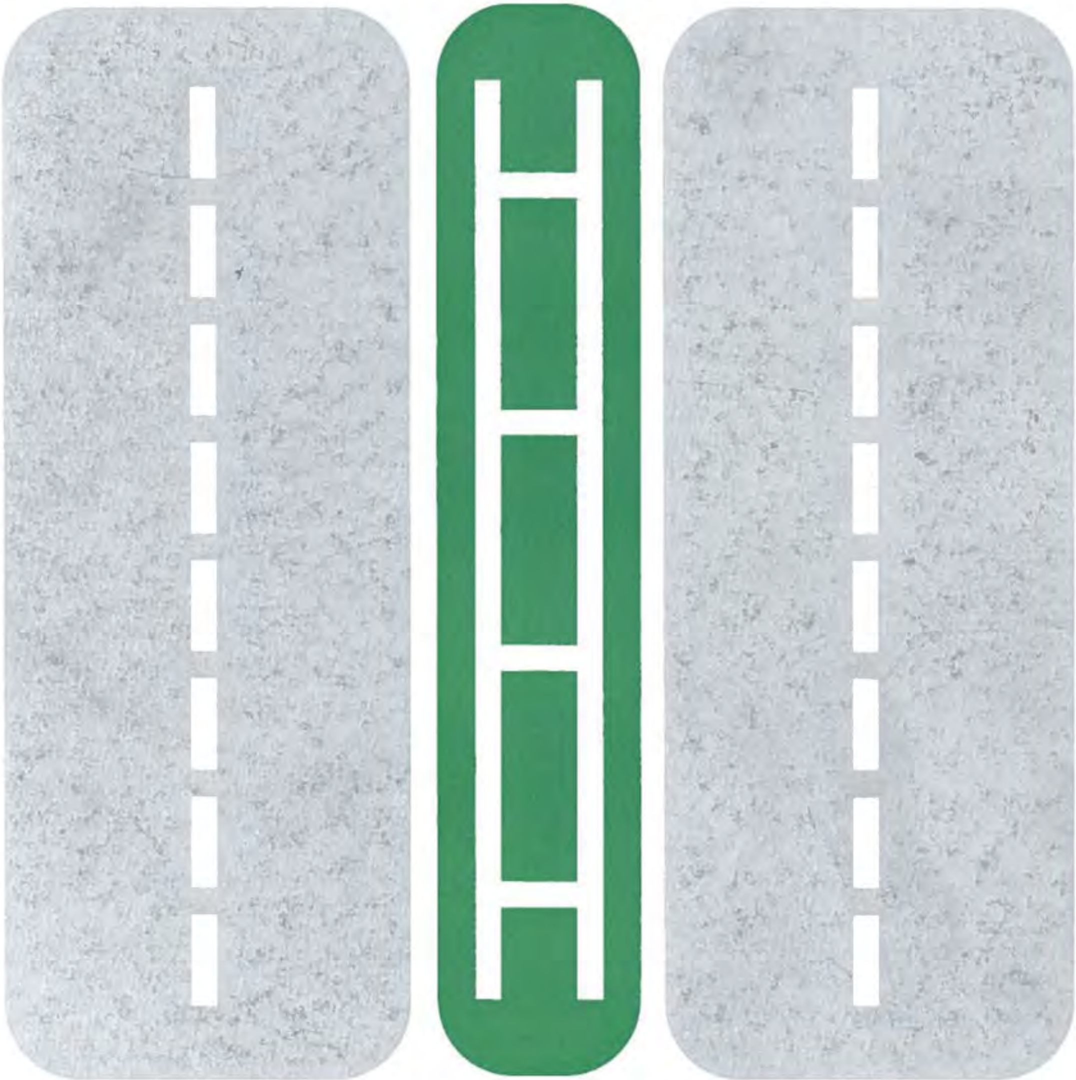
roadside safety structures

SWOV



Roadside safety structures

A description of the crash barriers developed in the Netherlands

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Institute for Road Safety Research SWOV

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Report 1970-6

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Foreword

This report on Roadside Safety Structures contains a description of crash barriers for central reserve areas and shoulders of highways, developed in the course of research, guided and carried out in the Netherlands by the Institute for Road Safety Research SWOV from 1963 to 1969.
The views it presents are based on the best practicable combination, at the time of publication of this report, of research and analysis in other countries, own experiments and study of accidents.
It deals mainly with the functioning of the various structures. To decide whether a crash barrier should or should not be built under given conditions and, if so, what type it should be, is a fairly complex process. Apart from consideration of road safety (what is the acceptable hazard?), a large number of other considerations, economic, practical and esthetic, are also of major importance. Assessment of these various considerations, which are often of different dimensions, is a policy matter; a scientific institute has at most an advisory role in this.
By arrangement with the principals (the Ministry of Transport and Waterways in the Netherlands) this SWOV report is limited to a description of the characteristic properties of the various types of crash barriers and to indicating the road safety factors that must be taken into account in the decision-making process.
It will constantly have to be borne in mind that most of the conclusions are based on full-scale tests. The conditions chosen for these tests are rather extreme, for instance as regards impact angle and speed. Such severe collisions do not often occur in practice. Their frequency is not known, either from statistics in the Netherlands or others. A logical consequence of the gradual improvement of crash barriers is of course that severe, complicated collisions will appear relatively more in accident statistics. Because of the effectiveness of the barrier, minor impacts will often be of little consequence, so that the vehicle can resume its journey without an accident report being made.
To enable the reader to assess these questions better, this report occasionally goes into the research in greater detail. It does not give an exhaustive description of all the aspects of the research, which might also be regarded as the scientific basis. The SWOV has all the research data available and they may be persued at the Institute.

The SWOV made an interim report which was handed to the Ministry early in 1966 and was based on an initial series of tests, extensive literature research and the study of accident statistics. The standards applied by the Ministry's Central Directorate were based on this interim report. As a result of this interim report prior to completion of the research, standardised crash barriers have been installed in the Netherlands of considerably better quality (the 'offset guide rail' type) than those used as standard structures in the Netherlands and also in other countries before our research was commenced. In this first series of full-scale tests, offset rails were also tested with the very flexible posts with 'Wiegel spheres' (named after their inventor H. P. Wiegel). Although the effectiveness of these spheres together with the appropriate form of post could not yet be clarified, tests with structures provided with 'Wiegel spheres' were so favourable that the Ministry installed a 5-kilometre trial stretch on State Road 12 near Veenendaal at the SWOV's advice. In practice, too, this structure proved more effective that any other already installed. The structure developed during the further research and described in this report is based on the same principles that make that with 'Wiegel spheres' so good. Some disadvantages it had have been remedied in the recommended structure.

In anticipation of this report Roadside Safety Structures, the Institute for Road Safety Research SWOV published in August 1967 a report on discontinuities in safety structures for roadsides, bridges and viaducts*, which is, as far as applicable, now incorporated in the present report.

* SWOV (F. C. Flury). Discontinuïteiten in beveiligingsconstructies voor bermen en kunstwerken. Rapport 67-2. SWOV, Den Haag, 1967.

The report Roadside Safety Structures gives a compact review of the information needed for installing crash barriers, which appears to be widely needed in the Netherlands.
The report is arranged as follows:
Section 1 formulates the requirements a crash barrier must satisfy.
This is followed in Section 2 by a review of the types of structures resulting from the research, the reader being presented with a number of terms concerning subdivision according to type and functioning. It is made clear that, in view of its effect, the flexible two offset guide rail barrier is the most suitable.
The method of installing barriers is the subject of a separate section, Section 3: Installation.
Section 4 deals not only with the ideal structure already mentioned, but also with a number of others, which may be suitable under certain conditions, while Section 5 goes into all the structures in greater detail.
Lastly, Section 6 contains some remarks on discontinuities and some comments of a more general nature.
A number of drawings are appended. Drawings 1 to 10 show a number of structures. Others not shown can be inferred from these.
Drawings 11 to 18 show details of all component parts.
Drawings 19 and 20 show the stay bushes used by the Rijkswaterstaat.
Drawings 21 and 22 show various junctions and a fork.
Drawings 23 and 24 show details of grooves that must be made in a hardened (central) reserve to allow the barrier to deflect.

The present report disregards special barriers for flyovers, underpasses, etc. or for shielding obstacles at forks or in other adverse situations.

The Institute for Road Safety Research SWOV would like to thank all who took part in the test and studies or assisted in any other way. Besides the undersigned and the compiler of this report, M. Slop, work on the part of the Institute for Road Safety Research SWOV was done by F. C. Flury, E. Thöenes, W. H. M. van de Pol and A. A. Vis.

E. Asmussen
Director Institute for Road Safety Research SWOV

1. Introduction

1.1. Location

The purpose of crash barriers is to provide facilities less dangerous than the hazard area which they shield. The hazard area may consist of another carriageway with oncoming traffic (to protect with a barrier in the central reserve) or of a steep slope, a canal (to protect with a barrier on the shoulder). Rigid obstacles may also constitute a hazard. The degree of danger may vary greatly; it is also affected by the location of the hazard area relative to the carriageway. The farther the hazard area is from the carriageway, the less dangerous it will be; hazard areas far removed from the carriageway will not have to be shielded at all.

American research* suggests that the distance between the carriageway and the place where a vehicle that has run off the road and comes to a halt in the central reserve on the shoulder, rarely exceeds 12 metres. It is not known, however, whether this applies in the Netherlands. Yet this information will have to serve as the basis for deciding the width of the central reserve** or shoulder for which a crash barrier is not needed.
It is, however, necessary for this unprotected area to be *free from obstacles* (See 2.3.2.). Moreover, the ground must be level and firm enough, so that no unexpected forces are applied to the wheels of a vehicle that has run off the road. In that event the central reserve or the shoulder itself would have to be regarded as a hazard area.
A crash barrier can be considered if the central reserve or the shoulder is narrower or does not satisfy more specific conditions. Occasionally, changing the road lay-out will reduce the risk sufficiently.

As the various crash barriers also entail a certain hazard, depending on their characteristics and design, they should always be located as far from the carriageway as possible. In order to function satisfactorily in all ways, however, a good barrier requires a certain space in front of it and behind (see also 1.2. and Section 4.). But this does not mean that a crash barrier is never needed in a narrow central reserve or shoulder. On the contrary, in that case the hazard area becomes more dangerous (it is nearer), and therefore the use of a non-ideal barrier with a relatively high risk may be justified.
It must be realised in that event that the road as a whole remains more dangerous than it would be with a wider central reserve or shoulder. This report allows for the fact that the desired space is often not available on existing roads, nor can it be obtained by modifying the road lay-out. Solutions are also suggested for such cases.

* D. F. Huelke, P. W. Gikas. Non-intersectional Automobile Fatalities – A Problem in Roadway Design. The University of Michigan Medical School. Not published.

** The width of the central reserve is defined as the distance between the carriageway sides of the edging lines on each side of the central reserve.

1.2. Requirements

The *first requirement* on which the research was based was that if a vehicle hits the structure it must not crash through it or over it, nor run or burst or turn over it or under it.

That is to say, the structure must be strong enough to repel vehicles which run into it at expected angles and expected speeds (see end of this Section). The point at which the car first touches the barrier must if possible be higher than the car's centre of gravity, but not so high that there is a danger of the car going under it. During the impact the reactive force against the vehicle must continue to be applied at about this height.
It is fairly easy to design a structure to meet this requirement only. A reinforced concrete wall of suitable shape would suffice.

But there is a *second requirement:* injury to the driver and passengers, damage to the barrier and vehicle must be reduced to a minimum.

This can be achieved by making the vehicle decelerations longitudinally and transversely, and round any axis as small as possible. Discontinuities in design and mechanical properties of the barrier should be avoided wherever possible. And by preventing direct contact with the wheels damage to this vital component is prevented and the car can still be driven after the impact. Big decelerations upon impact can generally be prevented by means of substantial changes in the shape of the colliding bodies. As far as concerns crash barriers one might have enough sidewards flexibility to allow the barrier to deflect.

If such changes should be mainly elastic, however, this clashes with the *third requirement,* i.e. that the barrier must not throw vehicles back on to the road.

Only a small part of the energy absorbed by the structure through the impact must be returned to the vehicle. This can be effected by aiming at plastic changes in shape and form.
There are also limitations to the changes in shape and form. In the case of a central reserve, for instance, it will not be advisable to allow parts of the structure to deflect as far as the other carriageway. But this will not always be avoidable with very severe impacts. The curves given in Section 4 (Figures 12 to 19) showing the deflection of various crash barriers will make it easier to determine the width of the central reserve and the appropriate barrier.
The aim should be that after impact the vehicle whether or not guided by the driver travels roughly parallel to the axis of the road (preferably by moving along the barrier) and comes to a halt in this position.
If the structure is too close to the carriageway, there is a great risk, especially on a road with a high traffic density, of a vehicle being run into from the rear even if it comes to a stop against the structure. Apart from the serious consequences such an accident may have, this often causes a multiple collision. In order, therefore, for the barrier to function satisfactorily in this respect as well, a recover area is advisable between the carriageway and the structure. Bearing in mind the breadths of vehicles on the road (up to 2.50 metres), an appropriate width would be 2.60 metres.
Where there is a hard shoulder (refuge area) at the right*, this requirement is automatically satisfied at that side. If there is not, it is advisable to keep an area of some width free between the carriageway and the crash barrier wider at the right of the carriageway than at the left.
It must be possible for cars to stop, whatever the reason, also when they have not collided with the barrier. The usual place will be at the right of the carriageway.
If both the refuge and recover area are level and firm enough, so that a driver need not lose control of his vehicle on it, this will also reduce the number of collisions with the structure by cars that run off the road.

* In this report right handed traffic is assumed.

The *fourth, and last requirement* is that after an impact the barrier must continue to function and can be repaired quickly and simply.

From the aspects of road safety and of traffic movement it is important for the average damage per impact to be as slight as possible and for quick repair to be possible without of of the lanes having to be closed.

All these requirements must be met for as many types of vehicles as possible. In view of the great differences among them, this is a major problem, because no barrier functions the same when run into by a passenger car of 500 kgf as with a truck and trailer of, say, 20 tf.
In developing the optimum barrier, therefore, the greatest difficulty was that meeting the first requirement (prevention of bursting through) for heavy trucks could hardly be matched with the second requirement (slight decelerations) for light passenger cars. At first, therefore, an effort was made to produce a barrier with the optimum effect for the category of vehicles involved most in such impacts, and at the same time to obtain the best possible outcome with impacts by other categories. This choice was guided by the accident statistics, showing that 90% of all central reserve accidents in the Netherlands in the period 1960 to 1965 involved passenger cars only.

During the course of the investigations, however, the idea of a barrier with a progressive effect was elaborated. This will deflect in the case of a minor impact, yet is strong and stiff enough to turn the vehicle in case of a major impact. This idea can be shaped in various ways.
The progressive effect is clear in the type of barrier now recommended. Tests with passenger cars of 500 to 2000 kgf at speeds up to 100 km/h and with trucks of 3500 to 7200 kgf at speeds of 85 and 60 km/h respectively were very satisfactory. Research in Germany* indicates that the same barrier can turn trucks at least up to 15 tf at speeds of 80 km/h, all at an impact angle of 20°. This angle is used internationally as the standard test criterion and is rarely exceeded in impacts with barriers parallel to the carriageway, except with low impact speeds and with wide carriageways (more than two lanes). If the structure is not parallel to the direction of driving or if there are a number of directions forming an angle with one another (for instance at forks), bigger impact angles may occur at high speeds. Proper functioning of the barriers discussed in this report cannot be guaranteed under such conditions.

* Anfahrversuche an Leitplanken. Innenministerium Baden-Württemberg. Stuttgart. 1969.

2. Conclusions from the research

2.1. General

The four requirements mentioned in Section 1 are met best with steel barriers consisting of the following main elements:
a. *guide rails* as shown in Drawing No. 11 (known as type A);
b. *spacers* as in Drawing No. 12 (known as German type B);
c. *posts* as in Drawing No. 13 (SWOV design).

Two guide rails with spacers fixed between them form a horizontal beam. This beam can be fixed to the posts in various ways.

Allowing for the functioning of the barriers, as set forth below, the *ground* in which the posts are fixed is the fourth main element.

2.2. Structures where sufficient space exists

The best effect is obtained with a comparatively stiff beam, supported by a single row of posts in such a way that it can easily be moved sideways so that the entire barrier deflects even with a minor impact.

This functioning is due largely to the way the posts act. Owing to their design they meet with little resistance at right angles to the barrier. When run into they cut easily through the soil, especially if this has a loose structure. The posts pivot, so to speak, around a point more or less close to their base. This allows the structure to turn for part of its length around an imaginary underground axis.

Horizontal lateral displacement of the beam is particularly important for proper functioning of the barrier (Figure 1). Although in most cases this will not exceed 1 metre with an impact from a passenger car, it may be over 2 metres in special cases of major impacts from trucks (See Section 4.2.).

Owing to their low resistance, the individual posts cannot apply any big reactive forces to the beam. Partly because of the beam's stiffness, the horizontal force is distributed over a large number of posts and the barrier deflects gradually. The length over which it does so will be about 40 times that of the maximum lateral deflection. This factor of 40 is the optimum for correctly guiding the vehicle during and immediately after an impact.

The distance between the posts also affects the way the structure deflects. It was found that for gradual deflection as mentioned above, this distance should be about 4 metres, i.e. equal to the effective length of the individual sections of rail.

Structures with the above properties have become known as 'flexible', but this can be misleading. The term 'flexible' is applied to an object that is easily bent or bends. But the beam bends very little and if any part of the support bends it does so very slightly only.

The flexibility of a crash barrier should be defined as its property, even with a minor impact, of deflection, and especially of this deflection occurring over a comparatively great length.

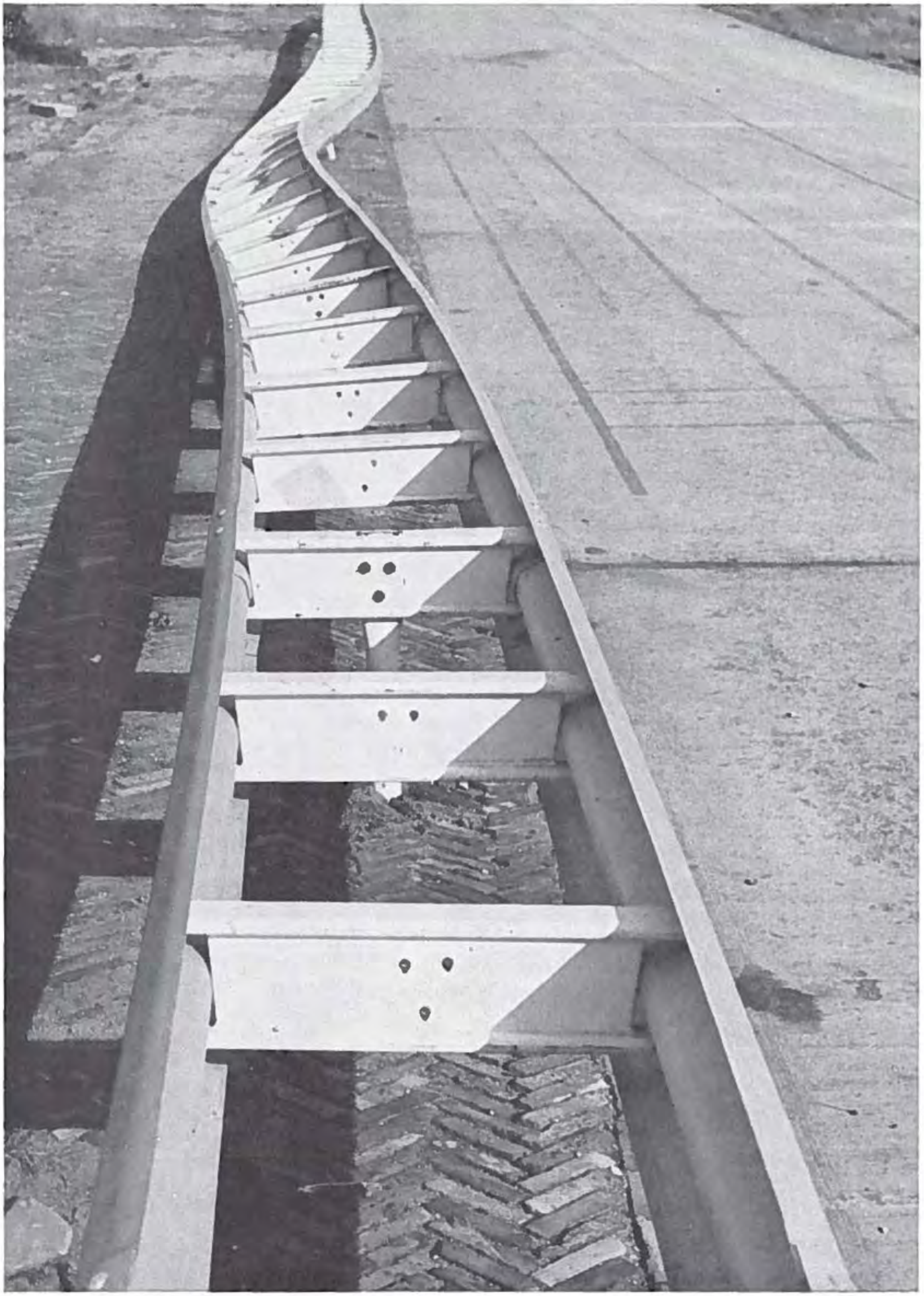


Figure 1. Horizontal deflection of the beam, important for proper barrier functioning.

If the resistance of the barrier as a whole is at first slight, however, so that it deflects considerably upon impact, the resistance gradually increases as the lateral deflection is greater. A number of factors contribute to this, such as torsional stresses in the horizontal beam, tensile stresses in the guide rails and also an increasing ground resistance to the posts the further they move from their original position. Hence, a slight impact brings the structure to a certain final position, depending on how severe it is.
The importance of this progressive resistance with increasing deflection of the barrier was already pointed out in Section 1.
The pivoting movement of the posts means that in major impacts there is a fundamental danger of the vehicle hitting them. A collision with one or more posts usually causes great longitudinal decelerations. But it has special disadvantages in the following circumstances:
1. If the posts are firmly seated in the ground and at the same time firmly fixed to the top of the beam. In this case there is a danger of the vehicle running up against a post.
2. If the posts turn so far that the bottom ends pull out of the ground.

The former circumstances apply mainly in the first stage of deflection. By placing the guide rail at the front (impact side) some distance out from the posts (i.e. 'offsetting' it) impacts with the posts in this first stage are, however, prevented as much as possible.
The latter circumstances may apply if the structure continues to turn over as it bends further out. This can be counteracted by similarly 'offsetting' the rail at the back of the barrier.

This produces a barrier *with two offset rails* (Figure 2). The rails offset at both front and back, however, have another purpose. This will become clear from the following description of what happens in a severe collision.
The turning motion of the barrier at first raises the front rail slightly, and moves the back rail down. As stated, the front offset rail prevents the posts from being run into.
Impacts of moderate severity push the back rail on to the ground, and the distribution of forces in the barrier is greatly changed. The resistance of the structure as a whole then increases considerably. (This progressive function is known as the 'two-stage effect'). In this position the front rail is again at about the same height as before the impact (Figure 3) and, because the spacers then act as struts, it will usually not move down any further.
Under ideal conditions the incline of the beam when the back rail contacts the ground will be between 35° and 40°, depending on how close the posts' pivot is to their base. When the structure is in this position, a distribution of forces is possible in which the turning moment applied to the post is very small, so that the structure almost stops turning.
With more severe impacts further movement of the structure is mainly lateral, with the back rail pushing over the ground. The structure still turns a little further, but there is no immediate danger of hitting the posts.

The foregoing in major impacts shows that the offset on the side of the barrier away from the impact is important, like that on the impacted side, even though their functions are different.

A situation like that outlined is attainable only if the posts' pivot is low. On the whole the barrier functions better, the lower the pivot of the posts is located.
The location of this pivot depends largely upon how the posts are put in the ground. There are two possibilities:
1. By driving them in (piling method).
2. By drilling holes into the ground, inserting the posts and filling the holes (drilling method).

This subject is discussed further in Section 3.

As a flexible, two offset rail barrier takes up a relatively large amount of space, it will usually have to be built closer to the carriageway than the structures discussed in Section 2.3. This means that more impacts (on average lighter ones) will have to be taken for granted in order that the consequences of major ones will be less severe.

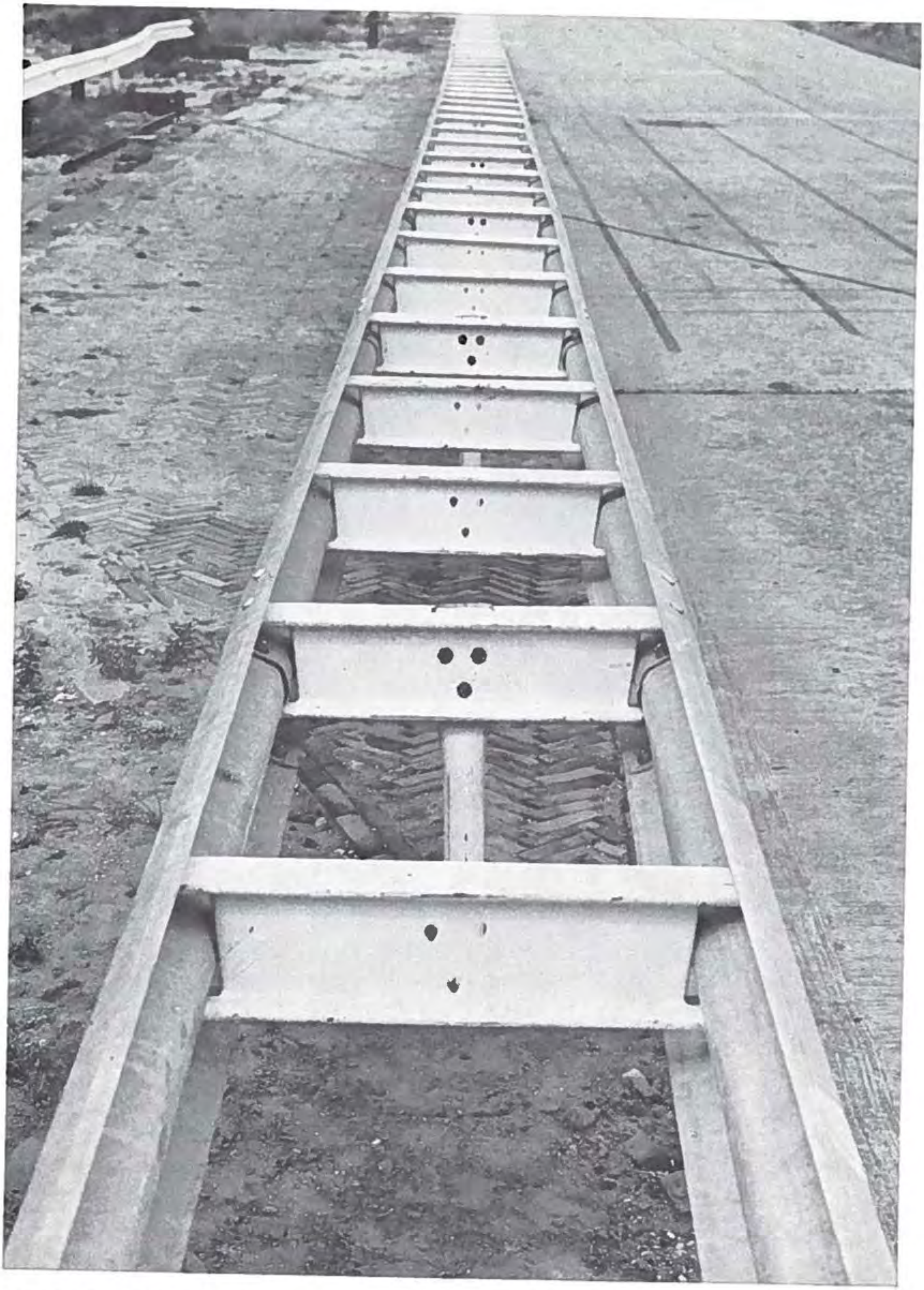


Figure 2. Two offset rail barrier

Figure 3. Deflection of a flexible two offset rail barrier following medium-heavy impact.

2.3. Structures where less space is available

As stated in Section 1, the space necessary for proper functioning of the optimum type of crash barrier will not always be available. Solutions will then have to be sought which may be the best in these circumstances but necessarily involve bigger hazards in case of impact.

In general, there are two distinct cases:
1. The available central reserve or shoulder is too narrow.
2. There are one or more rigid obstacles in the central reserve or on the shoulder.

2.3.1. Narrow central reserve or shoulder

Based on the optimum structure described in 2.2, the question of a narrow central reserve or shoulder can be approached in three ways:
1. Some of the space required for effective functioning in front of and behind the structure can be used;
2. A stiff barrier can be installed;
3. The offset can be reduced.

2.3.1.1. Narrowing of recover and/or deflection areas

Narrowing the recover area between the carriageway and the structure leads to more impacts against the crash barrier. The risk of serious consequences through collisions from the rear is also increased. The maximum possible impact angle, however, becomes less because the barrier is closer to the carriageway. If the structure is located too close to the carriageway, a reduction in effective carriageway width owing to 'barrier effect' must be allowed for. It is not yet sufficiently known to what extent a crash barrier influences driving habits. It may be greater in some cases than the normal fear of the shoulder. But it is also possible that a crash barrier positioned in a certain way will in fact lessen this fear. The recover area should in any case not be made narrower than necessary.
For structures that have to function both ways the recover area at both sides should also (partly) be reserved for the barrier to deflect from an impact against the other side. In this case the area definitely cannot be made too narrow, as there will be more chance of the barrier being bent out on to the carriageway where it may constitute a danger to traffic.
If a hard shoulder (refuge area) along the carriageway takes over the function of the recover area, there will also be less inclination to narrow this area because it would detract from the importance of the hard shoulder which, of course, has other functions as well. Where space is short, a crash barrier can on the whole be placed a little closer along a hard shoulder than would be warranted along a traffic lane.
One must be careful about narrowing the area allowed for deflection behind crash barriers even at the right side of the road. If a severe impact should bend out the back rail past the crown of a slope, it would no longer be supported by the ground, and severe impacts might have far more serious consequences.

2.3.1.2. Use of stiff structures

The behaviour of crash barriers especially regarding deflection following an impact, is determined mainly by:
a. the distance between posts;
b. the stiffness of the beam;
c. the resistance of the posts, i.e. the forces of the individual posts reacting horizontally upon the beam.

With the recommended flexible structure, there is an optimum relationship between these factors. A change in one disturbs this optimum relationship, and one or more of the requirements of 1.2. is satisfied only partly if at all. This may be partly corrected by altering other factors as well.

Allowing for the above, a structure can be made less flexible in various ways. This causes greater decelerations of the impacting vehicle both laterally and around the vertical axis.

Ways of reducing flexibility are:

a. *Reducing distance between posts*

This is the simplest way of making a structure more stiff. It is effective with both minor and major impacts.
In view of the position of the holes already drilled in the rails by the manufacturer for a flexible barrier, the obvious step is to reduce the distance between the posts to about 2.67 metres. No substantial lessening of deflection, however, is obtained until the distance between posts is reduced to 2 metres, for which extra holes will have to be drilled in the rail.

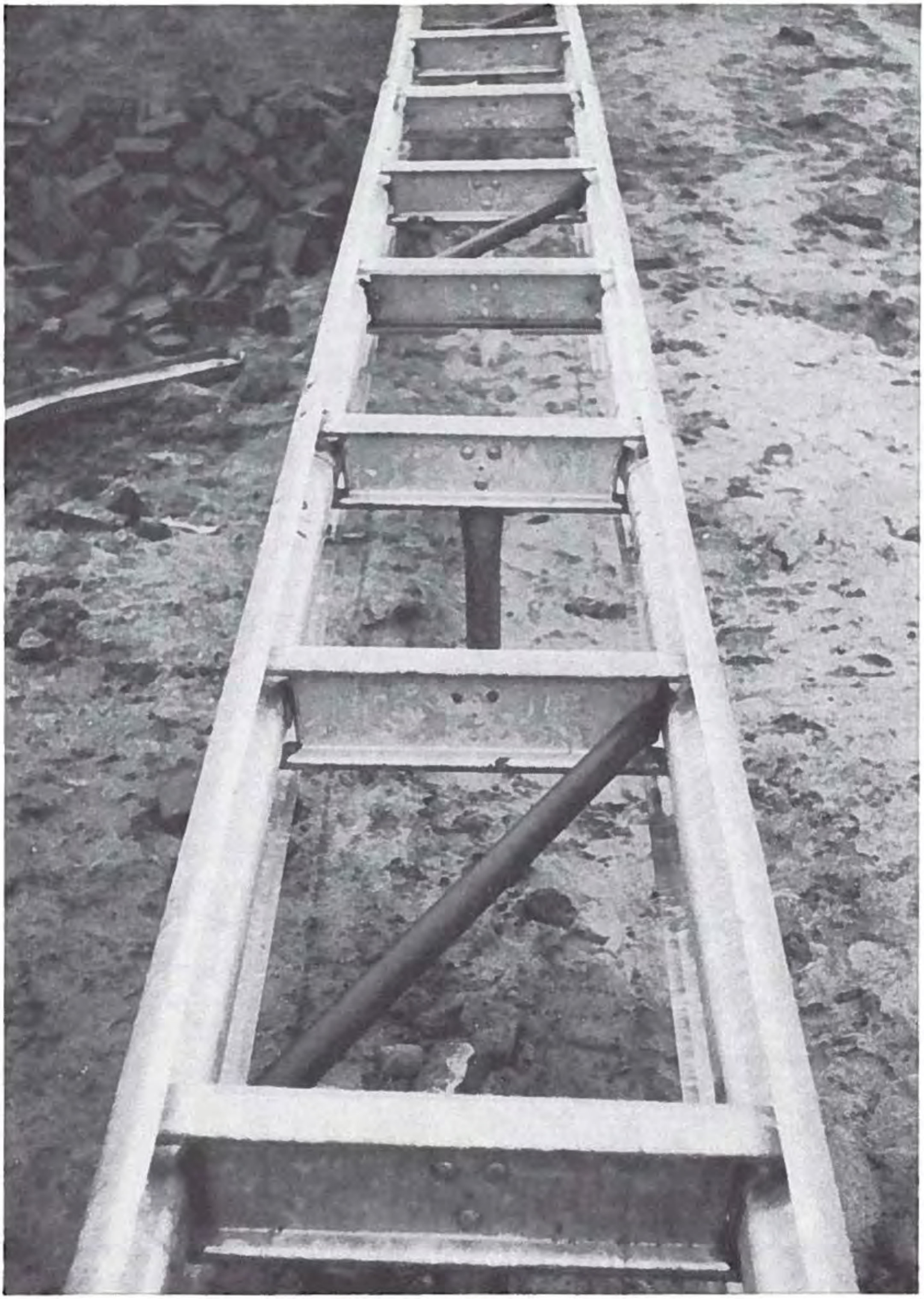


Figure 4. Beam strengthened with diagonal bars

If greater stiffness is desired by reducing the distance between posts, suitable distances will be about 1.33 metres and 1 metre respectively. In the latter case additional holes will again have to be drilled.

The shorter the distance between posts, the less favourable the form of deflection becomes. Its length is reduced increasing the danger of large deflection angles and uncontrolled re-propulsion into the vehicle's own traffic flow. In some cases it may be an advantage to reduce the weight of the structure per post.

b. *Stiffening the beam*

The joint between the two rails, formed by the spacers, is such that the beam's total inertia moment can hardly be taken as more than the sum of the two separate rails' inertia moments.

The beam can be stiffened in the case of structures whose spacers are 1.33 metres apart. A diagonal bar can be fixed in the middle field (formed by the rails and spacers) of each piece of rail (Figure 4). There is no point in inserting diagonal bars in the other fields because the oblong holes there eliminate the effect of the diagonals.
This is another reason why only distances from post to post of 4 metres, 2.67 metres and 1.33 metres are in principle usable for the stiff beam using the present rail. If it is difficult to assemble the structure with posts about 2.67 and 1.33 metres apart owing to the inherent inaccuracies in driving them into the ground, this can be solved by using oblong holes in the *spacers* and not in the rails since the latter will interfere with proper functioning of the diagonals.
It is emphasised that the joint between the diagonal bar and the rail must be of a high standard. A joint with an M16 bolt of at least 8.8 grade is satisfactory.
Considerable stiffness is obtained with this beam, also with minor impacts, and deflection (as the ratio between its length and extent) remains very favourable.

As only horizontal bending stiffness is increased by installing the diagonals and not that in the vertical plane, however, torsinal stiffness is not increased. With major impacts, this beam will thus tend to twist more, so that there will be a danger of the posts being hit (Figure 5). This may cause major lengthwise decelerations in the colliding vehicle. This twisting of the beam becomes less serious if the distance between posts is reduced and/or the ground resistance to bending over by the posts increases.

By increasing the vertical bending stiffness, the structure's torsinal stiffness can be increased. This can be done, for instance, by fitting additional rails against the posts under the actual beam (Figure 6). The existence of any other advantages or disadvantages of this construction has not been investigated.

The severity of impacts with the posts can also be lessened by making a rupture construction where the spacers are fixed to the posts (See also 5.4.1.). But this may increase the extent of deflection again.

The method can also be used in combination with these mentioned in 2.3.1.2a.

c. *Increasing the post resistance*

Ground resistance to the posts can be increased by fixing 'stabilising plates' along them to prevent them cutting through the soil to a certain extent.
This method of obtaining greater stiffness should be used *only* if the post-to-post distance is reduced (See 2.3.1.2a.), since with a normal distance the type of bending would be too detrimental and there would be a danger of the rail pocketing. The use of a stiff beam is most advisable if stabilising plates are used.
The additional stiffness is considerable. Its effect is also noticeable with minor impacts.

Figure 5. Impact with posts with a badly twisted beam.

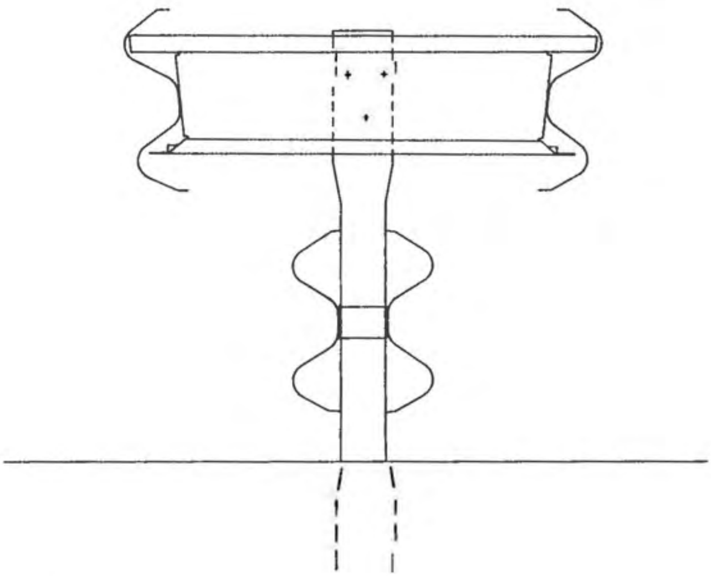


Figure 6. Applying additional guide rails to posts in order to increase vertical bending stiffness with a stiff beam.

If the post resistance is made too great, which may happen especially in firmer soil, there will be a danger of plastic deformation of the posts, and a collision with them will be almost unavoidable.
As conditions in this case are very unfavourable (post firmly in the ground and secured tightly to the top to the beam), this situation must emphatically be avoided by using stabilising plates with discretion. The type used out of the three mentioned in 5.5.3. must be suitable for the nature and state of the ground in which the posts are placed.

With the drilling method (See para. 3.2.), post resistance can be increased, instead of applying stabilising plates, by filling up the holes with a material providing greater resistance against cutting through the soil than that normally used.

It is not rational, however, to increase the post resistance over greater lengths (See 5.5.3.).

2.3.1.3. Reducing the offset

With structures required to function towards one side only, the rear rail offset can be reduced. This rail is then fixed close to the posts (Figure 7).

Such a single offset rail structure in the first stage of deflection, functions practically the same as the two offset rail type. The drawbacks, however, become apparent in major impacts.
By reducing the rear offset, the barrier first turns over further than the two offset rail barrier before the rear rail touches the ground. The beam is then inclined about 55° or more. Partly owing to the post's excentric positioning, the distribution of forces always occurring in the structure in this situation applies a relatively great bending moment to the post. It therefore tends to turn further still, but its pivot is now the point where the rear rail touches the ground, as a result of which the bottom of the post leaves the ground and the vehicle is almost bound to hit it (Figure 8). The height of the structure in this position has also become much less by reducing the offset.
Apart from these drawbacks, the advantage of the 20 cm saving in this structure's width is lost again because the two-stage effect is less pronounced and occurs later, and consequently this structure's deflection will be greater than that of the two offset rail barrier in case of heavy impacts.
To obviate all these effects as fully as possible, reduction of the rear offset will normally require a much more stiffened structure, as already described (See 2.3.1.2.). Flexible, single offset rail barriers will only be suitable in specific cases.
These single offset rail barriers differ from those built in the Netherlands in the past in having a second rail along the back of the posts. In an impact, the barrier retains its structure, the spacers remain the same distance apart and pocketing is prevented. It was this pocketing with the former single offset rail barrier (with one guide rail only) which caused passenger cars to have big deflection angles and trucks to crash through the barrier.

Existing structures of this type can be simply and rather substantially improved by fixing a strip along the back (See also 4.5.). This partly eliminates the drawbacks. Fixing a rail along the back would produce a stiff single offset rail barrier, as mentioned above, but this also necessitates replacing the spacers.

If there is a very great shortage of space, the front offset can also be reduced. But this quickly increases the risk of wheels jamming up against the posts. Such a collision usually has serious consequences because great lengthwise decelerations occur. It is therefore advisable to retain the front offset if at all possible.

Moreover, serious consequnces can be avoided by stiffening the structure still, for instance with a stiff beam, by greatly reducing the distance between posts (to 1.33 metres or even 1 metre), and if need by using stabilising plates. Such structures will be described as very stiff.

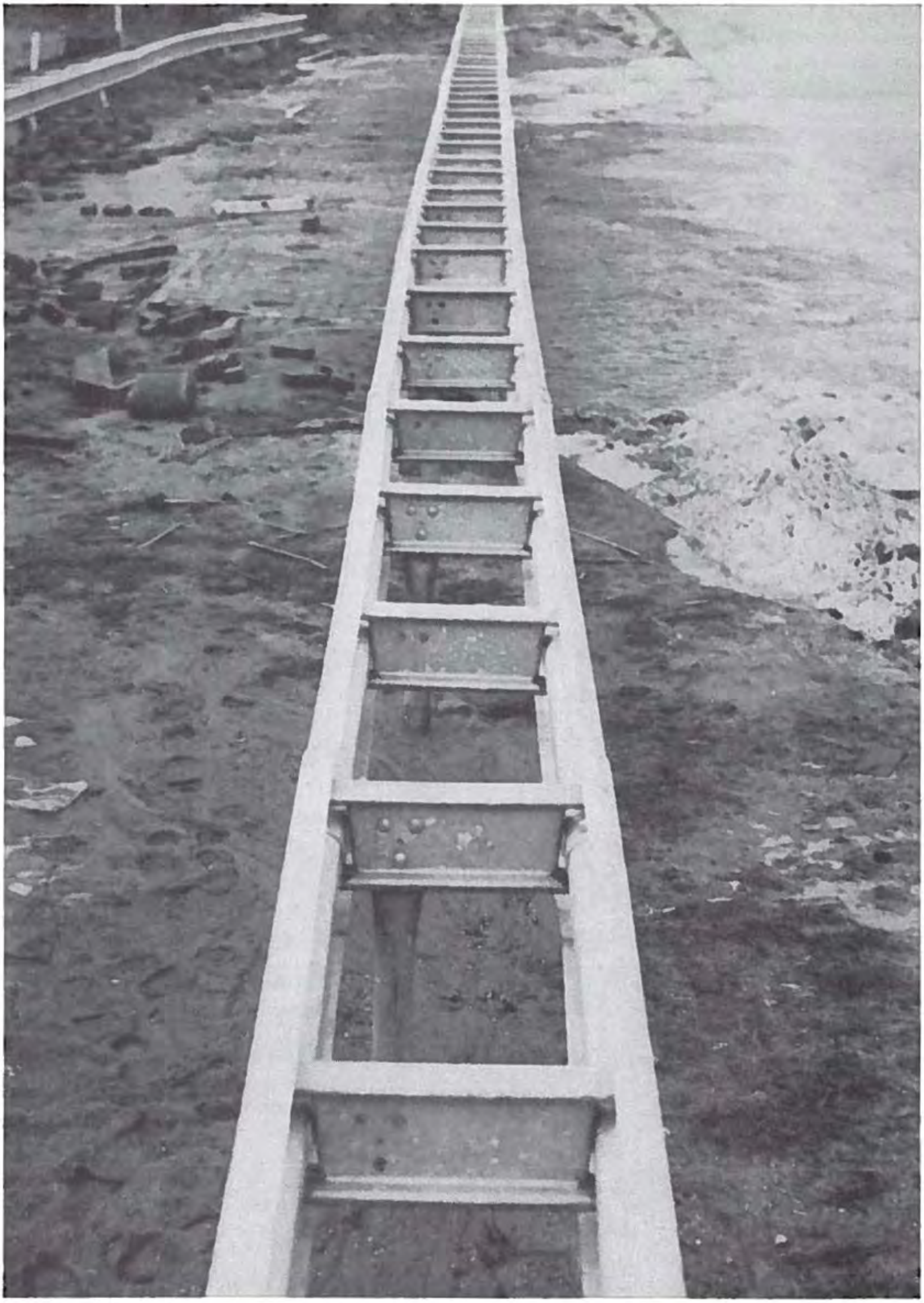


Figure 7. Single offset rail barrier

Figure 8. Impact with posts with a badly bent single offset rail barrier.

In the case of barriers that have to function on both sides, the two offsets must not be reduced except in case of a very severe shortage of space, and then only as little as possible, while the structure is stiffened much more at the same time.
Conversely, there is little point in retaining the offset, especially at the back, if for any reason use would have to be made of very stiff structures whose back rail will not bend over to the ground anyway. It must, however, be remembered that with a stiff beam the single offset rail barrier will deflect more than the two offset rail type (See Section 4).

A smaller offset is obtained by using shorter spacers than normal (See 5.2.).

It is difficult to say which of these measures is preferable in every specific case because the technical aspects of functioning of the barrier are not the only factor. The following are some general observations.

Narrowing the recover area does not detract from the functioning of the barrier in the stricter sense: its flexible character is completely retained. Bearing only the quality of the structure in mind, therefore, this will be the most appropriate method.
As stated above, narrowing the deflection area has serious drawbacks both in a central reserve and in a shoulder, as regards the functioning of the barrier. These drawbacks will have to be weighed from case to case against those of a stiff structure.

Whatever method of stiffening the barrier is chosen, the transverse decelerations around the vehicle's vertical axis caused by an impact will be greater, and the average consequences of collisions will be greater. But provided the structure is not too stiff, the two-stage effect will continue to appear with the two offset rail structure, but will first occur in more severe impacts than would be the case with a flexible structure.
Again bearing only the quality of the barrier in mind, reducing the offset will be the least

appropriate measure because it affects the barriers' various functions so much that none of the requirements mentioned in Section 1 are any longer properly satisfied.

2.3.2. Obstacles

In deciding the location of light standards, etc. allowance should be made for the possibility of a crash barrier being built, special attention being paid to the space required for it to function properly in case of impact. This applies even more if safety structures already exist. *It is basically incorrect to put fixed obstacles in the area over which an already existing safety structure must be able to deflect*, because their effectiveness is often then no longer guaranteed. This applies especially to light standards, etc. *between* the two rails of a barrier. This causes a very great danger of impacting vehicles being guided along the barrier up against these obstacles.* A possible exception is the existence of small obstacles *at the rear* of two offset rail barriers.

If obstacles already exist or are unavoidable, *two* barriers should be built on a central reserve one on each side of the obstacles. At the side of the road the barrier should run in front of the obstacles.

Perhaps in future it will also be possible to provide certain obstacles with a rupture device, or else to design them so that the consequences of colliding with them are limited to minor damage to the vehicle. The requirements such structures must satisfy are being examined. In that case, the relative location of crash barriers and these objects should not cause so many problems.

Where obstacles exist, the same measures are possible on the whole, as mentioned in 2.3.1. for a narrow central reserve or shoulder (narrowing of recover and/or deflection area, stiff structure, reduction of offset).

As regards stiff structures, however, the following may be added:
If obstacles with small dimensions (such as light standards) are *just inside* the area which has to be allowed for a flexible two offset rail barrier to deflect, a flexible barrier can still be built instead of a stiff one. In that case a major impact, after having bent over the back rail to the ground and perhaps having showed it over the ground for some distance, will push it up against the obstacle. The progressive resistance of the barrier may thus be increased, but there is a possibility of the rear rail being dented.
To prevent the front (impacted) rail bending less uniformly in such a major impact, this solution necessitates one of the spacers (one to which no post is secured) being omitted at the location of the obstacle (See Figure 9).
For barriers with a stiff beam, however, omission of a spacer causes an excessive localised reduction in stiffness.

Single offset rail barriers are very liable to topple if the back rail has bent to the ground. The above solution is therefore unsuitable for this type of barrier.

2.4. Summary of conclusions of research

A number of questions are formulated below on whether or not crash barriers may be built in a central reserve or on a shoulder.
No definite answers can be given at this point. Reference can only be made to the sections (or sub-sections) and the figures, providing the information needed for the necessary policy decisions.

* W. H. M. van de Pol and M. Slop. Flexibele geleiderailconstructies en lichtmasten in middenbermen (Flexible guide rail structures and light standards in median strips). Wegen 43 (1969) 12:358-361.

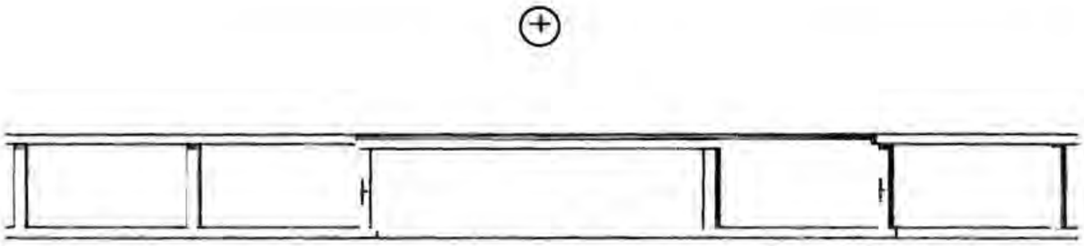


Figure 9. Model when a narrow obstacle is inside the deflection area behind a two offset rail barrier.

a. *When must a crash barrier be built?*

This will be necessary when a potential hazard area is a greater danger to road safety than a crash barrier.
The degree of danger due to a hazard area depends on its nature (existence of obstacles, a slope, etc.), and its distance from the carriageway (See 1.1.). The degree of danger due to the barrier depends on its type and design (See 6.4.), its construction and location (distance from carriageway). This is dealt with at various places in this report (See also references with questions b. and c.).

If a barrier is decided on, the next question is:

b. *Where must it be located?*

This depends upon how much space is available and how it is desired to utilise it. The following factors are of importance:
Space is needed for the recover area (See 1.2. and 2.3.1.1.).
Space is also needed for the barrier to bend out. This depends on the type of barrier (See question c.). The space acceptable for each type will be influenced by the expected impact angles, speeds and weights of impacting vehicles. Figures 12 to 19 give the information essential in order to decide on this.

Lastly, there is the question:

c. *What structure must be used?*

This depends on the area available for it to bend out and the nature of the hazard area (existence of obstacles, a slope, etc.) (See 2.3.2.).
The following possibilities exist:
two or single offset rail barriers (See 3.2. and 2.3.1.3.).
flexible – piled (See 3.1., 4.2., 4.3. and Figures 12 and 13).
flexible – drilled (See 3.1., 4.2., 4.3. and Figures 12 and 13).
made stiff with more posts (See 2.3.1.2a., 4.4. and Figures 14 and 16).
made stiff with a stiff beam (See 2.3.2.2b.).
made stiff with a stiff beam and more posts (See 2.3.1.2b., 4.4. and Figures 15 and 17).
made stiff with stabilising plates (with more posts), (See 2.3.1.2c. and 4.4.).
made very stiff with a stiff beam and stabilising plates (with more posts), (See 4.6. and Figures 18 and 19).

The choice between alternative structures should be governed by the extent to which they satisfy each of the requirements formulated in 1.2.:
preventing crashing through it or over it, or running, bursting, or turning over it or under it,
limiting injury and damage,
no rebound into the vehicle's own flow of traffic,
maintaining function after impact and simplicity of repair.

In discussing the individual barriers (See references given above) attention is paid to the extent to which each barrier satisfies these requirements.

3. Design requirements

3.1. Piled posts

As the reactive force applied by the posts to the beam depends on the nature and state of the ground in which the posts are fixed, the flexibility of a barrier built by the piling method is not uniformly distributed.

In order to obtain sufficient flexibility in compact (or frozen) soil, i.e. to avoid the structure not properly satisfying the requirements of 1.2. under such conditions, the spacers must be secured to the posts with rupture bolts (See 5.4.1.). If the reactive force of a post against the horizontal beam reaches a given value owing to too much resistance from the ground, the beam will be released from the post by the bolts breaking, and hence be able to deflect further at that point. Once the post is loose it can easily be knocked over in the direction of travel (Figure 10).
The rupture bolts are intedned as a stand-by in case the barrier fails to function normally as described in 2.2. In case of greater deflection they also prevent the conditions mentioned in 2.2. in which there are very great disadvantages in hitting the posts. The fixture with rupture bolts is not firm enough for this.
The rupture bolts must break quickly enough to guarantee the flexibility of the barrier if these is too much ground resistance. On the other hand they must remain intact as long as possible if the barrier deflects as desired, in order to limit the damage, but especially so as not to interfere with the barrier's progressive effect, and in order to keep the front rail at the right height.
The dimensioning which is a compromise, as the foregoing shows, is such that the rupture bolts are always broken by major impacts, even if the posts function as intended, but usually until after the two-stage effect has occurred.

Where flexibility has to be limited, rupture bolts should *not* be used, except perhaps with stiff beams with distances between posts bigger than 2.67 m (See 2.3.1.2b.).

In pure sand and/or black soil, the piling method with rupture bolts can readily be applied. The loose soil structure in such cases makes the desired behaviour of the posts possible, though the point around which a post pivots will not be as close to its base as might be desired. This pivot will generally be about 60 to 80 cm below the surface. The rupture bolts will break prematurely only if the ground is frozen.
In compact or adhesive soil, however, the rupture bolts will always function prematurely, and the average damage to posts and rupture bolts per impact will be relatively great. In there cases, therefore, posts positioned by drilling will be preferably. (See 3.2.).
The same may apply to looser soil, where a barrier with piled posts may tend to subside. In most cases the posts will at first be supported partly by adhesion (along the outside), but this cannot be relied upon. For calculating purposes the entire base of the post, looked upon as a plane surface (about 32 cm^2), will act as a support. The soil in the partly flat (concave) post is greatly compacted when it is driven in, and also provides support by adhering to the post's *inner* side.
Owing to vibration caused by traffic it is advisable to allow an ample safety coefficient. If this is taken as 2.5, it can be calculated that for reliable use of the piling method, with a post-to-post distance of 4 metres, there must be a sounding of about 12 kgf/cm^2 at the base of the post, i.e. at about 1 metre deep. If the posts are closer, this figure can be reduced approximately in proportion.

Subsidence can also be prevented by enlarging the base of the post, for instance by welding on an angle piece (Figure 11). This will make it more difficult to drive in. If the angle piece is not too big it will hardly, if at all, affect the functioning of the barrier.

The barrier is checked for height in the same way as with pile driving: the posts are first driven

Figure 10. Post run over after breakage of rupture device.

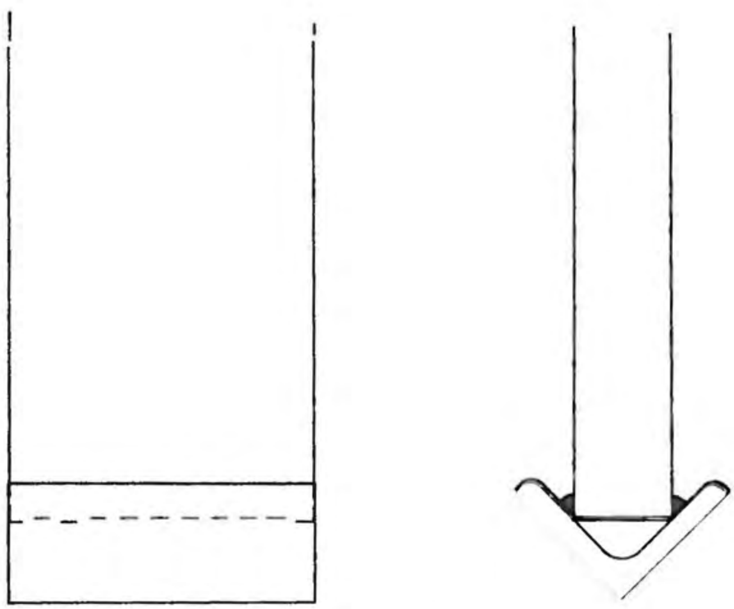


Figure 11. Making base of post bigger to prevent piled barrier from subsiding.

in to just above the required depth and, after the spacers and rails have been fitted, to the right level by a few blows with a hammer.

3.2. Posts in drilled holes

The behaviour of the posts and hence the flexibility of the barrier can be made more predictable and optimalised, regardless of the quality and state of the surrounding soil, by inserting them in drill holes filled with sharp sand of some other material which will similarly resist the post cutting through it.

By placing a concrete dish in the bottom of each hole (See 5.6.2.), the height of the posts can be fixed, so that support by the ground will no longer present any problems. Besides this, the pivot will generally be lower and thus better, which is an important argument in favour of this method.

The different behaviour of a barrier with posts in drilled holes as compared with piled posts causes still greater difficulties in correct dimensioning of the rupture bolts.
Owing to the bigger guarantee of constant, high flexibility, there is less need for rupture bolts, however, and they could be dispensed with. In the piling method, they had an additional function when an impact with the posts caused very great deflection. Lack of the rupture bolts with the drilling method, however, is not a drawback in this respect, because before there is any danger of the posts being hit the barrier has been bent so far that the posts are no longer fixed firmly in the ground. Thus the vehicle will no longer join up against them.
Dispensing with the rupture bolts also avoids problems in getting the correct beam height. The use of the dishes makes it impossible to do this by hammering in, while there are practical drawbacks in locating the dishes at the exactly correct depth.
The beam is positioned at the correct height with a clamp fixed to the spacer, allowing adjustments in height of about 4 cm (See 5.4.2.).

In filling the drill hole with sharp sand, the problem of the ground freezing up occurs in winter. Originally it was believed that mixing the sand with petrochemical products would make the ground sufficiently frost-free, but tests have disproved this.
The frozen ground will prevent the post from cutting through it, so that when struck it will bend at ground level, with the consequent danger of it being run into.
One might decide for the Netherlands to accept this risk during the comparatively short time the ground is frozen. Otherwise the problem can be solved by using a rupture device in fixing the spacer to the post. Rupture bolts cannot be used for this, however, owing to the need for adjustment with the drilling method. The post might have a telescopic top with a rupture device (See 5.4.3.). But this system has not been tried out.
Another possibility would be to fill the drill hole with a polyurethane-based foam. This is made in situ by mixing three components, after which it expands to about 50 times its original volume. Equipment for filling the drill hole already exists. If a material density of about 30 gr/ltr is used, the filling is guaranteed frost proof. What material density is needed for the post resistance required for good flexibility is not yet known. Higher densities could then be applied if a greater post resistance is required for making a stiff barrier.
An incidental advantage of the foam is that it adheres tightly to the post, making the dish unnecessary.
The barrier with a drilled hole filled with foam, however, has not been tried out.

Of the requirements mentioned in para. 1.2. the first (no crash-through) is complied with to about the same extent in both methods (piling and drilling).
The second requirement (limitation of injury and damage) is satisfied better by the greater flexibility of the drilling method, especially with minor impacts. With more complicated impacts the piling method may sometimes have less serious consequences owing to the use of rupture bolts.

The third requirement (limitation of rebound) is on the whole satisfied better with the drilling method.
As regards the fourth requirement (possibility of quick repair), the drilling method is also preferable. A barrier positioned with this method can often simply be pulled straight after a collision without further repair work being needed.
If the drill hole is filled with polyurethane foam, the space caused by impact can be filled up with fresh foam or – in case of minor damage – with sand.
The fourth inquirement also implies that the barrier continues to function. Here too the drilling method is usually better, due to the fact that the fixture between the posts and the spacers is not damaged.

Maintenance and repair costs are likely to be lowest with the drilling method; installation costs, however, are lower with the piling method. Owing to the lower pivot of posts in drilled holes, the deflection of a barrier with such posts will usually be more than that of a barrier with piled posts.

Before choosing the method, however, the mechanical properties of the soil must be studied.

3.3. With stay bushes

If it has to be possible to remove the barrier by simple means there is a localised continuous road surface, the stay bush method may be used (Drawing No. 19). Upon impact, the posts must bend over at the road surface level.
As part of a flexible barrier, rupture bolts must also be used with this method, but not as part of a stiff one.
In special cases, for instance in tunnels, waterproof stay bushes may be needed (Drawing No. 20).
The model with stay bushes has not been tested.

It is clear however that bending of the posts at road surface level makes it possible to run into them, which may be dangerous, especially without rupture bolts.
It would therefore be advisable to design a stay bush structure with a rupture device in the post at road surface level, for instance fixed with flanges with rupture bolts. A rather heavier impact will then break one or more posts, allowing the structure to deflect. Any necessary limitation of flexibility, similarly to a normal barrier, can then be obtained by shortening the distance between posts and/or using a stiff beam.
Although this structure has never been made or tried out, tests with similar bridge crash barriers indicate that it will function excellently if carefully dimensioned.

4. Types of barrier

4.1. Introduction

There is a basic difference between flexible and stiff and between two offset and single offset barriers. This gives four types of structure.

Differences in method (piling or drilling; with or without rupture bolts) require a further sub-division. Not all conceivable combinations, however, are suitable for (extensive) use. If they are, they are dealt with in this Section, reference being made in each case to the drawings at the end of this report (Nos. 1 to 10).

The following drawings give details of all the structures:
Guide rails: Drawing No. 11
Spacers : Drawings Nos. 12.1 to 12.3
Posts with or without spacers: Drawings Nos. 13.1 to 13.3
Fixture of spacer to post: Drawings Nos. 14.1 to 14.3
Stabilising plates: Drawings Nos. 15.1 and 15.2
Stiff beam: Drawing No. 16
Dish: Drawing No. 17
Bolts and nuts: Drawing No. 18

For case of reference a code is used where necessary to indicate the structures:

F stands for flexible structure;
S_p stiff structure with reduced post-to-post spacing;
S_b stiff structure with stiff beam;
S_{bp} stiff structure with stiff beam and reduced post-to-post spacing;

2 two offset rails;
1 one offset rail;

P inserted by piling method;
D inserted by drilling method.

w with rupture bolts;
n no rupture bolts;

(A) with stabilising plates, model A;
(B) with stabilising plates, model B;
(C) with stabilising plates, model C.

At the end of this Section there is a tabulated list of the possible combinations (See 4.7.).

Tests showed that all these structures function best if the height of the top of the rails relative to the ground level is 0.75 metres at the point where a vehicle's wheels are as the vehicle hits the structure. Differences of 5 cm more or less are acceptable.

The offset is normally 40 cm from the centre of the posts. Non-offset rails extent about 20 cm from the posts' centres. In some cases intermediate distances might be used.

In view of the large number of variables in an impact with a crash barrier, it is not possible to give general standards for each barrier's maximum deflection. The deflections were, however, noted in all the experiments. These data, together with those obtained by research in other countries and in practice make it possible to indicate a rough curve for each barrier showing the

likely deflection, depending on the severity of the impact.
These curves are given in Figures 12 to 19. The continuous lines are based on actual impacts with the barrier itself and with equivalent barriers. They are an average of the area in which observations of these impacts are located. Extensions of these curves with the dot-dash curves are based on discernments obtained in the tests and not on direct observations. If the dot-dash curve stops at an impulse below 7000 kgfsec., this means that a vehicle making a more severe impact will possibly crash through or over the barrier.

The standard impact severity has been taken as the degree of movement of the impacting vehicle at right angles to the structure, i.e.:

$$\frac{G \times V}{3.6\,g} \text{ sine } i \text{ kgfsec, in which:}$$

G is the vehicle's weight in kgf;
V is its speed in km/h;
g is acceleration of gravity in m/sec²;
i is the impact angle.

In putting these curves in general terms it must be borne in mind that they have been arrived at in tests with an impact angle of 20°.
The curves therefore apply approximately to the range between impact angles i = 10° and i = 30°. At smaller impact angles, there is likely to be less deflection with the same V × sine i value, and probably more with bigger impact angles.

With piled structures it must also be taken into account that the tests were made in gravelly, loamy sand. If a piled barrier is in ground with an unusual resistance to the post cutting through it, an unusual deflection curve is also likely.

All barriers' deflections will not exceed a given value in most impacts. If too little space is available for a given structure to function properly, its use may still be justified; the risk of a major impact with more deflection than available space permits is then accepted. The alternative is to use a stiff structure, which a major impact still bends out within the available space but which has worse consequences especially with minor impacts.
Such decisions will have to be taken from case to case. The former alternative may be preferred; for instance, where, owing to the pattern of traffic (few heavy trucks) there is less fear of serious collisions, the latter where there are dangerous obstacles.

4.2. Flexible two offset rail barriers

Drawing No. 1 shows the flexible two offset rail barrier with piled posts, with rupture bolts (F2Pw).
Drawing No. 2 shows the same barrier, but with posts in drilled holes, without rupture bolts (F2Dn). With Drawing No. 2 it should be noted that the drill hole shown is only one of the possible forms. A hole can quite easily be designed which equally allows the intended movement of the post but is of a smaller volume, so that less filling is needed.
The post-to-post spacing is 4 metres, the width 0.80 metres. The two rails are joined together with a spacer about every 1.33 metres. The weight of these barriers is about 145 kgf per post.

The barriers function both ways, making them particularly suitable for an obstacle-free *central reserve*.
If the central reserve is very wide the barrier may be placed in it excentrically, but a recover area of at least 2.60 metres should be left on the narrow side.
Based on a recover area of 2.60 metres (See section 1.2.) the central reserve will have to be

at least 6 metres wide for this type of structure to function properly in all respects. If less space is available, the areas at each side of the barrier after it is positioned will not be wide enough to accommodate all types of vehicles, with a consequent danger of collisions from the rear.
With a narrower central reserve, however, a flexible two offset rail barrier can still be used; in the axis of the reserve, leaving enough room on each side for a vehicle to get back on to the road and to accommodate a vehicle, as far as possible after an impact.
The narrower the central reserve is, however, the less suitable it will be for the type of barrier now described, especially if there is no longer enough space for it to bend out.

Figure 12 shows the likely deflections with impacts of varying severity against this type of barrier.
On the whole the piled structure deflects less than that with posts in drilled holes. The two-stage effects begins with the latter barrier in the case of deflections greater than about 95 cm; with the piled barrier at about 75 cm, in both cases with about the same impact.
Piled barriers have a more pronounced two-stage effect, but since more and more rupture bolts break as impacts increase in severity, the curve is still fairly steep even with major collisions.
Where posts are inserted by drilling, there is a possibility of their being hit, if the structure deflects about 1.40 metres or more. As already observed in Section 3.2., however, the posts are only loosely in the soil with such great deflection, and the vehicle will not run up against them. As the rear offset tends to prevent the barrier turning further, heavy impacts against structures with posts in drilled holes do not usually have serious consequences.
With piled barriers the rupture bolts are dimensioned so that they break before there is any danger of impact with the relative post. After that, the posts can safely be run over.
Without rupture bolts, the posts can be expected to be hit in this type of structure with deflections of 1 metre and more.

The 0.75 metre already mentioned for the height of the barrier above the ground level (or hard shoulder) is not so critical that, if there is a slight difference between the height of the two carriageways, two separate barriers must be built immediately. The permissible difference can be taken as 5 cm, more or less, so that a single barrier with two offset rails can be kept where a central reserve has a maximum transverse gradient of 1 in 8.

If there are obstacles in the central reserve, however, two barriers should be built, one on each side of the obstacles. If there is enough space, these may be of the flexible two offset rail type.
Also with a narrower central reserve containing obstacles, two flexible two offset rail barriers can still be used by running them relatively close in front of the obstacles. This of course means that major impacts will push the rear rail against the base of the obstacle (See 2.3.2.).

Lastly, this type of barrier can also be used on shoulders if space is sufficient. Here, too, if little space is available the fact that major impacts will push the rear rail against an obstacle may have to be accepted before a stiff structure is decided upon. But if this structure, notwithstanding the observations in 2.3.1.1., is too close to the crown of a slope, there is no point in having a rear offset because the two-stage effect cannot occur anyway.

4.3. Flexible single offset rail barriers

Drawing No. 3 shows a flexible single offset rail barrier with piled posts and rupture bolts (F1Pw).
Drawing No. 4 shows the same barrier, but with posts positioned by drilling and without rupture bolts (F1Dn).
The post-to-post distance is 4 metres, width 0.60 metre. The two rails are joined by a spacer about every 1.33 metres. These barriers weigh about 140 kgf per post.

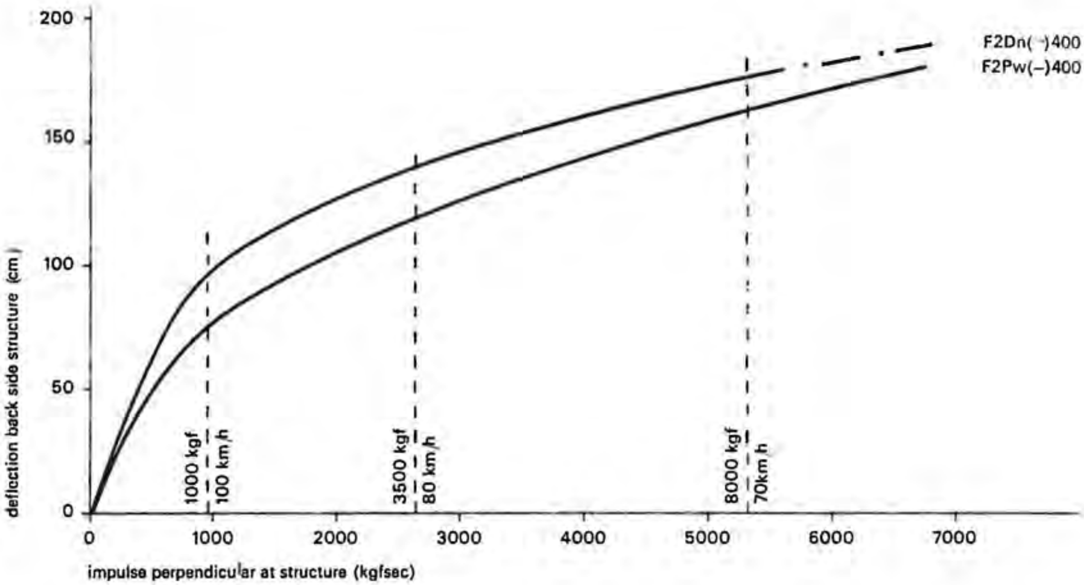


Figure 12. Likely deflection of flexible two offset rail barrier.

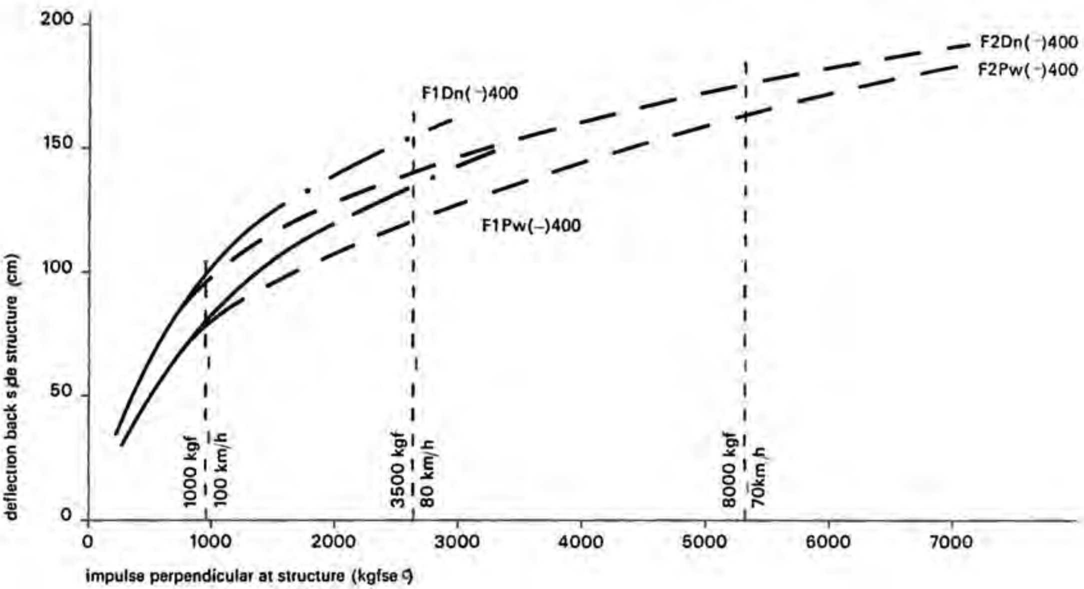


Figure 13. Likely deflection of flexible single offset rail barrier.

The offset side is regarded as the front. The barriers function at this side only, though where appropriate the rear can function well as a cycle path barrier.

Figure 13 shows the deflections that can roughly be expected from impacts of varying severity with this type. For comparison, the curves for the two offset rail barrier are included.
With minor impacts, there is no noticeable difference in behaviour compared with the two offset rail type. Where the rear rail of a two offset rail type would have touched the ground, however, there is a difference. Deflection is increased to about the same extent because there is hardly any two-stage effect. The rear rail first touches the ground with deflections of about 95 cm for a piled-post barrier, and of about 115 cm for the drill-hole type. Owing to the drawbacks of these barriers as mentioned in 2.3.1.3., they are really only unsuitable for minor impacts. They may, however, be considered where major impacts are unlikely because there are few trucks on the road.

4.4. Stiff two offset rail barriers

Stiff barriers are suitable where deflection has to be limited (See para. 2.2.). As flexibility is usually greater with the drilling method than with the piling method, it is not logical to build stiff barriers over long distances with posts placed in drilled holes. In this case the piling method is always preferable but – likewise in order to limit flexibility – without rupture bolts. With stiff beams and greater post-to-post distances, however, rupture bolts might still be considered in order to avoid impacts with the posts.

Drawing No. 5 shows this barrier, which has been made stiff by reducing the distance between posts to 2 metres (S_p2Pn).
Its width is 0.80 metre. No spacers are fitted between the posts. It weighs about 80 kgf per post.

Figure No. 14 shows likely the deflections with impacts of varying severity. The curve for the flexible barrier with rupture bolts is included for comparison.
The greater stiffness is already noticeable with minor impacts. The two-stage effect is pronounced because there are now no rupture bolts.

As already stated in 2.3.1.2b., the barrier as a whole can be made stiff with a stiff beam.

Drawing No. 6 shows this barrier, with two offset rails, with about 2.67 metres between posts, indicated as (S_{bp}2Pn).
Its width is 0.80 metre. The spacers are also at intervals of about 1.33 metres again. The barrier weighs about 110 kgf per post.

The likely deflections of this barrier are given in Figure 15.

This barrier can also be made more stiff by reducing the intervals between posts to about 1.33 metres. This gives likely deflections as also shown in Figure 15.

Instead of this latter structure, stabilising plates could be added for short distances to a barrier with about 1.33 metres between posts, for instance S_p2Pn(C). No deflection curve can be given for this barrier based on our research. Its great stiffness will, however, apply immediately even with impacts of moderate severity, and the curve for minor impacts will certainly be under that of S_{bp}2Pn in Figure 15. Owing to the great resistance of the posts, however, the type of deflection may be very unfavourable, and there will be a danger of large deflection angles (the vehicle bouncing back into its own stream of traffic). A stiff beam will prevent this if stabilising plates are used and will also limit deflection by severe impacts. In major impacts, one or more posts will often show plastic deformation just above ground level, followed by a danger of running into them.

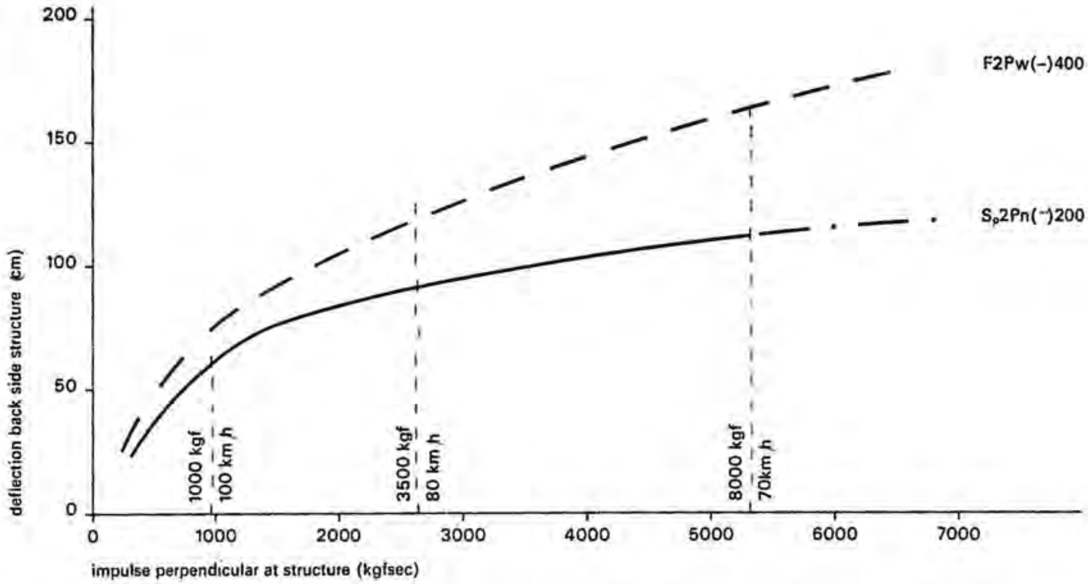


Figure 14. Likely deflection of two offset rail barrier with posts 2 metres apart.

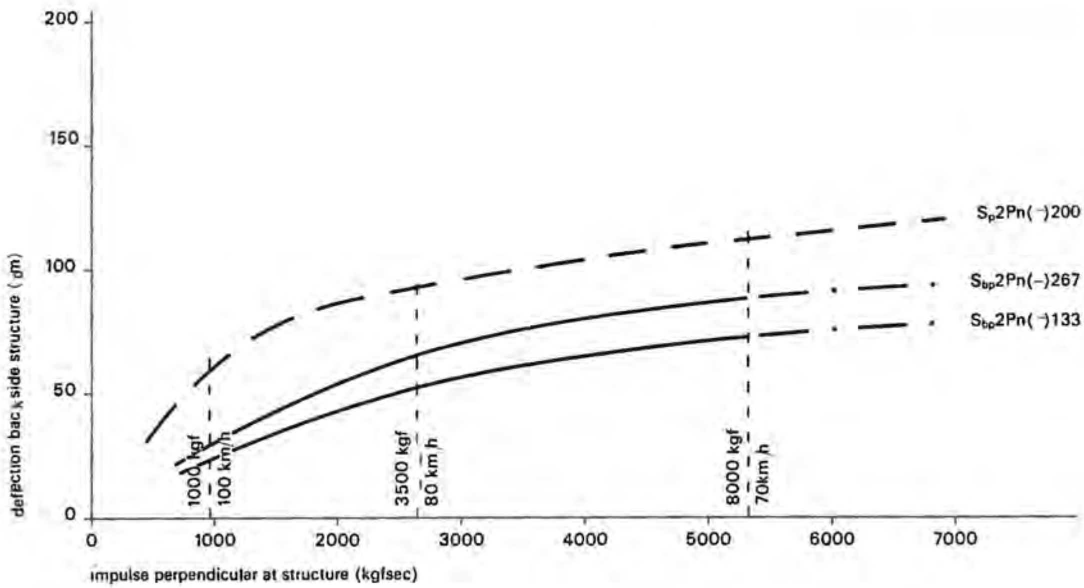


Figure 15. Likely deflection of two offset rail barrier with stiff beam and posts 2.67 metres and 1.33 metres apart.

Nothwithstanding the first paragraph of this Section, practical considerations (for instance the non-availability of a pile-driver at the site), a stiff barrier may be built for a short distance – for instance along bridge piers that have to be shielded – by the drill-hole method if the rest of the barrier has also been built in this way. To prevent great deflection, however, stabilising plates should then be used (See 5.5.3.), or the drill-hole should be filled with a material to counteract the post cutting through the ground.

Drawing No. 7 shows a barrier made stiff by reducing the distance between posts to about 1.33 metres and using stabilising plates. This may be described as S_p2Dn(C).
It is 0.80 metre wide. It weighs about 80 kgf per post. Owing to the use of stabilising plates deflection depends less upon the type of structure. On the whole, therefore, the same deflections are likely as with the structure just described with a rather smaller stabilising plate.

If the transverse gradient of a central reserve is greater than 1 in 8, but not greater than 1 in 6, the two rails at each side of the posts may be fixed at different heights. But they must then be 2 metres (in exceptional cases about 1.33 metres) centre-to-centre to avoid the spacers not joined to the posts having to be of a different type. The barrier can then be classified as a stiff two offset rail type. Two 'half' spacers are placed on the posts, one just above the other, with no rupture bolts. The tops of the posts must then be 0.20 metre longer than normal, and also have a double set of holes.

4.5. Stiff single offset rail barriers

While there is practically no use for flexible single offset rail barriers, there is more use for the stiff single offset rail type.
By making them reasonably stiff some of the drawbacks of omitting the rear offset are eliminated.
Even more than in 4.4., it is now preferable to use the piling method without rupture bolts.

Similarly to the two offset rail barrier, the post-to-post distance can be reduced. The likely deflections with 2 metres between posts (S_p1Pn) are given in Figure 16.

Drawing No. 8 shows a barrier made more stiff with a post-to-post distance reduced to about 2.67 metres and with a stiff beam (S_{bp}1Pn).
It is 0.60 metre wide. The two rails are connected by a spacer at intervals of about 1.33 metres. Diagonal bars are fitted in the fields every 4 metres (See 2.3.1.2b.). The barrier weighs about 105 kgf per post.

Figure 17 shows the likely deflections with impacts of varying intensity against this barrier and against the corresponding barrier with about 1.33 metres between posts.
Unlike the situation with the non-stiffened beam, a difference in deflection is observable with the stiff beam, even in case of minor impacts, as between single and two offset rail barriers. This is due to the lower stiffness of the single offset rail barrier (owing to its being narrower). No two-stage effect is discernible.

For short lengths, it may appropriate to stiffen the barrier by combining a shorter post-to-post distance with stabilising plates. The remarks regarding the adverse form of deflection (See 2.3.1.2c.), however, apply to this as well.

If it is nevertheless desired, for practical reasons, to construct a stiff single offset rail barrier for a short distance using the drilling method, stabilising plates can be used (as also in 4.4. for the two offset rail type).

Drawing No. 9 shows this latter barrier, which may be called S_p1Dn(C). Distance between posts is about 1.33 metres, width 0.60 metre. The barrier weighs about 80 kgf per post.

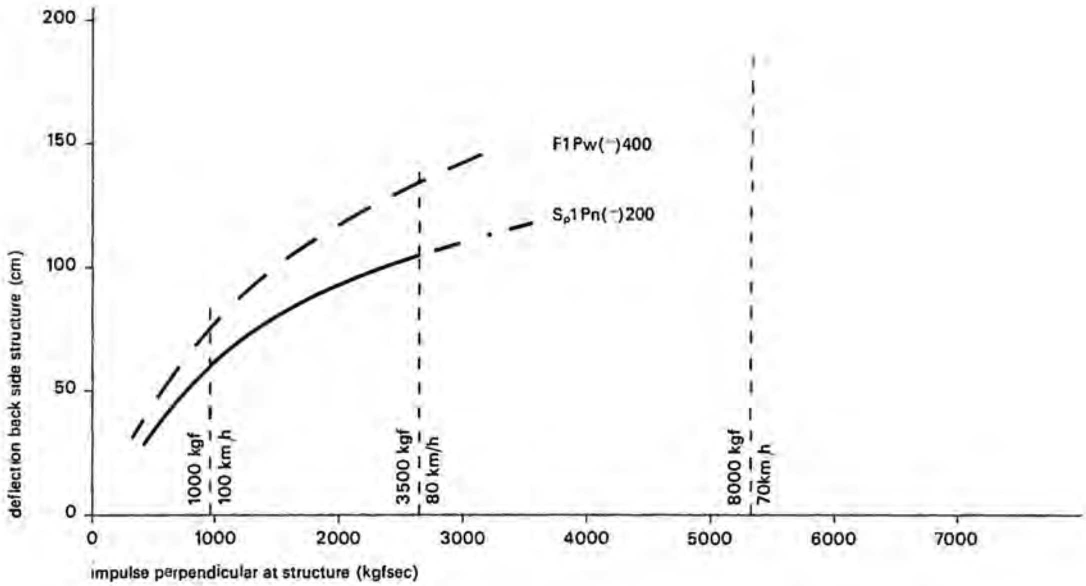


Figure 16. Likely deflection of single offset rail barrier with posts 2 metres apart.

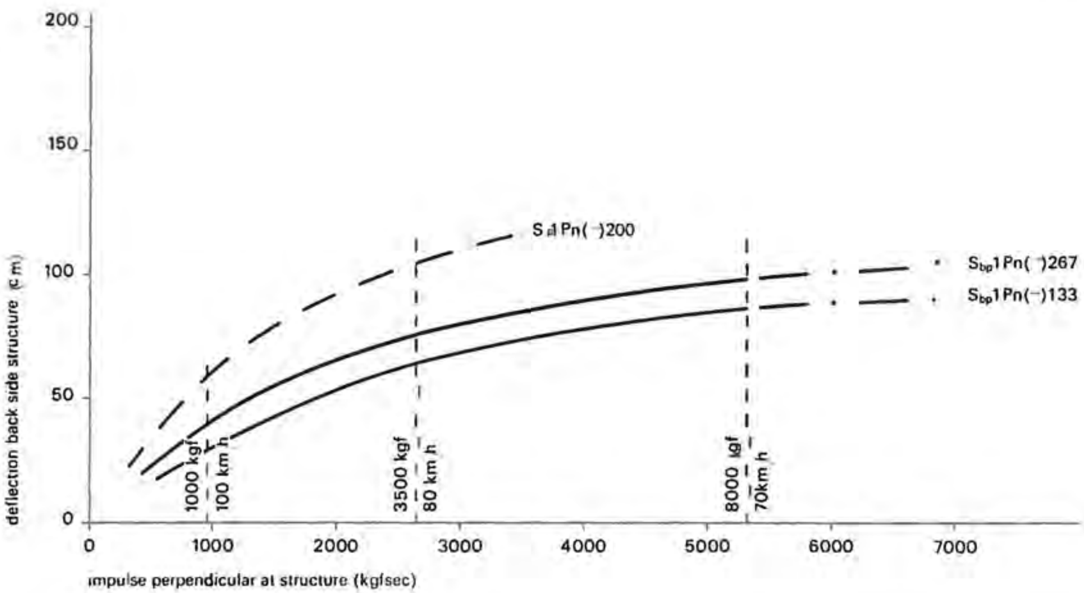


Figure 17. Likely deflection of single offset rail barrier with stiff beam and posts 2.67 metres and 1.33 metres apart.

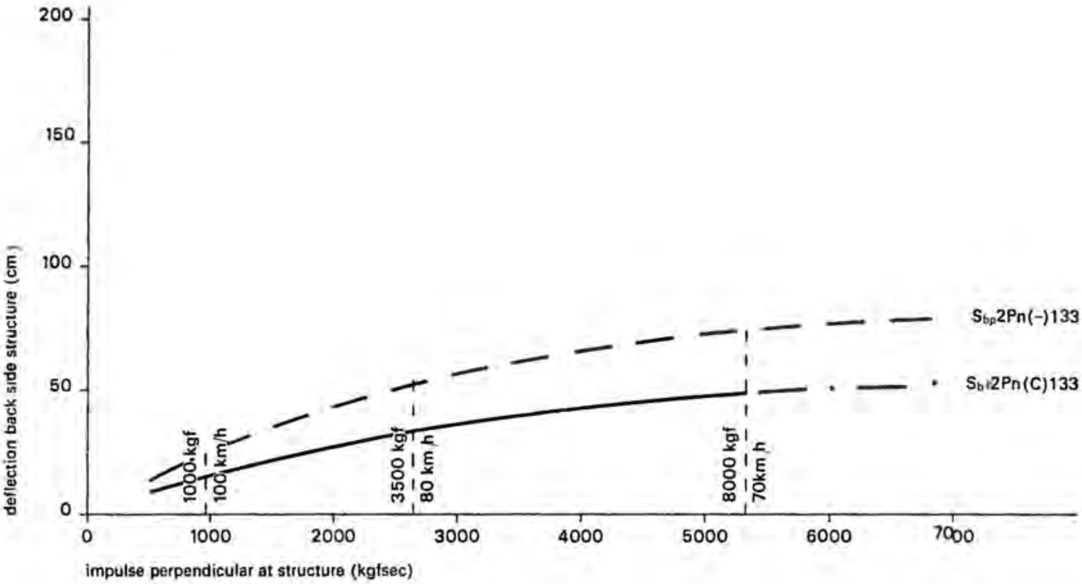


Figure 18. Likely deflection of two offset rail barrier with stiff beam and posts 1 33 metres apart, and with type C stabilising plates.

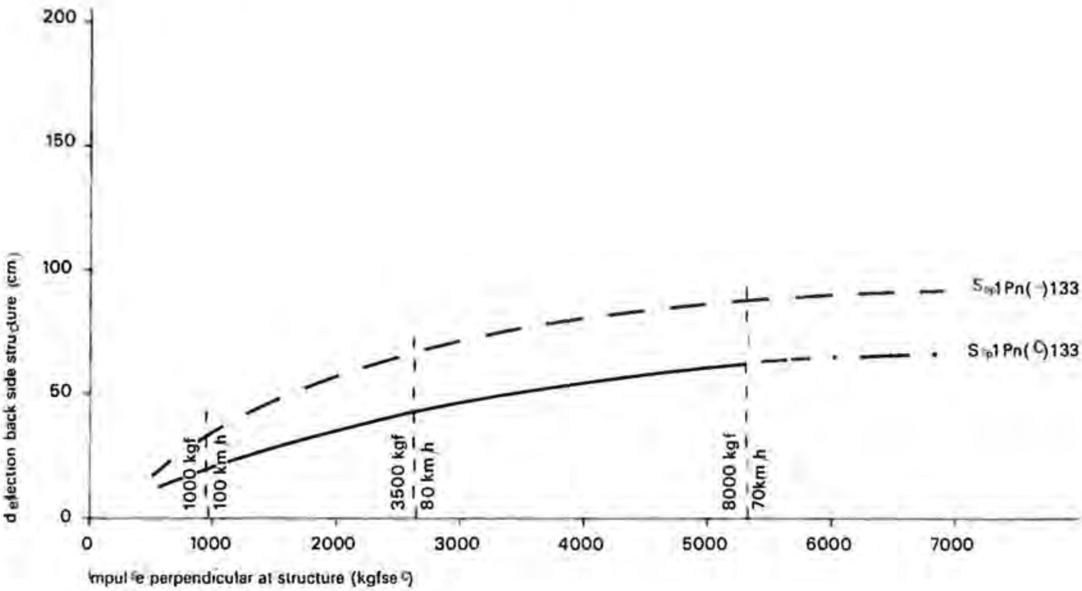


Figure 19. Likely deflection of single offset rail barrier with stiff beam and posts 1 33 metres apart with type C stabilising plates

Drawing No. 10 shows a possible improvement of stiff single offset rail barriers already existing in the Netherlands which no longer satisfy current requirements. Fixing a strip along the rear of the barrier produces a comparatively big improvement in its functioning. This barrier, however, remains inferior to that with a rail along the rear, especially when the rail is set off.

4.6. Very stiff barriers

Extrapolating the tendencies found for the different deviations from the optimum flexible two offset rail barrier, makes it possible to design very stiff structures.
These may be suitable where space is very cramped. Generally only the first and third requirements of Section 1 (no crash through and no rebound) can be adequately met. See also 2.3.1.3.

Figures 18 and 19 show the expected deflections for two offset rail barriers and single offset rail barriers with stiff beams, post-to-post 1.33 metres, with type C stabilising plates.
Expected deflections of the corresponding barriers with types A and B stabilising plates are between the deflection curves in Figures 18 and 19.

4.7. Review types of barrier

Table 1 is a compilation of the various types of barrier.

Versions	Method	Rupture bolts	Type			
			Flexible		Stiff	
			two offset rail	single offset rail	two offset rail	single offset rail
Versions	Piling method	with rupture bolts	**Drawing 1**	**Drawing 3**	Too flexible for rational use	
		without rupture bolts	Not normally used owing to possibility of non-flexibility in compact or frozen soil		**Drawing 5** **(S_p)** **Drawing 6** **(S_{bp})**	**Drawing 8** **(S_{bp})**
	Drilling method	with rupture bolts	Not normally used; flexibility already ensured with drilling method		Too flexible for rational use	
		without rupture bolts	**Drawing 2**	**Drawing 4**	**Drawing 7** **(S_p)**	**Drawing 9** **(S_p)** **Drawing 10** **(S_p)**

Table 1. Types of barrier. (Those indicated in Drawings 7 and 9 are suitable for short lengths only).

The combinations with a reasonable range of uses are **printed bold**. The other combinations may be suitable in special cases. These are not gone into further in this report, but can if desired be designed by the reader by reference to the principles evolved.

5. Technical details

5.1. Guide rail

In this research the guide rail in general use, type A (German Standard RAL-RG 620) **(Drawing No. 11)**, proved suitable for an effective guide rail structure.
It is inadvisable to deviate from the customary thickness of the galvanising layer (60 microns), as a thicker layer is more susceptible to mechanical damage while a thinner one gives less protection.

5.2. Spacer

Tests in the Netherlands and Germany have disclosed that the spacer is a critical element in guide rail barriers.*
Comparative experiments have shown that the spacer known in Germany as type B is the best.* It consists of sheet steel 3 mm thick, shaped as an I section, with some additional working. The various methods and types require differently formed spacers, but all are variants of this same type.

Drawing 12.1 shows the model recommended for two offset rail barriers with piled posts. The design of this type of spacer aims at maintaining the beam structure as fully as possible upon impact. It is then also necessary for the front rail to move up while bending laterally, or at least not to move down: this stops the vehicle from tipping over and reduces the risk of it crashing over the barrier. Besides having to have a certain minimum stiffness in order to guarantee this effect, the spacer is designed so that the rail to be fitted to it inclines forward, 6° from the vertical. The top corrugation of the rail is thus closer to the carriageway than the lowest corrugation and the initial contact between vehicle and rail causes a torque that induces the required movement.
Spacers used hitherto lack this. In such types, therefore, there is a risk of a contrary moment occurring, so that the front rail moves down and the vehicle can tip or crash over the barrier (Figure 20). This may also happen if the spacer is not fixed firmly enough to the post.
The inclined rail also ensures that its reactive forces are applied to the vehicle as high as possible for a longer time and the overloading of the bottom corrugation of the rail that quickly occurs if different spacers are used is counteracted. A major load on the bottom corrugation of the guide rail, even if it is inclined, is nevertheless often unavoidable (Figure 21). If, moreover, trucks' wheel bolts tear the bottom corrugation, this may cause the rail to break. This has proved to happen especially when rigid spacers are used, when the bottom corrugation cannot be dented. This hazard is counteracted with a suitable design of the bottom spacer-flange. The end of this flange is weakened so that it snaps under a comparatively minor load, whereupon the rail is able to bend out at this point. Thus the rail is not torn and hence there is no breakage (Figure 22).

Drawing No. 12.2 shows the design recommended for two offset rail barriers with posts in drilled holes and without rupture bolts. The only difference is in the number and shape of the holes in the body and the way they are made.
Drawing No. 12.3 shows the spacer for single offset rail barriers with piled posts. This is 20 cm shorter at the non-offset side.
The spacer in **Drawing No. 12.4** of single offset rail barriers with posts in drilled holes, without rupture bolts is also 20 cm shorter, while the holes in the body also differ.

If it is also desired to reduce the front offset or, in a very narrow central reserve, both offsets, the spacers should be shorter still. The maximum reduction on either side is 20 cm.

* Anfahrversuche an Leitplanken. Innenministerium Baden-Württemberg, Stuttgart, 1969.

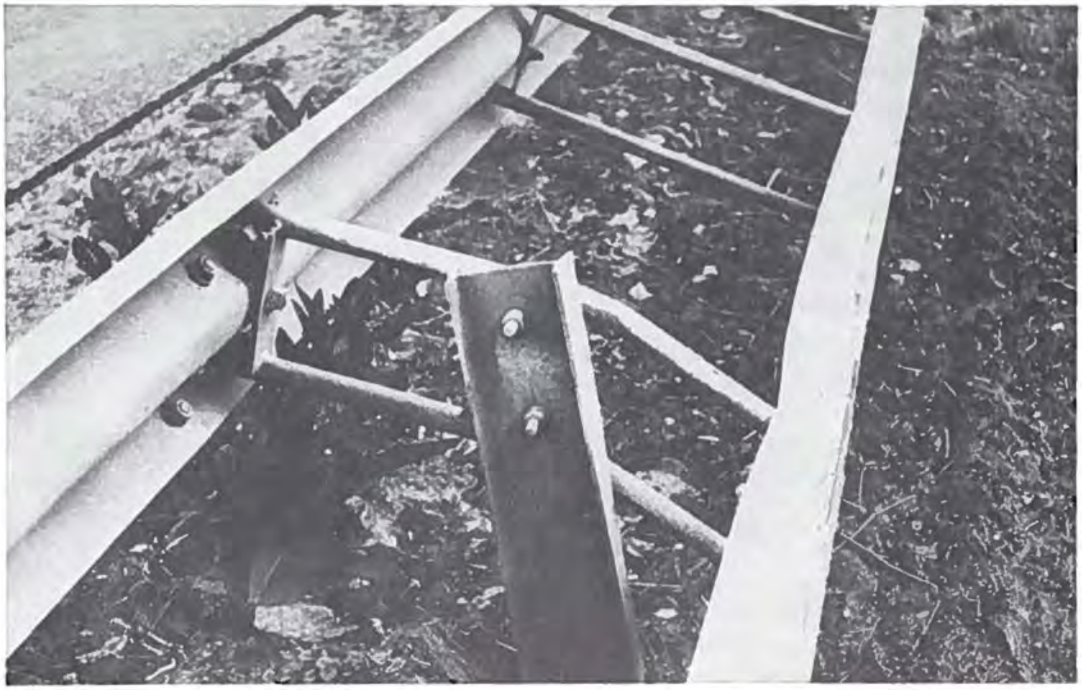


Figure 20. Front rail pressed down with insufficiently stiff spacer.

Figure 21. Denting of bottom corrugation in front rail with severe impact.

5.3. Post

The post developed during the research is dimensioned so that it easily cuts through the ground on lateral loading, whereupon the barrier turns around an underground axis (Figure 3) This behaviour of the posts provides the various barriers with the desired degree of flexibility. Locating the pivot of the posts as low as possible reduces the risk of hitting them. The posts are made of 76 mm diameter steel tubing flattened along a given length. With the chosen design, the post's wall thickness, 5 mm, ensures good resistance to buckling at right angles to the axis of the road. The middle part of the post between ground level and spacer is kept round in order to limit the damage to a vehicle's rims should its wheels glance against the post. The posts, like the spacers, are not the same for all methods and types, yet are all variants of the same type.

Drawing No. 13.1 shows the design recommended for barriers with piled posts and rupture bolts.
Drawing No. 13.2 shows that recommended for barriers with posts in drilled holes without rupture bolts. Only the top of the post is different.
Drawing No. 13.3 shows the design for barriers with piled posts without rupture bolts.
The differences are due to the method of fixing the spacer to the post (See 5.4.).

5.4. Fixing the spacer to the post

5.4.1. For piled posts

If a barrier with piled posts had to remain flexible under all conditions, the spacer must be fixed to the post with a rupture device (Figure 23). A special claw **(Drawing No. 13.1)** is first screwed tight to the spacer. It is next pushed round the post and fixed to it with two special bolts (rupture bolts, **Drawing No. 18,** under 3; fixture, **Drawing No. 14.1**). When the barrier is heavily loaded these bolts rupture and the joint between post and spacer is broken (See also 3.1.). The barrier is designed so that an impact only loads the rupture bolts with a shearing stress.

Where there is no avoiding a less flexible barrier the spacers must be fixed direct to the posts **(Drawing 14.3).**

5.4.2. For posts in drilled holes

For simple height alignment of the beam relatively to ground level, a clamp is used for posts in drilled holes in order to join the spacer to the post **(Drawing No. 13.2).**
This clamp is first fixed with four nuts to the spacer and then slid around the post, the nuts being half tightened. Next the barrier is aligned for height and the spacer is fixed in position by tightening the nuts **(Drawing No. 14.2).**
The possible adjustment is about 80 mm between the two outermost positions.

5.4.3. Telescopic top for post

The possibility of adjusting the height with a separate telescopic top was put forward during the research. If this can be done, it will have the advantage that the same post bottoms and spacers can be used regardless of the version and whether rupture bolts are used. Only the tops of the posts will differ, according to whether rupture bolts are required or not. With the piling method, hammering would not then be needed for height adjustment, and it would be easy to raise subsided barriers, at least to a certain extent.

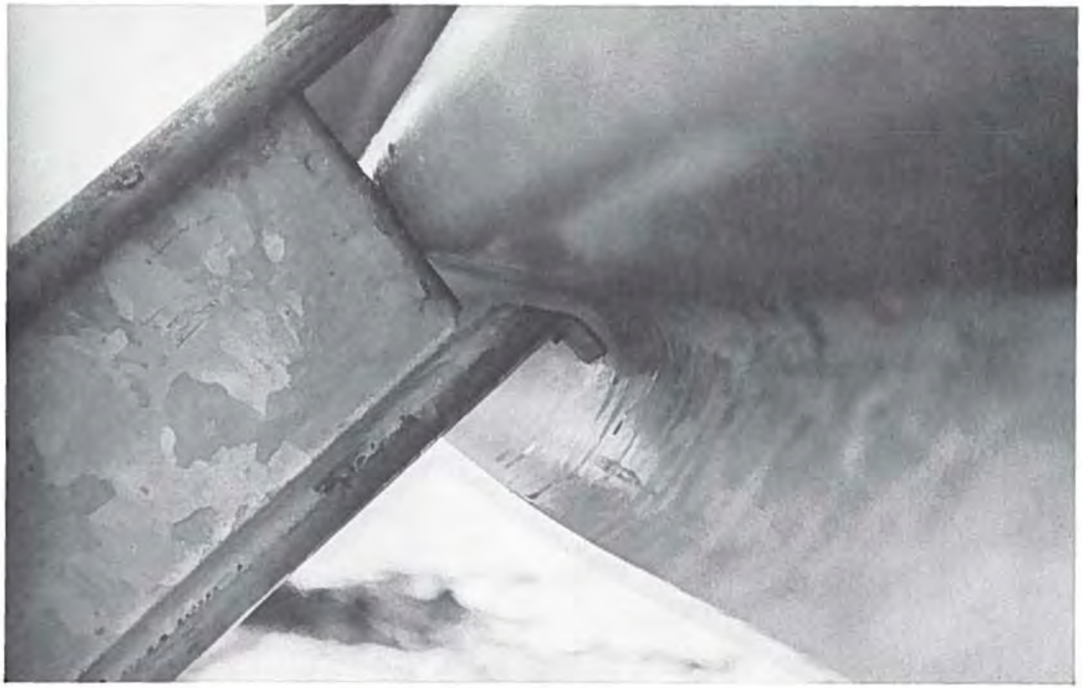


Figure 22. Functioning of weakened end of bottom spacer-flange.

Figure 23. Rupture device in post-to-spacer fixture.

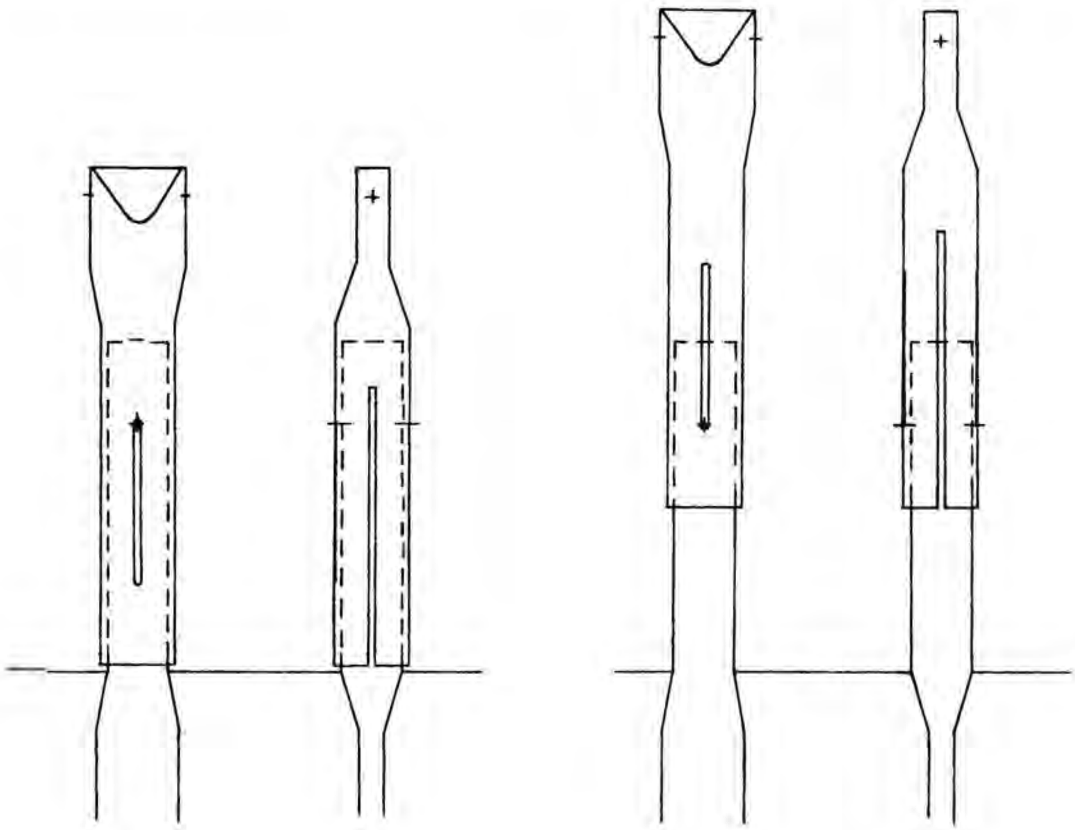


Figure 24 Basic drawing of telescopic top of post.

Figure 24 shows the principle of the telescopic top and the post. This structure has not been tried out.

5.5. Stiffening the structure

5.5.1. Reducing post-to-post distance

Reducing the distance between the posts is the simplest way of making a barrier more stiff. No detailed drawings are needed for this.

5.5.2. Stiffening the beam

Drawing No. 16 shows how the beam of a two offset rail barrier can be stiffened by fitting diagonal bars. The diagonals should be fixed so that an impact applies a tensile stress to them owing to the longitudinal force generated in the rail by friction. This also means that the sharp corners of the triangles formed by the diagonals, rails and spacers must point in the direction of travel, thus being less dangerous in extremely unfavourable impacts. If a barrier can be hit from both directions (for instance a roadside barrier on a single carriageway road) the diagonals should be positioned so that these sharp corners give in the direction of travel of the nearer stream of traffic.

5.5.3. Increasing post resistance

If parts of a barrier already stiffened by reducing post distances have to be made still more stiff, the posts can be furnished with stabilising plates, with both piling and drilling methods, so as to increase their resistance. If the posts are too far apart, however, they may show plastic deformation just about where they emerge from the ground, increasing the risk of hitting them.

Drawing 15.1 shows three types of stabilising plates of different sizes, to permit a choice depending on the nature of the ground, and also to make gradual transitions (See also Section 6.1.). The plates are fixed to the posts with nuts and bolts. The holes are made so that each type of plate can be fixed in one position only.
It should be remembered that to deliberately stop posts cutting through the ground conflicts with the basic principle of crash barriers described in this report. Hence it is not logical (apart from being expensive) to use stabilising plates for long stretches. Stabilising plates must be regarded as a means of adjusting the localised functioning of a barrier in special cases. If stabilising plates are used, rupture bolts should be dispensed with. In a barrier with rupture bolts these should preferably be omitted as from 12 to 20 metres before the point where the structure is stiffened (See **Drawing 21** for a possible method).

The model with posts in drilled holes can also be stiffened in places by filling the drill holes with a higher-density material. This clearly allows scope for gradual transition. But it is likewise contrary to the basic principle of the structures evolved. Rupture bolts must not of course be used in this case.

5.6. Securing the barrier

5.6.1. Against tilting forwards

Single offset rail barriers, especially with posts in drilled holes, may tend to lean forward owing to the excentric support. This can be counteracted by putting a loose concrete tile (for instance half a paving tile, no special quality required) in the ground in front of the post **(Drawings 4 and 9)**.

5.6.2. Against subsidence

To protect the barrier with posts in drilled holes against subsidence, SWOV has designed a concrete dish **(Drawing 17)** which is placed in the bottom of the drill hole when this is filled up with sand, and on which the post rests. The top of the dish is a hollow cone with an angle of 40°. It thus rights itself when a new post is put in for replacement or when a barrier is realigned after an impact.
Theoretically this dish makes it possible for the pivot of the post to be right at the bottom. There is a hole in the dish to make it easier to place.

If an unusual form of drill hole is used, the form of the dish will also have to be modified. With reference to the requirements mentioned above for the SWOV dish, an optimum form can also be found for the modified one.

Piled barriers may also tend to subside after some time in less firm soil. It is therefore advisable to take into account the mechanical properties of the soil in which the crash barrier is to be placed. A number of soundings are usually advisable, especially so that the measured value found is level with the foot of the post. If subsidence is feared, the area of the base of the post should be made bigger (See Section 5.1.) or the piling method should not be used.

6. General

6.1. Discontinuities

For the guiding capacity of crash barrier to be as effective as possible it is essential that the continuity of the structure as regards both its geometry and its mechanical properties, especially strength and flexibility, should be maintained to the fullest extent possible over its entire length.
This applies both for breaks in the continuity of the road – such as entrances and exits, bridges and viaducts and intersections – and for structural details in the design of the structure itself.
Discontinuities in crash barriers are defined as places where there is an abrupt change in the geometry or mechanical properties of the structures.
The risk factor for collisions is in general higher at discontinuities than for the rest of the barrier. For some types of discontinuities the risk factor is very high, with the result that a large proportion of all collisions with such discontinuities have fatal consequences.
It is accordingly highly important to avoid discontinuities as much as possible or, if they are unavoidable, to execute them in such a way that the risk factor is kept as low as it can be.
The principal point to be borne in mind when avoiding discontinuities is the consideration that the vehicle must be able to move along the barrier for a certain distance during the impact.
In the case of serious glancing impacts against crash barriers this distance can amount to several tens of metres.

6.1.1. Commencent discontinuities

The commencements are some of the most dangerous of all discontinuities, since most crash barriers possess practically no lengthwise flexibility. A collision with the commencement of a crash barrier may therefore be compared with a head-on collision with a rigid object, in which case very great decelerations may occur even at quite moderate speeds.
When vehicles collide with the commencement of a guide rail barrier the rails are very often torn from their supports and pierce the vehicles. The risk can also be much greater with impacts shortly after the start of a guide rail barrier than in the case of ordinary glancing impacts, since the rail tends to move lengthwise with the vehicle and bulge outwards. This makes pocketing all the more likely.
The risk of collisions with the commencement of rather stiff beams can be appreciably reduced by introducing a transitional zone in which the beam gradually rises from ground level to the desired height. This, however, entails the risk of a vehicle mounting the beam and then turning over. This risk is nevertheless a small one if the angle at which the beam rises is kept very small.
According to research done in the United States*, using American cars, this angle may not be greater than 1:15 (4°). For most European cars, which have a narrower track width and are shorter, the risk is of course greater, making it advisable to select an angle of 1:25 (2°).
The likelyhood of a collision with the commencement of the structure can be greatly reduced by having the structure start as far as possible from the roadside. The structure should converge gently with the carriageway (maximum 3°, see 6.1.3.), until the desired distance between the structure and the edging lines of the carriageway is reached.

* Highway Guardrail. Determination of need and geometric requirements, with particular reference to beam-type guardrail. H.R.B. Special Report 81. Highway Research Board, Washington D.C., 1964

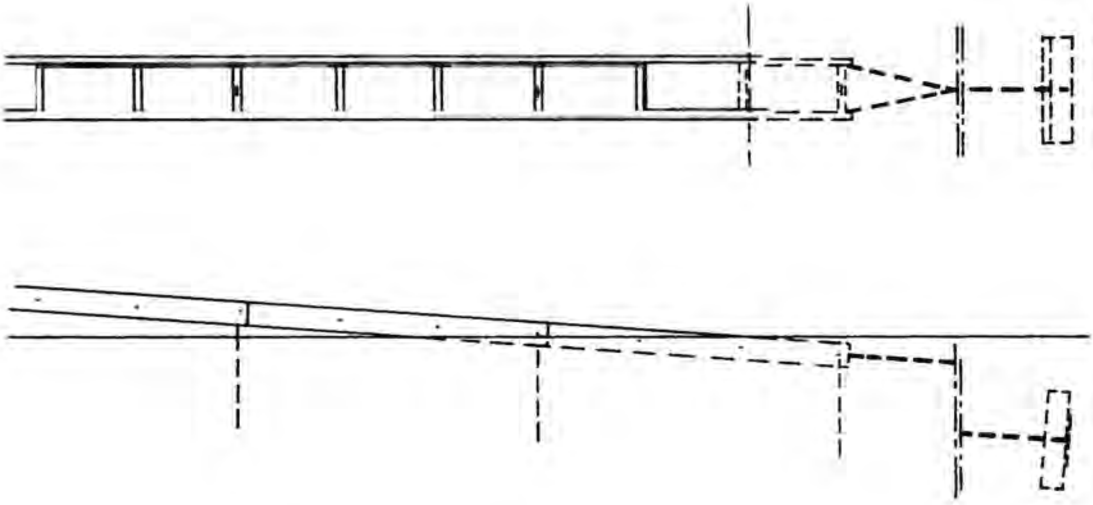


Figure 25. Principle of anchoring able to absorb substantial forces.

6.1.2. Anchoring the barrier

The research showed that the beginning and end of a guide rail structure can absorb hardly any longitudinal forces without some further provision. The ratio of the total length of the bend to the bend itself thus becomes less than 40:1, so that an impact has adverse consequences. This can be avoided by anchoring the barrier, and preferably the guide rails, at the ends.
The forces this anchoring must be able to absorb depend on the barrier's model and length.
Owing to the heavier load on the beam, stiff beam barriers need an anchor that can absorb big longitudinal forces. A non-stiffened beam barrier can be anchored somewhat less firmly.
If the structure can be run into along its entire length and must therefore function adequately along it, a stiff beam may require anchors at the beginning and end each able to absorb about 40 tf. For a non-stiffened beam these forces may be reduced to about 25 tf if the same conditions have to be met.
Figure 25 shows the principle of a suggested anchoring. This structure can absorb the necessary forces depending on the nature of the ground.

If the rails cannot be anchored for any reason, more posts may be fixed at the end of the barrier; if necessary with stabilising plates turned 90° (the fixture will then have to be different), in order to absorb the longitudinal forces. With the drilling method, the last posts can then be cemented in.

If the barrier is not anchored at all the structure will, in order to function properly, have to be longer than strictly necessary. If an end anchor is dispensed with, the structure will have to continue at least 40 metres after the hazard area which it has to shield. Its end will have to enter the ground at a gradient of about 1 in 25. With this method, however, there is a danger of a major impact against, say, the final 40 metres of the structure still letting vehicle crash through or over it.
If an anchor is dispensed with at the beginning, an impact against, say, the first 50 metres of the structure may cause pocketing with large deflection angles, and even crash-through. This can be done, therefore, only if this first 50 metres cannot be run into.

Here again, it is advisable to allow the structure to emerge from the ground with a gradient of about 1 in 25 so that the posts driven in completely at the end can still absorb some force.

To guarantee proper functioning of the operative part, the length of the structure in both cases, or in a combination of these, should be at least 100 metres.

6.1.3. Directional discontinuities

Directional discontinuities are parts of a crash barrier which are arranged in such a way that the guide element forms an angle with the direction in which the traffic is moving. Two types may be distinguished.
Convergencies are directional discontinuities in which the crash barrier becomes progressively closer to the road in the direction of the traffic.
Divergencies are directional discontinuities in which the structure diverges steadily away from the road, in the direction of the traffic.
Only in the case of convergencies does the risk of a collision increase. The maximum possible angle at which vehicles may collide with the structure increases with the angle of convergence of the discontinuity in question.

In many cases directional discontinuities are unavoidable. They are to be found particularly at points where a crash barrier has to be led around obstacles; with barriers in shoulders at places where roads converge, and with barriers at the end of hard shoulders and acceleration lanes.

In order to limit the risk at convergencies as much as possible, the angle of convergence should be made as small as is possible.

The outcome of a collision with a crash barrier depends to a large extent on the angle of impact. Big impact angles combined with high speeds may have serious consequences even with very good crash barriers.
As said before the maximum impact angle actually possible on a dual carriageway at a speed of 100 km/h is about 20° to a crash barrier put up parallel to the main axis of the road.
If the structure converges relative to the main axis of the carriageway bigger impact angles become possible. An angle of convergence of maximum 3° is therefore acceptable.

6.1.4. Transitions

If it is necessary for any reason to change over from one barrier to another, possible discontinuities in the barriers' characteristics, which may lead to accidents having more serious consequences, should be watched for.
Not all barriers can simply be joined together. It will often be necessary to use one or more different barriers for a certain stretch in order to obtain a more gradual transition. The length of the necessary transition area depends mainly on the difference in flexibility between the two structures. As a guide, the transition from a completely flexible barrier to a completely rigid one should be 60 to 100 metres long. **Drawing 21** shows an example of this.

In the reverse situation, i.e. a transition from a completely rigid barrier to a completely flexible one, about half this length will suffice. It should however, be certain that the barrier cannot be run into from the other direction.
In case of transitions between two barriers with less difference in flexibility, a comparatively shorter transition length will suffice.
On the whole, a change in type of barrier should not be allowed to coincide with a change in method.

Table 2 shows guide rail structures which can safely be joined together and how the transition between greatly varying structures can be made. These are based on the structures described in Section 4. The junctions shown in broken lines are unattractive ones.

In some cases it is not possible to link together two different barriers, in this case a combination of a terminal point and a commencement is introduced. The hazard of this point can be greatly reduced by arranging the last part of the barrier preceding the interruption in such a way that is screens the following commencement.
This is possible by overlapping the commencement by the last part of the barrier preceding the interruption.
In this case the possible deflection of the nearby barrier should be incorporated (see Section 4).
When the width of the central reserve or shoulder is big enough, it is possible to make the terminal point and the commencement to be placed staggered. This lay-out is especially desirable when a passage has to be left open.
In the case that the line between the end of the operative part of the preceding barrier and the beginning of the operative part of the following barrier diverge 30° or more with the main axis of the carriageway, it can be said that the interruption is screened completely if both barriers are adequately anchored. It has to be borne in mind that the maximum convergence should not exceed 3° (see 6.1.3.).

While constructing the interruption ,the possibility that the traffic is diverted to one side of the road (e.g. while works are carried out) should be taken into account, for in that case the arrangement is directed against the traffic flow. The terminal points are becoming commencements and they have to be suitable for this purpose (anchorages, etc.).

6.1.5. Forks

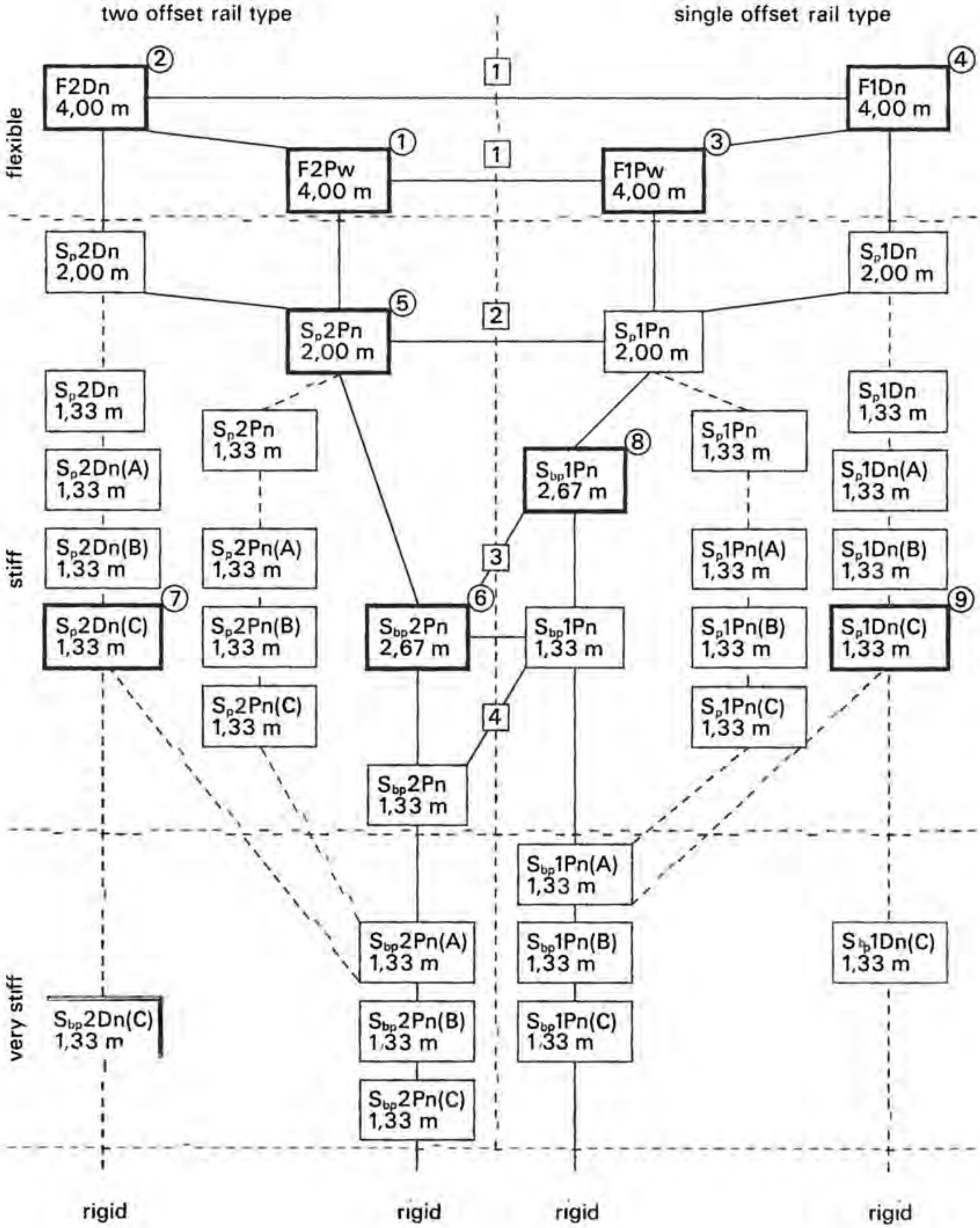
In a central reserve, for instance near bridge columns, a single barrier functioning on both sides may have to change over into two barriers each required to function at one side only.
Drawing 22 shows how a flexible two offset rail barrier with piled posts (with rupture bolts) can be split into two single offset rail ones. Other forks are made correspondingly.

6.2. Quality of the verge

For an impact with a crash barrier to have no serious consequences the verge in front of it must be flat and connect smoothly with the road surface. Besides this, the texture of the ground of the verge should not be so loose that vehicles' wheels can sink into it. It may therefore be necessary to provide the verge with a simple hardened surface continuing underneath the rail, preferably behind the post. But in the latter event the post must still be able to cut through the ground. For this, a space 10 cm wide can be left in the hard surface behind the post at right angles to the axis of the road. Its length depends on the type of barrier and the deflection to be allowed for.

If the post is to be allowed to bend out until the rear rail touches the hard surface the length of the space as from the rear of the post should be as follows:
two offset rail type, drilled: 70 cm
two offset rail type, piled: 60 cm **(Drawing 23)**
single offset rail type, drilled: 90 cm
single offset rail type, piled: 70 cm (**Drawing 24**)

If the two offset rail barrier can be hit from both sides, a space should also be provided on both sides.



Tabel 2. Diagram of possible transitions from flexible to completely rigid.

Explanation and notes on page 54

Explanation and notes to table 2

S_p2Pn 2,00 m ⑤ (bold box)	structure with drawing-number and distance between the posts.
S_p2Pn 1,33 m (thin box)	structure (usually a transition structure)

F flexible
S_p stiff by reducing post-to-post spacing
S_{bp} stiff by stiffening the beam and reducing post-to-post spacing

2 two offset rail barrier
1 single offset rail barrier

P inserted by piling method
D inserted by drilling method

w with rupture bolts
n no rupture bolts

(A) with stabilising plates model A
(B) with stabilising plates, model B
(C) with stabilising plates, model C

1. Transition area 4 m, with 2 posts and 2 spacers of different length.
2. Transition area 4 m, with 1 post and 1 spacer of different length.
3. Transition area 4 m, with 1 post and 2 spacers and 1 diagonal bar of different length.
4. Transition area 4 m, with 2 posts and 2 spacers and 1 diagonal bar of different length.

With stiff barriers, where deflection is limited, shorter spaces may be considered. From the deflection curves given in Section 4 and the likely severity of impacts against the barrier it can be inferred to what extent one may do this.
It can be taken into account that if the barrier is stiffened by increasing the post resistance the space will not need to be as long. Its minimum length, using type C stabilising plates for instance, will be 10 to 15 cm, depending on the ground resistance.

6.3. Visual guidance

It is incorrect only to build a crash barrier for visual guidance because a risk is always involved in impacts with such a barrier. If a purely visible guide is wanted, other means should be sought which can cause less or no damage at all to the vehicle.

Nor is there any ready justification, without further research, for emphasising the visual guidance of rails built for normal purposes, for instance by painting them white. There are cases, however, where the functions of visual guidance and crash barriers can be combined, as in bends for instance.

Acknowledgements

The initial years' research finalised with this report was led by a team chaired by E. Asmussen, Director of the Institute for Road Safety Research SWOV. Its members were Prof. G. J. v. d. Burgt, of the Delft University of Technology, Department of Mechanical Engineering, P. C. de Man, Chief Engineer at the Rijkswaterstaat, Department of Roads and Road Traffic, and P. J. Baartman, Chief Scientific Officer at the Delft University of Technology, Department of Civil Engineering, L. P. van Eck was attached to the team temporarily for planning full-scale tests.

The drive and guide system for the full-scale tests was designed by Prof. G. J. van der Burgt. The winch and reversing sheaves were made by Nellen's Machinefabriek-Constructiewerkplaats en Technische Bureau N.V., Rotterdam.
The release mechanism (between cable and car) was designed and tested by P. J. Jillesma of the Vehicle Research Laboratory of Delft University of Technology.

The work put in by this laboratory, and by Professor Van der Burgt and his colleagues personally, made it possible to run a series of tests in summer and autumn 1964. The very first full-scale trials, organised in teams, provided the basic principles for continuing the SWOV's further research in the subsequent years.
The Vehicle Research Laboratory designed equipment for investigating the behaviour of posts upon impact and the resistances they meet with in cutting through the soil. Special mentions should be made of the work by E. F. Faber, then a student, now a qualified engineer. A swingarm pendulum installation for the same purpose was later developed by H. H. 't Hart, of the Institute for Mechanical Construction TNO-IWECO, Experimental Technical Mechanics Department, based on a suggestion by G. J. Bos, Senior Technical Officer of the Rijkswaterstaat.
Tests regarding the firmness of the soil of (central) reserve were made by Lt.Col. J. H. Ackerstat and N.C.O. C. J. v. d. Heyde, (Royal Netherlands Engineers) and R. W. Trense, Royal Netherlands Engineers Advisory Office, Research and Mathematics Department. Advice was given by the Soil Mechanics Laboratory, Delft.

The tests were recorded photographically and electronically. The photography was done by the High-speed Photography Section of Central Technical Institute TNO, led by D. Zaalberg and by a camera team of the Institute for Film and Science, Utrecht, led by W. van den Berg. Electronic recording was by P. D. v. d. Koogh and H. H. 't Hart, Experimental Technical Mechanics Department TNO-IWECO.
Contractors in charge of construction were L. G. van Zijl, Bunnik, and Messrs. Kramer, Elst, Utrecht.
Organisational assistance at the De Vlasakkers site, Amerfsoort – where the impact tests were made and which was made available by the Ministry of Defence – was given by Major F. H. Dolleman (Cavalry) and N.C.O. J. Stavast (Cavalry) succeeded, in the course of the research, by N.C.O. Instructor J. H. Haazen (Cavalry).

Photographic material on collisions with guide rail structures at test sections on trunk roads was collected by the Special Motorway Patrol of the State Police Traffic Division, in charge of A. C. Vogel, Commanding Officer State Police.

We wish to record our gratitude to all the above persons and authorities who collaborated in this work.

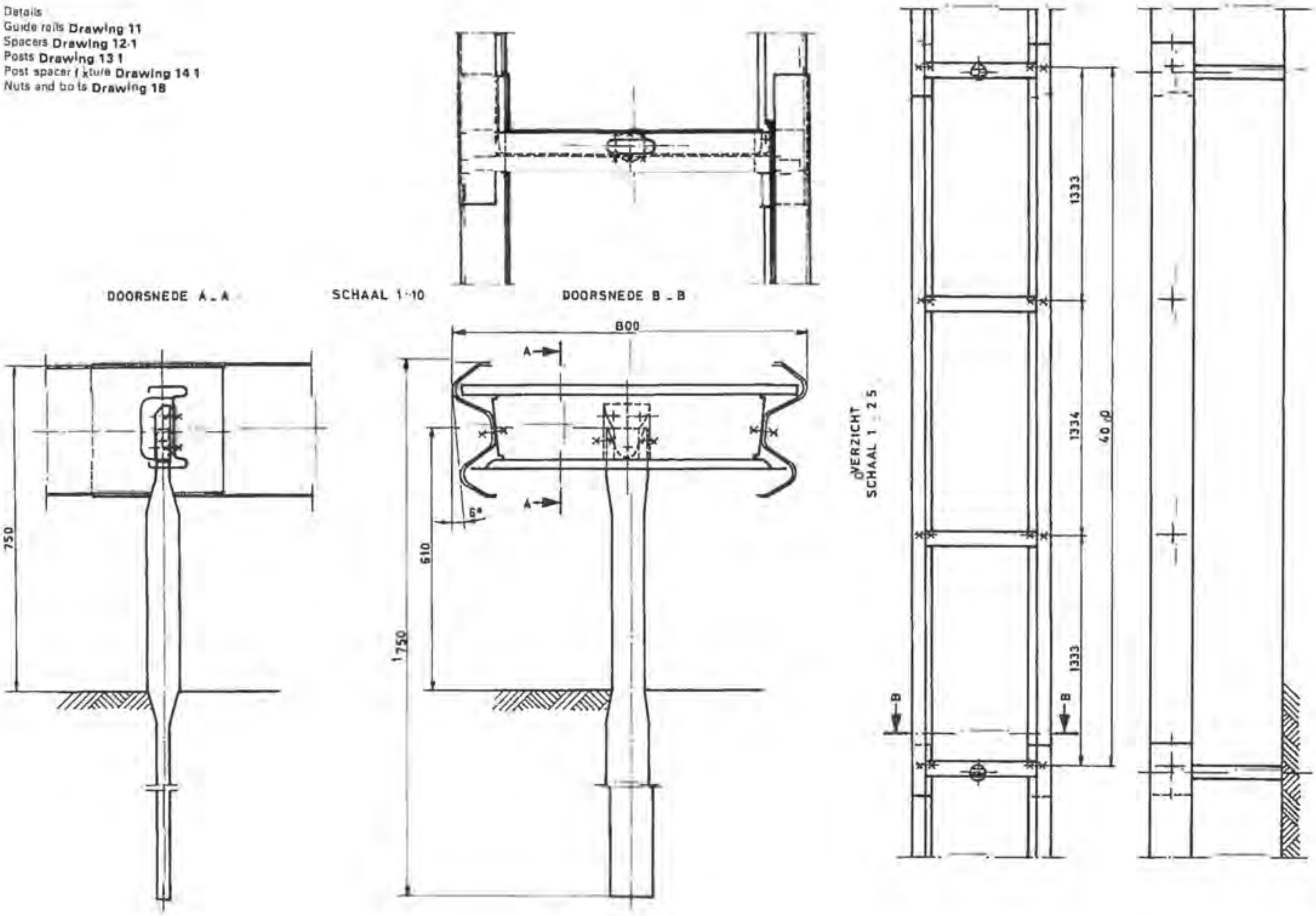
Annex

Translation into English of terms in the Dutch language occuring in the drawings

Drawing 1–11, 14.1–14.3, 22.1–22.2 Doorsnede – Section
Drawing 1–24 Schaal – Scale
Drawing 1–10 Overzicht – Survey
Drawing 4 Tegel – Tile
Drawing 10 Aanzicht – View
Drawing 10 Vgl. pijl a – According to arrow a
Drawing 11, 13.1, 19, 20 Detail – Detail
Drawing 11 Uitgeslagen plaat – Developed sheet
Drawing 11 Rijrichting verkeer – Traffic direction
Drawing 13.1, 19, 20 Paal – Post
Drawing 13.1 Paalkop – Top of post
Drawing 13.1 Bevestigingsklauw – Fixation claw
Drawing 13.2 Klembeugel – Clamp
Drawing 13.2 Sluitplaat – Closing plate
Drawing 15.2 Plaat – Plate
Drawing 15.2, 19, 20 Lassen – Welds
Drawing 16 Vulplaat – Piece plate
Drawing 16, 20 Dikte – Thickness
Drawing 16 Diagonaal – Diagonal bar
Drawing 16 Buis – Tube
Drawing 16 Eénzijdig uitgebouwd – Single offset rail
Drawing 16 Tweezijdig uitgebouwd – Two offset rail
Drawing 19 Afdichtdeksel – Packing cover
Drawing 19, 20 Zonder breekbout – Without rupture bolts
Drawing 19, 20 Met breekbout – With rupture bolts
Drawing 19, 20 Op hoogte instelbaar – In height adjustable
Drawing 20 Rubber afdichtring – Rubber joint ring
Drawing 22.2 Trekstrip – Tension strip
Drawing 23, 24 Verharding – Surfacing
Drawing 24 Zandbed – Sand bed

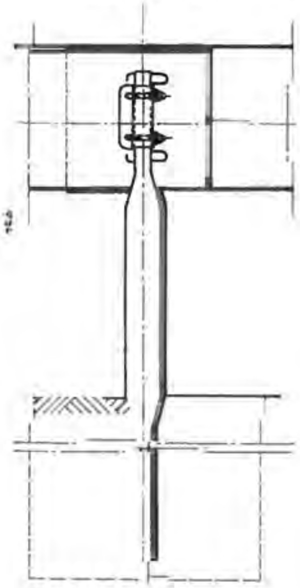
Drawing 1. Flexible two offset rail barrier with piled posts and rupture bolts F2Pw

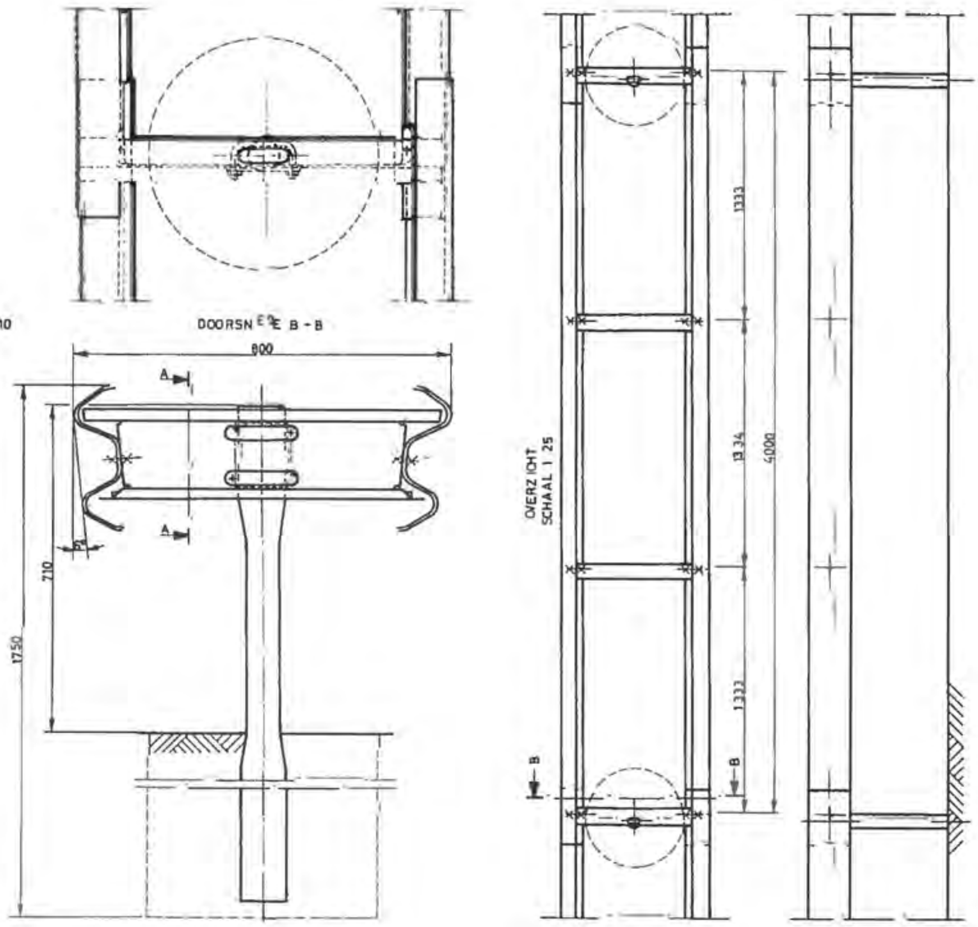
Details:
Guide rails **Drawing 11**
Spacers **Drawing 12.1**
Posts **Drawing 13.1**
Post spacer fixture **Drawing 14.1**
Nuts and bolts **Drawing 18**



Drawing 2 F ex b e tw n df ect ra l barrier w th posts in dr lled holes w ho ut u pt e bol s F2Dn

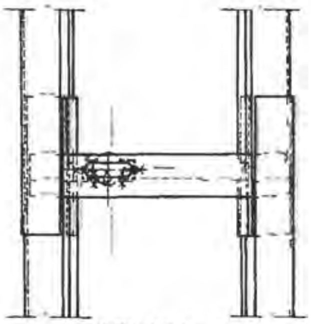
Details
Guide rails **Drawing 11**
Spacers **Drawing 12 2**
Posts **Drawing 13 1**
Post spacer fixture **Drawing 14 2**
Dish **Drawing 17**
Nuts and bolts **Drawing 18**

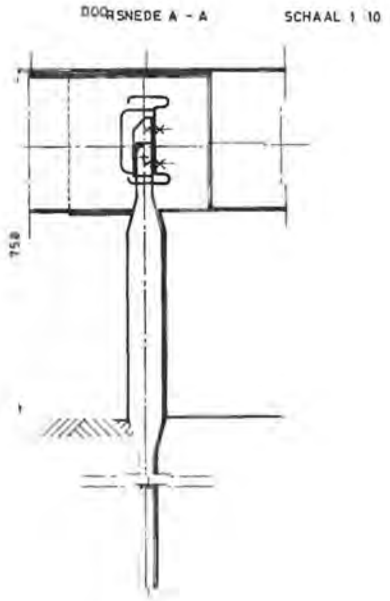


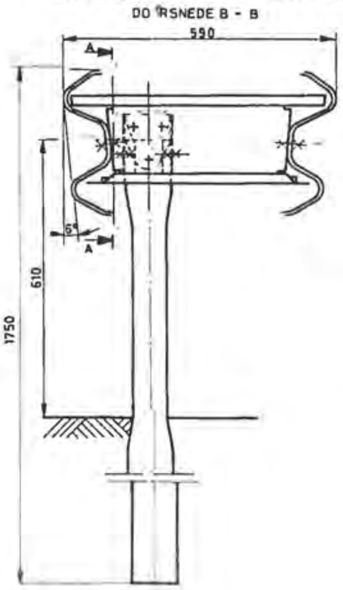


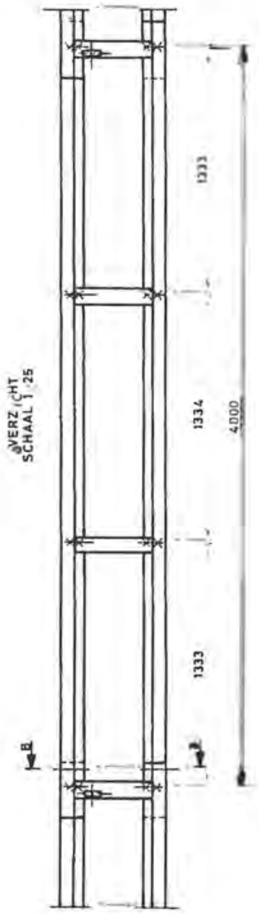
Drawing 3. Flexible single offset rail barrier with piled posts and rupture bolts F1Pw

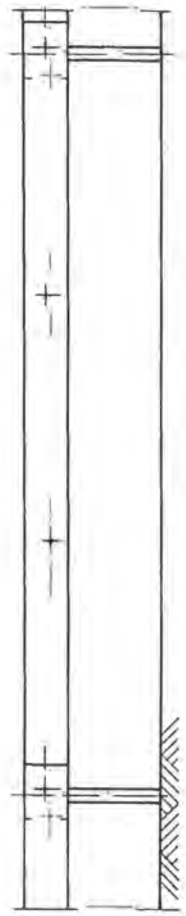
Details:
Guide rails **Drawing 11**
Spacers **Drawing 12.3**
Posts **Drawing 13.1**
Post-spacer fixture **Drawing 14.1**
Nuts and bolts **Drawing 18**





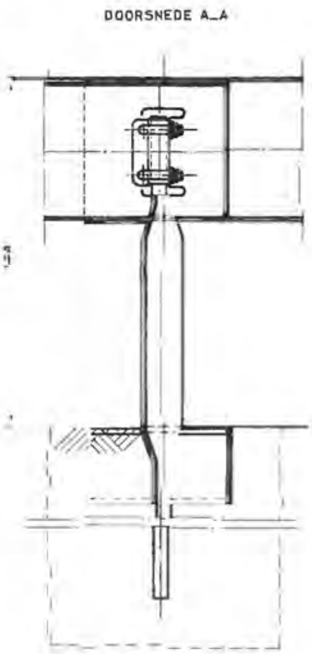


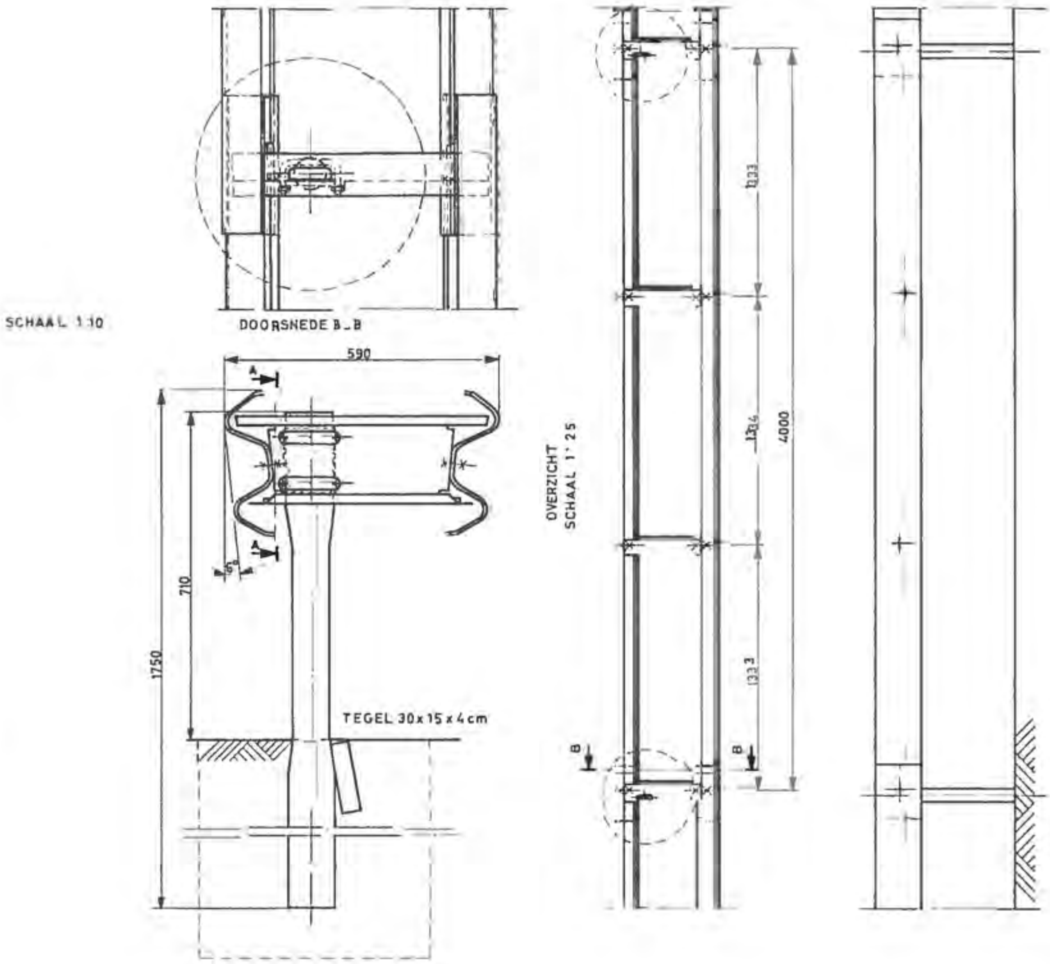




Drawing 4 Flexible single-sided rail barrier with posts in drilled holes, without rupture bolts F1Dn

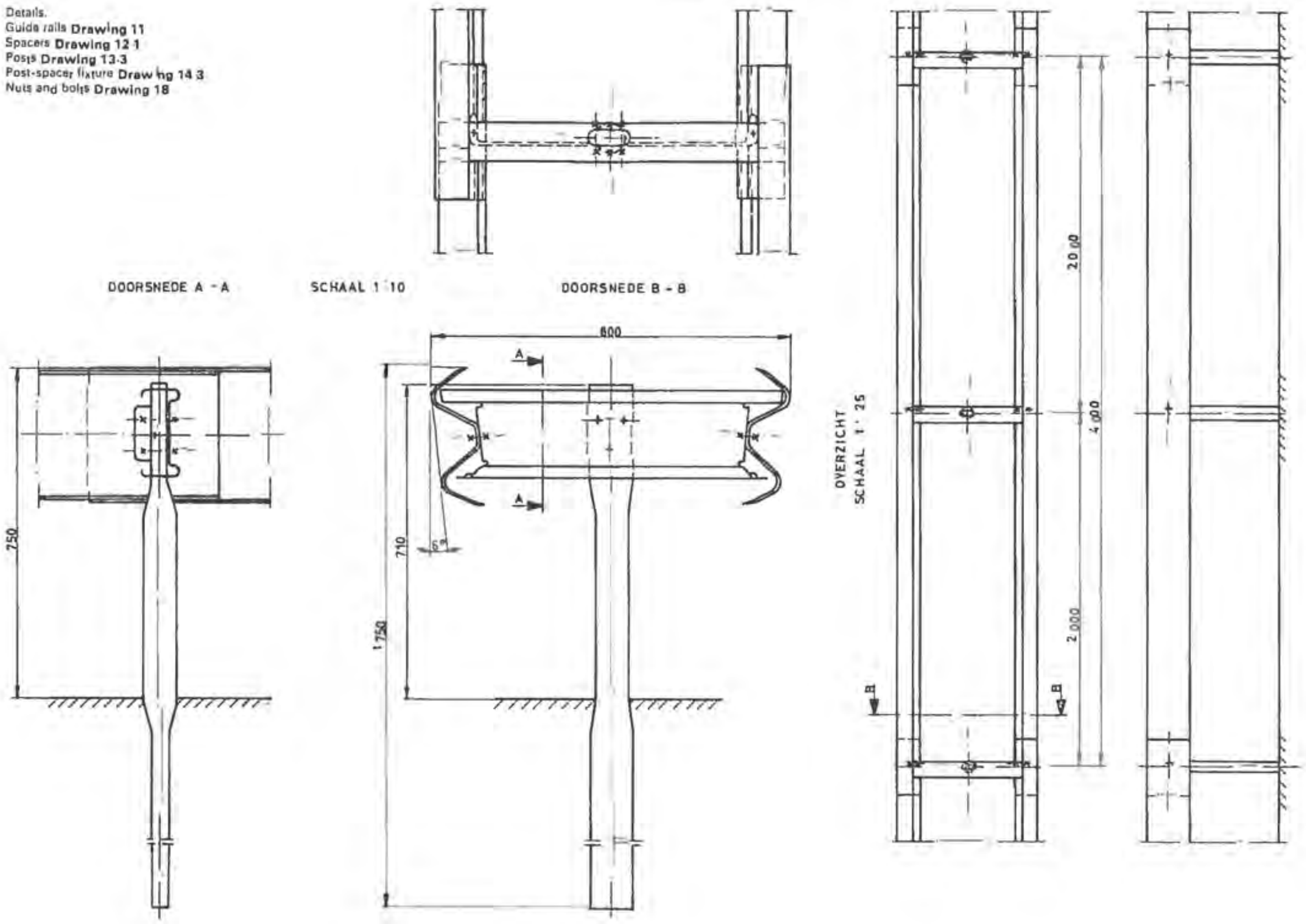
Details
Guide rails Drawing 11
Spacers Drawing 12.4
Posts Drawing 13.2
Post spacer fixture Drawing 14.2
Dish Drawing 17
Nuts and bolts Drawing 18





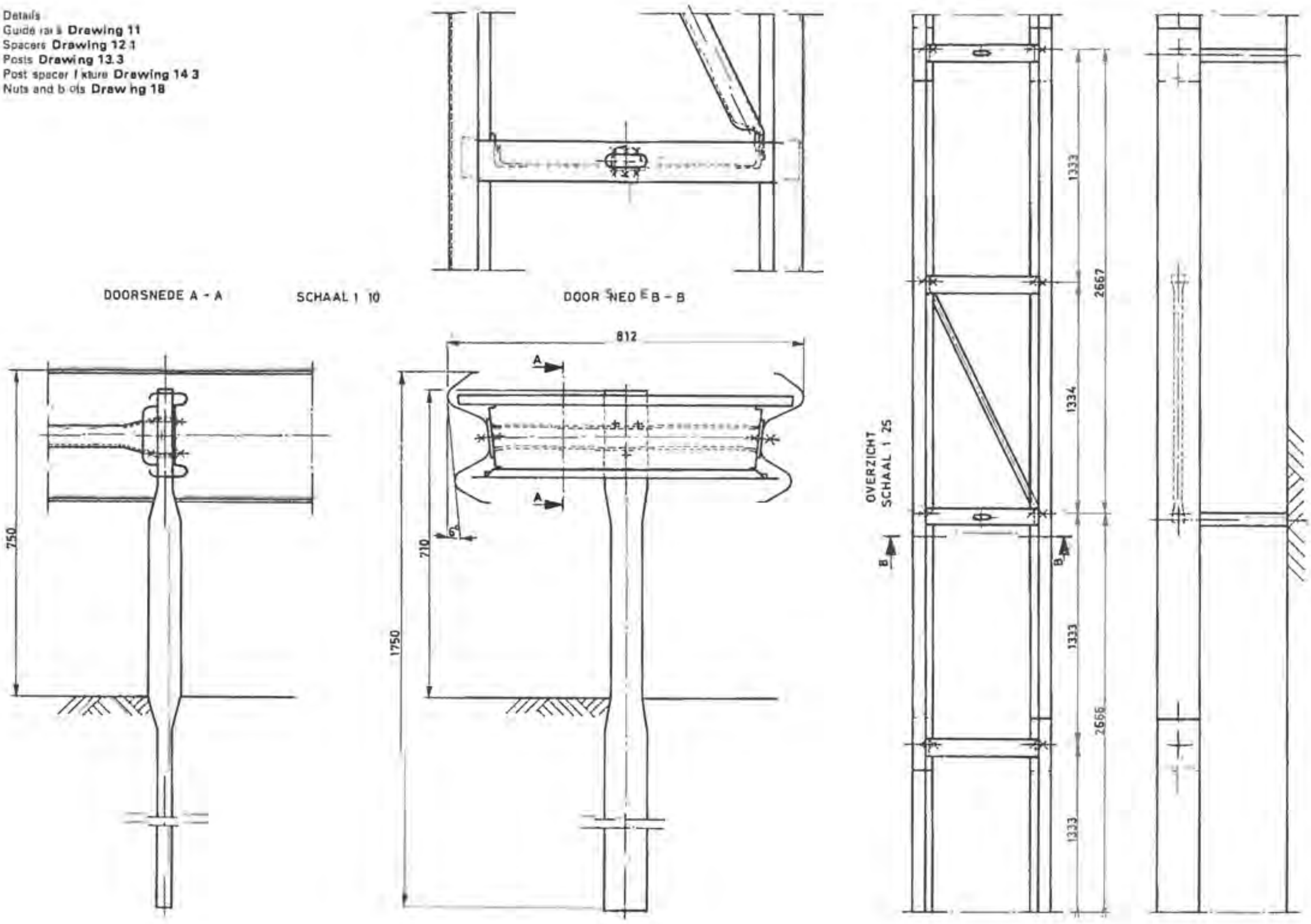
Drawing 5. Two offset rail barrier with piled posts without rupture bolts, stiffened by reducing post to post distance S_p2Pn

Details.
Guide rails **Drawing 11**
Spacers **Drawing 12 1**
Posts **Drawing 13-3**
Post-spacer fixture **Drawing 14 3**
Nuts and bolts **Drawing 18**



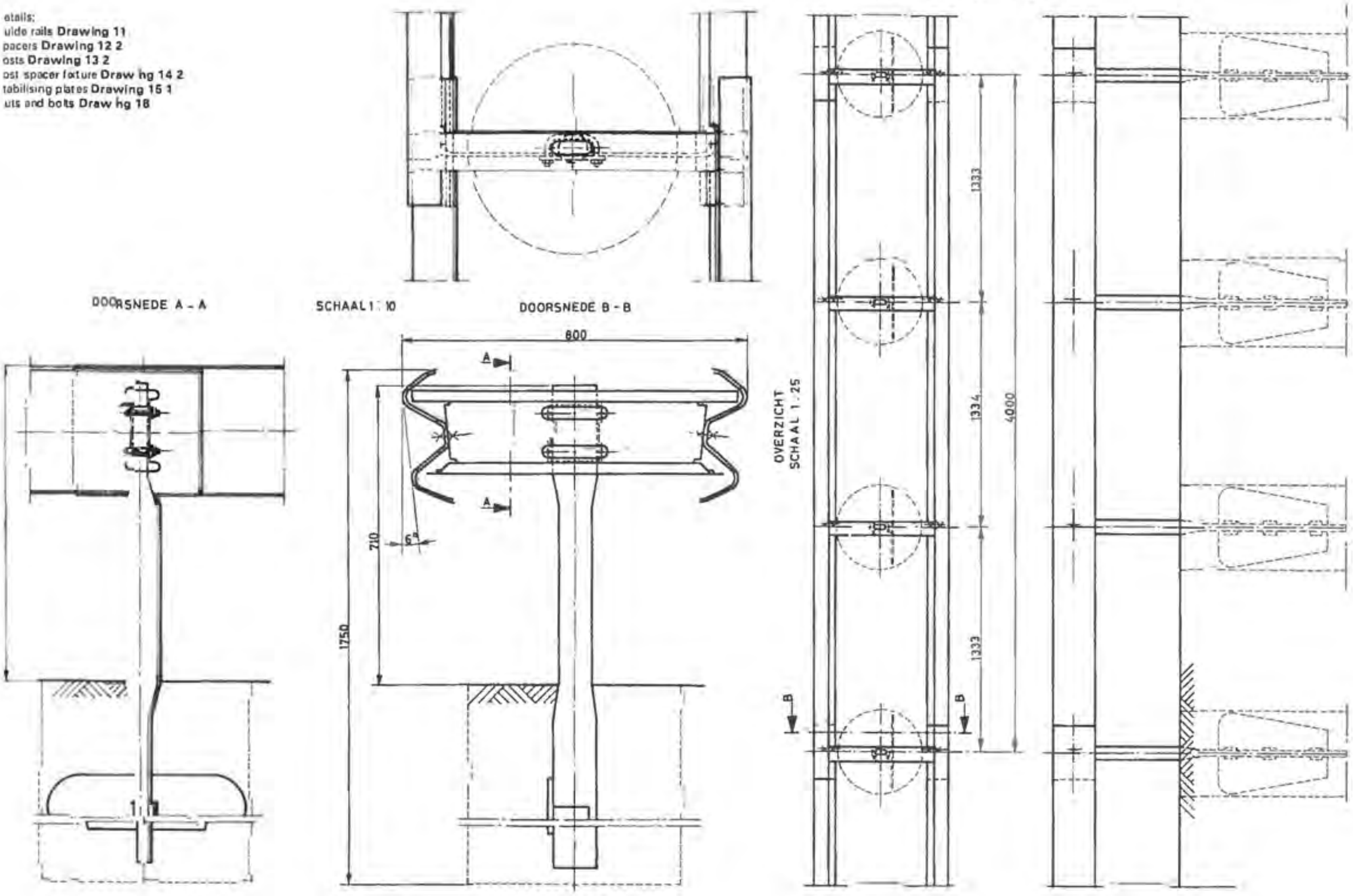
Drawing 6: Two offset rail barrier with piled posts, without rupture bolts - stiffened with beam having diagonal bars and with reduced distance between posts $S_{bo}2Pn$

Details:
Guide rails **Drawing 11**
Spacers **Drawing 12.1**
Posts **Drawing 13.3**
Post spacer fixture **Drawing 14.3**
Nuts and bolts **Drawing 18**



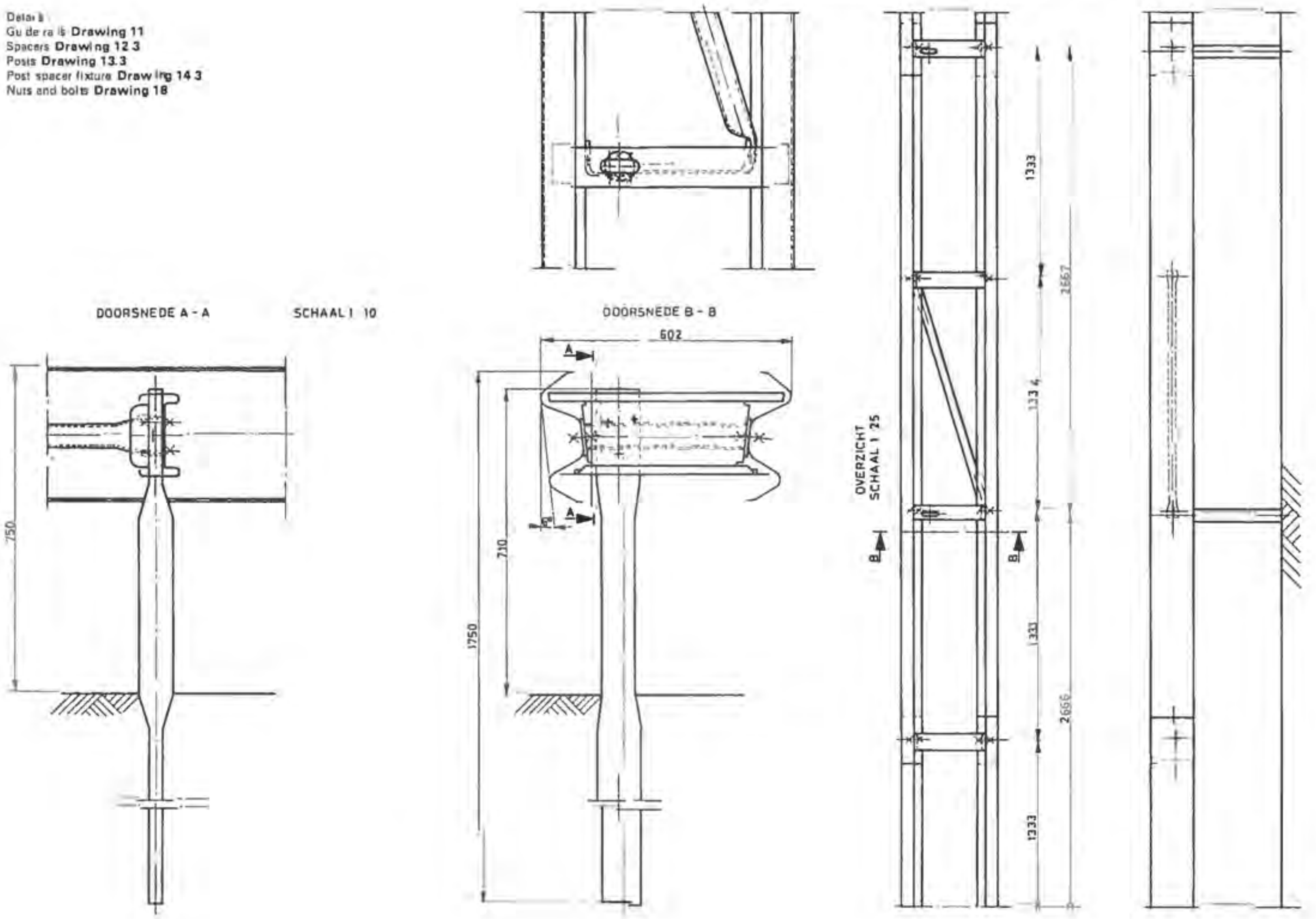
Drawing 7. Two offset rail barrier with posts 'n drilled holes, without rupture bolts, stiffened by reducing post to post distance and with stabilising plates. $S_p2Dn(C)$

etails;
uide rails **Drawing 11**
pacers **Drawing 12 2**
osts **Drawing 13 2**
ost spacer fixture **Draw hg 14 2**
tabilising plates **Drawing 15 1**
uts and bolts **Draw hg 18**



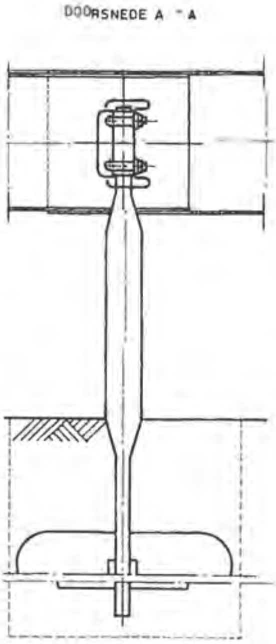
Drawing 8. Single offset rail barrier with piled posts without rupture bolts stiffened with beam having diagonal bars and with reduced distance between posts S_b d Pn

Details
Guide rails **Drawing 11**
Spacers **Drawing 12.3**
Posts **Drawing 13.3**
Post spacer fixture **Drawing 14.3**
Nuts and bolts **Drawing 18**

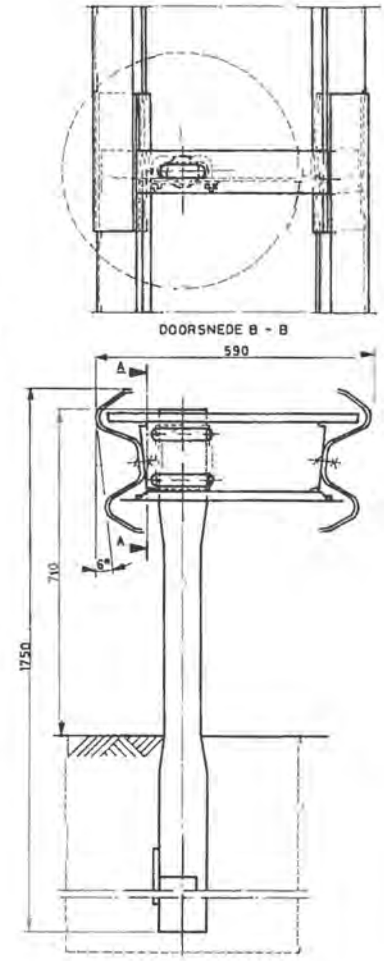


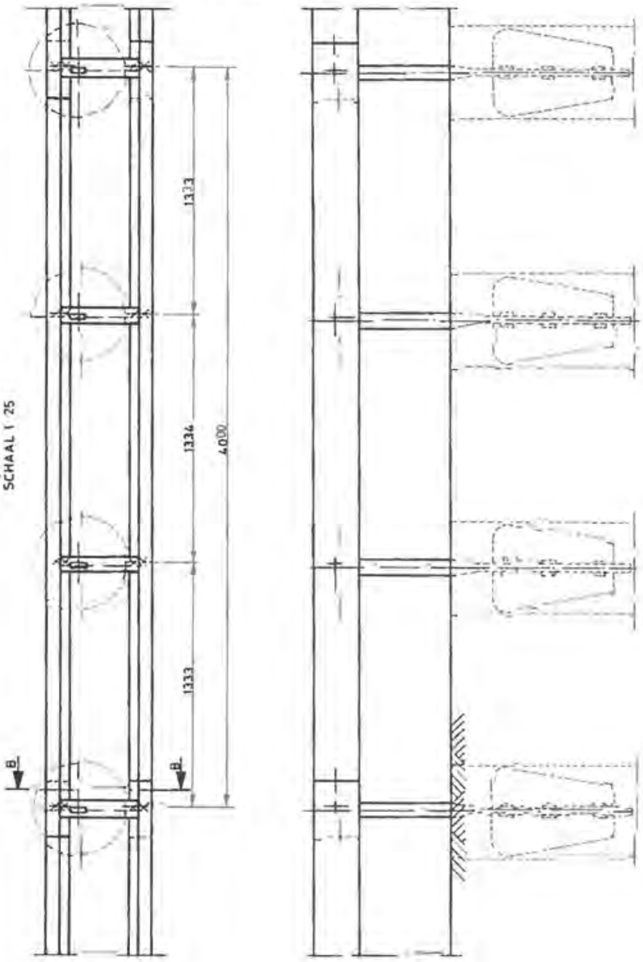
Drawing 9. S ngle offset ra l barrier with posts in drill d holes without rupture bolts, stiffened by reducing post to-post distan e and with b sing plates $S_p10n($

s
b ra s Drawing 11
rs Drawing 12 4
s Drawing 13 2
spacer fixture Drawing 14 2
lising plates Draw hg 15 1
and bolts Draw hg 18



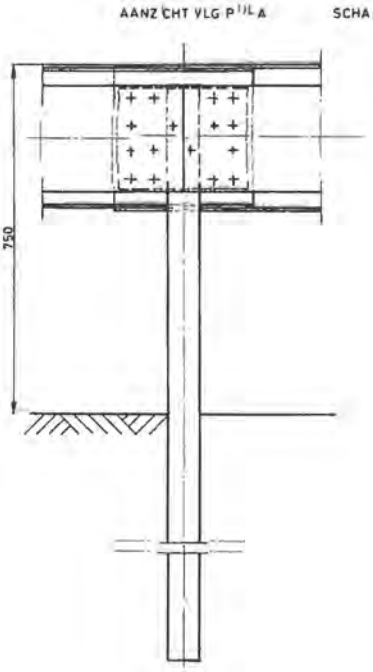
SCHAAL 1 10

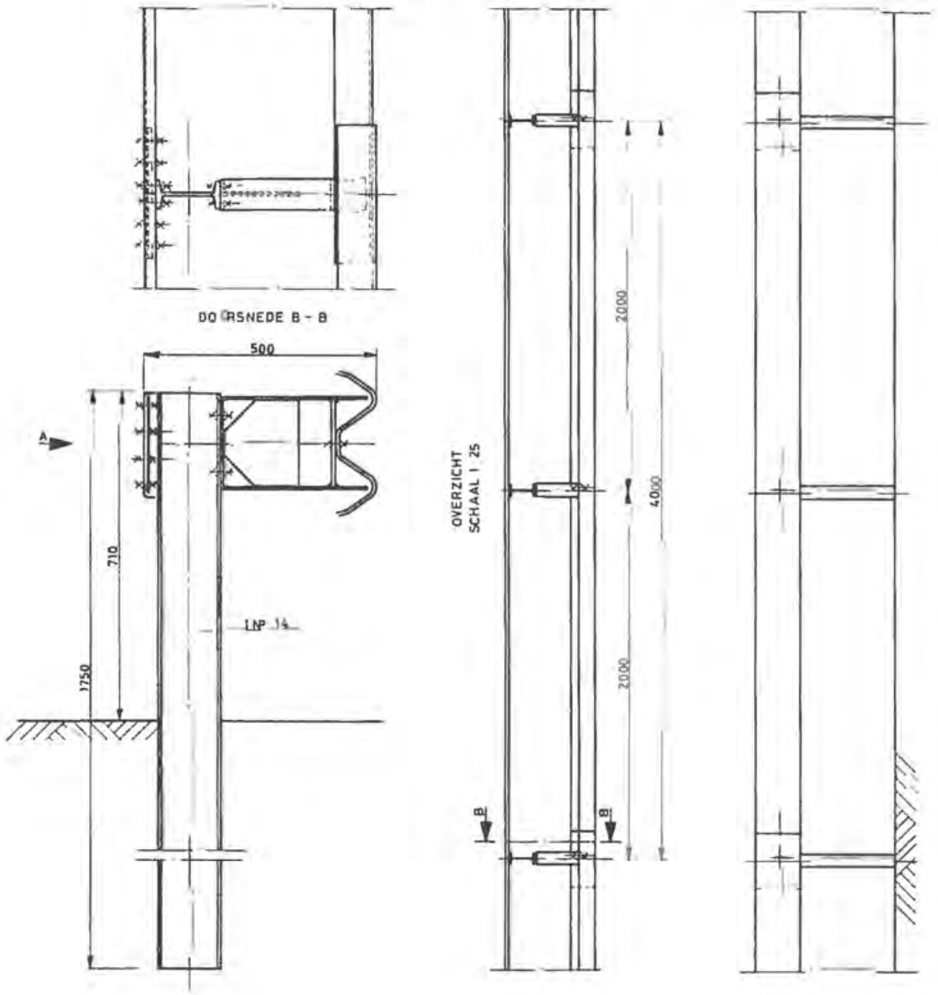




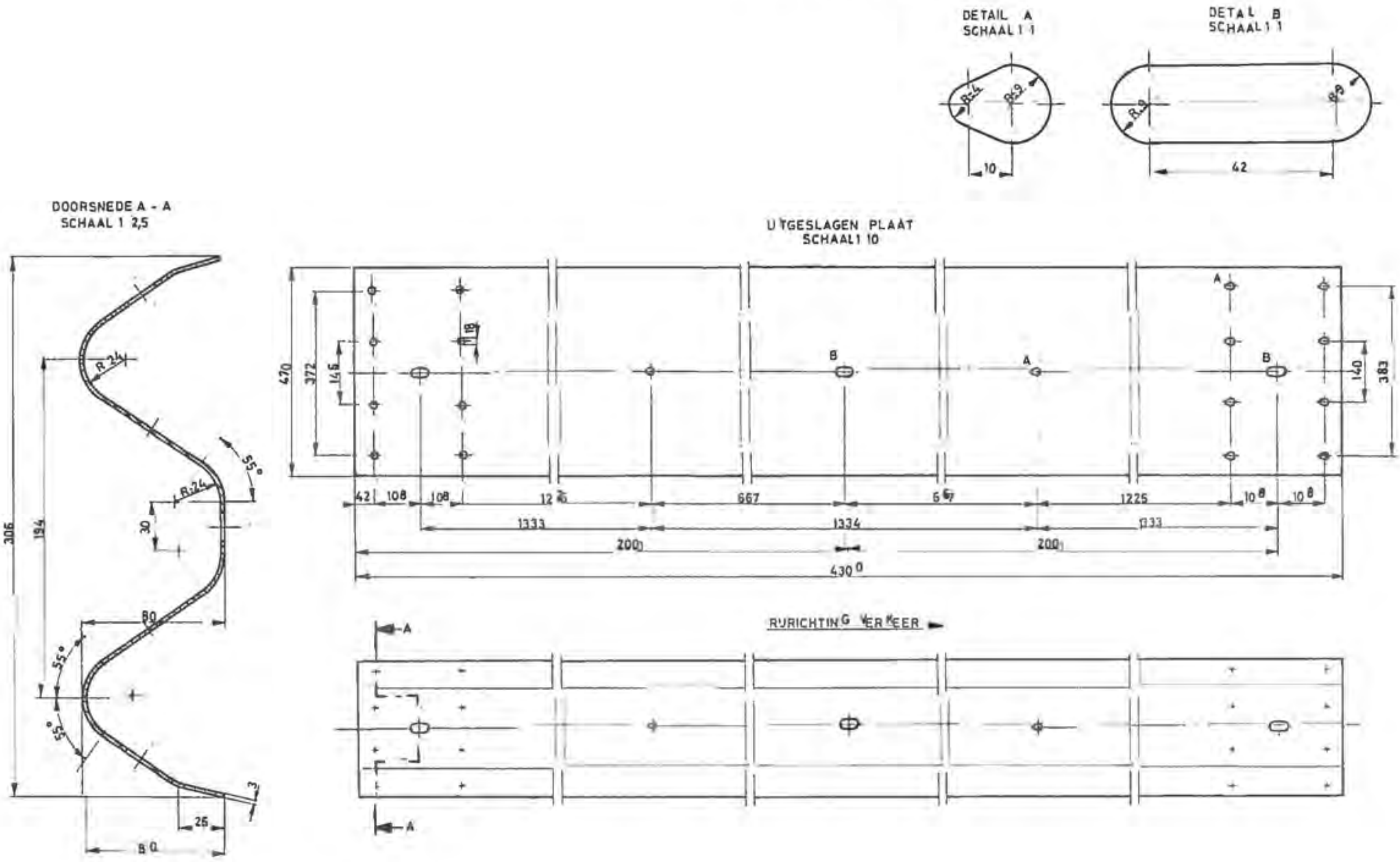
Drawing 10. Method of improving existing single offset rail barrier with piled posts without rupture bolts, by means of a strip S_p1Pn

Details.
Guide rails **Drawing 11**

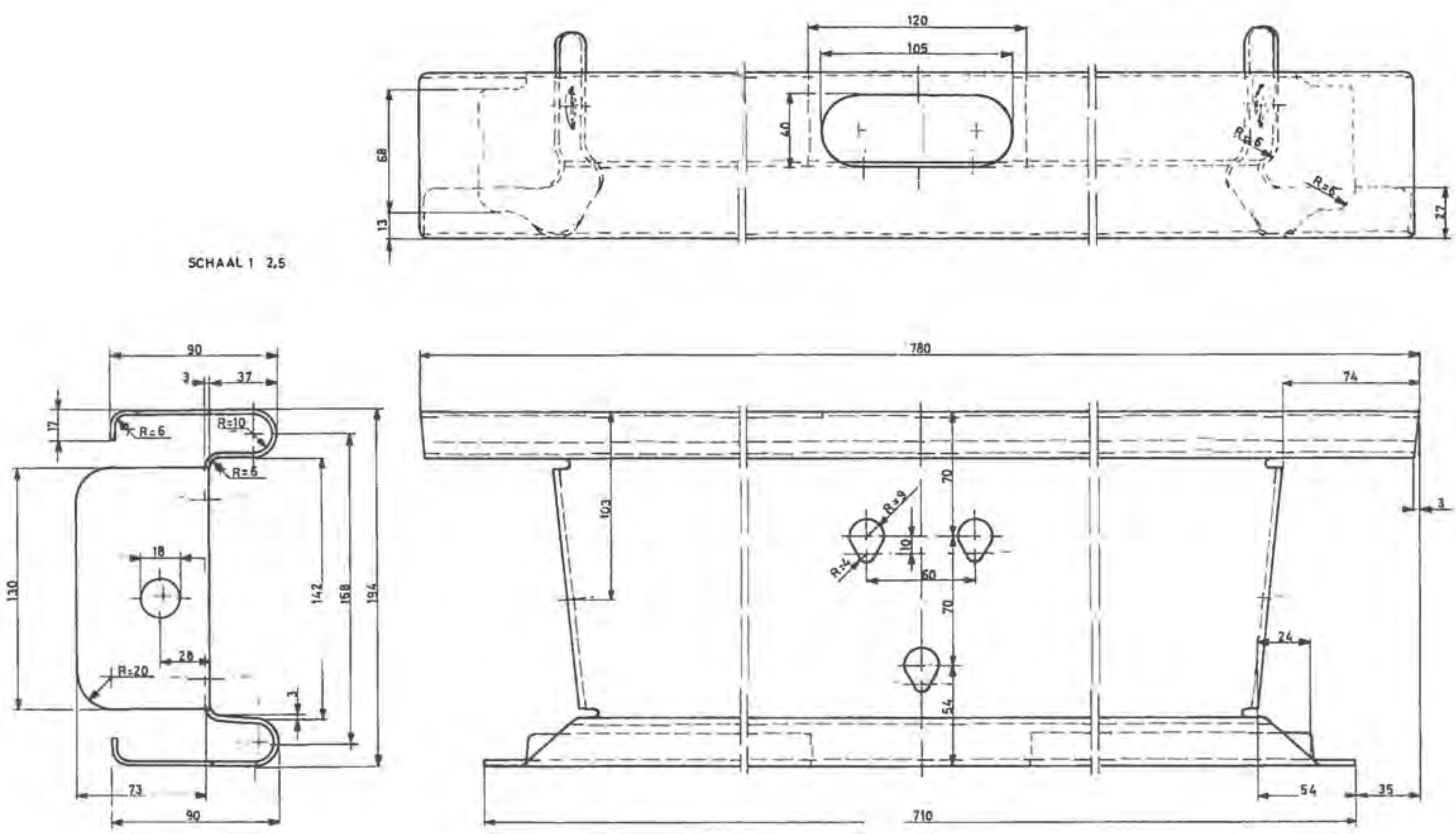




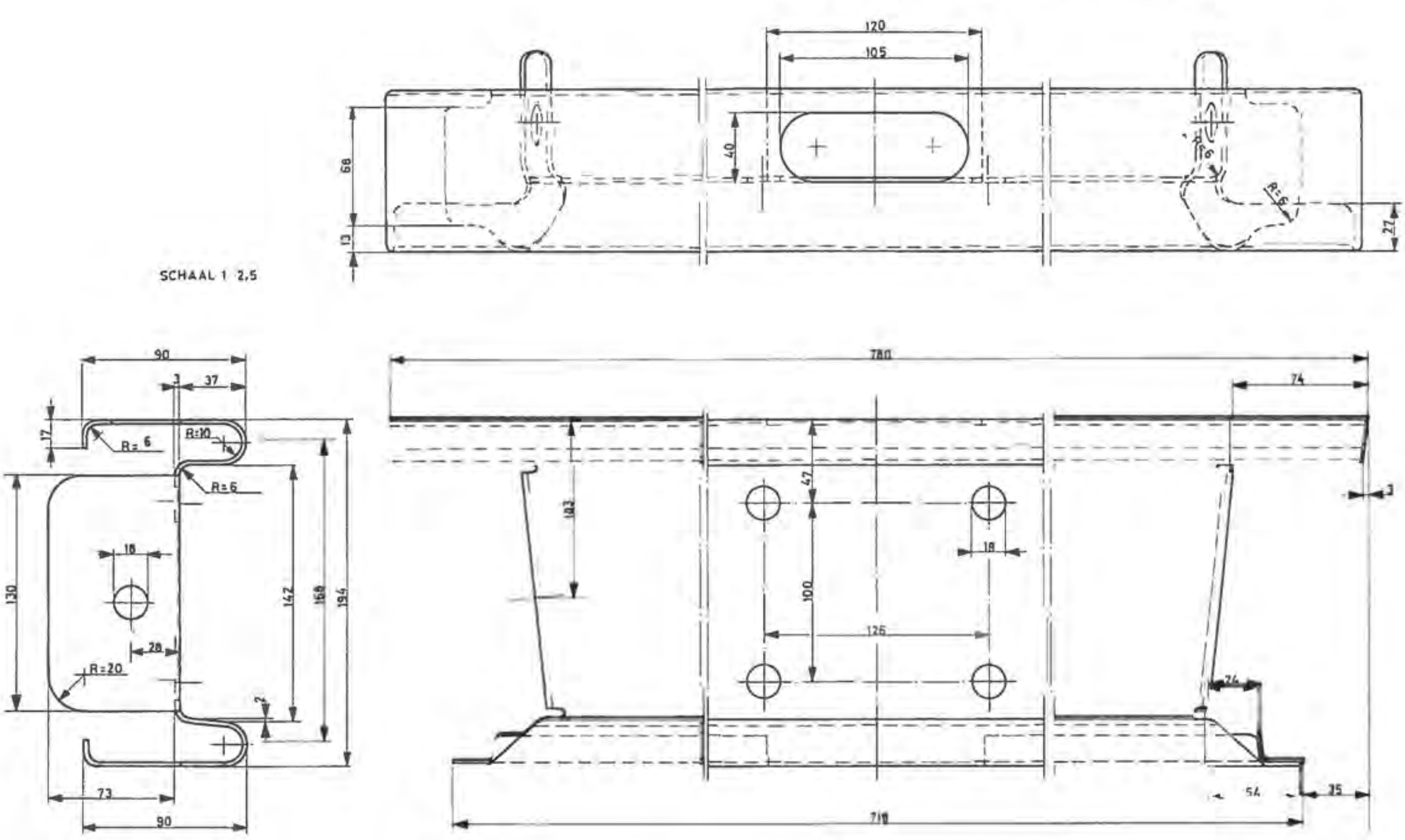
Drawing 11 Guiderails



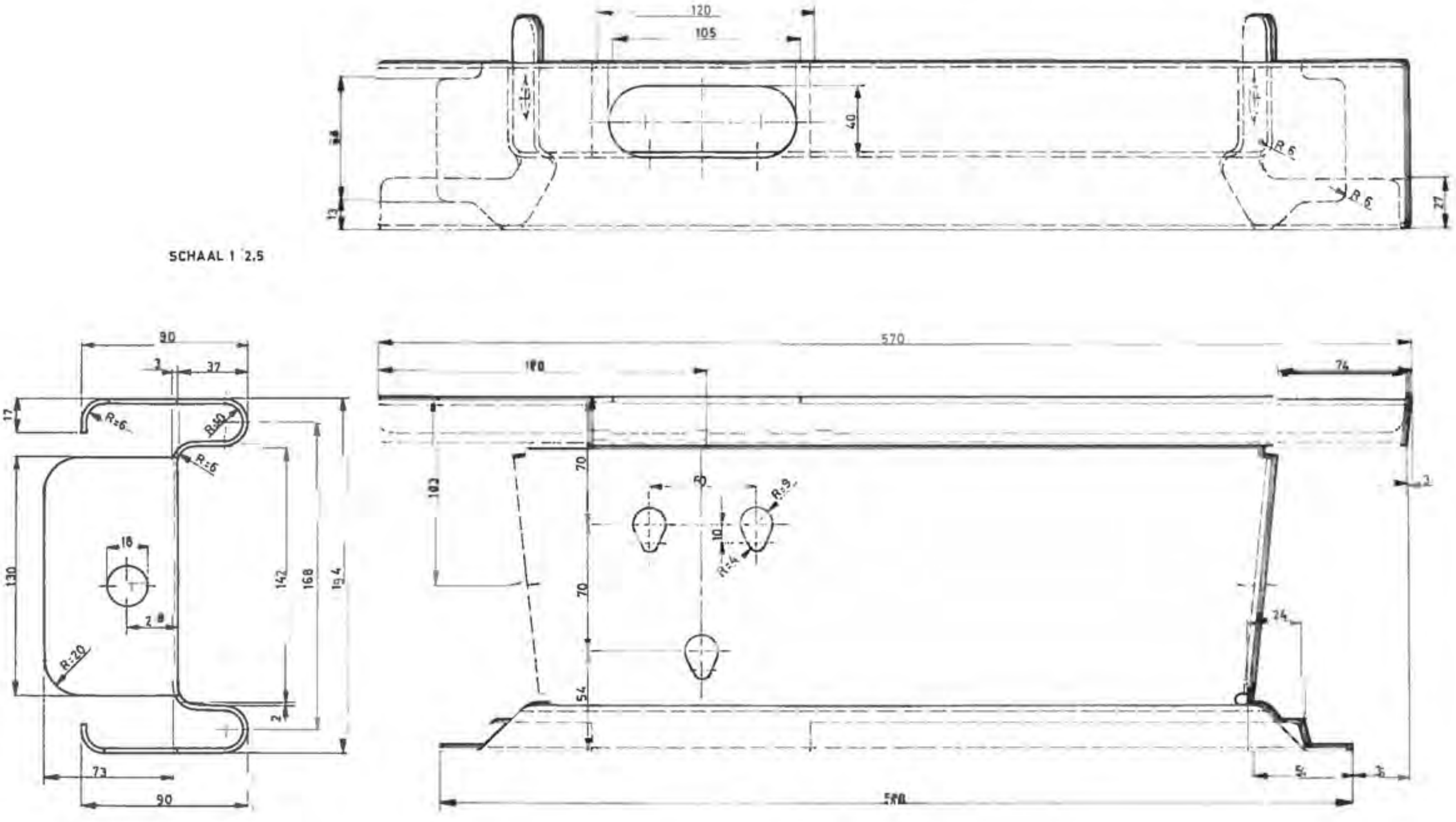
Drawing 12 1. Spacer for two offset rail bars with [illegible]



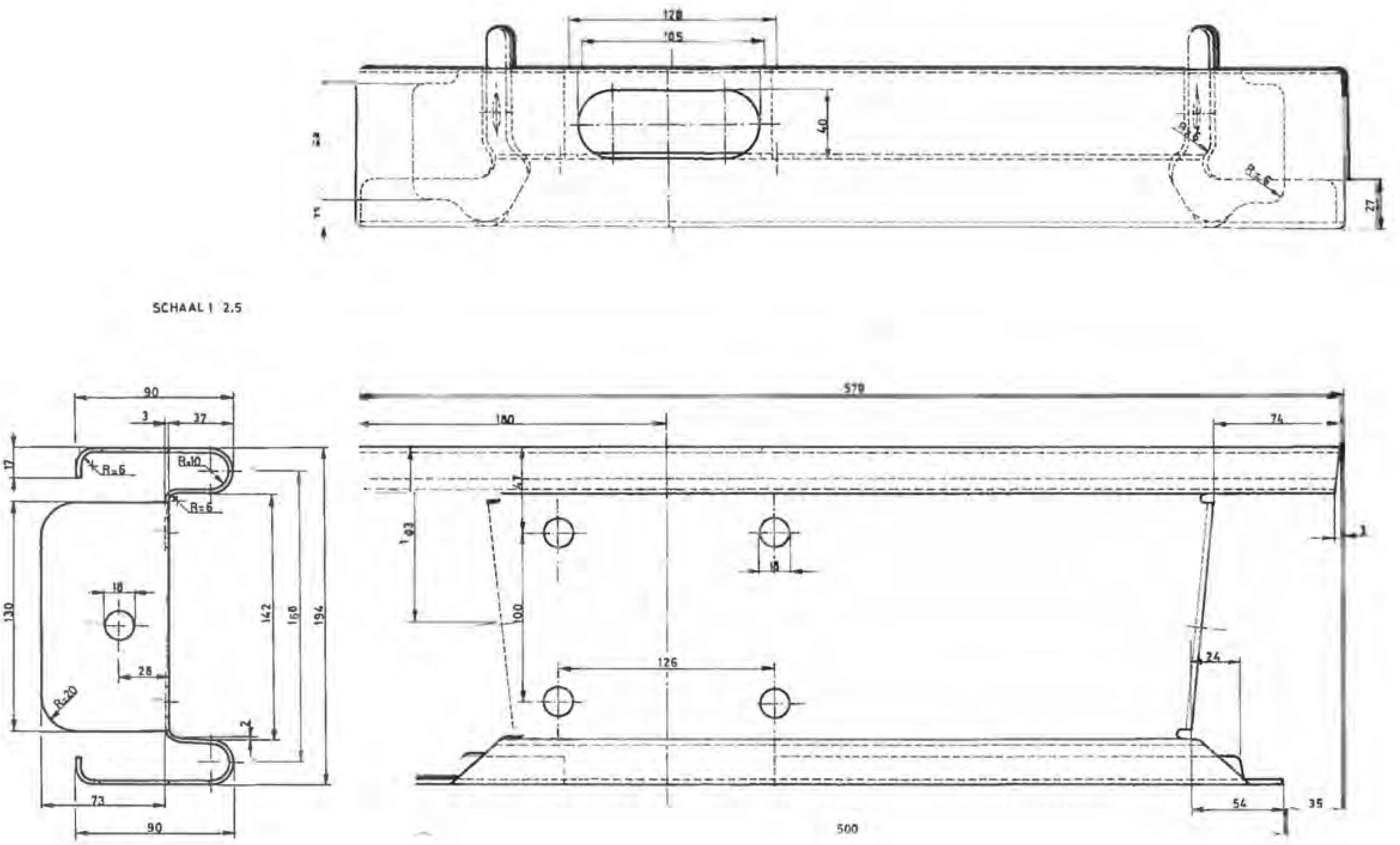
Drawing 12 2. Spacer for two offset rail barrier with posts in drilled ho es



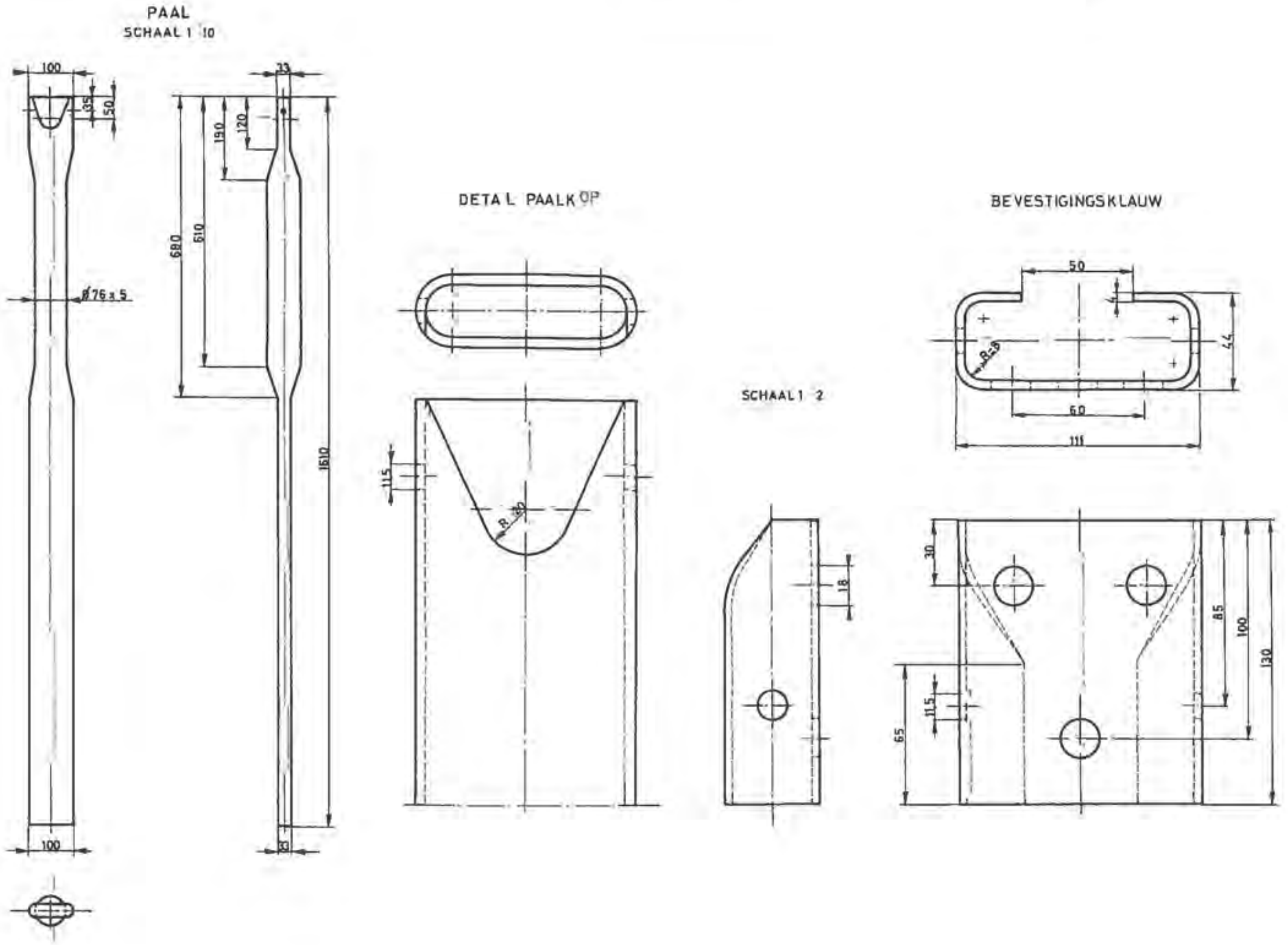
Drawing 12.3 Spacer for single offset rail barrier with piled posts



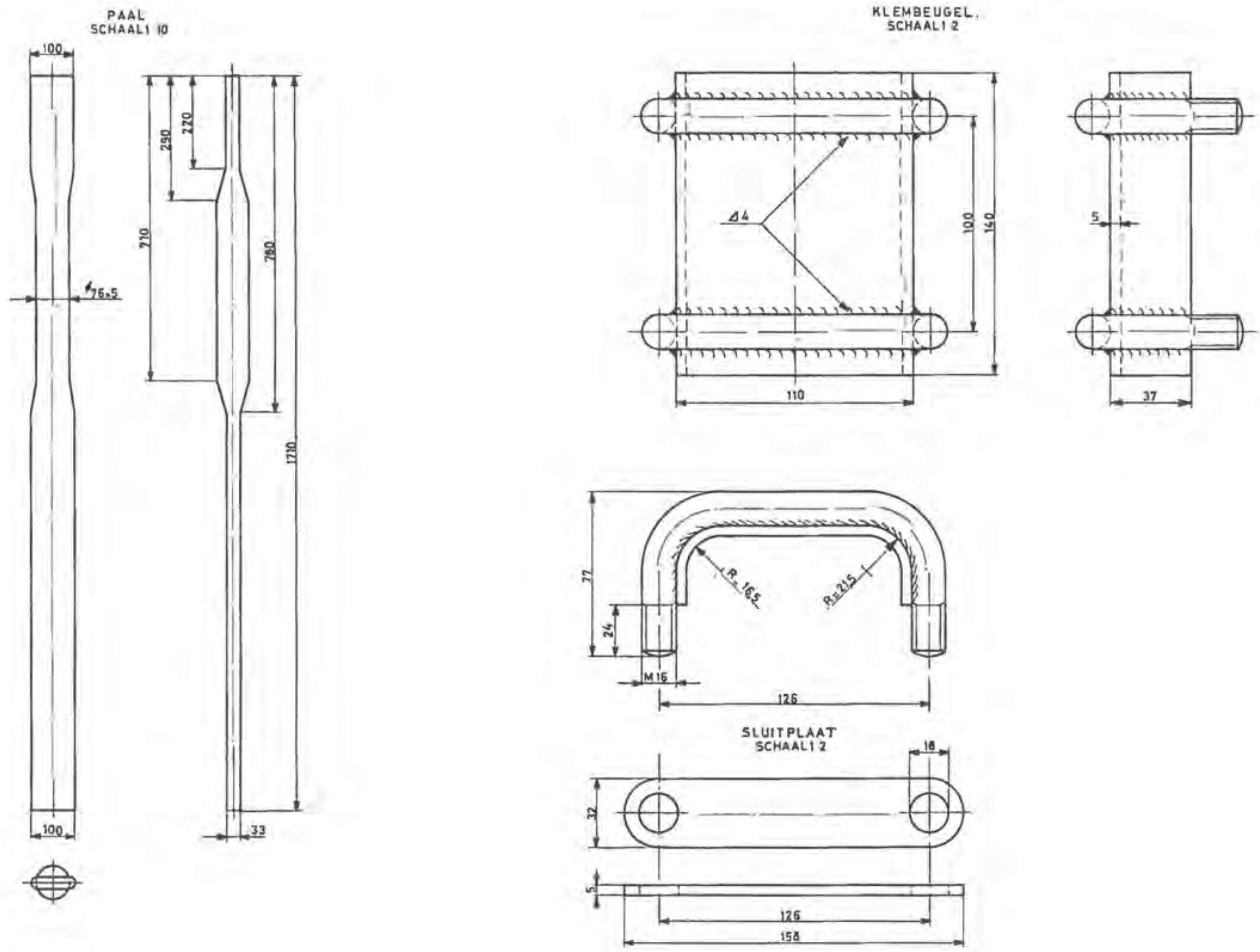
Drawing 12.4 Spacer for single offset rail barrier with posts in drilled holes



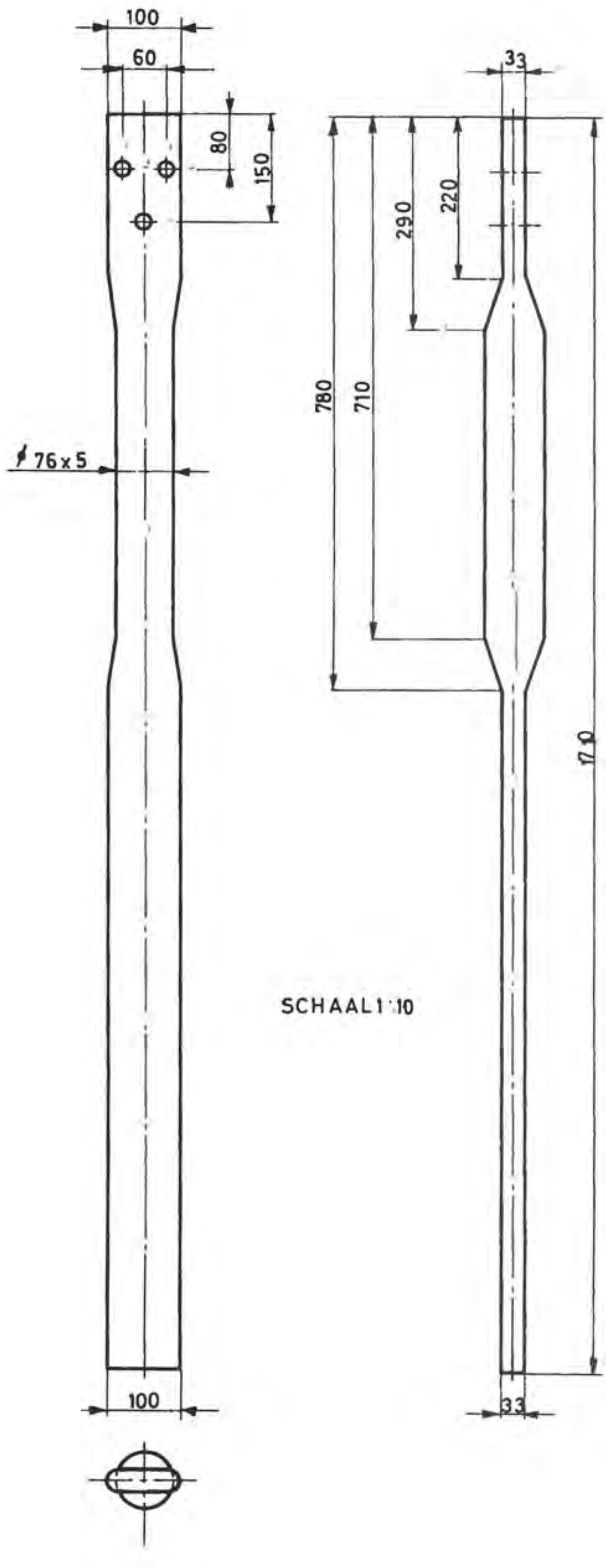
Drawing 13.1- Post and claw for barriers with piled posts and with rupture bolts



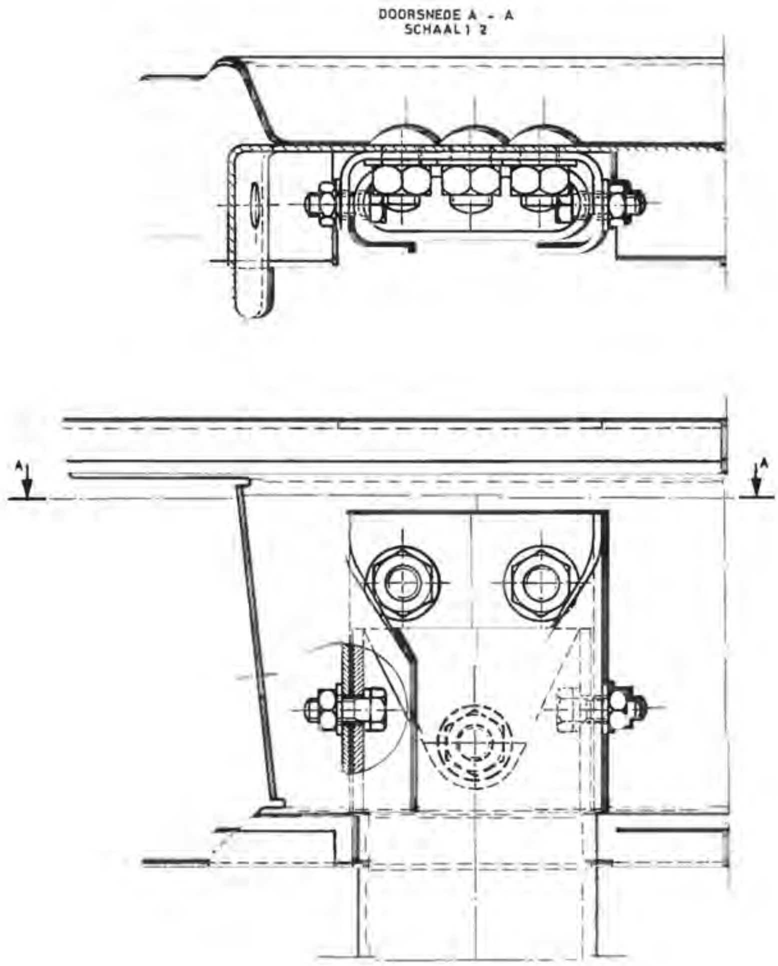
Drawing 13.2. Post and clamp for barriers with posts in drilled holes without rupture bolts



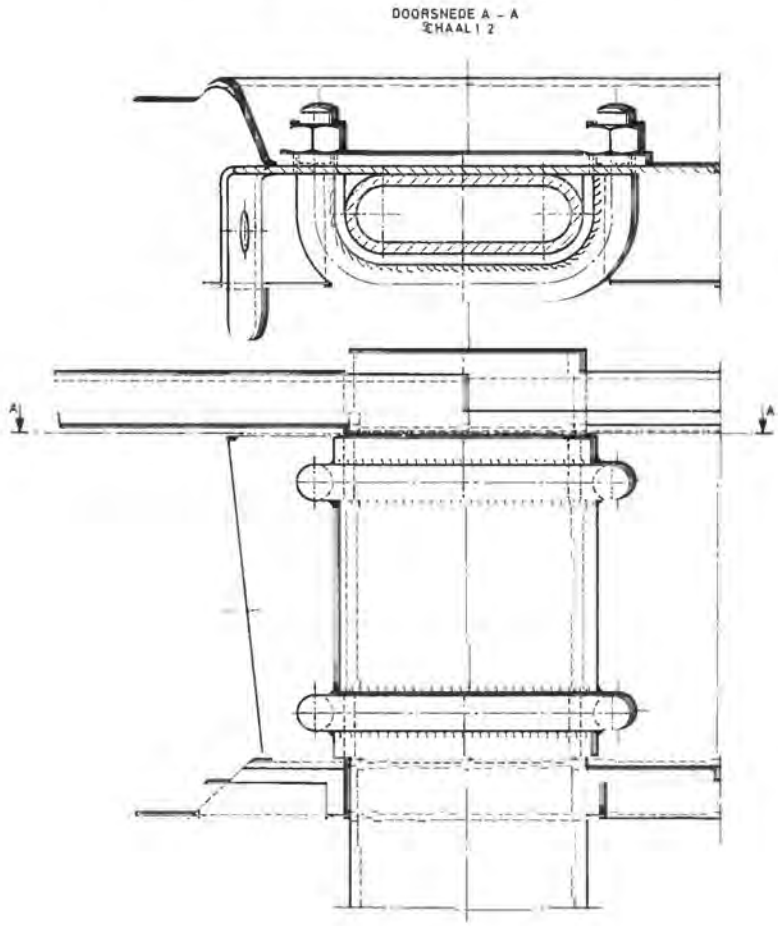
Drawing 13.3. Post for barriers with piled posts without rupture bolts.



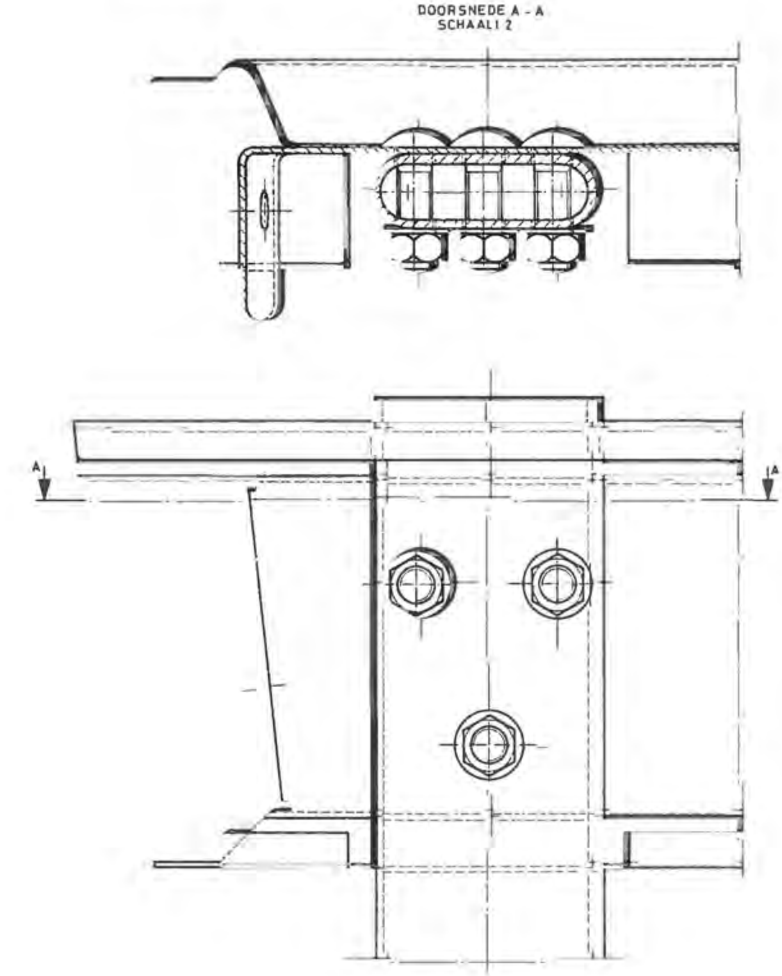
Drawing 14.1 P[illegible] fixture [illegible] with piled posts and rupture [illegible]



Drawing 14.2 Post spacer fixture for barriers with posts in drilled holes without rupture bolts

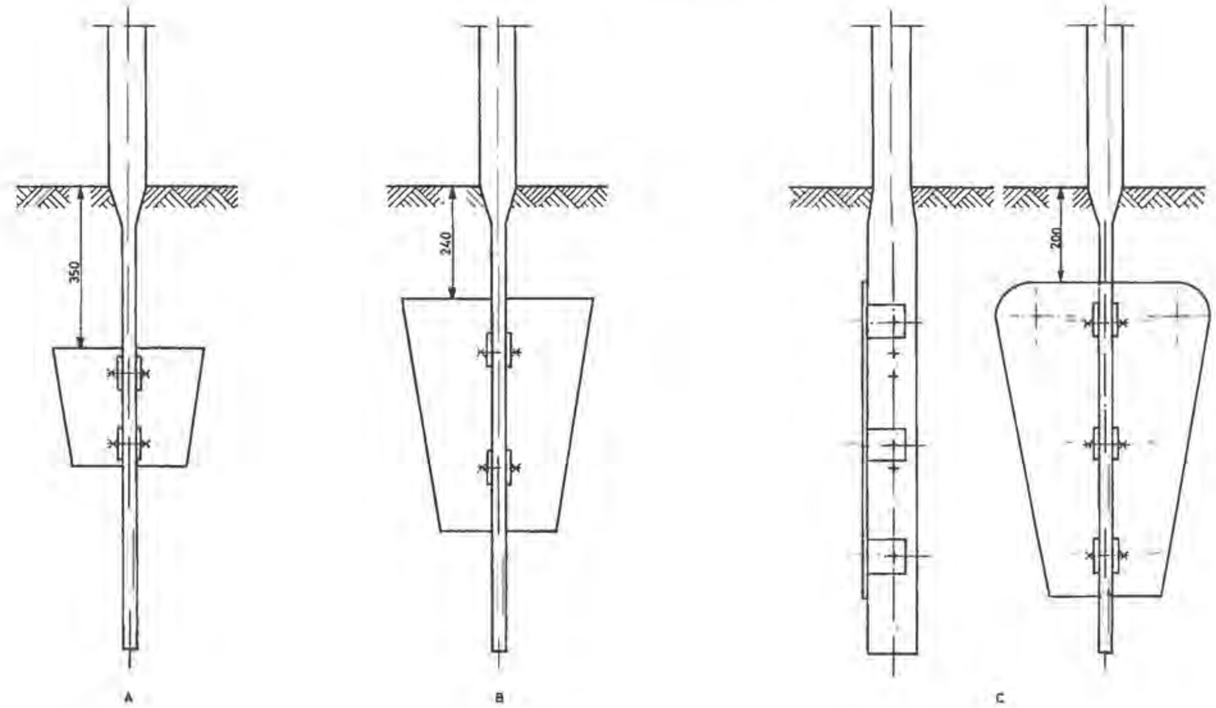


Drawing 14.3. Post spacer fixture for barrier with profiled posts without rupture bolts

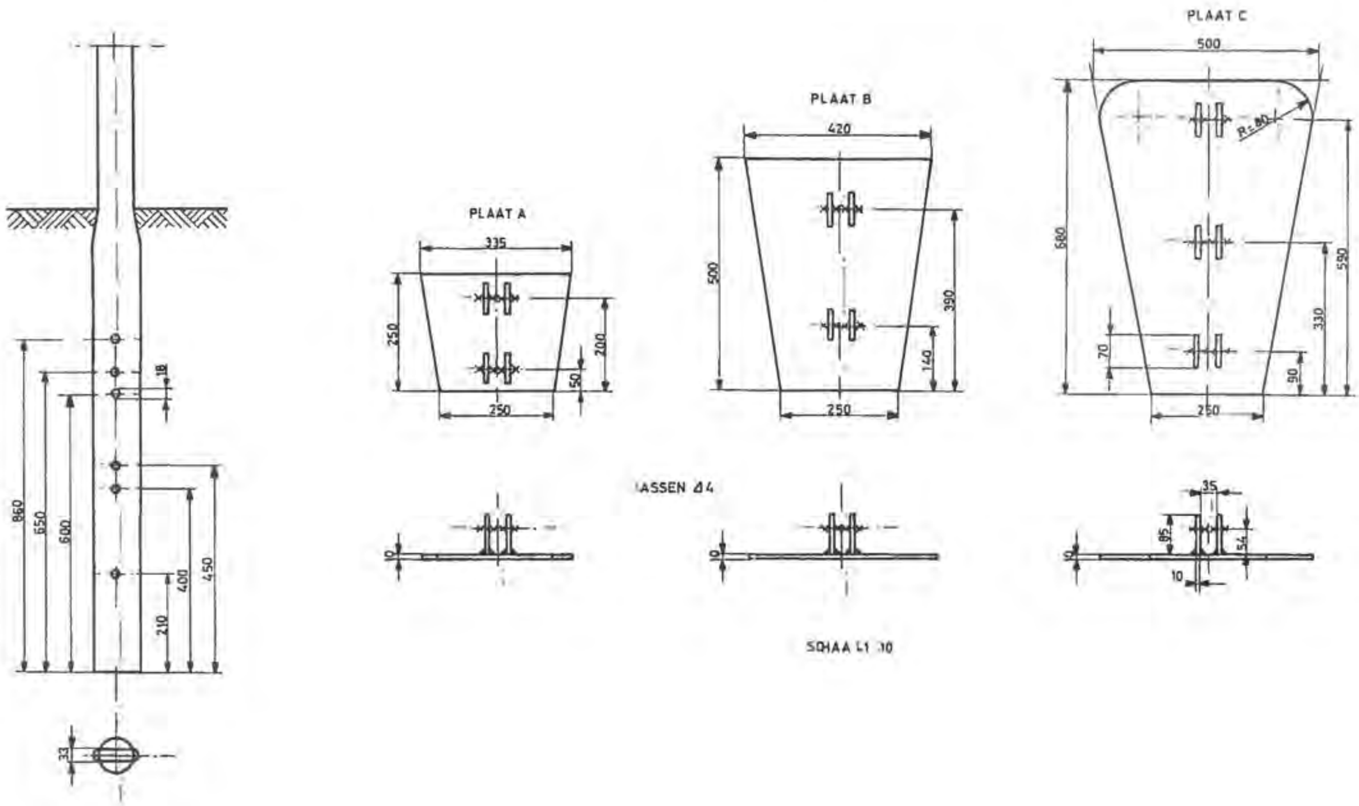


Drawing 15.1. Fixing the three types of stabilising plates to post

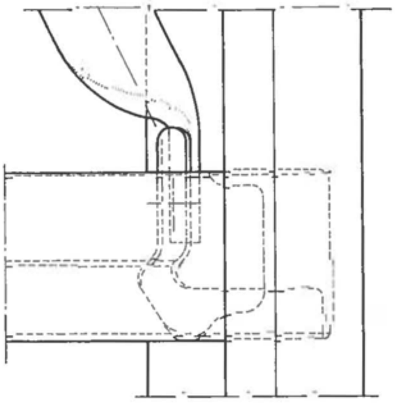
SCHAAL 1:10



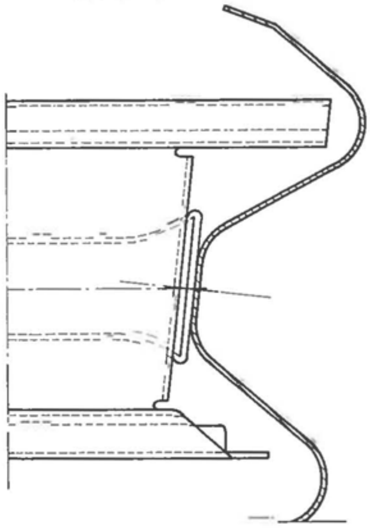
Drawing 15 2. The three types of stabilising plates



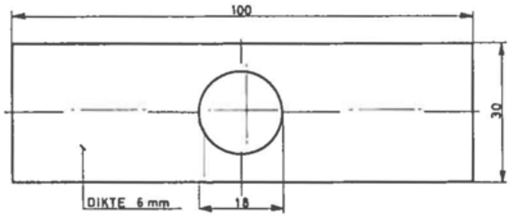
Drawing 16 - Structural details of beam with diagonal bars



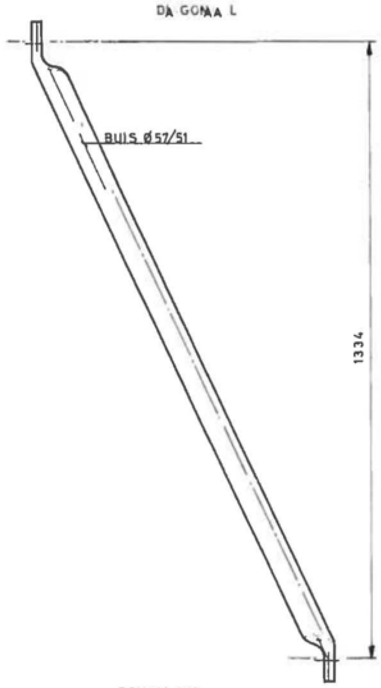
SCHAAL 1:25



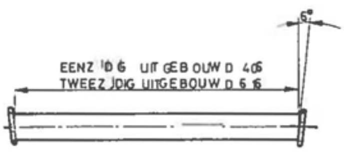
VULPLAAT
SCHAAL 1:1



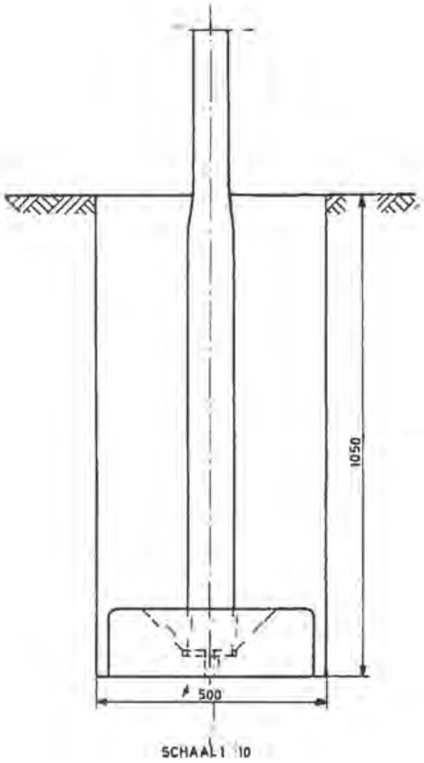
DIAGONAAL



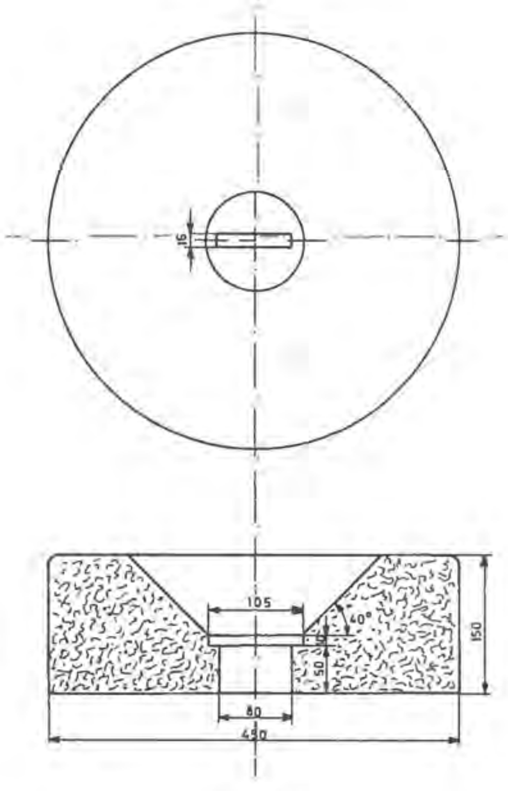
SCHAAL 1:10



Drawing 17 - Dish

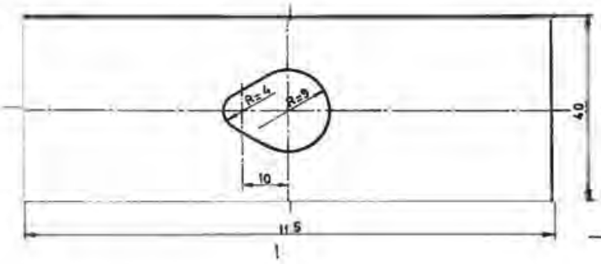


SCHAAL 1 : 10

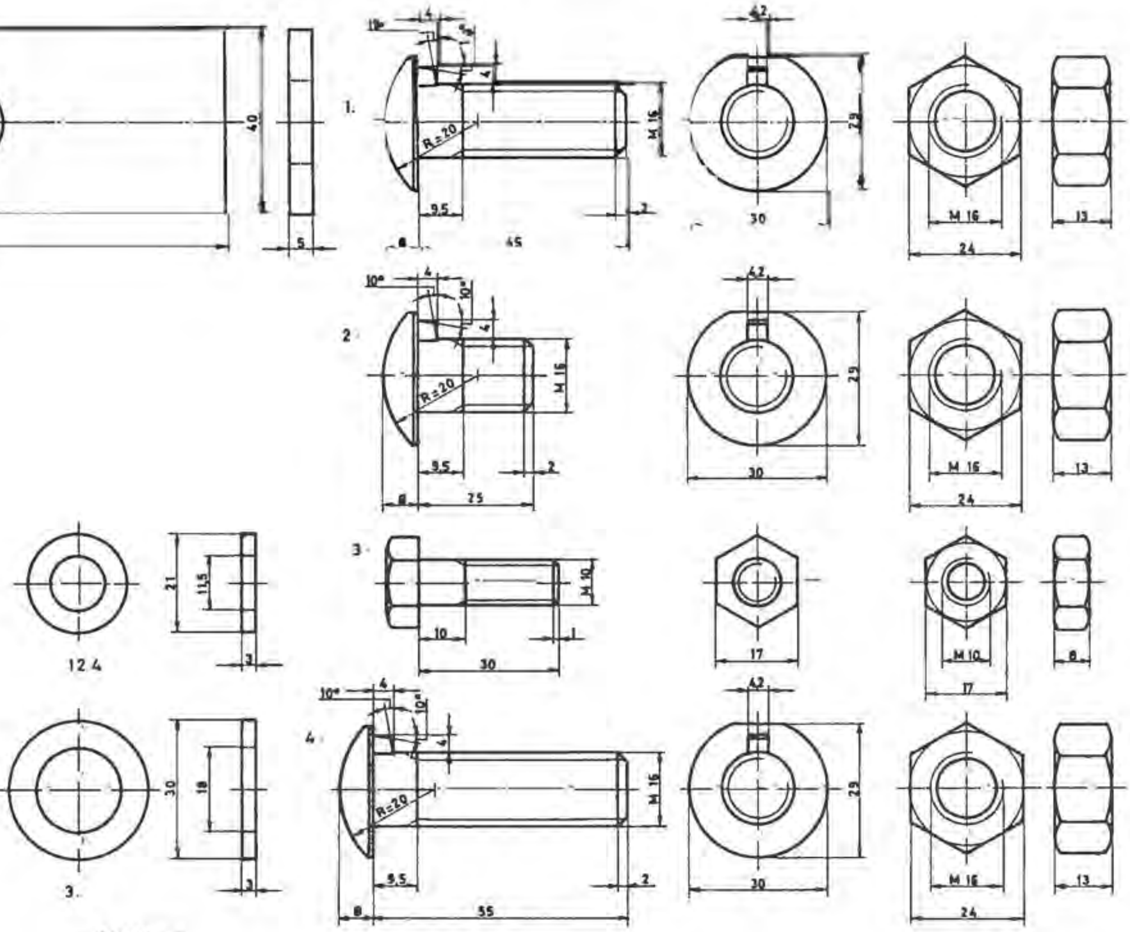


SCHAAL 1 : 5

Drawing 18. Nuts and bolts

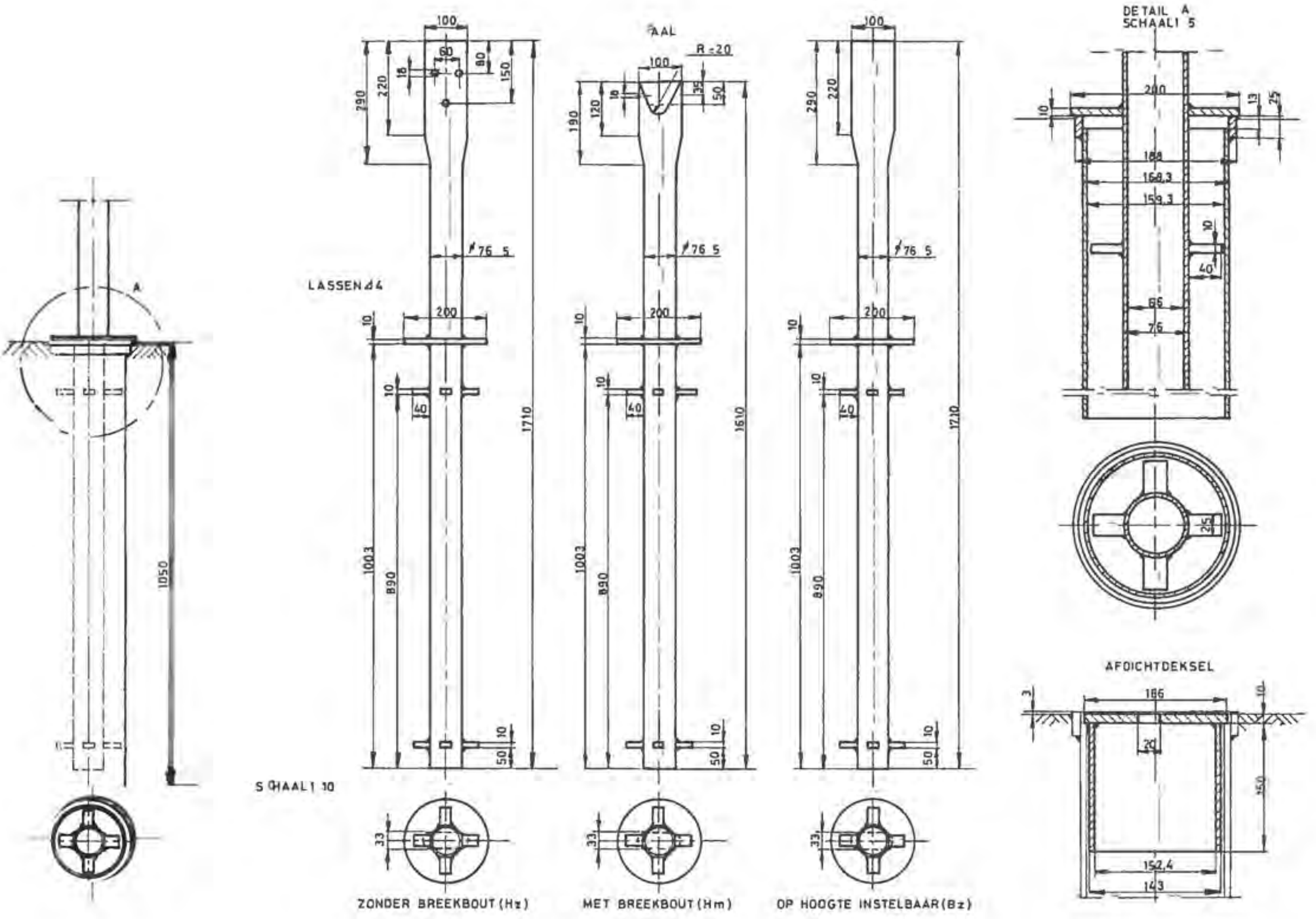


Fixture
1 Rail spacer
2 Rail rail
2 Claw spacer
3 Claw post (ruptura bolt)
4 Post spacer

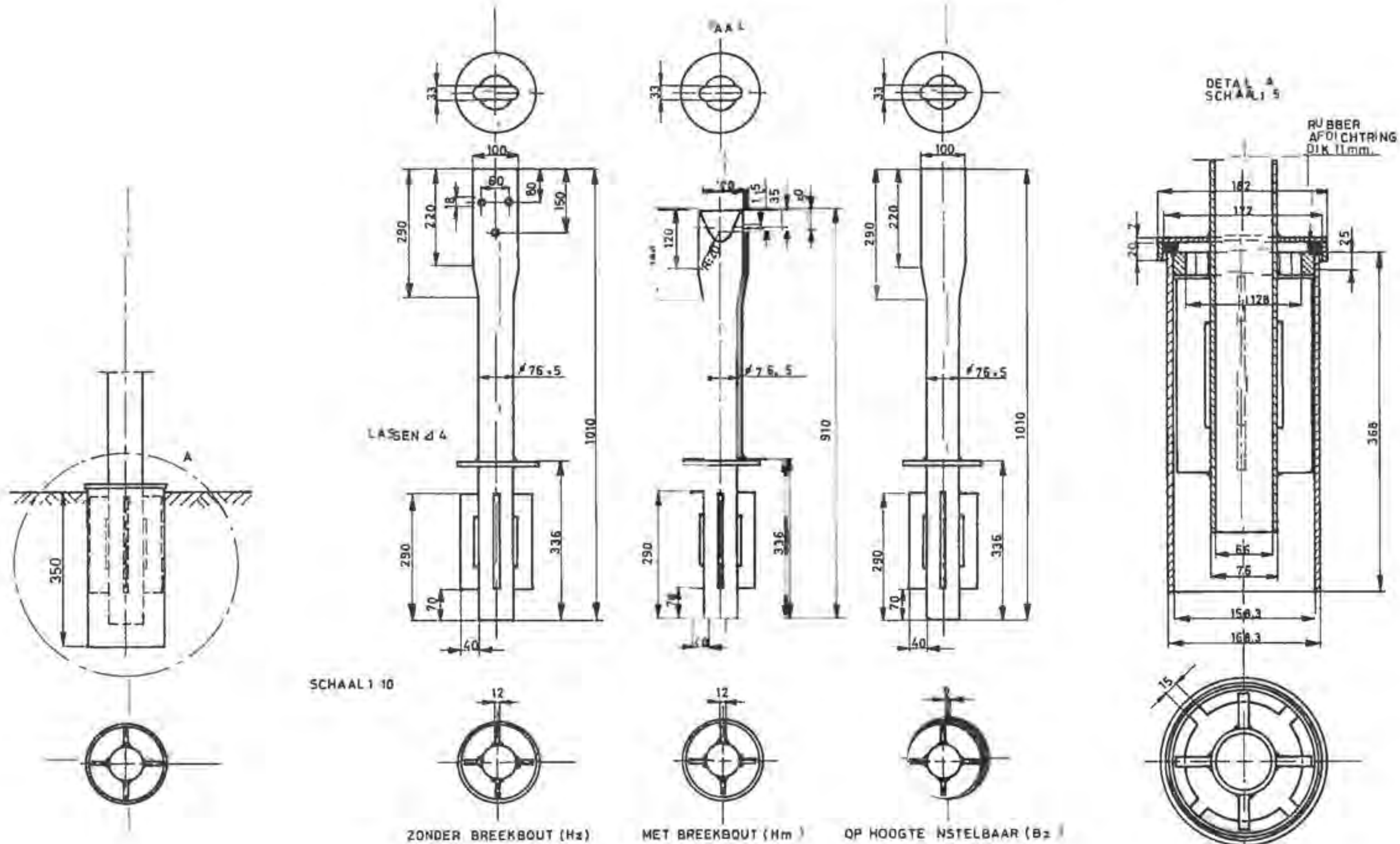


SCHAAL 1:1

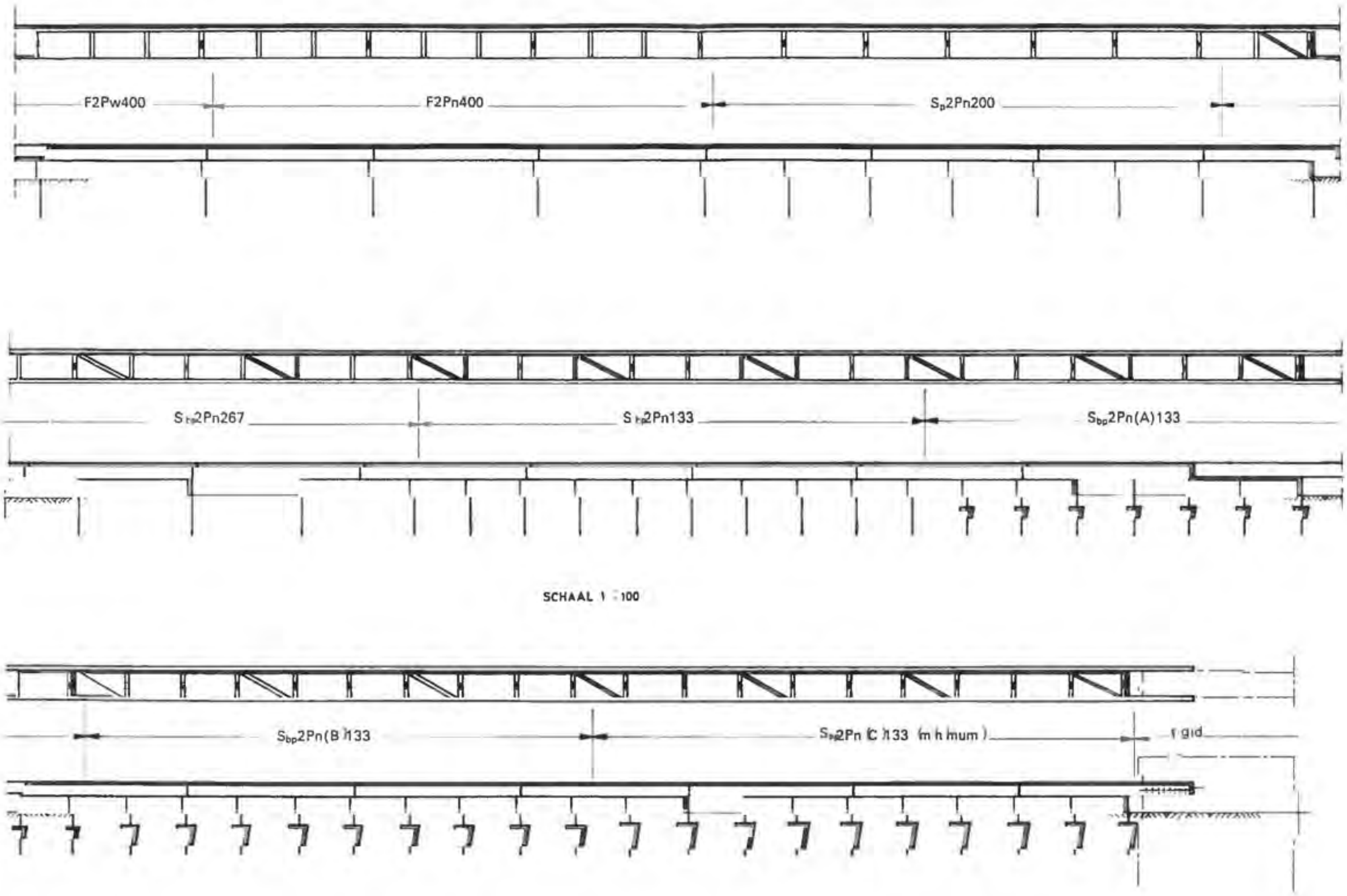
Drawing 19. Stay bush construction



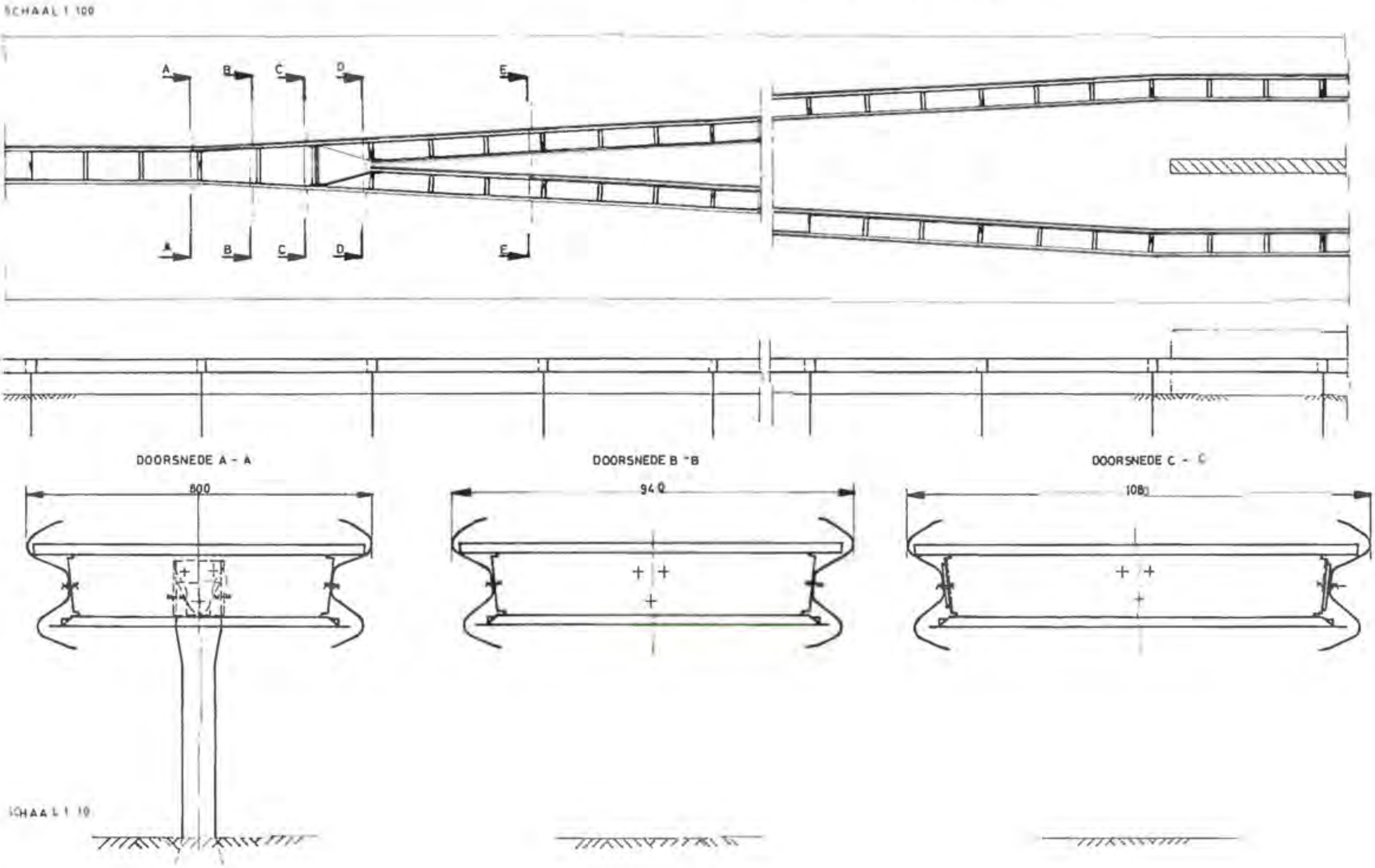
Drawing 20. Waterproof stay bush construction



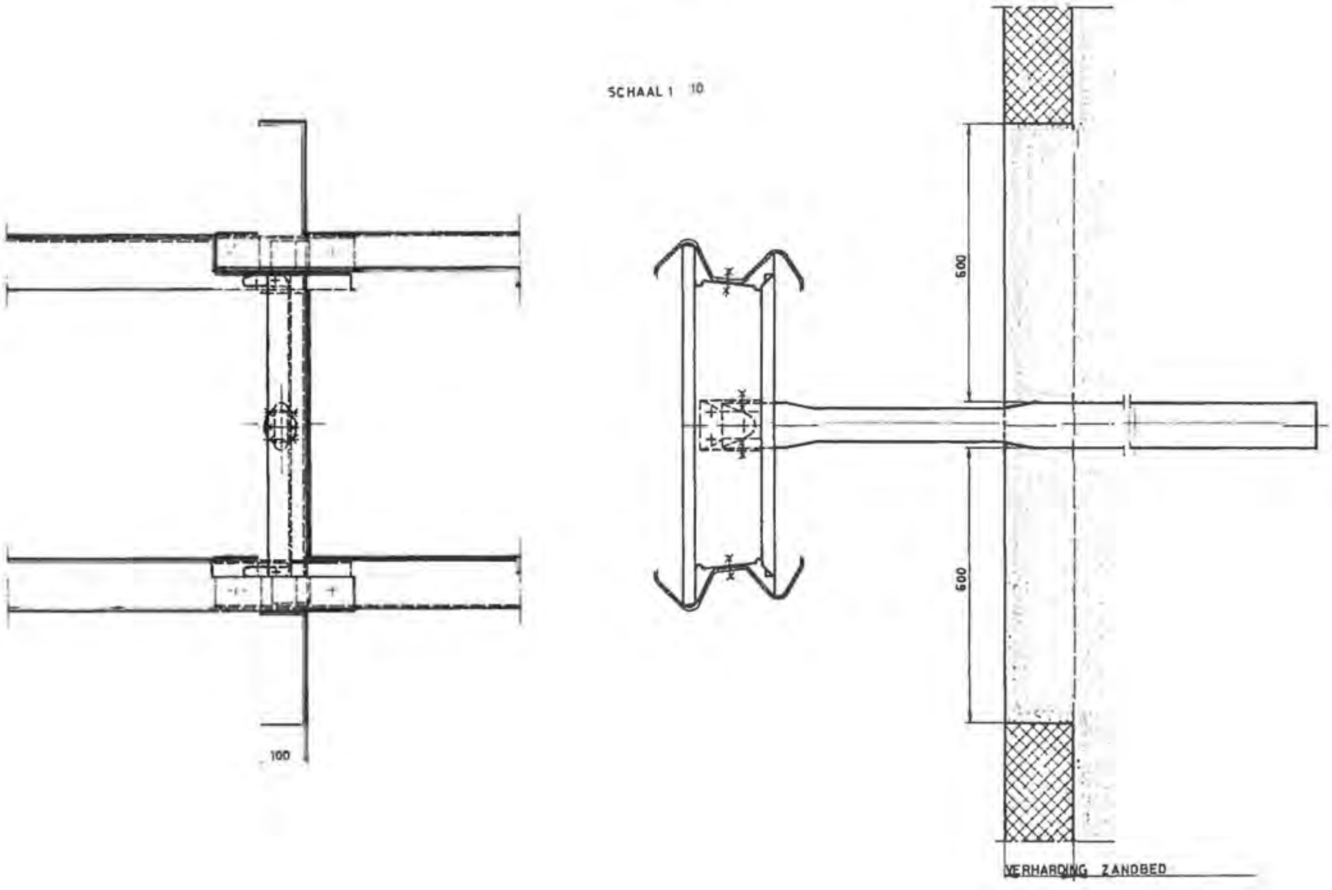
Drawing 2.1 Transitions from a flexible barrier to a completely rigid barrier.

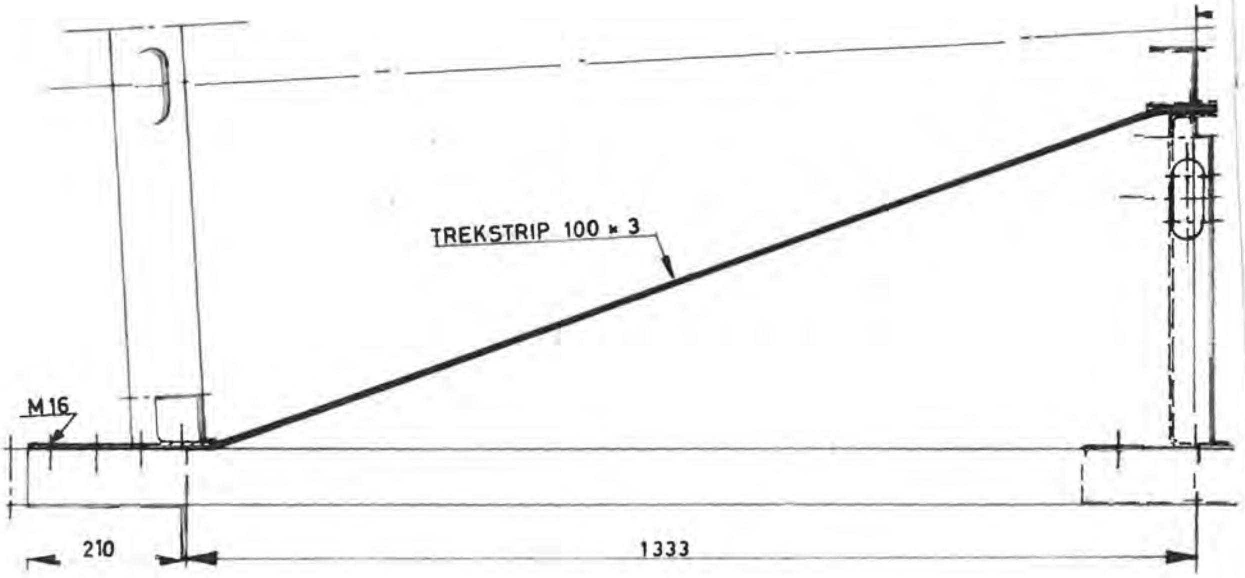


Drawing 22.1. Fork of a flexible two offset rail barrier to two single offset rail barriers. Both barriers with piled posts and rupture bolts. F2Pw – 2 × F1Pw



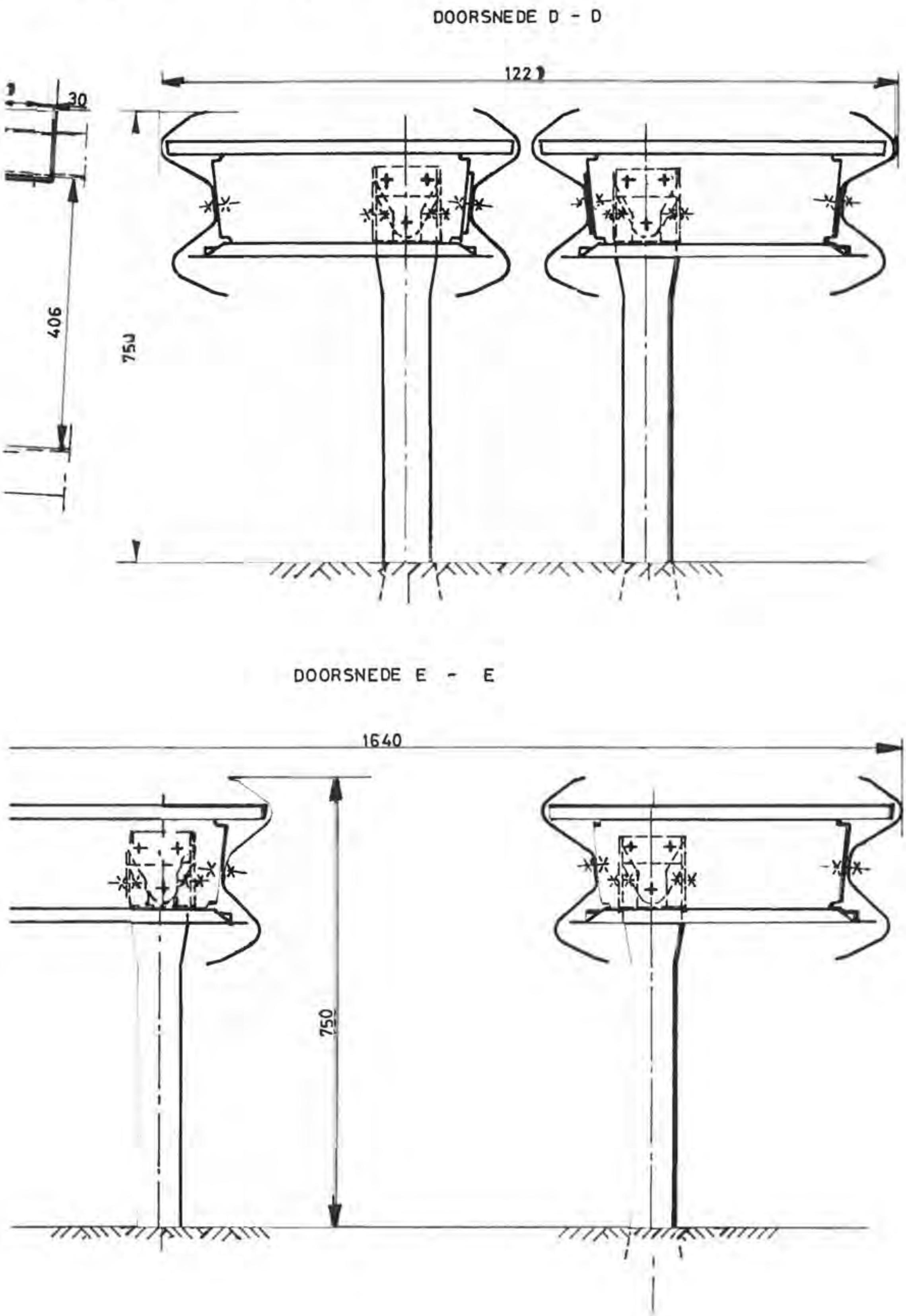
Drawing 23 Spa e h hard surfa e f ? l ex b e tw o ffset r ail barr er w th p ed p ats





SCHAAL 1:10

Drawing 22.2. Structural details of fork.



Drawing 24 Space in hard surface for flexible single offset rail barrier with placed posts

SCHAAL 1:10