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 testing

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1. SHIELDING RIGID OBJECTS ON ROAD SHOULDERS

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1.1. Introduction

Traffic accidents on the shoulders of roads receive considerable attention from the road authorities. This is the reason why some years ago the then Minister of Transport and Public Works instructed a working group to study ways of making road shoulders safer. The working group is now composed of representatives of the Ministry of Transport and Public Works (the Public Works Department (Rijkswaterstaat) and the Road Safety Directorate (DVV), the provinces and the municipalities. The adviser to the working group is the Institute for Road Safety Research SWOV.
One of the studies that has been carried out involves research into impact attenuators.
In cases where rigid objects are located close to the carriageway, they need to be shielded, particularly if the road is a motorway. If there are so many objects present that they constitute a danger zone, continuous shielding is needed, for instance with guardrails. If the object in question stands alone and cannot be removed or shielded with guardrails, an impact attenuator is the only solution.

1.2. The extent of the problem

In 1980 352 fatal accidents were recorded in The Netherlands involving collisions with fixed objects. The number of accidents involving injuries was considerably greater. Three times more fatal accidents of this type occur outside built-up areas than inside them.
Figure 1 contains a graph charting the number of fatal accidents in The Netherlands over a period of 10 years (1971 to 1980). The line of the total number of fatal accidents shows a clear decrease, unlike the line of the fatal accidents involving fixed objects, which has remained roughly constant (SWOV, 1982).

1.3. Present situation

The Public Works Department of the Ministry of Transport and Public Works has been looking for ways of shielding individual objects since 1975. In the first instance it concentrated on the impact attenuators which were already on the market. An advisory report (SWOV, 1980) found that some impact attenuators developed in the United States were suited in principle, but had been constructed to deal with U.S. cars, which are much heavier than European models. Modifying the U.S. versions to meet the needs of the "average" car on Dutch roads, based on design standards for vehicles (RWS, 1980), would have entailed a great deal of development research. Other important reasons for not proceeding with such modifications were patent rights and price.
Despite the known restrictions of sand-filled barrels, the Public Works Department placed them in places where frontal collisions could have very serious consequences. The use made of them remained extremely limited, however; they were used mainly for rigid objects located in gore areas of highways and where traffic is heavy and travels at high speed.

1.4. The development of a new impact attenuator

The advisory report prepared by the Institute for Road Safety Research SWOV on the U.S. types of impact attenuators prompted the Public Works Department of the Ministry of Transport and Public Works to request SWOV to formulate the requirements which impact attenuators would have to meet. This led in due course to the drawing up of a number of functional requirements. With the approval of the working group, the Public Works Department then instructed SWOV to develop an impact attenuator which would meet these requirements. The working group already referred to would guide the project.
Under the supervision of SWOV, Dutch firms designed and manufactured a prototype of a new type of impact attenuator: the crumpling-tube impact attenuator (RIMOB, an abbreviation of the Dutch name: Rimpelbuis obstakelbeveiliger).
The Institute for Road Safety Research SWOV has presented a final report on the development and testing of the RIMOB to the working group, which has approved it.

At an early stage in the development of the RIMOB, it was decided to apply for a patent in most European countries, the United States and Japan.

1.5. Uses of the RIMOB

Impact attenuators can in principle be used in three different situations. First, they can be used to shield rigid objects (such as columns supporting road signs) in gore areas. Second, they can be used to shield objects standing alone on the shoulder of the road. Often such objects can be shielded with guardrails running for about 100 m. There are situations, however, in which there is too little room available for such structures, or in which they would obscure drivers' vision, or both. The third use is to shield objects which are only temporary, for instance where roadworks are being carried out.

It was implicit in SWOV's terms of reference that the new type of impact attenuator should be capable of being put to as many uses as possible. In the first instance the RIMOB was designed for high impact speeds and the type of situations which can be expected on motorways. It was also designed, however, to be suitable for use in situations which differ from those on motorways, for instance in urban areas outside the built-up area. A variant to be used in situations in which little room is available, has already been developed and tested. This RIMOB-P is made to withstand impact speeds of 70 km per hour.

In order to avoid having to test all the variations on the RIMOB, SWOV is developing a mathematical model which will make it possible to calculate variations and determine dimensions.

1.6. Foundation and erection of the RIMOB

The prototype of the RIMOB developed by SWOV has now been made ready for production by the Public Works Department, in consultation with the SWOV. Attention was paid not only to ensuring that the method of production was as economical as possible but also to the way in which it is to be assembled on the spot. A system has been chosen in which the RIMOB will be delivered to the site in one piece and then lowered

on to its foundation plate. The prefabricated foundation plate is constructed in such a way that it can resist the reaction forces of the RIMOB when it is hit either from the front or the side. Equally, however, it is able to resist the reaction forces in case of collisions with guardrails attached to the RIMOB.
When a traffic sign or other object is placed in position, the foundation for the RIMOB can be incorporated the same time, which cuts down costs.

1.7. Conclusion

The working group believes that the study carried out by SWOV has produced a very versatile impact attenuator, which is also relatively cheap. Public Road Department will start using them on Dutch roads in the near future; they are particularly likely to be placed in gore areas of highways and on road shoulders, where they have distinct advantages over guardrails. The way in which the RIMOB is designed means that it is particularly well suited for a variety of uses on Dutch roads.

2. DEVELOPMENT RESEARCH: FUNCTIONAL REQUIREMENTS, DESIGN AND TESTING

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2.1. Introduction

A new type of crash cushion, known as the RIMOB, designed to shield individual objects sited on the shoulder of roads, is developed in The Netherlands by the Institute for Road Safety Research SWOV for the Public Works Department of the Ministry of Transport and Public Works (Rijkswaterstaat).

The research began with the drawing up of a list of the functional requirements which impact attenuators would have to meet. On the basis of these requirements, a number of principal conditions were formulated with which an impact attenuator would have to comply; these formed the basis for the design. Following various dynamic and static tests of the most important elements of the RIMOB, a few further modifications were made to the design, the cushion being intended specifically for the situation in The Netherlands.

The development of the RIMOB was concluded by means of ten vehicle impact tests carried out at the Research Institute for Road Vehicles TNO, Delft. The tests were intended to test the operation of the cushion under various impact conditions.

2.2. Functional requirements for impact attenuators

Impact attenuators must be capable of being incorporated into the existing situation on the roads. They must also be adjusted to the characteristics of the road, the traffic which the road carries and the accidents which occur at the spot in question.

Furthermore, road users who collide with the attenuator must not suffer serious injury and other road users may not be put at risk as a result of such a collision.

Finally, an impact attenuator must satisfy a number of practical requirements which are of particular importance to the road authorities concerned.

2.2.1. Functional requirements based on road characteristics

Road characteristics which are of importance to impact attenuators relate in the first instance to the area of application: what are the dimensions of the objects to be shielded and of the area which is available for the attenuator?

When an impact attenuator is used at a gore area where roads fork it should be of such a size that it fits into the available space or more or less follows the contour of the gore area. To be able to determine the dimensions of a "standard" attenuator, use was made of a standard specification drawing of constructions on motorways (RWS, 1975). The hatched area in Figure 2 shows the space which is approximately available for an impact attenuator. On the basis of this information, it is possible to state that one of the functional requirements is that the "standard" attenuator have the following maximum dimensions:

- nose width : approx. 1 m
- top angle : approx. 13 degrees
- length : approx. 8 m
- width of base: approx. 3 m.

This means that the attenuator can be V-shaped, which implies that guardrails as used in The Netherlands can be attached to it.

Normally, there will be sufficient space on the shoulder to place a V-shaped crash cushion of this type. If necessary, consideration can be given to reducing the width of the base. Where principal carriageways with traffic in the same direction are divided, various situations can arise in which there is too little room for a V-shaped cushion. In such cases a narrower impact attenuator is needed, for instance a crash cushion with sides which run parallel. In other situations as well, there may be too little space available to place a "standard" crash cushion. This is why various alternative crash cushions are needed.

When road works are being carried out, it may be desirable to erect a crash cushion to provide protection. A further functional requirement is therefore that both the crash cushion and the foundation must be transportable.

For reasons of road safety, an impact attenuator must also be constructed in such a way that it fits with the character of the road shoulder. For example, a shape which resembles the used guardrails is well suited for use on roads which are equipped with a construction of this type. Requirements regarding the distance between the crash cushion and the edge of the road, which is important since it affects the extent to which the road appears narrower to drivers, can be derived from the Guidelines for Motorway Design (RWS, 1975). Finally, it is important that the crash cushion is shaped and sited in such a way that it does not limit the width of any recovery area.

2.2.2. Functional requirements based on traffic characteristics

The impact attenuator should be designed to take account of the type of traffic carried by the road in question, for instance the types of vehicles and the speeds at which they travel.
Broadly speaking, the vehicles can be devided into four categories: two-wheelers (motorbikes, mopeds, etc.), cars, delivery vans and trucks/buses. In theory, an impact attenuator must be designed with the safety of all four categories in mind. The construction of an attenuator designed to deal with the impact of two-wheelers entails, however, a good many constructive problems. Similarly, an attenuator designed to cope with the heaviest category would have to be of extremely large dimensions. The accident statistics are examined in section 2.2.3. below to ascertain which categories benefit most from an impact attenuator. The design must also, however, take into account as far as possible the other categories of road users.
Allowance must be made not only for the types of vehicles but also for the speeds at which they travel, because they largely determine the speed of encroachment, i.e. the speed at which a vehicle which has left the road approaches the impact attenuator.

2.2.3. Functional requirements based on accident characteristics

The functional requirements are determined in part by the following accident characteristics, namely the type of vehicle, the speed and angle of encroachment. Table 1 shows the number of persons killed in

accidents on road shoulders, divided according to whether they occurred inside or outside built-up areas (SWOV, 1982). The occupants of cars are apparently the category most involved in accidents of this type: 78.2 per cent are killed in accidents outside built-up areas and 64.4 per cent in accident within built-up areas. These percentages show that impact attenuators must be designed especially for accidents involving cars. To minimise the risks for drivers of two-wheelers, efforts must be made to ensure that the impact attenuators contains no sharp or protruding parts.
In this connection, the most important data regarding cars are the following:
- mass (unload): 600-1150 kg (source: CBS; car-sales data for 1967-1976);
- height of centre of gravity: 49-55 cm (estimate based on information supplied by the "Automobildynamische Versuchsstelle").
In determining the mass the distorting effect of exceptionally light and exceptionally heavy vehicles is eliminated by omitting the 7½ per cent of vehicles at either end of the scale. Other statistics were obtained from the report on Vehicle characteristic for road design (RWS, 1980), made on the basis of the car-sales data for 1969-1975.

Another important accident characteristic is the speed of impact. Little is known about it, however. Since impact attenuators generally have to be placed at a fairly short distance from the carriageway, the speed of impact will in most cases be not much lower than the speed of encroachment. Some information on speeds of encroachment is available from the literature, although the data are not though to be very reliable. It is, after all, exceptionally difficult to determine the speed of a vehicle in the event of an accident. It is assumed on the basis of information from various sources in the literature that the speed of encroachment is under 100 km per hour in 85 per cent of the cases. This speed can therefore be taken as the maximum speed when designing impact attenuators for use on motorways.

The literature also shows that there is a connection between the speed and angle of encroachment: the greater the speed of encroachment is, the more the average angle of encroachment is decreasing. The following maximum angles of encroachment can be assumed based on a maximum speed of 100 km per hour:

- speed of 100 km per hour: maximum 10 degrees
- speed of 80 km per hour: maximum 15 degrees
- speed of 60 km per hour: maximum 25 degrees

2.2.4. Functional requirements based on behaviour in a collision

Impact attenuators must satisfy two important general requirements: in the event of a collision, the occupants of the vehicle involved must not suffer any serious injury, and other road users must not be put at risk as a result of the collision.

The seriousness of a collision in a test situation can be worked out from the rate at which the vehicle decelerates in three directions, namely longitudinally, laterally and vertically. Since it is their combined effect which influences the movements of the occupants of the vehicle, they must be assessed collectively. A criterion has been developed for this purpose in the USA known as the Acceleration Severity Index (ASI), (Ross & Post, 1972). This criterion is a dimensionless figure, to which researchers attach the following limit values, with a certain amount of caution:

- ASI < 1.0: occupants without seatbelt suffer no serious injury;
- ASI < 1.6: occupants with seatbelt suffer no serious injury.

The ASI criterion is based on measurements of the vehicle.

Direct measurements can also be made using test dummies. Two criteria can be used. In the first place the head acceleration may not exceed a given level. Therefore, a criterion known as the Head Injury Criterion (HIC) has been developed (Chou & Nyquist, 1974). Secondly, there is the severity of injuries of the chest as results of seatbelts forces. This belt-force criterion can be derived from literature data.

In order to be able to assess the behaviour of a vehicle in a collision with an impact attenuator, a distinction has to be made according to the principle on which the construction of the attenuator works. If the collision occurs on the nose of a crash cushion, the vehicle must be halted in an acceptable manner within the length of the cushion. The vehicle may not in the process either dive under the cushion or shoot over it. If a vehicle collides with the side of a crash cushion, the cushion must guide the vehicle in an acceptable manner. In particular the departure angle must be small.

If a vehicle collides with an impact attenuator, the other road users may not be put at risk. This means that the vehicle involved in the collision may not come to a stand still on the carriageway after the collision. Similarly, no parts of the attenuator must be hurled free by the impact, since other road users could then either be hit or be panicked into taking avoiding action.

2.2.5. Functional requirements of a practical nature

The following functional requirements of a practical nature are important to the road authorities:

- assembly and erection must be as simple as possible;
- repair after a collision must be simple;
- durability must be comparable to that of guardrails;
- the construction must be able to withstand vandalism;
- the price must be reasonable.

2.3. Design of a new type of crash cushion

The various functional requirements listed above formed the basis for the design, and led to the formulation of six principal conditions with which crash cushions must comply. The basic elements of the RIMOB were derived from these conditions (Figure 3). The six principal conditions, and the relevant basic elements, are as follows:

1. In the event of a collision on the nose of the crash cushion the vehicle must be safely brought to a stand still.

The cushion must be able to telescope together in such a way that the kinetic energy of the colliding vehicle is absorbed. The researchers chose a construction made of segments which can telescope into one another and which consist of energy-absorbing material.

2. *In the event of a crash with the side of the crash cushion the vehicle must be guided.*
The side of the cushion must function as an energy-absorbing longitudinal beam. Moreover, it must be possible to attach usual guardrails. Since the cushion must be able to telescope, it was decided to use short overlapping sections of rail (the side rails).

3. *The maximum angle of the "standard" crash cushion must be 13°. The nose width must be approx. 1 m.*
The cushion must be constructed in the shape of a V. This shape entails, however, a number of complications. The cushion cannot telescope without jamming. As a result, deformation strips have been developed which enable the side rails to telescope into one another (Figure 4).

4. *Assembly and erection of the crash cushion and its foundation must be as simple as possible.*
The RIMOB was designed to have only two anchorage points: the base of the cushion which is rested against a foundation support, and the first segment whose legs are enclosed in a longitudinal guide. In the event of a frontal collision, the legs slide out of the guide.

5. *Vehicles must be brought to a controlled stop or guided in a controlled manner. In the event of a collision the vehicle may not dive under the crash cushion or shoot over it. Nor may any parts of the cushion break free upon impact.*
The cushion must have sufficient stability. In addition to the side rails which telescope into one another and the two anchorages, the upper and lower plates of the segments provide stability.

6. *The crash cushion must be capable of bringing both light and heavy cars (including delivery vans in some cases) to a halt. It must also be possible to manufacture variations on the "standard" cushion.*
The foremost part of the cushion must be made of light materials in order to cater for collisions at low speeds and collisions involving light cars. The main way in which this is done is by incorporating a nose segment made of light materials. Less energy-absorbing material is also used in the foremost segments. This material consists of thin-

walled tubes which are encased in the segments in longitudinal direction. When subjected to an axial load, they crumple and telescope into one another (see Figure 5). This crumpling can reduce them to about 80 per cent of their original length. When using these tubes, it is possible to vary their diameter and also the thickness of their walls. In this way it is possible to design a crash cushion which operates progressively. More tubes can be used in the last segment, for instance, which can then serve as a buffer zone for collisions involving relatively heavy vehicles. Tubes which crumple when subjected to an axial load are called crumpling tubes. Crumpling tubes have the advantage that they can absorb a relatively large amount of energy per unit of mass.

2.4. Tests of parts

Before the RIMOB could be constructed of the basic elements described above, it was necessary to test the individual parts. The tests were carried out in the following stages:
Research into crumpling tubes (dynamic);
Research into the stability of the segments individually and collectively (static);
Research into the operation of the various segments and the entire construction (dynamic).

Research into crumpling tubes

The crumpling tubes have to be able to absorb the energy of the colliding vehicle. The points which needed to be established were what type of material and what dimensions were best suited for this purpose. Aluminium was chosen for the material because of its anti-corrosive properties and its price. The dimensions were first calculated using an approximation formula (Croker, 1974). Afterwards the dimensions obtained in this way were checked by means of dynamic tests on crumpling tubes. The research resulted in the application of crumpling tubes of two different diameters: thin for the first two segments to allow for a relatively "soft" impact, and thicker for the remaining segments. Another reason why differing diameters were chosen was to rule out the possibility of mistakes in assembly.

Static stability tests

The segments with the upper and lower plates (the box elements) have to provide a very large part of the stability of the RIMOB. Static tests showed that the box element could resist a great deal of force in the lateral direction. This force is limited not by the deformation of tearing of the plates but by the resistance of the tubes to crumpling. A test was also carried out to establish how much force was needed to compress a box element - without the three crumpling tubes - in the axial direction. The reason for the test was that if considerable force was needed, the crumpling tubes would have to be constructed more lightly. A static test showed that the force required was only about 5 per cent of the force needed to crumple three tubes.

Dynamic operation of the RIMOB

To evaluate the operation of the various segments of the RIMOB individually and collectively, dynamic tests were carried out, first with impact sleds and later with test vehicles. The tests showed that all the basic elements of the construction had functioned well with the exception of the side rails, which did not overlap sufficiently and had bent outwards. The side rails were therefore lengthened. It was also found that the torque which the vehicle brought to bear on the RIMOB in the horizontal plane was too large to be resisted. The construction was therefore shortened, the last segment being equipped as a buffer and the front two segments being made more easily compressible. After these modifications had been made, the tests of the various parts were concluded. It remained necessary, however, to verify that the RIMOB actually worked in practice as well as expected.

2.5. Verification tests

2.5.1. Results of impact tests

The final stage in the development of the RIMOB was to carry out tests to ascertain whether it complied with the functional requirements governing its ability to cope with collisions (see section 2.2.4.). The RIMOB was subjected to ten tests. The test vehicles used were Opel Kadetts (average mass: 753 kg). A variety of types of collision were carried out in the tests: full-frontal, frontal at an angle, frontal off-set and side collisions.

In the case of the three full-frontal collisions the test vehicle was brought to a halt in a reasonably acceptable way. The speeds of impact were 100 km per hour. If the collisions had actually occurred in practice, occupants of the car who were wearing seatbelts would have escaped without serious injury, according to the ASI-criterion. Occupants who were not wearing seatbelts, however, could well have suffered serious injury. During the collisions the test vehicles did not change course. The overcapacity of the RIMOB was about 70 cm, not including the buffer zone, which was still intact.
The damage to the RIMOB affected the nose segment, the upper and lower plates, the crumpling tubes and the deformation strips. Figure 6 shows the situation before a test and Figure 7 the situation after full-frontal collision.

One other frontal collision was carried out in which the vehicle collided with the front of the RIMOB at an angle of encroachment of 15 degrees. The impact speed was 80 km per hour. The RIMOB showed that it was sufficiently stable in this test. The ASI-value was acceptable for people wearing seatbelts. The nose of the RIMOB kept a good grip on the vehicle, which was deflected from its course by only 18 degrees. Two other frontal tests involved off-set collisions. In these cases, the centre line of the vehicle was 50 cm away from the centre line of the RIMOB. The impact speeds were 70 and 80 km per hour. The ASI-values were relatively low in these tests (1.1 and 1.3). In both cases, however, the vehicle rotated by approximately 90 degrees. Depending on the distance of the RIMOB from the carriageway (which itself depends on whether or not there is a refuge or recovery area), the vehicle can come to a standstill either partly or fully on the carriageway. It is assumed that the rotation of the vehicle observed in this test is inherent in this type of collision.

In the case of the side collisions, the vehicles collided with the RIMOB at three different places, in front, in the middle and at the rear. The vehicle which collided with the middle had a speed of impact of 65 km per hour and an angle of encroachment of 22 degrees. Both other tests were carried out with an speed of impact of 80 km per hour and an angle of encroachment of 15 degrees. The test vehicles were well guided by the RIMOB: the damage to both the vehicle and the RIMOB was slight, and the departure angle of the car was also restricted to 4 degrees. The rates of deceleration were high, however. In one test measurements were made with test dummies in the front seats. It showed that the high rates of deceleration would not have had a great effect on the occupants. According to the HIC-criterion as to the belt-force criterion, the chance of serious injury would have been small.

A special RIMOB was also designed for narrow central shoulders on roads where the speeds of impact are not anticipated to be above 70 km per hour. The cushion was constructed from four segments and the sides run parallel to one another. It was given the name RIMOB-P. As in the case of the RIMOB-V's, the last segment was constructed as a buffer, in this case by adding one extra crumpling tube. This extra tube not only increases the buffer capacity but also provides extra stability. A full-frontal test collision was carried out with the RIMOB-P. The speed of impact was 70 km per hour. The ASI-value was 1.2. The cushion still had some residual capacity after the collision and the buffer zone remained intact.

2.5.2. Review of impact tests

The side collisions showed that the ASI-criterion does not give an accurate prediction of the chance of injury in this type of collision. This is because the vehicle rotates in a very short space of time. It is assumed that measurements carried out on test dummies give a more accurate prediction of the chances of injury. Further research into this point is desirable.
The RIMOB functioned satisfactorily on the whole during the impact tests, although in the case of the frontal collisions the cross supports were not all pressed backwards in the perpendicular position. Much attention has been paid to this point throughout the entire research. The fact that the cross supports were out of the perpendicular position did not, however, have any great effect on the outcome of the collisions.

The information which has been obtained in the impact tests will be used for developing a mathematical model. Such a model has the advantage that variations on the RIMOB can be calculated without the need to carry out impact tests. It will also make it possible to analyse the way in which the various parts of the RIMOB operate and thus to improve them.

2.6. Summary and conclusions

A new type of impact attenuator was designed on the basis of a number of functional requirements relating to the situation in The Netherlands. These requirements comprise two principal conditions: the incorporation of the impact attenuator into the road shoulder, and the functioning of the attenuator in the event of a collision.
The RIMOB was designed on the basis of the results of research. In essence it is a crash cushion which operates by the ability of crumpling tubes to absorb energy. Tests showed that the V-shaped RIMOB met the functional requirements to a large extent.
The RIMOB is able to bring cars, which comply with certain design standards, to a halt in the case of frontal collisions. Only in the case of frontal off-set collisions is it likely that the vehicle will deviate from its course.
If occupants of vehicles are wearing their seatbelts, they will not suffer any serious injury in the event of a collision with a RIMOB. If they do not wear them, however, the risk of serious injury cannot be excluded.
When a vehicle collides with the side of the RIMOB, the car is guided well by the RIMOB with small departure angles. The risk for the occupants of the vehicle is small, particularly if they are wearing seatbelts.
Variations on the RIMOB are possible. This has already been shown from a test with a RIMOB with parallel sides. Other variants do not need to be tested empirically, but can be tested by calculations based on a mathematic model which is currently being designed.

2.7. Organisations and firms involved in the project

The following organisations and firms took part in the project:

Accompaniment: Governmental Working Group (BOWG) on Roadside obstacles

Research: Institute for Road Safety Research SWOV, Leidschendam

Design RIMOB: Van Schie Engineering Consultants, Strijen

Prototypes RIMOB: Erfmann & Co., Strijen and Prins NV, Dokkum

Impact tests: Research Institute for Road Vehicles TNO, Delft

Film recording: Foundation Film and Science SFW, Utrecht

Final production design RIMOB: Public Works Department, Department of Bridges

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* Only in Dutch

TABLE AND FIGURES

Table 1. Persons killed in accidents on road shoulders (1974 to 1977 incl.) divided according to mode of road traffic and accident spot: outside or inside built-up area per road authority (Municipality, Province, State).

Figure 1. Fluctuations in total number of fatal accidents and the number of fatal accidents involving fixed objects over the years 1971 to 1980 (incl.).

Figure 2. The space available for an impact attenuator in a gore area of highways.

Figure 3. The basic elements of the RIMOB.

Figure 4. Movements under impact of the side rails of a V-shaped RIMOB, with and without deformation strips.

Figure 5. When subjected to an axial load, the crumpling tubes are compressed.

Figure 6. The RIMOB before an impact test.

Figure 7. The RIMOB after a frontal impact test (100 km/hour).

Mode of road traffic	Killed in accidents on road shoulders outside built-up areas								Killed in accidents on road shoulders inside built-up areas							
	Numbers				Percent				Numbers				Percent			
	MUN	PROV.	STATE	TOT.	MUN	PROV.	STATE	TOT.	MUN	PROV.	STATE	TOT.	MUN	PROV.	STATE	TOT.
Cars	624	526	267	1417	74.7	82.3	78.8	78.2	282	37	19	338	62.2	86.0	70.4	64.6
Trucks + buses	12	14	15	41	1.4	2.2	4.4	2.3	2	-	-	2	0.4	-	-	0.4
Delivery vans	13	8	15	36	1.6	1.3	4.4	2.0	6	-	1	7	1.3	-	3.7	1.3
Motorbikes + scooters	51	39	25	115	6.1	6.1	7.4	6.3	51	3	2	56	11.3	7.0	7.4	10.7
Mopeds	112	37	14	163	13.4	5.8	4.1	9.0	87	3	4	94	19.2	7.0	14.8	18.0
Bicycles	10	5	1	16	1.2	0.8	0.3	0.9	13	-	1	14	2.9	-	3.7	2.7
Pedestrians	1	5	-	6	0.1	0.8	-	0.3	4	-	-	4	0.9	-	-	0.8
Other	12	5	2	19	1.4	0.8	0.6	1.0	8	-	-	8	1.8	-	-	1.5
Total	835	639	339	1813	100	100	100	100	453	43	27	523	100	100	100	100

Table 1. Persons killed in accidents on road shoulders (1974 to 1977 incl.), divided according to mode of road traffic and accident spot: outside or inside built-up area per road authority (Municipality, Province, State).

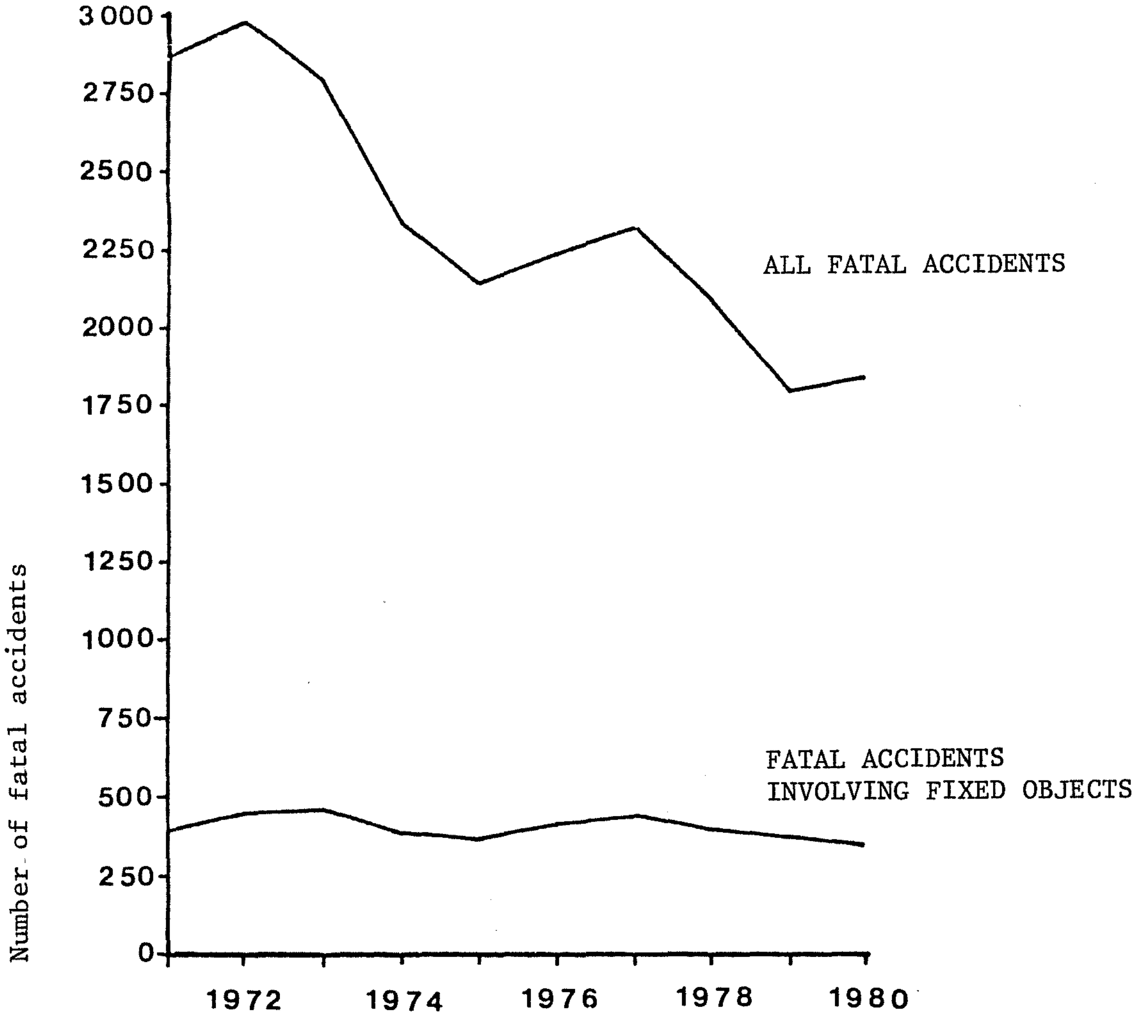


Figure 1. Fluctuations in total number of fatal accidents and the number of fatal accidents involving fixed objects over the years 1971 to 1980 (incl.).

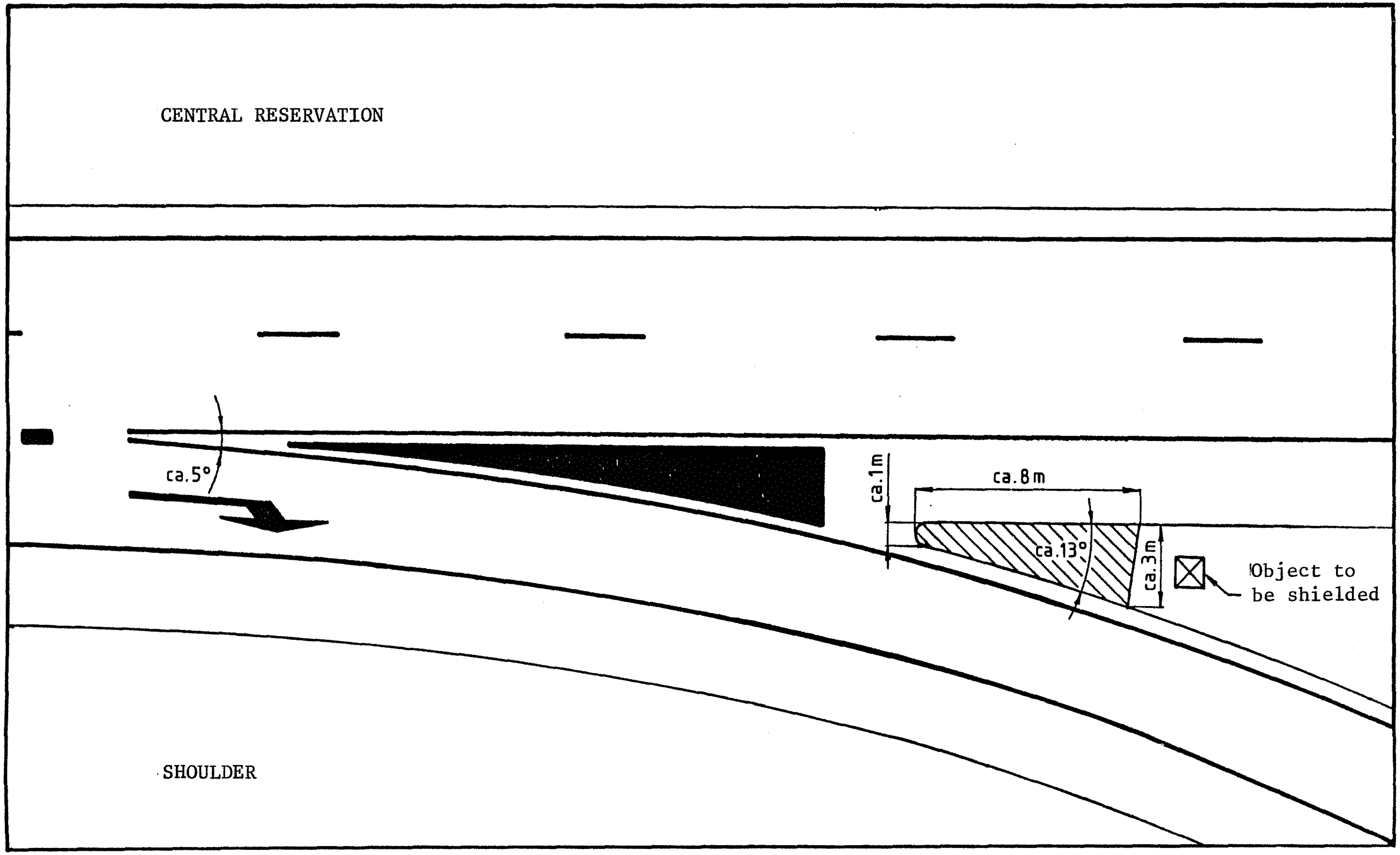
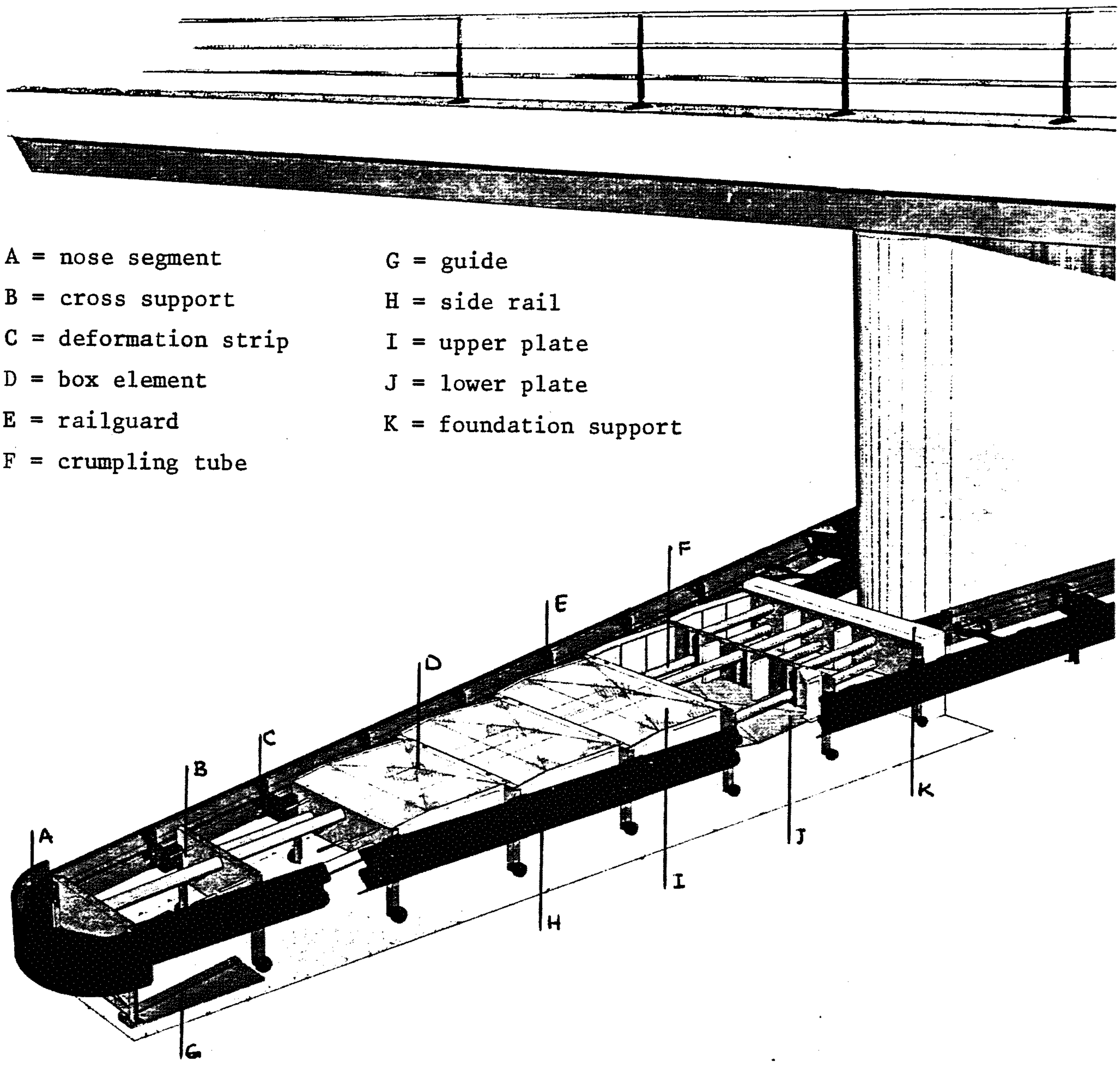


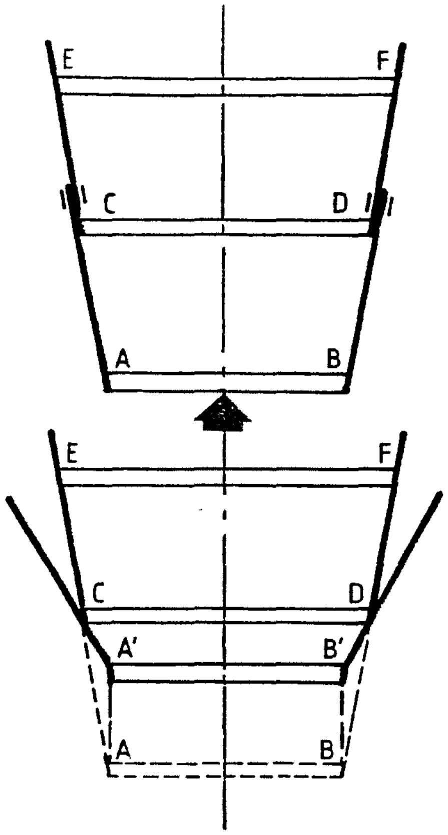
Figure 2. The space available for an impact attenuator in a gore area of highways.



A = nose segment
B = cross support
C = deformation strip
D = box element
E = railguard
F = crumpling tube

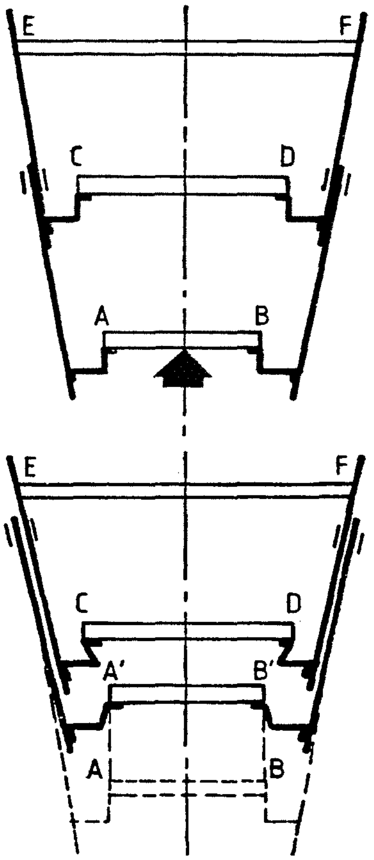
G = guide
H = side rail
I = upper plate
J = lower plate
K = foundation support

Figure 3. The basic elements of the RIMOB.



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.

Figure 4. Movements under impact of the side rails of a V-shaped RIMOB, with and without deformation strips.

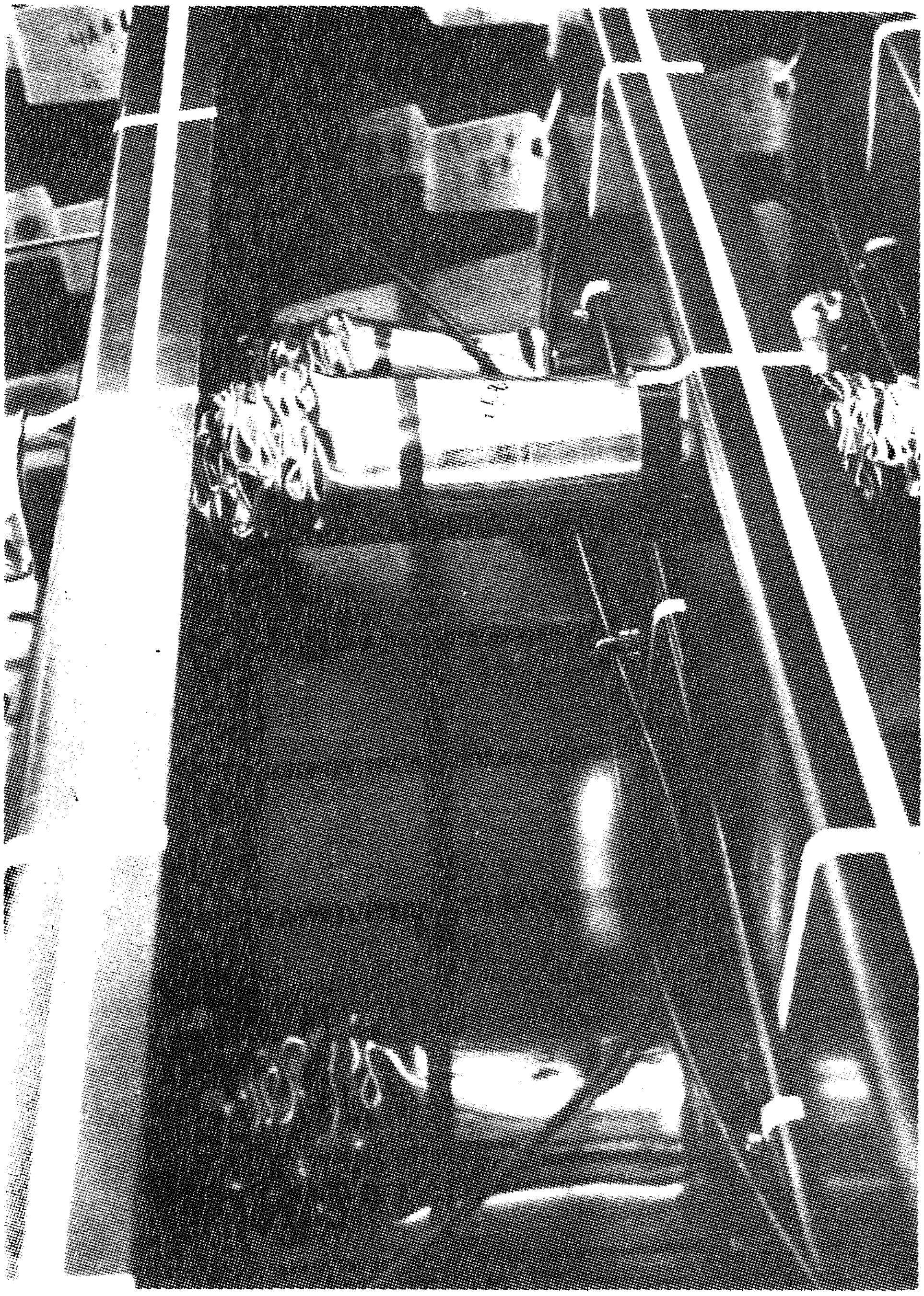


Figure 5. When subjected to an axial load, the crumpling tubes are compressed.

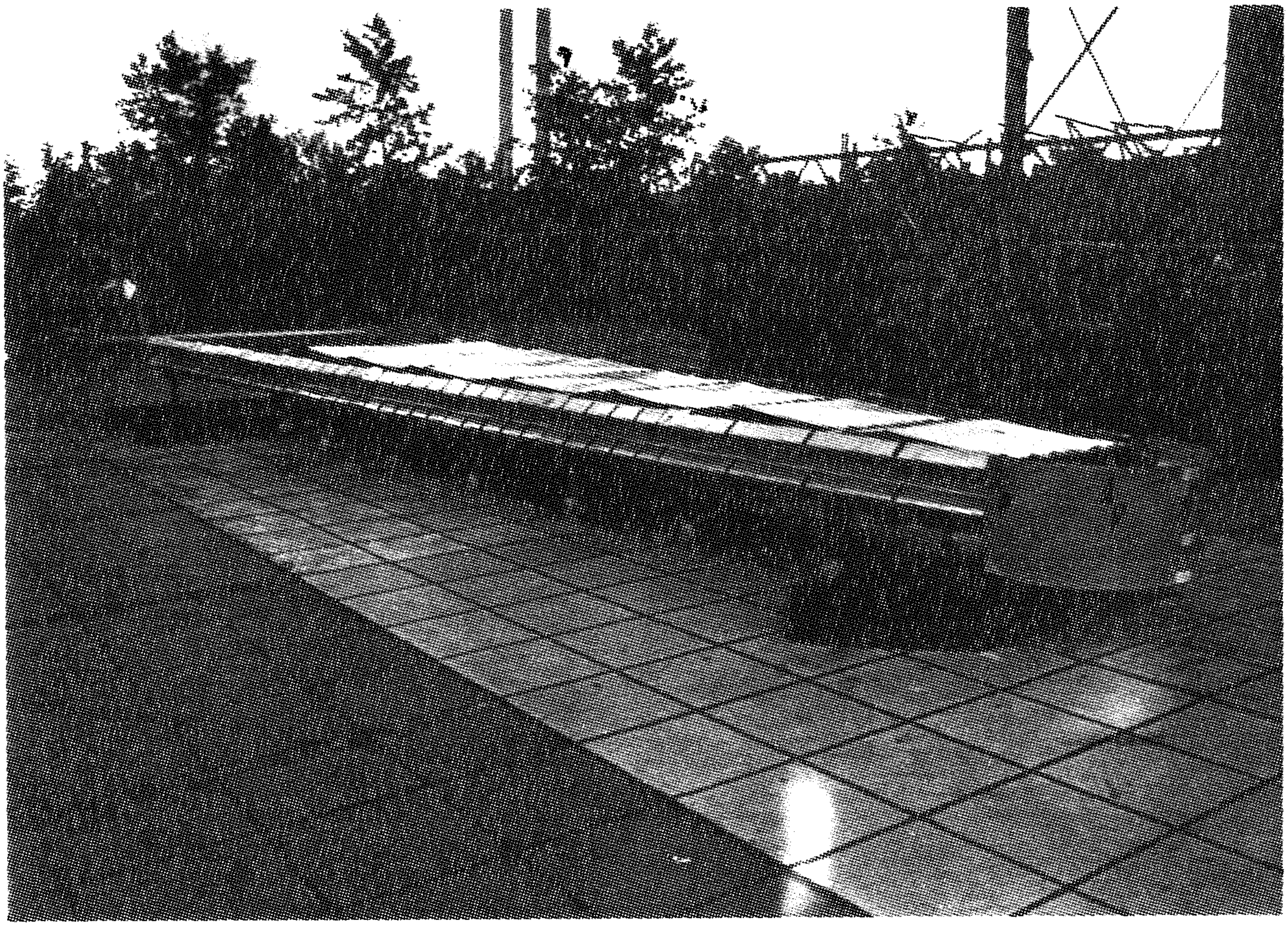


Figure 6. The RIMOB before an impact test.

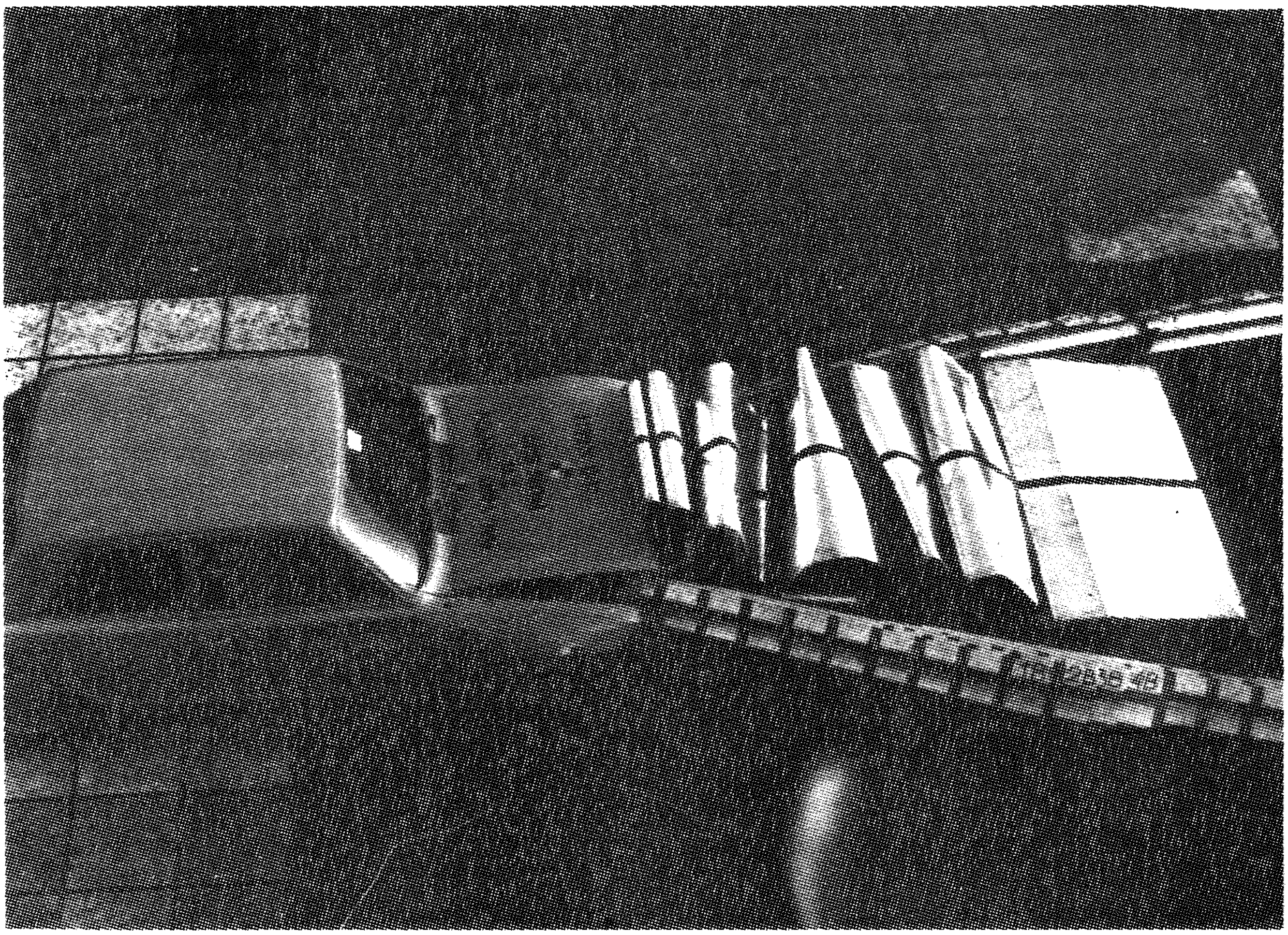


Figure 7. The RIMOB after a frontal impact test (100 km/hour).