of an evaluation the following subjects were considered important:
- to verify if RIMOB functions safely in collisions for the car occupants and for the other road users;
- to technically assess the effectiveness and--if necessary--to propose adaptations;
- to verify if the installation criteria of RIMOB in the Netherlands meet requirements.

### 2.2. Execution

In the first instance an overview is given of all RIMOBs installed since 1982, completed with the collisions with them. Road authorities and the manufacturer supplied the data.
Practical aspects like installation, location, replacement after a collision and costs form part of the inventory.

The following subjects, being important for the evaluation, have been dealt with:

#### Installation criteria

On the basis of the practical situation an investigation was made whether RIMOB was installed according to the criteria. An inventory was made for this purpose by two departments of RWS (the provinces of Zuid-Holland and Utrecht). In this inventory problems of fitting into the road scene and durability were considered also.

#### Safely functioning in a collision

On the basis of accident figures RIMOB was tested on its effectiveness in collisions. Depending on the availability of data two calculation methods to determine the accident severity may be used:
1. The severity of the injuries in RIMOB collisions is compared to that caused by unshielded objects. The comparison is executed by means of a classification of the severities of the primary collisions.

2. On the basis of the severity of the damage to RIMOB an estimation is made of the severity of the collision if RIMOB would not have been there. The second way of calculation is rather speculative, because severity of injuries has to be estimated when nothing is known about use of the safety belt or deformation characteristics of the vehicle concerned e.g.
If the first method is used both types of accidents can objectively be compared. For that reason this method has been used.

Technical assessment

On the basis of displacement and deformation of RIMOB and its parts the necessity of improvements to the construction has been studied. In many cases photographs of RIMOB were made after a collision. They were used for the analysis.

## 3. RESULTS OF THE INVENTORY

### 3.1. Number of RIMOBs installed and collisions

In the following table the number of RIMOBs installed since 1982 is given, split up into locations with and without collisions. The number of RIMOB collisions is also given (as at 1 June 1989).

| Type of RIMOB | Number locations with RIMOBs | | | Number locations without coll. | | Number locations with collision | | Number hits | |
|---|---|---|---|---|---|---|---|---|---|
| | A | % | | A | % | A | % | A | % |
| V-270 | 135 | 80 | | 103 | 80 | 32 | 80 | 79 | 81 |
| | | 100 | --> | | 76 | | 24 | | |
| V-185 | 24 | 14 | | 19 | 15 | 5 | 13 | 10 | 10 |
| | | 100 | --> | | 79 | | 21 | | |
| V-150 | 1 | 1 | | 0 | 0 | 1 | 3 | 1 | 1 |
| P-110 | 9 | 5 | | 7 | 5 | 2 | 5 | 7 | 7 |
| Total | 169 | 100 | | 129 | 100 | 40 | 100 | 97 | 100 |
| | | 100 | --> | | 76 | | 24 | | |

In this table RIMOB type V-270 appears to be the most frequently installed, 80% of the 169. At 24% of the locations RIMOB collisions have taken place. The difference between the V-270 and the V-185 is small.

In the following table the average yearly number of hits of a RIMOB is shown.

| Type of RIMOB | Average number of hits per year Locations with collisions | | | All locations |
|---|---|---|---|---|
| | minimum | maximum | average | |
| V-270 | 0.2 | 2.8 | 0.9 | 0.2 |
| V-185 | 1.3 | 3.7 | 1.9 | 0.2 |
| P-110 | 1.1 | 3.0 | 1.5 | 0.5 |
| All types | 0.2 | 3.7 | 1.0 | 0.2 |

The averages of the locations with accidents refer to the locations, where RIMOB had been installed for at least one year. From the table the average RIMOB appears to be hit once in 5 years (0.2 per year). The P-110 is more often hit than the other types.

Certain locations are more vulnerable than others. On the locations with accidents RIMOB appears to be hit once a year, on the average. V-270 has a

more favourable figure (0,9) than V-185 and P-110 (1.9 and 1.5 accidents a year respectively).
An analysis of the characteristics of the locations where RIMOB is more often hit than average, can give an insight into possible causes of accidents. On that basis installation criteria can be adapted.

3.2. Data of locations

From the inventory of two regional departments (the provinces of Utrecht and Zuid-Holland) more data on the locations of 66 RIMOBs are known. First an overview is given of the types of shoulders where RIMOBs have been installed.

| Type of shoulder | RIMOB A | V-270 % | V-185 A | % | P-110 A | Total A | % |
|---|---|---|---|---|---|---|---|
| Gore area | 13 | 24 | 6 | 60 | 2 | 21 | 32 |
| Median | 3 | 5 | | | | 3 | 4 |
| Outer separator | 22 | 41 | 3 | 30 | | 25 | 38 |
| Shoulder | 16 | 30 | 1 | 10 | | 17 | 26 |
| Total | 54 | 100 | 10 | 100 | 2 | 66 | 100 |

Most RIMOBs appear to be installed on the outer separators; gore areas take the second place, with mostly V-185.

To which extent guide-rail constructions have been connected to RIMOBs is indicated in the following table. If there is no guide-rail construction attached to RIMOB a guide-rail end is built. The rigidity of the connected guide-rail construction is expressed in the post distance. To which side of RIMOB the guide-rail construction is connected is indicated by main lane and secondary lane. For the shoulders only the main lane is important.

| Type of connection | Gore area, median, main lane | | outer separator, secondary lane | | Shoulder main lane | |
|---|---|---|---|---|---|---|
| | A | % | A | % | A | % |
| Guide-rail construction | | | | | | |
| -post distance 133 | 26 | 53 | 30 | 61 | 6 | 35 |
| -post distance 267 | 11 | 22 | 3 | 6 | 1 | 6 |
| -post distance 400 | 1 | 2 | | | 5 | 29 |
| End of guide-rail construction | 11 | 22 | 16 | 32 | 5 | 29 |
| Total | 49 | 100 | 49 | 100 | 17 | 100 |

The flexible construction (post distance 400 cm) appears to be hardly used, and the half-rigid constructions (post distance 267 cm) fairly often. Though the guidelines do not give directives which rail type is to be used, it is preferable to connect RIMOB to the rigid construction (post distance 133 cm).

## 3.3. Accident analysis

From 1982 to June 1989 97 RIMOBs have been hit (see Figure 8). This number is fairly well known, because repairs are executed after each collision. As the expenses are always charged to the driver or to the Guarantee Fund the registration is accurately kept up to date by the road authorities.

Though the number of collisions is known the police only filled out a statistical form in 38 cases only (degree of registration 39%). It means that in less than 50% of the cases general accident data are known. In some cases certain data could be obtained from the road authorities.

In the following tables distributions are given according to some circumstances, vehicle type, and type and severity of the collisions.

| Circumstances | Number | Percentage | Percentage |
|---|---|---|---|
| Light | | | |
| Daylight | 20 | 50 | |
| Night/twilight | 20 | 50 | |
| Total | 40 | 100 | 41.2 |
| Unknown | 57 | | 58.8 |
| Total | 97 | | 100 |

| | | | |
|---|---|---|---|
| Weather | | | |
| Dry | 29 | 67.4 | |
| Wet | 14 | 32.6 | |
| Total | 43 | 100 | 44.3 |
| Unknown | 54 | | 55.7 |
| Total | 97 | | 100 |

The 50% of the collisions by daylight correspond with the figure of 49% known from shoulder accidents outside built-up areas (SWOV, 1982, Casualties in the years 1974-1977). The figure of 32,6% in wet weather corresponds less well: earlier figures gave 18%.

The distribution according to vehicle type hitting RIMOB is given in the following table. The minimum and maximum vehicle masses are given between brackets. The Road Traffic Division (RDW) of the Ministry of Transport and Public Works supplied the data. RDW is responsible for the registration of the licence plates of motorized vehicles.

| Type of vehicle | Number | Percentage | Percentage |
|---|---|---|---|
| Cars (mass 642 to 1414 kg) | 43 | 91.5 | |
| Vans (mass 1515 kg) | 1 | 2.1 | |
| Lorries (mass 6210 to 16150 kg) | 3 | 6.4 | |
| Total | 47 | 100 | 48.5 |
| Unknown | 50 | | 51.5 |
| Total | 97 | | 100 |

In earlier publications on RIMOB it was stated that passenger cars were involved in 78% of the shoulder accidents. This figure was, however, related to all types of road outside built-up areas; two-wheelers were included in the distribution according to vehicle category.
In this research study nothing is known about collisions of motor riders with RIMOB, as the collection of data is based on the damage to RIMOB. A collision of a motor rider with a RIMOB will not cause serious damage to RIMOB. The lack of possible collisions of motor riders with RIMOB in this accident analysis is unsatisfactory: the insight into the extent of danger to motor riders is poor. National statistical data can also give little insight in this case, because RIMOB is not separately coded. We will give more attention to this aspect in section 4.3.

The following data are based on photographs of hit RIMOBs. The fact is that at the request of the Transportation and Traffic Research Division (DVK) of the Public Works (RWS) Department photographs have been taken of hit RIMOBs from the beginning. In most cases it was done at the factory site where the RIMOBs were taken after being hit. 79 out of 97 hit RIMOBs could be studied this way. Some results are given in the following tables.

| Type of collision | Number | Percentage | Percentage |
|---|---|---|---|
| Head-on (straight) | 36 | 45.6 | |
| Head-on (eccentric) | 15 | 19.0 | |
| Head-on (at an angle) | 6 | 7.6 | |
| Sideways/head-on | 16 | 20.3 | |
| Sideways | 3 | 3.8 | |
| Other | 3 | 3.8 | |
| Total | 79 | 100 | 81.4 |
| Unknown | 18 | | 18.6 |
| Total | 97 | | 100 |

92% of the collisions appear to have happened at the nose of the RIMOB; 72% head-on, 20% sideways/head-on, and only 4% at the side of the RIMOB. The extent to which RIMOB was compressed in the longitudinal direction is determined on the basis of the photographs; the damage in the sideways collisions was not taken into account. For all three types of RIMOB the result is:

| Compression (cm) | Number | | Percentage | | |
|---|---|---|---|---|---|
| 0 - 50 | 12 | | 18.8 | | |
| 51 - 100 | 7 | | 10.9 | | |
| 0 - 100 | | 19 | | 29.7 | |
| 101 - 200 | | 16 | | 25 | |
| 201 - 300 | | 16 | | 25 | |
| 301 - 400 | | 5 | | 7.8 | |
| 401 - 500 | | 5 | | 7.8 | |
| 501 - 600 | | 3 | | 4.7 | |
| 601 - 700 | | 0 | | 0 | |
| Total | | 64 | | 100 | 66 |
| Side-side/head-on | | 15 | | | 15.5 |
| Unknown | | 18 | | | 18.5 |
| Total | | 97 | | | 100 |

The minor collisions (compression to 1 metre) comprise 30% of the cases. In only 20% of the collisions RIMOB is compressed more than 3 metre.

The following table gives a distribution of the speeds at the moment of collision with RIMOB. The impact speeds of the passenger cars and the vans have been determined with the aid of a nomogram (Appendix 1). This indicates the relationship between vehicle mass, compression of the RIMOB and vehicle speed. The mass is equal to the empty weight of the vehicle.

Calculating the speed the occupants' weight was not included. Two reasons: it is not known how many occupants passenger car contained at the time of collision, and the kinetic energy of a passenger only contributes a certain (unknown) part to the RIMOB compression.

In only one third of the collisions considered (see following table) the impact speed of the vehicle could be determined, as the vehicle type was not known and the impact speed in sideways and sideways/head-on collisions can not be determined with the aid of a nomogram.

| Impact speed (km/hour) | Number | Percentage | Percentage |
|---|---|---|---|
| 0 - 20 | 0 | 0 | |
| 21 - 40 | 4 | 12.1 | |
| 41 - 60 | 11 | 33.3 | |
| 61 - 80 | 11 | 33.3 | |
| 81 - 100 | 2 | 6.1 | |
| 101 - 200 | 4 | 12.1 | |
| Total | 33 | 100 | 34 |
| Unknown | 64 | | 66 |
| Total | 97 | | 100 |

Most speeds were found to have been between 40 and 80 km/hour (67%). Four collisions took place with a speed of over 100 km/hour. It is striking that no collisions were found under 20 km/hour, whereas in 12 cases (19%) the RIMOB compression was less than 50 cm. From the basic tables it is seen that neither the police nor the road authorities have registered 9 out of these 12 cases (DHV, 1989). That is not surprising, as the vehicle will be able to keep going without help after such a collision.

### 3.4. Costs

Installation costs of RIMOB are set at Hfl 13,000 to Hfl 15,000 (exclusive of extensive adaptations to the road design).
According to the agreement between manufacturer and Public Works Department RWS a hit RIMOB is completely replaced and repaired in the factory. In only four cases RIMOB was repaired on the spot.
Repair costs vary from Hfl 2,000 to Hfl 14,000, with an average of Hfl 6,710.

N.B. In 9% of the researched collisions no repair amount was given by the road authorities.

An important part of the repair costs are the transportation costs of a hit RIMOB. They vary between Hfl 800 and Hfl 3,500 depending on the distance between manufacturer and accident location.

# 4. EVALUATION

## 4.1. Installation criteria and practical aspects of installed RIMOBs

The road authorities determined the installation criteria (RWS, 1988). The subjects determined are discussed here. The assessment was made on the basis of an inventory.

Most RIMOBs have been installed according to the installation criteria. RIMOBs installed before the criteria were formulated were also taken into consideration.

If there is a differentiation with the criteria the following points are concerned:

- the distance between the gore area and RIMOB is too long
- in some cases a certain length of guide-rail construction is provided where a guide-rail end would have been sufficient.

Sometimes the distance between RIMOB and obstacle is unnecessary long. Furthermore, the expression "central location" of RIMOB in outer separators in the criteria is not clear; installation criteria have to be changed in these respects.

The company installing the RIMOBs at the locations indicated problems with the fastening on the foundation block. This could be solved by some small adaptations, like the application of less narrow fittings.

Because the installation of RIMOB, and the construction of foundation and guide-rail construction are executed by different companies, problems arise regularly. The road authorities will pay attention to the problem.

An inventory in the provinces of Utrecht and Zuid-Holland of the state of maintenance of 66 RIMOBs showed the following:

- Most RIMOBs are missing one or more of the side-plates of polystyrene, or the side-plates have come loose. When they were first fastened the plates already caused problems.
- At the connection of the guide-rail construction to RIMOB some shortcomings were found. Most striking was the lack of a spacer closely behind RIMOB.
- In one case RIMOB was found to be too low because of new asphalt layers put onto the road. This point needs extra attention.
- The front guiding is often filled with sand; it is assumed that this not causing problems in collisions.
- In one case vandalism was found: the upper plates and the upper crumpling tubes were damaged.

- The holes for the outflow of water in the lower plates have not been made in the lowest spot.
- In no RIMOB rustiness was found.

### 4.2. Safe functioning in a collision

The effectiveness of RIMOB has been determined on the basis of accident severity. Accident-forms filled out by the police were used. As the police does not always register the accidents, in only 38 out of 97 collisions it is known whether there were any injuries. A split-up of the 38 cases according to severity shows the following:

- 32 collisions without casualties
- 6 collisions with casualties of which:
  - 1 collision with 2 light casualties (impact speed 115 km/hr)
  - 2 collisions with 1 light casualty each (impact speeds 70 and 80 km/hr
  - 1 collision with 1 hospitalization (cause of the collision was becoming unwell of this person; the impact speed could not be determined because of the collision type (sideways/head-on).
  - 1 collision with 1 transportation to the hospital, but whether hospitalization took place is unknown (impact speed 60 km/hr)
  - 1 collision with probably 1 casualty, according to eye-witness (impact speed 100 km/hr).

The following table shows the distribution of the 59 RIMOB collisions without police registration, of which the compression could be determined in 35 cases according to the extent of the RIMOB compression. The other figures are unknown.

| Compression (cm) | Number | | Percentage | | |
|---|---|---|---|---|---|
| 0 - 50 | 14 | | 40 | | |
| 51 - 100 | 3 | | 8.6 | | |
| 0 - 100 | | 17 | | 48.6 | |
| 101 - 200 | | 11 | | 31.4 | |
| 201 - 300 | | 3 | | 8.6 | |
| 301 - 400 | | 1 | | 2.9 | |
| 401 - 500 | | 2 | | 5.7 | |
| 501 - 600 | | 1 | | 2.9 | |
| 601 - 700 | | 0 | | 0 | |
| Total | | 35 | | 100 | 59.3 |
| Side-side/head-on | | 8 | | | 13.6 |
| Unknown | | 16 | | | 27.1 |
| Total | | 59 | | | 100 |

In almost half of the cases the compression was only 0-1 metre. Though no relationship was shown between the extent of compression and the severity of the injuries, the risk of a (severe) injury is supposed to be small in this kind of accidents.

From the photographs no passenger car appeared to have diven under the construction. In one case a lorry had gone over the side of RIMOB.
In no case loose parts of RIMOB had caused danger to other road users after a collision, as far as known.
According to accident forms filled out by the police after a collision with RIMOB, one secondary accident had happened involving other traffic participants. It had happened in one case out of 38 owing to the rotating of the colliding passenger car, but there were no casualties.

As indicated in Chapter 2 RIMOB accident figures will be compared to those with unshielded obstacles, like viaduct piers, sign posts and of guide-rail ends on gore areas. These types of obstacles have not been included in the accident database. They can only be selected by coupling the database with the database of locations. This has not been done for budgetary reasons.
As an alternative for a rigid type of obstacle the tree was selected, which is included as such in the accident database.
In the following table the severity of accidents with trees is compared to those with RIMOB. Car/tree collisions on motorways in the years 1986 to 1988 inclusive are taken into account.

| Accident severity | Collisions with trees | | RIMOB-collisions | |
|---|---|---|---|---|
| | Number | Percentage | Number | Percentage |
| Fatalities | 15 | 4.7 | 0 | 0 |
| Hospitalization | 38 | 12.0 | 1 à 2 | 3.9 (average) |
| Other injuries | 59 | 18.6 | 4 à 5 | 11.8 (average) |
| MDO* | 205 | 64.7 | 32 | 84.2 |
| Total | 317 | 100 | 38 | 100 |
| Severity | | 13.4 | | 0 |

* material damage only

The severity of accidents is here defined as:

$$\frac{\text{number of accidents with fatalities}}{\text{number of accidents with fatalities and injuries}} * 100\%$$

From the table the severity of collisions with trees is 13.4% and for RIMOB zero.
The other percentages of injury severity categories (hospitalizations, other injuries) are much lower for RIMOB than for the tree collisions. It should not be forgotten that only 40% of RIMOB accidents was included in the accident registration. As we concluded before we assume that at least half of the non-registered accidents will belong to the lighter category.

4.3. <u>Technical assessment</u>

To assess the (internal) performance of RIMOB the following parts and aspects have been studied:
- stability, in the lateral and vertical directions;
- way of compression in the longitudinal direction;
  - successive compression
  - compression of the last segment
- inclination of cross supports
- performance of the nose segment
- performance of the deformation strips (spacers between cross supports and guide-rail elements)
- deformation of the upper plates
- performance of the polystyrene side plates
- sharp parts possibly dangerous to motor riders

For the analysis 79 photographs of RIMOBs damaged were available. They were made after transportation of the RIMOB to the factory following the accident (Figure 9).

<u>Stability in lateral and vertical directions</u>
Though the photographs after transportation do not give an exact picture of the lateral and vertical deformations, it could be determined that on the basis of guide-rail elements' deformation certain limits of load were exceeded or not. That is important to assess RIMOB stability.
In a number of cases the guide-rail elements appeared to have been slightly bent in the longitudinal direction. In no case they were broken. The conclusion is that RIMOB functions well in case of sideways collisions on the nose and in case of off-set collisions. In the vertical direction also stability is found. That is important especially for the prevention

of unwanted vehicle behaviour: diving under the construction or landing on top of it.

Longitudinal compression

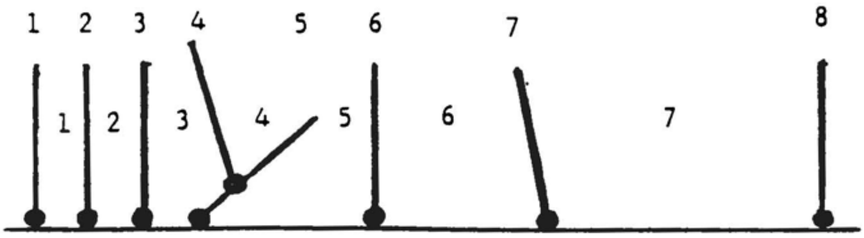
In a collision it is desirable for RIMOB to get deformed by being compressed segment by segment. This does not always happen. Often a following segment was seen to be partly compressed when the former had not yet been compressed completely. Though it does not influence the effective performance of RIMOB it causes higher costs of repair.
The problem can be solved by applying a more progressive action. The question is whether the higher costs of manufacturing (and the risk of errors) counterbalance the reduction of the costs of repair.
RIMOBs were three times compressed more than 5 metre, according to the figures in section 3.3 of this report. It was investigated if the last segment--the buffer segment taking care of the reserve capacity--was really used. Photographs showed that this was the case for only one RIMOB-V270, compressed for 10 cm, and for one RIMOB-V185 ca. 20cm. The crumpling tubes of the buffer segment of RIMOB-P were slightly crumpled or bent in two cases.
It may be worthwhile to make a lighter buffer segment.

Inclination of cross supports

In a heavy collision the deformation is ideal if the segments are completely compressed and the cross supports between the segments have been pushed backward vertically. On photographs of compressed RIMOBs, however, several cross supports appear to be inclining backward or forward (sometimes even to 45°). This is possible because the connection between cross supports and guide-rail elements exists of easily deformable deformation strips. The following general picture can be drawn of the inclining cross supports with the aid of the photographs of heavily damaged RIMOBs (See also Figure 9).

cross support number

segment number



The first three supports stand reasonably upright when RIMOB is completely deformed. The fourth one is pushed up and tilted somewhat backward. The top of the fifth support is tilted forward and is found more or less under the fourth. This picture is valid for the V-270.
The V-185 shows the same picture in heavy collisions, but the tilting begins one section earlier.
Photographs of the last tested V-270 in the development research show an equivalent picture (test OB F13; Schoon, 1982). An analysis of the film did not explain the inclination of the cross supports.
Possibly the following takes place for the V-270 in a heavy collision: first the first three segments are compressed vertically; no inclination of cross supports yet, because of the presence of the 25 cm long spacers in the segments. As the crumpling tubes are put in a triangle (one on top of the other two) there is more resistance on the lower side of the cross support than on the upper side. This gets manifest between the fifth and sixth cross supports: the upper-side of the segment is easier compressed than the lower, with the consequence that the fifth cross support gets tilted. The fourth cross support is hit by the fifth and is pushed upward.
For the V-185 the same explanation is valid, but the difference is that the process begins one segment earlier, possibly because the V-270 has spacers in four segments, and the V-185 in three only.
Because of the inclination of the two mentioned cross supports RIMOB will probably function less effectively only at severe accidents. One segment absorbs less energy, which causes the buffer segment to be earlier hit.

As this segment is not easily deformed the vehicle deceleration will increase. An other aspect of the inclination regards costs: more damage is done to RIMOB, on the one hand because RIMOB is more compressed, on the other hand by more torsion and bending. It is recommended to provide all segments with spacers, except the buffer segment.

Performance of the nose segment

In view of the fact that the first segments are compressed vertically the conclusion can be drawn that the nose segment works well. It also became clear from the damage patterns that the deformation of the nose segment had adapted well to the vehicle front in case of sideways on the nose and off-set collisions.

Performance of the deformation strips

As indicated above the deformation strips are the flexible connections between the segments and the guide-rail elements. They are especially important to the V-shaped RIMOBs. If the connections would be rigid the guide rail elements could not move over each other when the segments are compressed. In Appendix 2 the collision process is illustrated.
The photographs showed that the guide-rail elements moved well over each other. In the heavier collisions the distance over which they could move appeared to be well limited by the rail guards at the sides. These elements connect the guide-rail elements. They are so long that they also serve as spacers between two consecutive guide-rail elements.

Deformation of the upper and lower plates

Because of the pre-deformation of the covering plates these upper and lower plates have to bend respectively upward and downward in a collision. The photographs showed that the plates had functioned well. With reference to the development research the under plates were thought to be possibly too wide. In the tests an inclination of the cross supports was found, where the underside of the bent under plates had touched the underside of the cross supports. In this way they would hamper the vertical movement of the cross supports.
In this evaluation the photographs did not show that the under plates hampered the cross supports, so it is not necessary to make the plates less wide.

Performance of the polystyrene side plates

The side plates have only been put on to prevent damage in case of vandalism. They serve two aims, in the first place they (visually) shield the crumpling tubes, and in the second place they support the upper plate in case people walk on the segments.
In connection with the experience of the development the application of polystyrene plates was not the first choice, since three objections were given against it. The first is that the plates or parts of the plates may be propelled on the road and may cause shock reactions to road users. In the second place the plates may touch the crumpling tubes in a collision and deform them in the lateral direction.
Finally the plates may be compressed, magnifying an inclination of the cross supports, and giving the vehicle a rebound.

The evaluation research has not shown whether the objections mentioned come true in collisions. In combination with data on actual vandalism a differently shielding of the sides will have to be considered, if necessary.

Sharp parts

Because of the research design no practical data are available to determine whether sharp parts of RIMOB are dangerous for motor riders. From general research, however, it is known that motor riders involved in an accident often fall with their motor cycles. They will then touch mostly the underside of a construction on the shoulder, which will be the posts of a RIMOB, if they touch a RIMOB. In contrast to the round posts of the guide rails on the shoulders Rimob posts consist of an angled profile. When RIMOB is redesigned the posts will have to have a round profile also, or be covered by shock absorbing material.

Résumé of the propositions on technical adjustments

When RIMOB is redesigned the following elements need attention:
- application of spacers in all segments, except for the buffer segment;
- adaptation of the polystyrene side plates;
- to make the posts round or provide them with shock absorbing material;
- reconsideration of the dimensions of the buffer segment.

## 7. CONCLUSIONS

RIMOB appears to have a satisfactory effect in collisions. In a head-on collision RIMOB is compressed in the longitudinal direction and in sideways collisions RIMOB works as a rigid guide rail construction.
The construction was found to be stable in the lateral and vertical directions. The stability in the lateral direction was found in sideways and in sideways/head-on collisions on the nose, when the front side of RIMOB gets detached from the front guiding element.
Because of the great vertical stability a private car was never found to have gone over or under the construction.
The deformation in the longitudinal direction is to be called satisfactory apart from some minor criticisms. Often the segments are deformed successively in the right way. Because of the inclination of the cross supports, the application of spacers in all segments is recommended, except for the buffer segment.
In not one of the collisions considered the last segment--the buffer segment with extra crumpling tubes--was seriously damaged. It should be studied whether the dimensions have to be changed.
Analysis of the characteristics of the locations where RIMOB is hit more than average may give an insight into possible causes of accidents. On this basis the installation criteria can be adapted.

A total of 97 collisions was registered by the road authorities. In 38 cases the police filled in statistical forms.
From the accident figures RIMOB appears to shield objects effectively. Even though collision speeds have been found of over 100 km/hr no fatal accident was registered. Of the 38 collisions 6 resulted in injuries, of which 1 or 2 were taken to hospital and 4 or 5 only were slight injuries.
Of the 59 non-registered collisions in 35 cases the compression of RIMOB was determined: in almost 50% of the cases the compression was not more than 1 metre. In one case a RIMOB collision resulted in a collision with an other car; only material damage was found.
To assess RIMOB accident severity a comparison was made with the tree accident severity on motorways.
If the severity of accidents is defined as:

$$\frac{\text{number of accidents with fatalities}}{\text{number of accidents with fatalities and injuries}} * 100\%$$

the severity of collisions with trees can be calculated at 13.4% and with RIMOB zero. If injury categories are compared the percentages of RIMOB appear to be much lower than those for tree accidents.
Even if only 38 accidents were studied the conclusion can be that RIMOB functions effectively.
It is also recommendable to determine which indicator can be best used to express the RIMOB accident severity, in order to make it possible to compare the figures with those of other impact attenuators.
RIMOB accident figures should continuously be registered in order to make an evaluation study possible on the basis of more collisions.

The practical experiences with RIMOB are favourable. The construction can be installed fast for the first time and also in case of replacement, as it can be mounted as a whole on a foundation support. A disadvantage of this method is that in case of small damages of e.g. the nose segment a complete replacement has to be executed. Transportation costs then take a disproportionate part of the costs. Sometimes the mounting is difficult because of the too small tolerance in the points of anchorage; in a first mounting the connection between the guide rail and RIMOB sometimes causes a problem.
In general RIMOB is installed according to the criteria. The criteria might be sharpened regarding the aspects of "installation in outer separators" and "centric installations". In some cases road authorities install a certain length of guide-rail constructions where a short (guide-rail end) would have been sufficient.
RIMOB keeps well in practice. No rusting was found; vandalism was found in one case only. Certain polystyrene plates to shield the sides, however, were often found to be loose or lost. As these plates also cause problems in RIMOB mounting it is preferable to find an other solution.

LITERATURE

- DHV (1989). Evaluatie rimpelbuis-obstakelbeveiliger (RIMOB). Deel II: Inventarisatie. DHV Raadgevend Ingenieursbureau BV, Amersfoort, 1989.

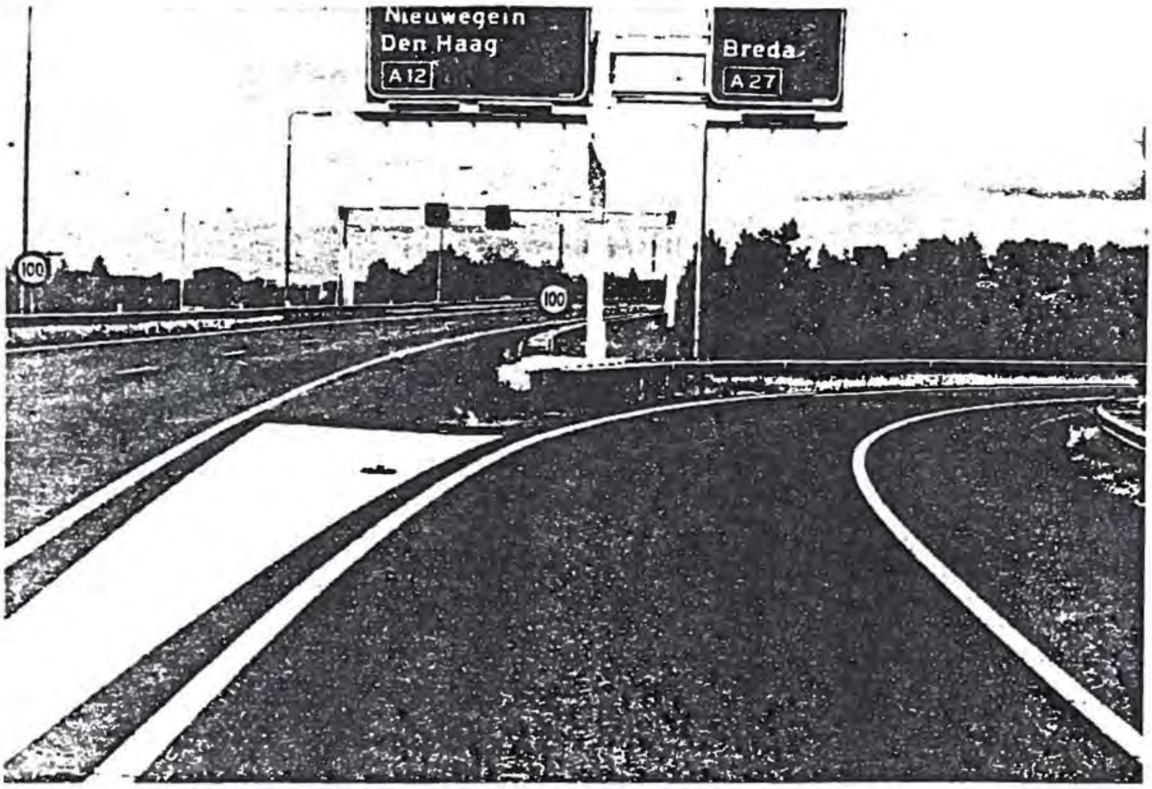
- RWS (1988). Richtlijnen Ontwerp Autosnelwegen (ROA); Veilige inrichting van bermen (concept). Dienst Verkeerskunde, Rijkswaterstaat, 1988.

- Quack, R.F.B. & Schoon, C.C. (1982). The RIMOB - A Dutch impact attenuator with crumpling tubes. A report of the development research: Inventarisation of the problem, functional requirements, development of design and the destiny. R-82-31, SWOV, 1982 Leidschendam.

- Schoon, C.C. (1982). RIMOB: Obstakelbeveiliger met rimpelbuizen; Een overzicht van functionele eisen te stellen aan obstakelbeveiligers en een beschrijving van de ontwikkeling en beproeving van een obstakelbeveiliger met rimpelbuizen. R-82-38. SWOV, Leidschendam, 1982.

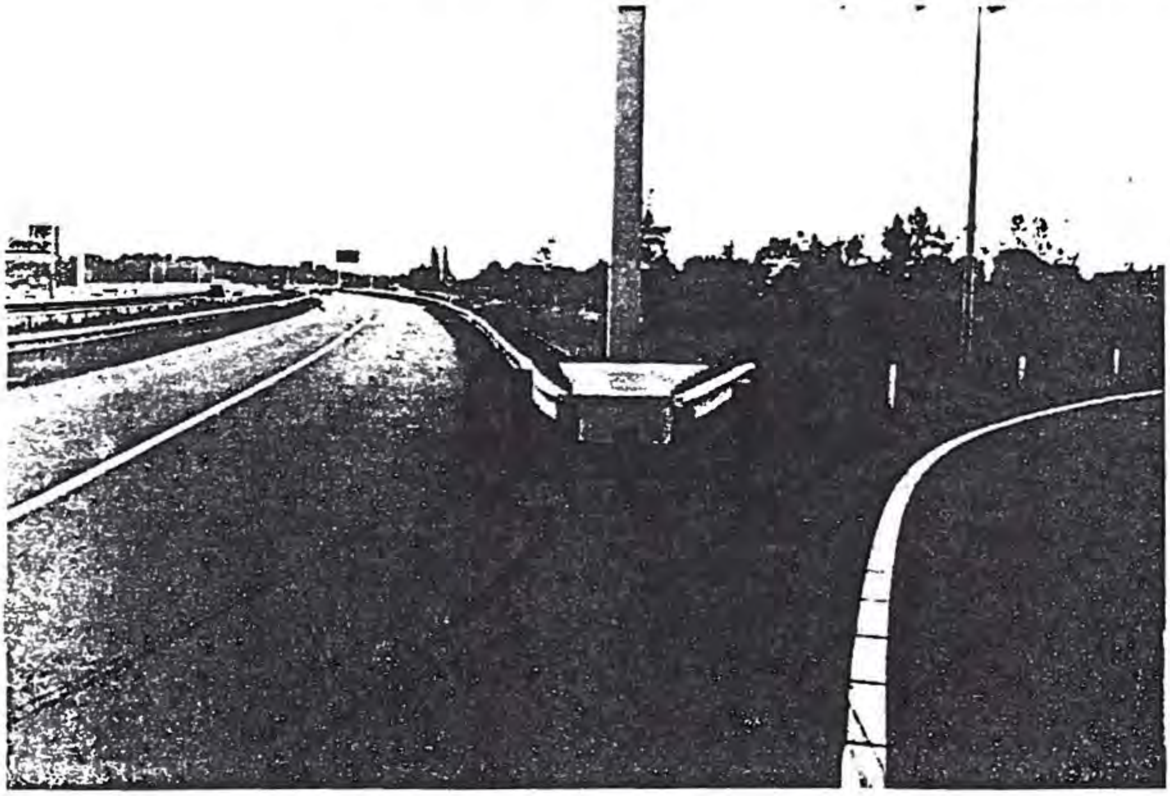
- Schoon, C.C. (1984). Rekenmodellen van de RIMOB; Een beschrijving van rekenmodellen voor de bepaling van de energie-absorptiecapaciteit en zijdelingse capaciteit van de rimpelbuis-obstakelbeveiliger (RIMOB). R-84-22. SWOV, Leidschendam, 1984.

FIGURES 1-9



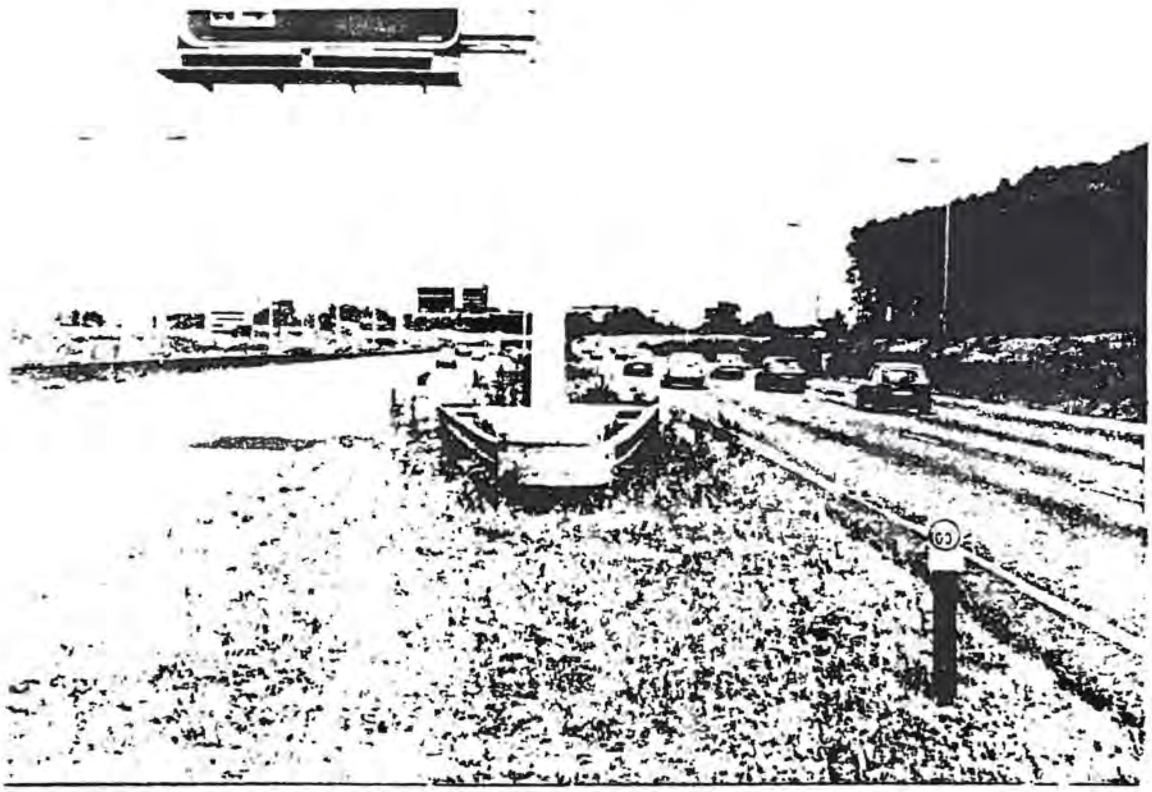

RW12, km 62,675

DHV



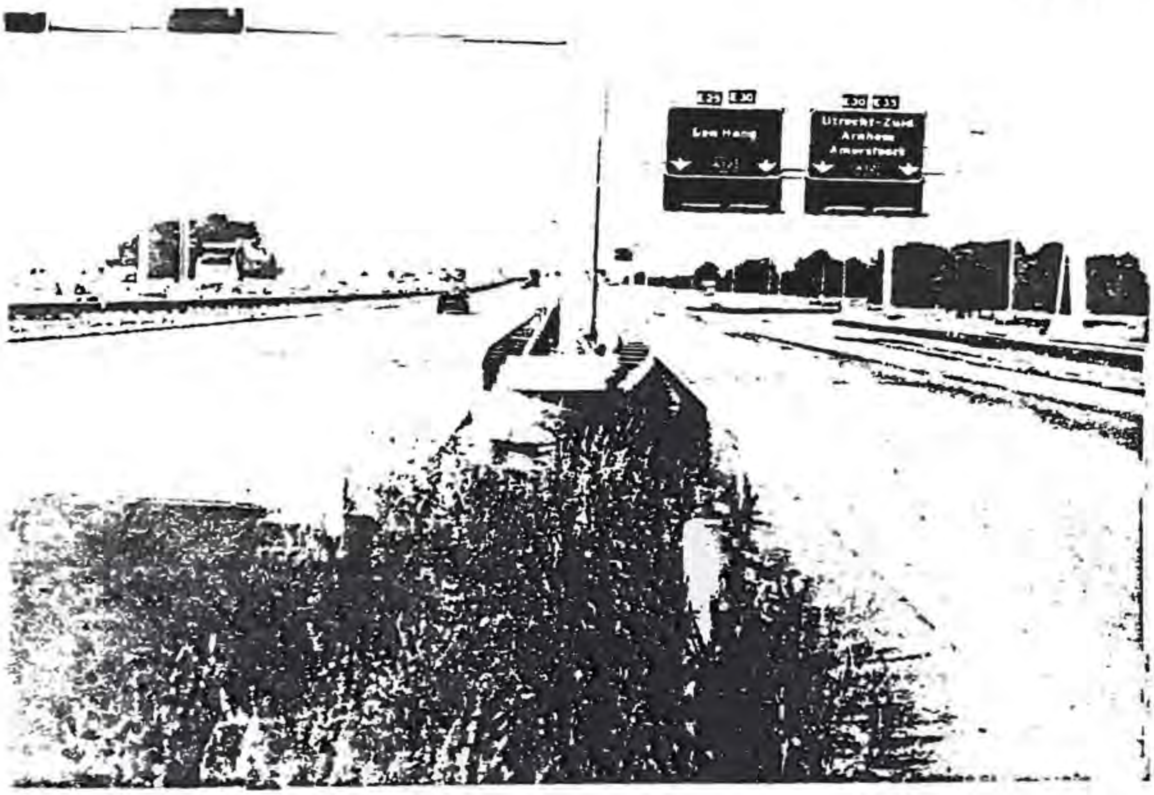
RW 27, km 80,330

Figure 1. RIMOBs installed in a gore area at an exit



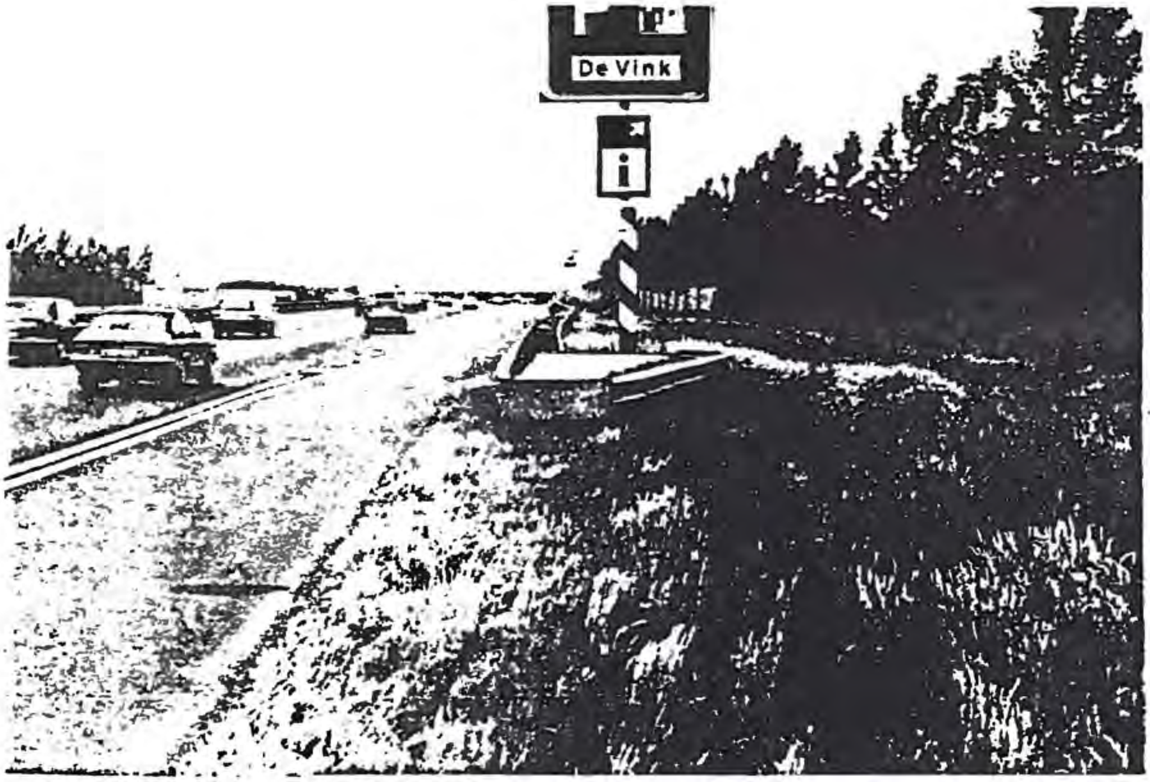
RW13, km 5,775

DHV



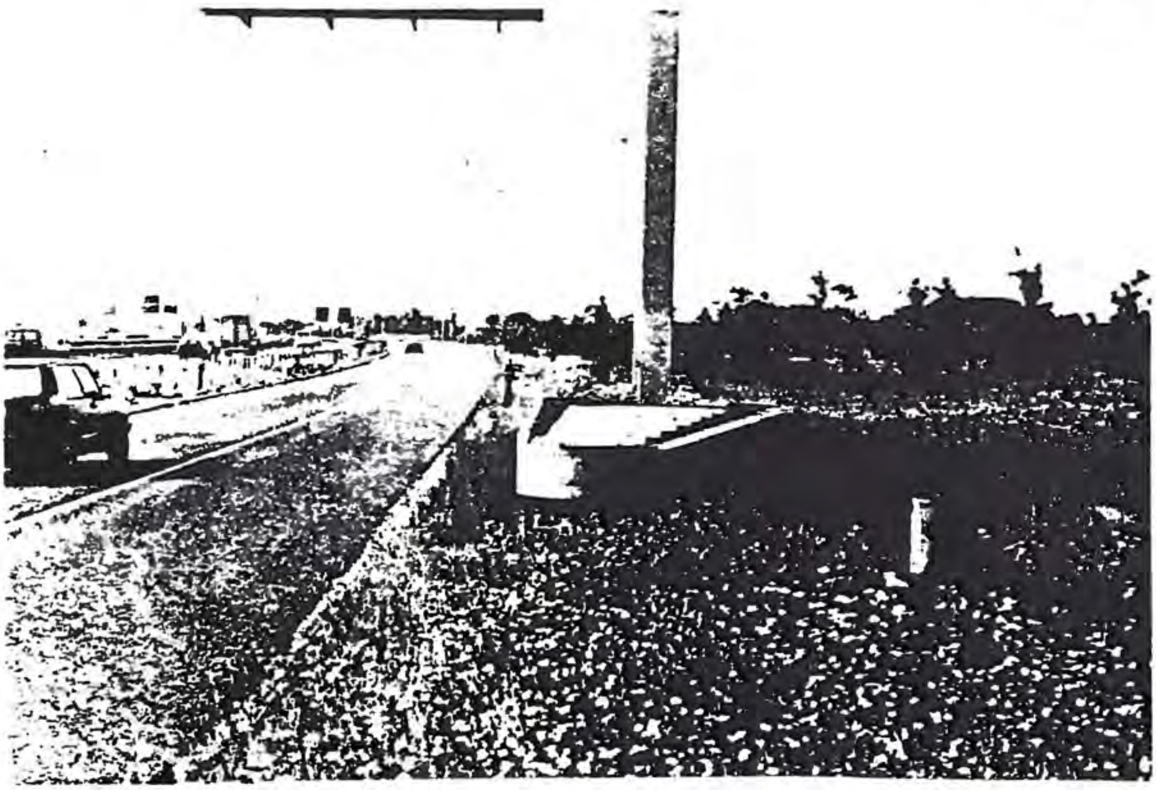
RW27, km 64,320

Figure 2. RIMOBs installed in the outer separators




RW20, km 39,620

DHV



RW27, km 79,850

Figure 3. RIMOBs installed in the shoulders

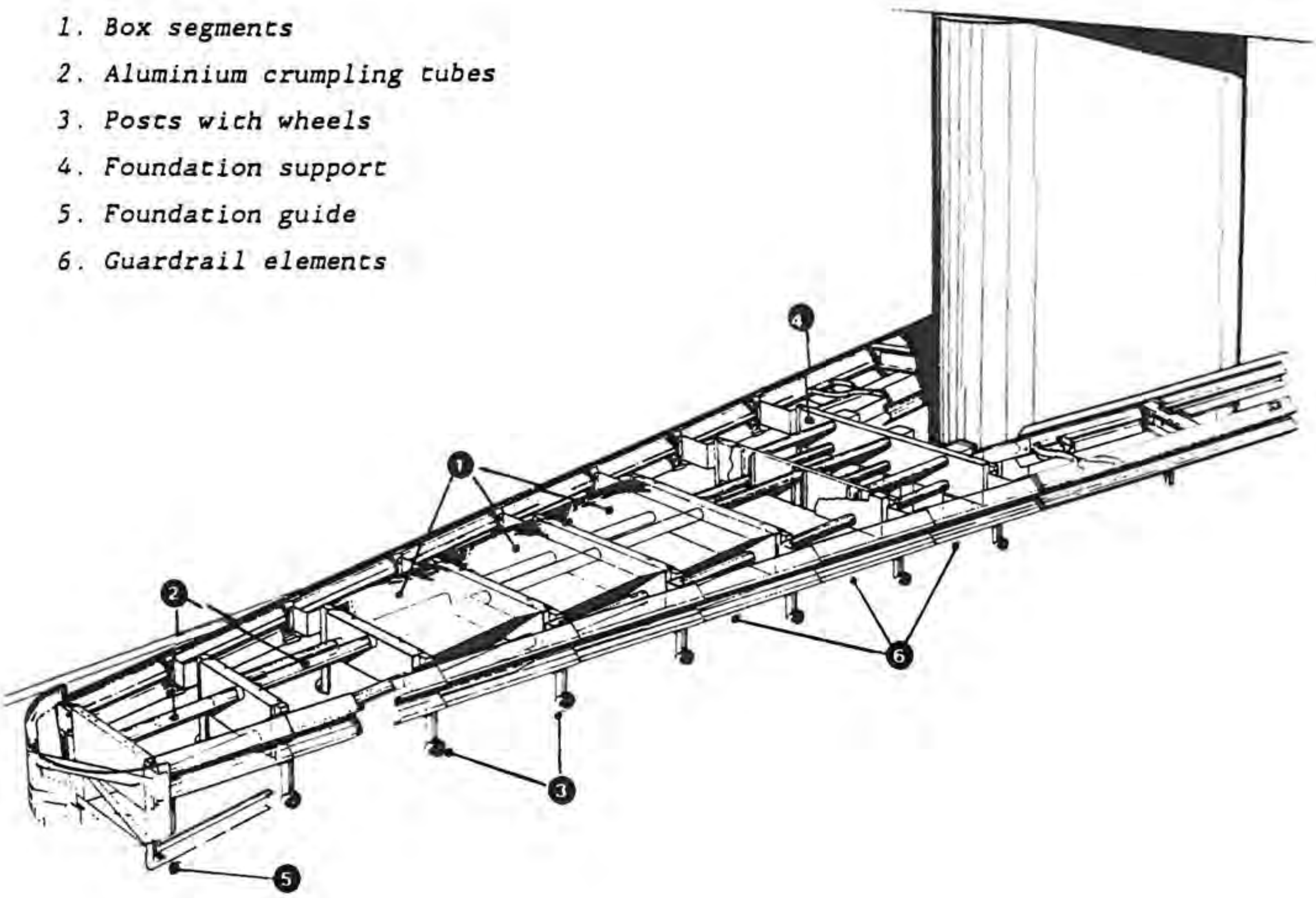



Figure 4. Open-worked drawing of RIMOB

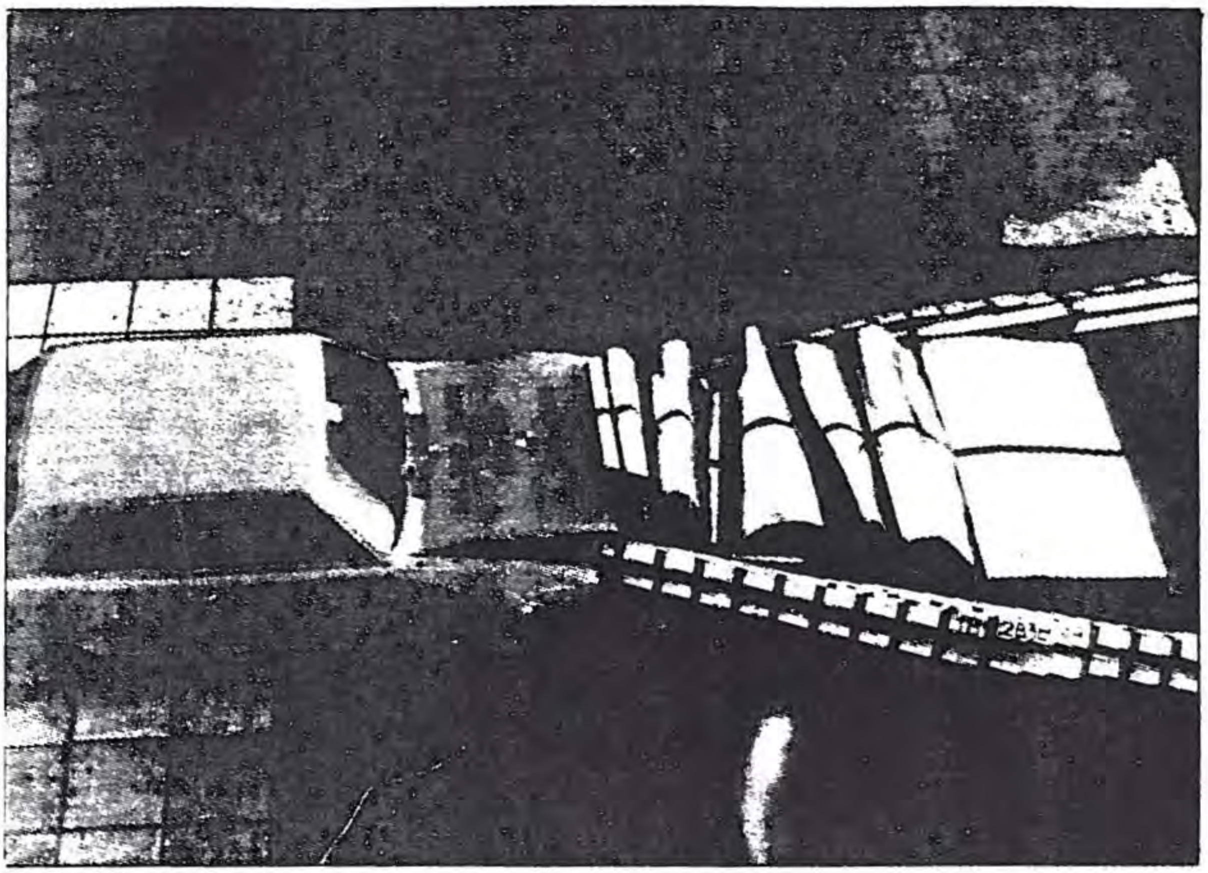


Figure 5. RIMOB after a collision test (100 km/h)

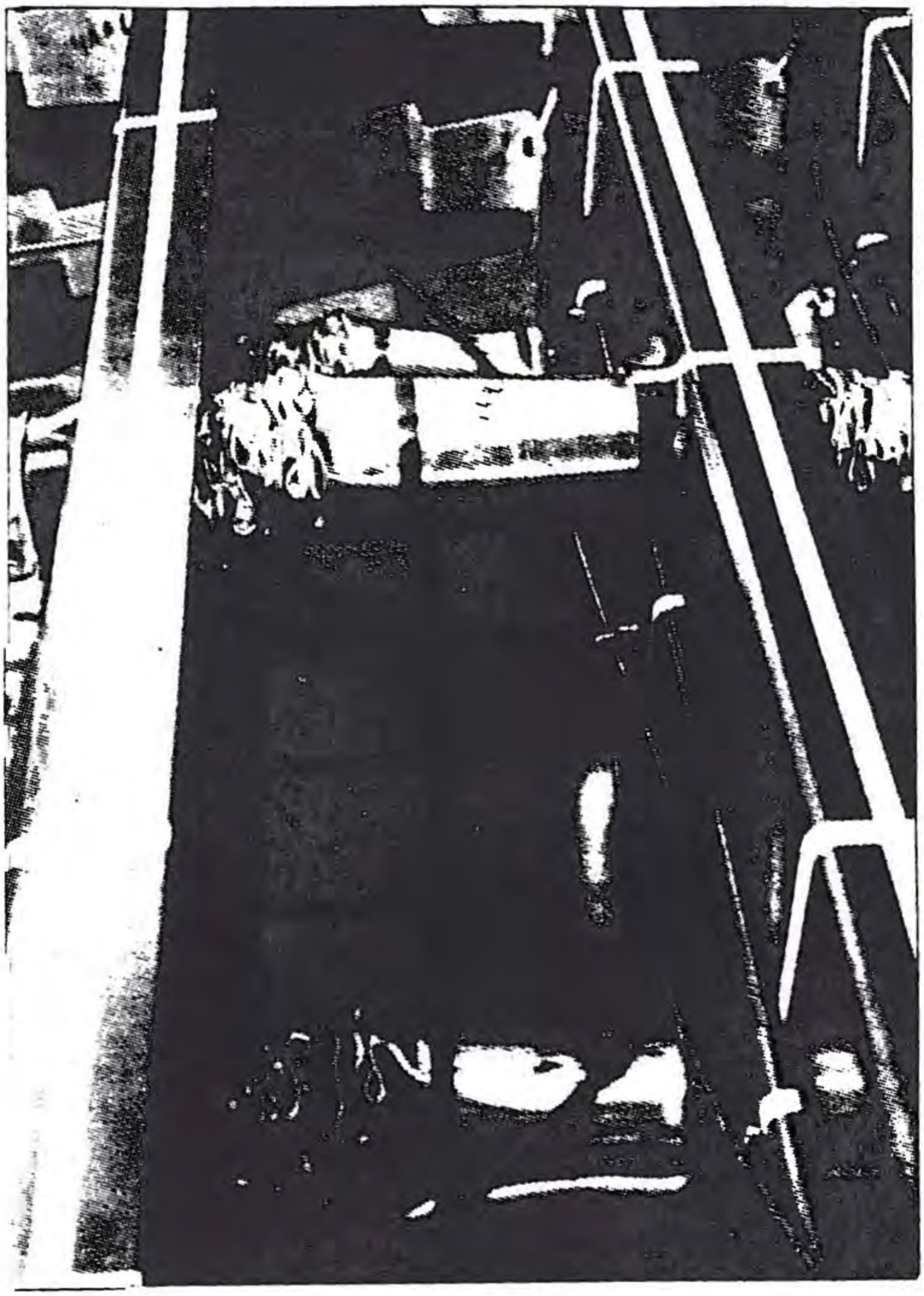


Figure 6. In case of an axial load the crumpling tubes are compressed (RIMOB in the development stage)

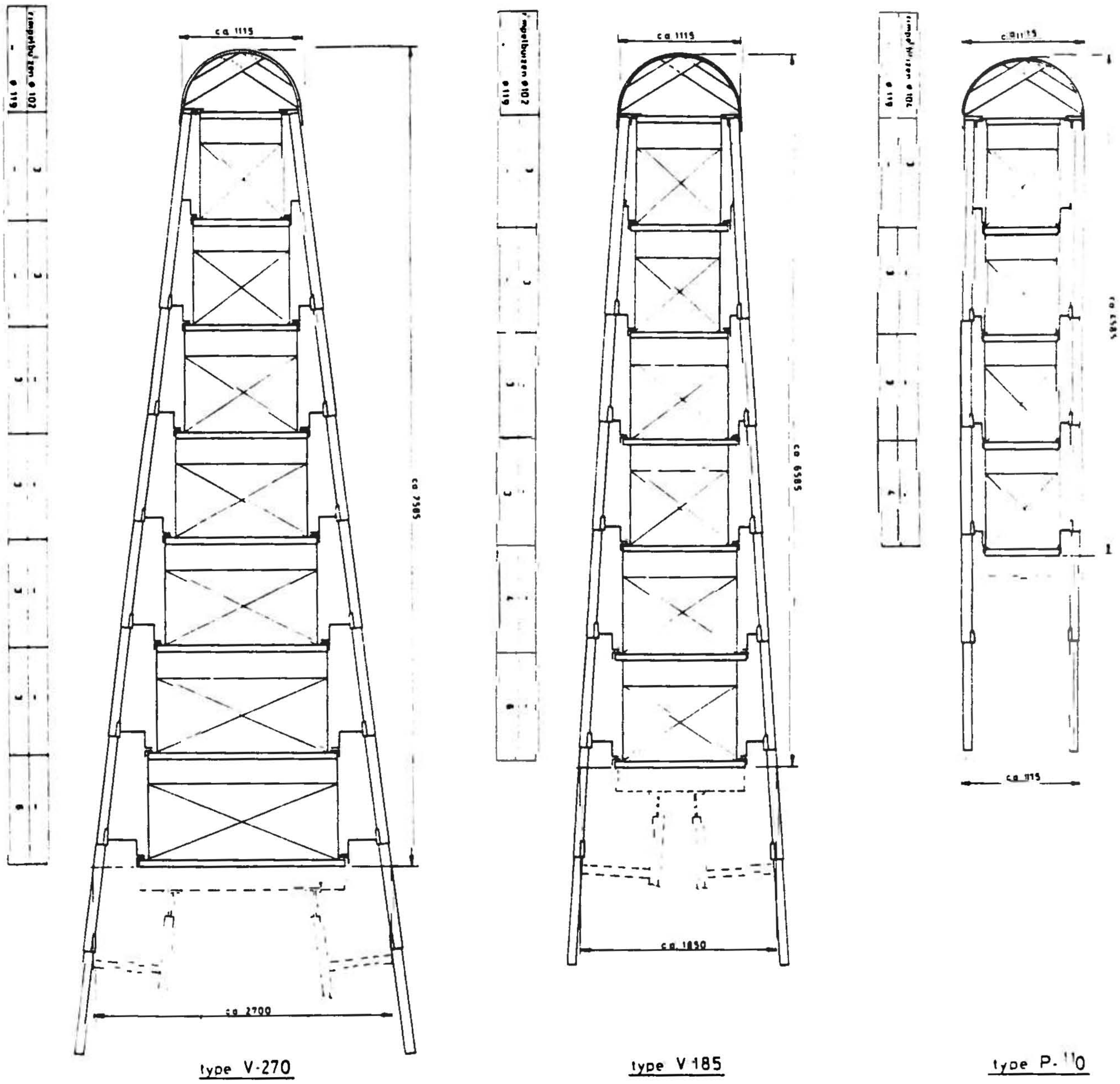



Figure 7. The three standard types applied in the Netherlands

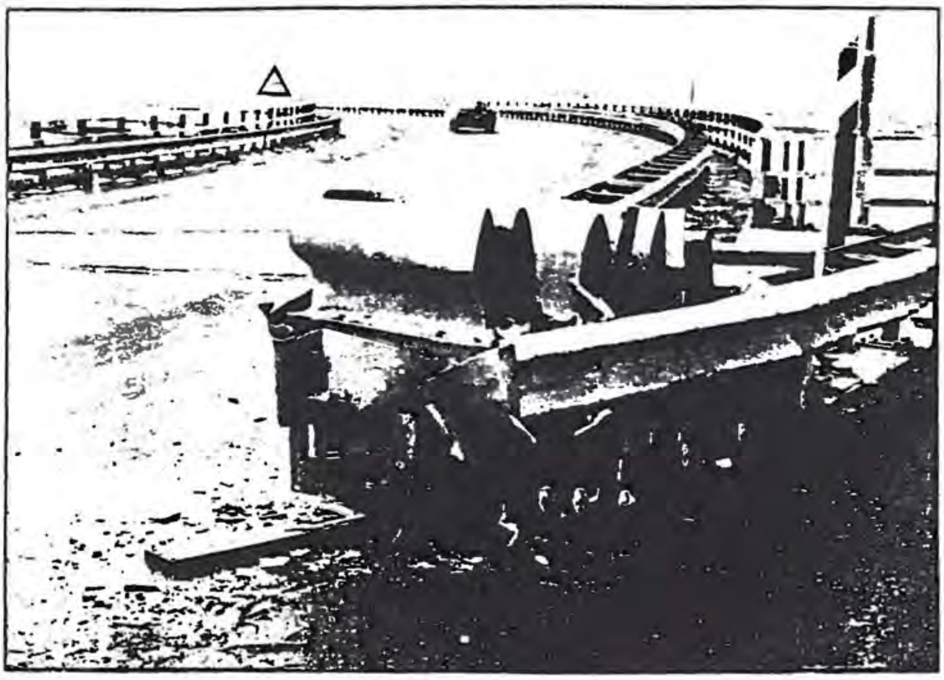


Figure 8. RIMOB after a collision

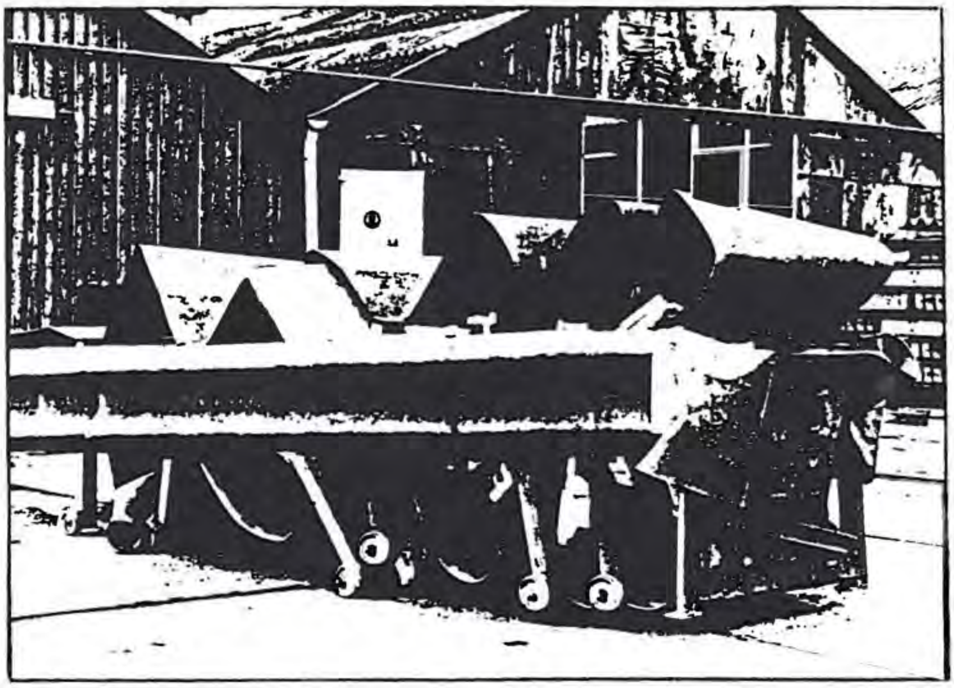


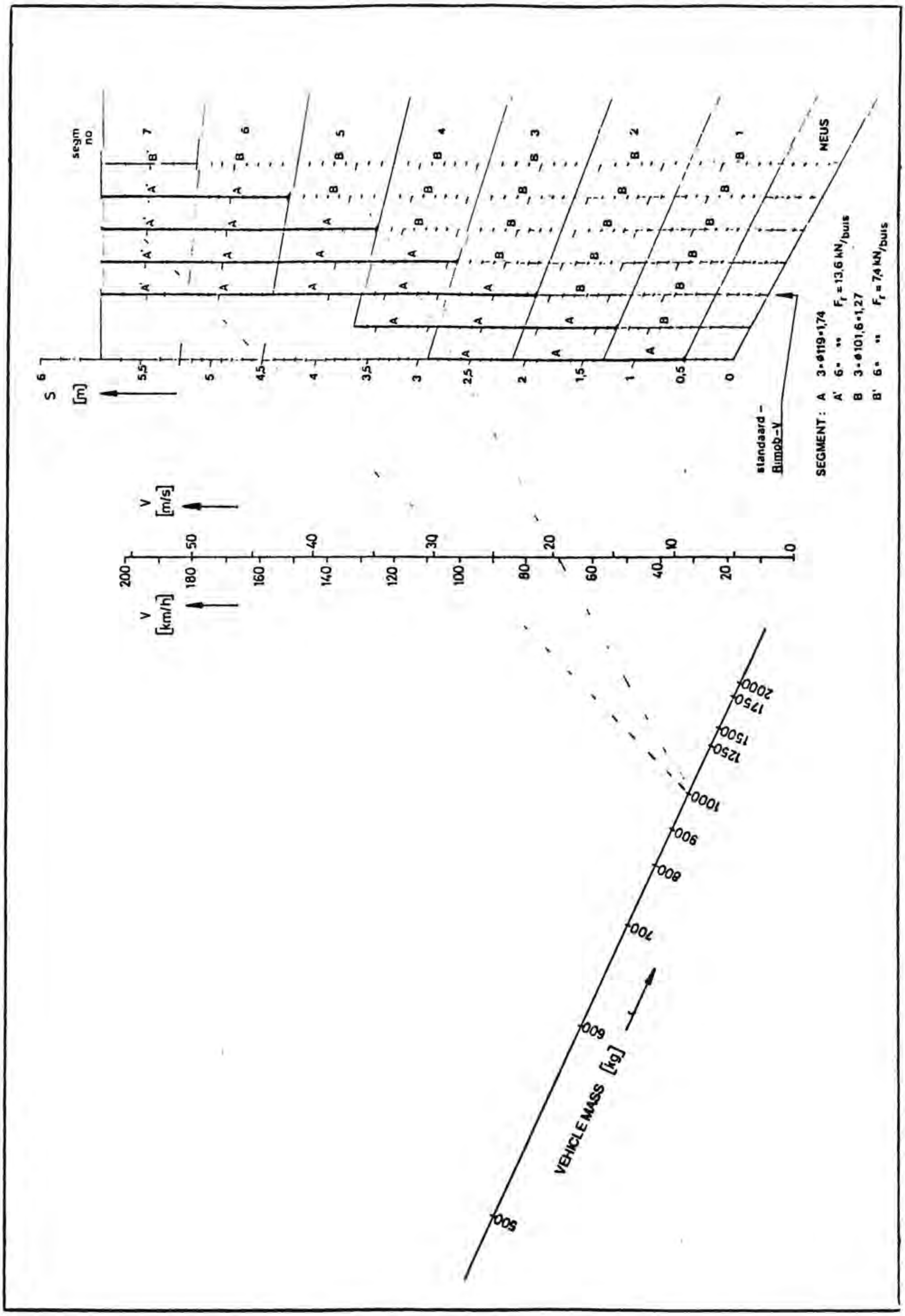
Figure 9. RIMOB after demounting; Inclination of the cross supports

APPENDICES 1 and 2

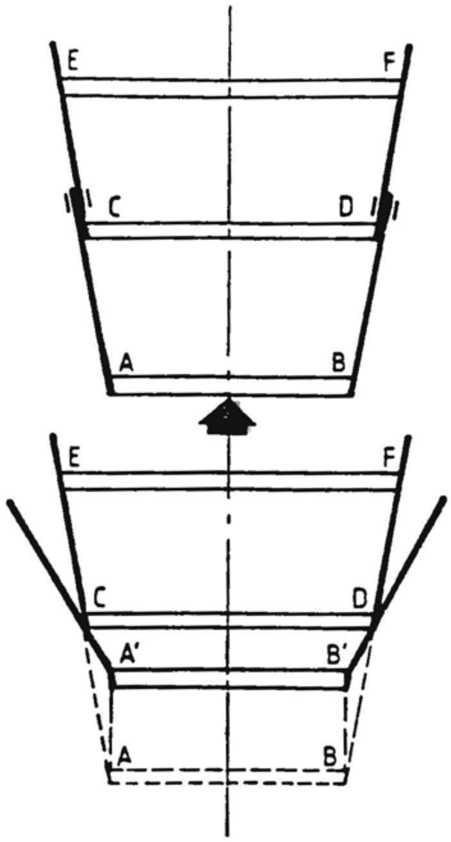
Appendix 1. Nomogram for the relationship between vehicle mass, speed and braking distance of RIMOB for a central collision against a RIMOB V-270.

Appendix 2. Movement pattern of the guide rail elements of a V-shaped impact attenuator, with and without deformation strips.

Appendix 1. Nomogram for the relationship between vehicle mass, speed and braking distance of RIMOB for a central collision against a RIMOB V-270.

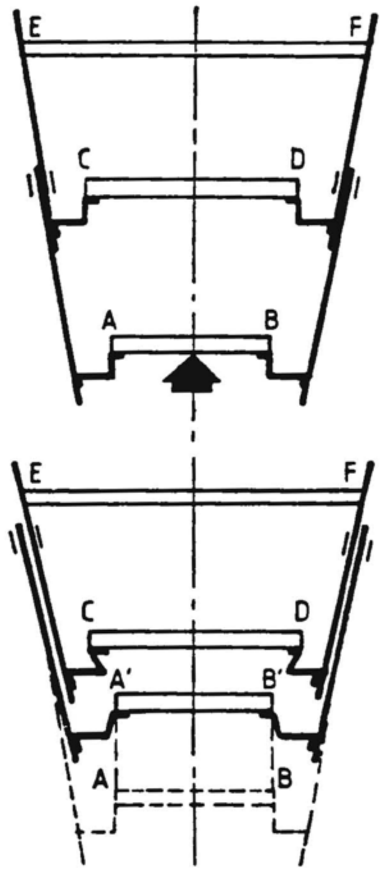


Appendix 2. Movement pattern of the guide rail elements of a V-shaped impact attenuator, with and without deformation strips.




WITHOUT DEFORMATION STRIPS

When AB is subjected to a load, it goes to A'B. C D are fixed points. The AC and BD side rails are forced to bend outwards. As a result, the railguards are broken.




WITH DEFORMATION STRIPS

The connection between A,B,C, and D and the sides is effected by means of deformation strips. When AB is subjected to a load, the C and D deformation strips bend inwards and the A and B strips outwards. In this way, the side rails remain parallel, with the help of the railguards which has been attached.