# red warning triangles

SWOV

Vehicle perceptibility 3

# Red warning triangles

Function, design and application

Institute for Road Safety Research SWOV

Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV

P.O.Box 71, Deernsstraat 1, Voorburg 2110, The Netherlands

## Contents

# Preface

In compliance to an E.C.E. proposal to make red warning triangles compulsory, in 1966 the Ministry of Transport and Waterways of the Netherlands instructed the Institute for Road Safety Research SWOV to undertake research into the functional standards for perceptibility and wind stability of warning triangles.
Following analysis of the conditions under which the triangles were used, theoretical standards were established for perceptibility and wind stability. A Ministerial Order, operative from January 1967, issued directives regarding the triangles, based on these standards.
Next, measurements were made of perceptibility and wind stability of a number of triangles commercially available in the Netherlands early in 1967.
Theoretical standards were thus tested in practice. The practical tests of perceptibility were made by the Institute for Perception RVO-TNO, Soesterberg (Dr. J. A. Michon, A. van Meeteren, H. J. Leebeek, A. Lazet). The Institute for Road Transport Vehicles TNO, Delft, (J. C. Bastiaanse and J. van der Weiden) made the wind stability measurements.
This was followed by recommendations for testing standards and testing procedures. The relevant work was carried out in collaboration with the Institute for Perception RVO-TNO, Soesterberg; the Institute for Road Transport Vehicles TNO, Delft; KEMA (N.V. tot Keuring van Electrotechnische Materialen), Arnhem (J. B. Moerman and J. Boersema); the Illumination Engineering Society in the Netherlands, Arnhem (F. Burghout) and the Paint Research Institute TNO, Delft (A. M. Berendsen).
These recommendations for testing standards and procedures, together with the research data, were given to the Ministry in 1968.

This report on Red warning triangles was compiled by D. J. Griep (Human Factors Department SWOV) and F. C. Flury (Basic Research Department SWOV) in collaboration with Dr. D. A. Schreuder (Basic Research Department SWOV), H. G. Paar (Road and Vehicle Department SWOV) and J. C. A. Carlquist (Statistics and Documentation Department SWOV).

E. Asmussen
Director Institute for Road Safety Research SWOV

## Summary

# I. The problem

## I.1. On unlit roads after dark

When a motorist approaches a stationary vehicle, he will usually only detect a difference in speed compared with that vehicle. Often, he will not detect immediately whether the vehicle is stationary. If he is travelling faster than about 120 km/h, the distance at which he detects the difference in speed compared with a stationary vehicle will usually be too short for him to stop in time.

## I.2. With street lighting and in daytime

In daytime, and on lighted roads at night, the approaching driver may be able to see from the position of the vehicle whether it is stationary or in motion. This may apply when the vehicle is *on the verge* or the *hard shoulder*. But if the vehicle is *stationary on the carriageway* it will often be impossible even in daytime to detect this far enough away.

## I.3. Warning signals

The foregoing shows the need for two warning systems: one for vehicles stationary *on* the carriageway and one for vehicles stationary *near* the carriageway. The warning sign for stationary vehicles *on* the carriageway must be used both in daytime and after dark. That for stationary vehicles *near* the carriageway must in any case be used at night-time, even if the stationary vehicle's lights are on, because its lights alone do not show whether it is stationary or in motion. Nor can it be seen whether it is in the approaching driver's lane or not.

## II. Possible solutions

'Official' warnings already in use are, for instance, the red warning triangle and automatic, continuous flashing of brake lights and/or direction indicators (as customary in the USA).
A combination of both is advisable; for instance a red warning triangle for vehicles *near* the carriageway and the 'American' system for vehicles *on* the carriageway.
It will in any case be abvious that such warning systems cannot prevent all collisions with vehicles stationary on the road.

# III. Scope for research in the Netherlands

As the choice of the warning system for Europe had already been decided—the red warning triangle—the terms of reference given by the Minister of Transport and Waterways in the Netherlands were limited to this. They asked for standards to be given for perceptibility and wind stability of red warning triangles.

This report analyses the practical conditions on which these standards have been based. It also contains a report on practical research into the perceptibility of a number of warning triangles commercially available early in 1967.

# IV. Theoretical requirements for warning triangles

## IV.1. Recognizability distance

Based on the braking distance required at a speed of 120 km/h (the speed which, on average, is exceeded by not more than 15% of drivers on roads with separate carriageways, 210 metres was found as the minimum required recognizability distance for warning triangles. This was based on a braking deceleration (on wet surfaces) of 4 metres/sec² and a reaction time for driver plus vehicle in sudden eventualities of 3 secs. Allowance was also made for the provision in the Traffic Rules and Signs Regulations in the Netherlands (Reglement Verkeersregels en Verkeerstekens RVV) that a warning triangle must be placed 30 metres away from the stationary vehicle.
A number of the triangles that were tested complied with this theoretical recognizability distance.

## IV.2. Wind stability

Wind velocities due to air turbulences behind moving vehicles, especially trucks, and also (the frequency of) the occurrence of wind velocities corresponding to the upper limit of wind force 11 (Storm) determined the wind stability standards for warning triangles. The requirement is that they must not move and/or tip over with a wind velocity of v = 20 metres/sec. This has implications regarding their weight and the dimensions of the base.
Some of the triangles tested also satisfied these theoretical requirements.

# V. Results of practical tests with warning triangles

## V.1. Recognizability distance after dark

1. Experiments show that a recognizability distance of 210 metres corresponds to a reflective power of 90 cd/m² per lux. For a warning triangle with the internationally recommended dimensions, this applies if the observer is dazzled by an oncoming vehicle's low-beam headlights. The conditions of the experiment, however, could not be regarded as the most critical for actual traffic conditions. In fact, no other objects had to be detected and recognized apart from a warning triangle. Moreover, only one oncoming vehicle (with low-beam headlights) was present. Under actual traffic conditions, other objects will usually have to be detected and recognized by the driver at the same time. What is more, the driver may be dazzled by the lights of more than one oncoming vehicle. This may shorten the recognizability distance.
2. The distance between (the centre of) the oncoming vehicle's low-beam headlights in the experiments was 1.20 metres. On some narrow vehicles it will be less than 1.20 metres. In that case, stronger glare will also reduce the recognizability distance.
3. The lateral distance between the oncoming vehicle's low-beam headlight closer to the triangle and the triangle itself was 3 metres.

If the lateral distance is shorter the glare the driver experiences from the oncoming vehicle's low-beam headlights will increase. A greater reflective power will then be required for a recognizability distance of 210 metres.

A reflective power greater than 90 cd/m² per lux is therefore advisable for the warning triangle. The standard in Western Germany is at least 125 cd/m² per lux. This is based on manufacturing facilities. It would also appear to be acceptable for the Netherlands.

## V.2. Recognizability distance in daylight and dusk

The recognizability distance for warning triangles in daylight and dusk is less than after dark. If a triangle is illuminated after dark by an approaching vehicle's low-beam headlights, the brightness contrast between the triangle and the surroundings is very much greater than in daytime.

In order to lengthen the recognizability distance in daytime and dusk, the triangle might be provided with a red fluorescent edging. Standards have also been worked out for this optional design.

## V.3. Location

The recognizability distance decreases if the warning triangle is not at right angles to the axis of the road, but is at an angle exceeding 30°.

## VI. The Minister of Transport and Waterways' Order

A Ministerial Order dated 21st October 1966, No. 63774, formulated the following requirements for warning triangles:

a. the length of the sides must be at least 45 cm;

b. the entire length of the sides must be provided with reflectorized material at least 5 cm wide;

c. if placed on the road in daytime, the triangle must be clearly visible to the driver of a motor vehicle 250 metres away;

d. if placed on the road after dark, the triangle must be clearly visible to the driver of a motor vehicle with low-beam headlights 250 metres away;

e. with or without an object to support it, the triangle must stand firmly on the road; regardless of the state of the road surface it must not slide away nor be tipped over by blasts of wind.

This visibility distance will usually even be exceeded after dark for triangles with the internationally recommended dimensions and with a reflective power of 125 cd/m² per lux. In many cases, such triangles will be recognized as such at that distance, and it is this recognizability that is essential. The adjustment of the vehicle's low-beam headlights which illuminate the triangle is not of primary importance provided they are adjusted so that the triangle 250 metres away is illuminated by the dispersed light still radiated above the edge of the beam.

## VII. The legal position

The present regulations in the Netherlands (Traffic Rules and Signs Regulations, Article 78) require the use of a red reflectorized warning triangle for motor vehicles with more than two wheels under the following conditions outside built-up areas:
*after dark*: 'if a stationary vehicle's regulation front and rear lights are defective';
*in daytime*: 'if the vehicle is stationary at such a place that it cannot be promptly observed by other drivers'.

This definition is incomplete. There are other conditions both in daytime and after dark when the use of a warning system is advisable. Visibility of (the lights of) the vehicle does not necessarily indicate whether the vehicle is stationary or moving. This applies particularly after dark, but also in daytime, especially when the vehicle is not at the side of the carriageway but on it. In a number of cases after dark, the approaching driver will still be able to detect a difference in speed compared with the stationary vehicle in time, from the apparent increase in distance between the stationary vehicle's rear lights as he approaches. The distance at which this difference in speed can be detected in this way will, however, usually be less than the necessary braking distance at speeds over 120 km/h. In this case, even a warning triangle with the recommended dimensions and reflective power, however, will provide too short a recognizability distance. For an approach speed over 120 km/h, this distance is shorter than that needed in order to stop before the vehicle 'safeguarded' by the warning triangle.
Facilities other than the warning triangle would therefore be more advisable. A distinction between stationary vehicles next to the carriageway, for instance on the hard shoulder, is also advisable.

Means that might be considered are:
1. Whether or not in combination with the warning triangle, the automatic *flashing* of brake lights and/or direction indicators of vehicles stationary *on the carriageway*, whether in daylight, on lighted roads or after dark. In fact, this system is already permitted at night and in bad visibility in daytime (Regulations, Article 69, para. 1).
2. The use of *warning triangles* when a vehicle is *on the verge* or the *hard shoulder*, regardless of whether this is in daylight, with street-lightning or after dark.

If a stationary vehicle is blocking more than one carriageway, a warning to drivers from one direction will not suffice. Such conditions occur when trucks with trailers come to a stop more or less at right angles to the road. A number of countries demand the use of two warning triangles in such circumstances. As far as present knowledge goes, however, better solutions would appear to be flashing brake lights, direction indicators and headlamps, the placing of red lamps or torches and/or the use of reflectorized material on the sides of tractor/trailer units.

# Research

# Meaning of symbols

$q$ = detection distance, i.e. distance at which a difference in speed compared with a (stationary) vehicle can be detected (m)

$p$ = width of a vehicle (m)

$v$ = speed of a vehicle (m/sec)

$\alpha$ = image angle of a vehicle or a warning triangle at distance q (degrees or radians)

$\Delta q$ = displacement of approaching vehicle in time $\Delta t$ (m)

$\Delta\alpha$ = change in image angle with displacement $\Delta q$

$\Delta t$ = (observation) time (secs)

$\frac{\Delta\alpha}{\Delta t}$ = speed at which image angle changes

$RT$ = reaction time (of vehicle and driver) (sec)

$a$ = deceleration (m/sec²)

$B$ = braking distance (m)

$E_{\Delta}$ = illumination of warning triangle (lux)

$E_{0}$ = illumination at observer's eye (lux)

$R$ = reflective power (of warning triangle) (cd/m² per lux)

$O$ = reflecting area (of warning triangle) (m²)

$z$ = length of sides of triangle (m)

$b$ = width of sides of triangle (m)

$u$ = radius of rounding of corners of triangle (m)

$I$ = luminous intensity (cd)

$D$ = distal (visibility and/or recognizability) distance (of triangle) (m)

$L_s$ = luminance of surroundings (equivalent veiling luminance supplied by two asymmetrical low-beam headlights) (cd/m²)

$L_{\Delta}$ = luminance of triangle (cd/m²)

$\theta$ = image angle of distance between glare source and observed object (warning triangle) (degrees or radians)

$K$ = variable depending, inter alia, on $\theta$ and observer's age

$n$ = variable depending on $\theta$

$d$ = lateral distance (between triangle and low-beam headlight) (m)

$\Delta L$ = difference (minimum required for visibility) in luminance (between observed object and surroundings) (cd/m²)

$W$ = load (at aerodynamic pressure point of triangle) (kgf)

$F_c$ = frontal area of a 'closed' triangle (m²)

$F_o$ = frontal area of an 'open' triangle (m²)

$V$ = air velocity (m/sec)

$C_w$ = coefficient of air resistance

$\rho$ = air density constant (kg/m³)

$l$ = length of base of triangle (m)

$\mu$ = coefficient of friction between triangle and road surface

$G$ = weight of triangle (kg)

$h_d$ = height of pressure point of aerodynamic force (m)

$h_\Delta$ = height of triangle (m)

$\gamma$ = angle between flow direction and direction of (triangle) tipping over (radians)

$s$ = arm of weight relative to supporting story (of triangle) (m)

# 1. Detecting and estimating differences in vehicle speeds

If two vehicles driving in the same direction approach each other, the driver behind has to decide whether the vehicle ahead is in his lane and/or he must detect and interpret any difference in speed between the two vehicles. In daytime and after dark on lighted roads he can judge whether the vehicle ahead is in his lane or not by observing its position relative to the lane marking.
If the vehicle ahead is on the hard shoulder or the verge, observation of this position may also indicate whether it is moving or not.
After dark on unlit roads and in daytime with poor visibility, the position of the vehicle ahead cannot be observed immediately owing to the lack of visible references with the surroundings.

If a driver approaches a stationary vehicle in his own lane, he must be able to observe it far enough away to avoid a collision. He can do so by slowing down and/or swerving aside in time.
An essential condition for this is visibility of the vehicle ahead. But visibility alone is unsufficient for observing whether the vehicle is stationary or moving.

The approaching driver can judge whether the vehicle ahead is moving or not by indications such as:
1. Whether the position of the vehicle ahead changes in relation to fixed references, for instances trees along the verge.
In daytime the use of such references will often be possible; difficulties will arise only if they are too far from the carriageway or if the structure of the verges is too uniform.
After dark it will not usually be possible to see or locate the references properly.
2. The presence or absence of changes in light and shadow on the vehicle ahead, visible to the approaching vehicle's driver.
Such changes in light and shadow may occur both in daytime and at night: at night for instance due to road-lighting. These indications will not always be available.
3. The presence or absence of vertical movements by the vehicle ahead during driving on rough road surfaces ('bouncing' or 'bumping').
Such indications will not be detectable far enough away either at night or in daytime.

The conclusion can be that in most cases after dark a driver approaching a vehicle ahead will not be able to see right away whether it is stationary or not.

On the assumption that observation of a difference in speed between two vehicles nearing each other after dark can be described as a function of the apparent increase (for the driver of the vehicle behind) in the distance between the rear lights of the vehicle ahead (Diagram 1), a relation can be obtained between the detection distance and the speed of the approaching vehicle (Diagram 2). As the vehicle width p is very small compared with the detection distance q, and hence $\alpha$ and $\Delta\alpha$ also have very low values, we find as an approximation that: tg $\alpha = \alpha$ and also tg $(\alpha + \Delta\alpha) = \alpha + \Delta\alpha$.

$$\Delta\alpha = \frac{p}{q - \Delta q} - \frac{p}{q} = \frac{p \cdot \Delta q}{q^2 - q\Delta q} \qquad (1.1)$$

If the approaching vehicle is travelling at a constant speed v, then:

$$v = \frac{\Delta q}{\Delta t}, \text{ hence } \Delta q = v \cdot \Delta t$$

$$\frac{\Delta\alpha}{\Delta t} = \frac{p.v}{p^2 + q^2 - q.v.\Delta t}$$

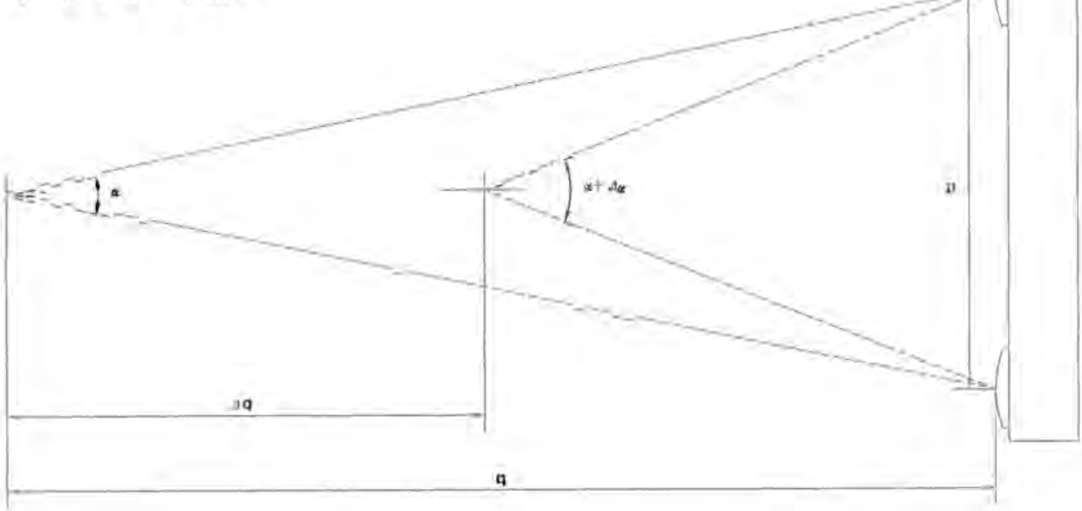



Diagram 1. Detection of differences in speed by assessing the change in apparent obstacle size.

Substitution in (1.1) gives:

$$\Delta\alpha = \frac{p \cdot v \cdot \Delta t}{q^2 - q \cdot v \cdot \Delta t}$$

from which it follows:

$$\frac{\Delta\alpha}{\Delta t} = \frac{p \cdot v}{q^2 - q \cdot v \cdot \Delta t} \qquad (1.2)$$

It is not possible to observe some slight increase in image angles, nor therefore the speed at which the image angle increases. The threshold value of the image angle averages 0.0006 radian/sec, when there is a reasonable contrast between the brightness of the obstacle and of the surroundings, provided the observer is not otherwise engaged (Graham, 1965).
Drivers of vehicles, however, are otherwise engaged, for instance in watching the road, detecting and interpreting traffic signs. A threshold value of 0.001 radian/sec might be a fair approximation for them. The width of most vehicles does not exceed 2 metres.
Upon approaching a vehicle ahead after dark, the distance between its rear lights is the criterion. This distance is usually not less than 1.5 metres.

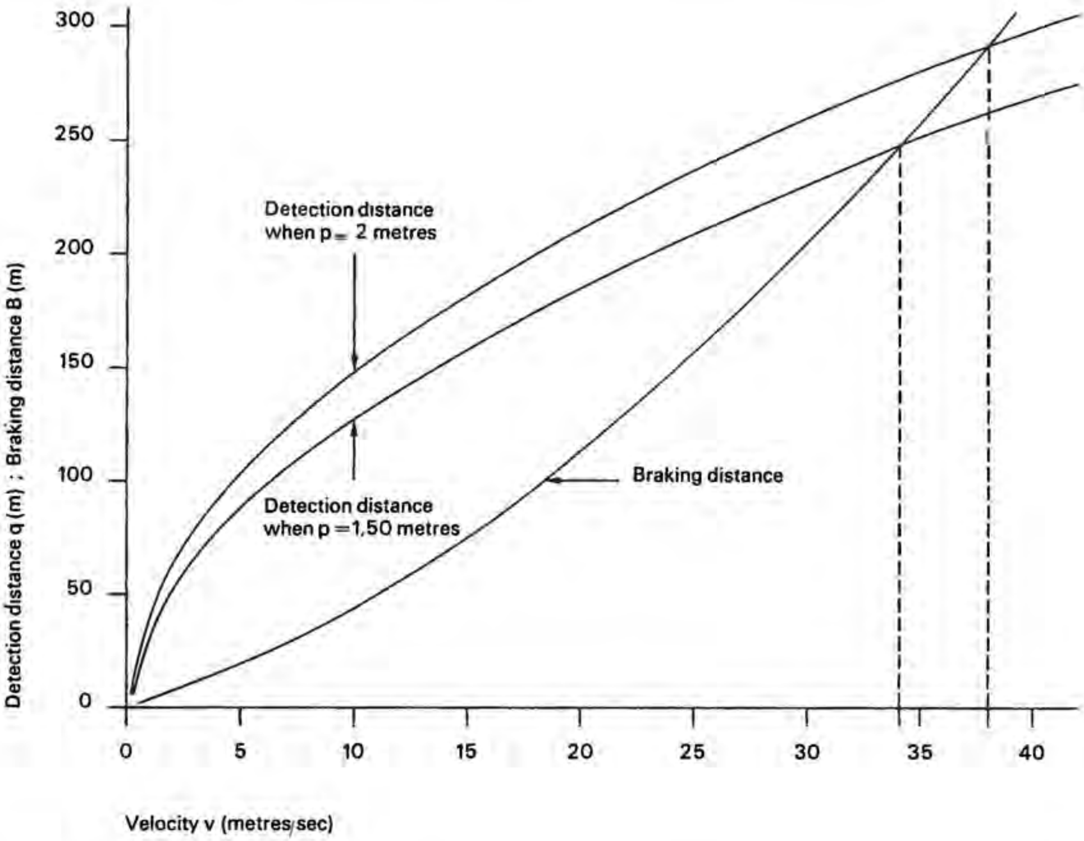



**Diagram 2. Detection distance (q) when p = 2 metres and when p = 1.50 metres, and braking distance B as a function of velocity v.**

Substitution in (1.2) of:

$\Delta t$ = observation time = 1 sec

$\frac{\Delta \alpha}{\Delta t}$ = threshold value = 0.001 radian/sec

p = vehicle width = 1.5 or 2 metres

gives:

$$v = \frac{0.001\ q^2}{1.5 + 0.001 \cdot q}\ ;\ \text{and}\ v = \frac{0.001\ q^2}{2 + 0.001 \cdot q} \qquad (1.3)$$

These formulae indicate the correlation between distance q at which the driver of a vehicle moving at velocity v can detect a difference in speed compared with a stationary vehicle 1.5 or 2 metres wide as being stationary, and speed v.

A critical situation arises if the detection distance is less than the required braking distance B. The latter can be approximated from:

$$B = RT \cdot v + \frac{v^2}{2a} \tag{1.4}$$

In order to respond to sudden eventualities, such as seeing a stationary vehicle on the road, a driver's reaction time RT of 3 seconds would not be exceptional. (This includes the time elapsing before the vehicle responds to the driver's action).

The legal minimum deceleration a—on a dry, clean road surface—is 5.2 m/sec for passenger cars. For most passenger cars, however, the maximum deceleration is determined not only by the brakes but also by the coefficient of friction between tyre and road surface, i.e. by the anti-skid properties of the road surface.
Deceleration obtainable in practice on a dry surface are in the order of 7 metres/sec²–10 metres/sec².
The anti-skid properties of wet roads, however, is often much less than of dry roads, and the coefficient is thus also lower. The State Road Laboratory (Rijkswegenbouwlaboratorium) regards a (State) road with a coefficient of 0.51 while wet as adequate. The decelerations obtainable for passenger cars on such a surface will be about 4 metres/sec².
Although buses and trucks on a dry surface often have lower decelerations—thel egal requirements for these are 4.5 metres/sec² and 4.0 metres/sec²—decelerations on a wet surface (with properly adjusted brakes) will not be much lower than for passenger cars. As buses and trucks usually drive slower than passenger cars, their situation is less critical. It is not unrealistic, therefore, to allow for an attainable deceleration of 4 metres/sec².

Substitution of:
$RT = 3$ sec
$a = 4$ m/sec²
in the equation for the braking distance (1.4) gives:

$$B = 3v + \frac{v^2}{8} \tag{1.5}$$

Equations (1.3) and (1.5) are shown as a graph in Diagram 2 (page 22). It can be inferred from the graph that the detection distance q when $p = 1.5$ m may be adequate (i.e. greater than the required braking distance) at speeds up to 34 metres/sec (120 km/h).
At speeds of $v > 120$ km/h, however, $q < B$ and a difference in speed compared with a stationary vehicle will no longer be detectable in time.

## Conclusions

The foregoing has shown the need to indicate vehicles *stationary in the carriageway*, so that approaching drivers can recognize them.
This applies not only to vehicles stationary on an unlit or inadequately lighted road after dark but also, though to a less extent, to vehicles stationary in the carriageway in daylight. But it applies less to vehicles stationary on the verge or hard shoulder, when it can often be seen from their location whether they are stationary. It must be added that such an indication is not a complete solution. The driver first approaching might be warned in time of the vehicle standing in the carriageway, but not the drivers of following vehicles which, bearing in mind the distance they are behind the vehicle ahead, will not always be able to avoid running into it from behind if its driver brakes.

## 2. Number of collisions with stationary vehicles on the road (in or next to the carriageway) in the Netherlands

Collisions with vehicles standing in the carriageway are not shown separately in the figures furnished by the Central Bureau of Statistics in the Netherlands CBS, since vehicles stationary in the carriageway are classified as 'moving vehicles'. Part of the total number of collisions with vehicles (in or next to the carriageway), i.e. cases in which the vehicle is in the carriageway, are classified by the CBS as 'collisions between moving vehicles'.
Consequently, these CBS statistics form an underestimate of the actual number of collisions with vehicles stationary on the road.
All vehicles stationary next to the carriageway (on the verge or a parking strip or hard shoulder) are classified by the CBS as 'parked', even in cases in which vehicles (except for buses) have stopped for goods or passengers to be taken on or off.
Owing to this, the statistics for the number of collisions between moving and parked vehicles form an overestimate of the number of collisions with stationary vehicles which under present legislation ought to be indicated as such with a warning triangle.
Available statistics are therefore inadequate for ascertaining the precise number of collisions with vehicles standing in or next to the carriageway. The extent of such accidents can therefore be estimated only very roughly from the number of 'collisions between moving and parked vehicles'. Table 1 shows figures for 1960 to 1963. Figures for subsequent years are incomplete. They cannot therefore be compared and have thus been disregarded.

Table 1 permits the following conclusions:
a. the total number of 'collisions between moving and parked vehicles' both inside and outside built-up areas (1960: 20,549; 1963: 29,850) is 10–15% of all accidents (1960: 177,469; 1963: 231,198);
b. the number of such accidents outside built-up areas (1960: 1319; 1963: 1851) is 3–5% of the total number of traffic accidents outside built-up areas (1960: 31,608; 1963: 41,495);
c. the number of such accidents outside built-up areas in the dusk and after dark is about 35% of the total number of collisions outside built-up areas.

Fully effective measures for vehicles standing in or alongside the carriageway would, at a very rough estimate, perhaps avoid about 2000 collisions between moving and stationary vehicles outside built-up areas.

It is not known to what extent such a result can be approached with a system like the warning triangle. Nor can any relevant estimate be made, because this would require unrealistic assumptions, such as:
a. that a system warning drivers that vehicles are stationary in or by the carriageway is sufficient to avoid collisions with such vehicles;
b. that a reduction in the number of collisions with vehicles standing in or by the carriageway is not accompanied by an increase in another type of collision (for instance between moving vehicles);
c. that the triangle has an adequate warning effect under all conditions.

This report will, however, examine the standards the triangle should satisfy as a warning system for vehicles standing on the road, but disregarding the aspects relating to:
a. the relative effectiveness of warning triangles compared with other systems, such as automatic, continuous flashing of brake lights and/or direction indicators;
b. the effectiveness of triangles measured by the pattern of traffic accidents before and after introduction of the warning triangle regulations.

| | Number of accidents in the Netherlands | Outside built-up areas | Inside built-up areas | Number of collisions between moving and parked vehicles | Number outside built-up areas | |
|---|---|---|---|---|---|---|
| | | | | | daytime | at dusk and after dark |
| 1960 | | | | | | |
| Fatal | 1,839 | 1,020 | 819 | 45 | 7 | 16 |
| With injuries | 41,633 | 10,507 | 31,126 | 1,785 | 129 | 150 |
| Car damage only | 133,997 | 20,081 | 113,916 | 18,719 | 740 | 277 |
| Total | 177,469 | 31,608 | 145,861 | 20,549 | 876 | 443 |
| 1961 | | | | | | |
| Fatal | 1,877 | 1,058 | 819 | 65 | 17 | 24 |
| With injuries | 43,146 | 11,486 | 31,660 | 1,917 | 145 | 184 |
| Car damage only | 145,257 | 22,746 | 122,511 | 20,998 | 916 | 321 |
| Total | 190,280 | 35,290 | 154,990 | 22,980 | 1,078 | 529 |
| 1962 | | | | | | |
| Fatal | 1,956 | 1,066 | 890 | 45 | 5 | 15 |
| With injuries | 43,024 | 11,248 | 31,776 | 1,948 | 148 | 165 |
| Car damage only | 160,004 | 23,992 | 136,012 | 22,554 | 870 | 298 |
| Total | 204,984 | 36,306 | 168,678 | 24,547 | 1,023 | 478 |
| 1963 | | | | | | |
| Fatal | 1,889 | 1,066 | 823 | 53 | 5 | 22 |
| With injuries | 43,402 | 11,537 | 31,865 | 1,863 | 169 | 155 |
| Car damage only | 185,907 | 28,892 | 157,015 | 27,934 | 1,093 | 407 |
| Total | 231,198 | 41,495 | 189,703 | 29,850 | 1,267 | 584 |

Table 1. Number of accidents in the Netherlands, inside and outside built-up areas, and number of collisions between moving and parked vehicles 1960–1963. (Statistics from 1964 on do not include these data).

# 3. Warning triangle regulations

## 3.1.

Article 78 of the Traffic Rules and Signs Regulations in the Netherlands prescribes the use of a red reflectorized warning triangle by drivers of motor vehicles with more than two wheels in the following circumstances:
1. If the regulation front or rear lights of a stationary vehicle are defective this vehicle must be indicated after dark outside a built-up area by means of a red reflecting triangle, placed properly visible on the road about 30 metres away from the vehicle:
a. facing traffic approaching from the rear if the rear lights are defective and the vehicle is standing at the right* of the road;
b. facing oncoming traffic if the front lights are defective and the vehicle is standing at the left of the road.
2. The foregoing paragraph applies similarly if a vehicle is stationary, even in daytime, in such a place that it cannot be observed by other drivers in time.
3. The Minister may issue detailed regulations regarding the triangle referred to in para. 1.
4. Drivers of motor vehicles with more than two wheels must carry a triangle as referred to in para. 1, in their vehicles outside built-up areas.

## 3.2.

The legislator's assumption appears to have been that the function of the warning triangle is: to make a stationary vehicle more conspicuous and not that it should serve as a means of indicating that the vehicle is stationary on the road.

If the regulation lights are not defective, however, this supplies no information on whether the vehicle in question is stationary or not. To promote road safety it is therefore desirable that the use of a warning system like the triangle should not be limited to vehicles with defective lighting standing on the road.

## 3.3.

The use of a warning triangle might also be advisable in daytime, especially by vehicles standing in the carriageway.
It seems insufficient to limit the use of a warning triangle in daytime to the cases now mentioned in Article 78 of the Regulations.
Moreover, the warning triangle or a similar warning system cannot be regarded as adequate for vehicles standing in the carriageway, either in daytime or after dark.
Lastly, a single sign (the warning triangle in this case) for vehicles standing in the carriageway and also next to the carriageway (i.e. outside the path of approaching drivers) may be confusing and quickly lose its value as a signal.

* In the Netherlands right handed traffic is prescribed.

3.4.

The legislator apparently assumed that vehicles would always be stationary either at the left or the right of the road. But it may also happen that a vehicle is standing in more than one lane. If this happens on a road with separate carriageways a warning is needed for traffic approaching from the rear and the present regulation suffices. If the vehicle is blocking more than one lane on a road without separate carriageways, however, a warning to drivers from one direction is insufficient. This latter case may easily occur, for instance, with buses and trucks (with trailers).
Some countries (among them Spain and South Africa) have made the use of two triangles compulsory in such cases.

# 4. The perceptibility of warning triangles

## 4.1. Analysis

### 4.1.1. Recognizability distance and braking distance

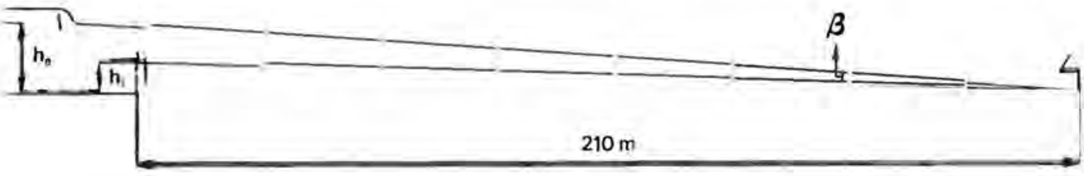
The requirement for perceptibility of the warning triangle is that it must be recognizable to an approaching driver such a distance away that he can stop his vehicle before the stationary vehicle in time. The distance at which the triangle can be recognized must thus be at least equal to the braking distance. If the vehicle speed v is taken at the 85% level in the distribution of vehicle speeds on roads with separate carriageways (= 120 km/h), if a is 4 metres/sec² and RT = 3 sec. (see para. 1.3) the braking distance B will be 240 metres, calculated by formula (1.4).
On this basis the recognizability distance of the warning triangle set up near the vehicle would have to be at least 240 metres.
If the triangle is placed 30 metres away from the stationary vehicle as required by Article 78 of the Regulations, a recognizability distance of 210 metres would suffice.
A recognizability distance of 240 (210) metres means that the reflective power must be of a relatively high standard.
This determines the illumination caused at the plane of the eye by a warning triangle illuminated by low-beam headlights. The relationship between visibility distance and reflective power will be ascertained below.

### 4.1.2. Visibility distance and reflective power

Diagram 3 is a sketch of the conditions under which the driver of an approaching vehicle observes a warning triangle located on the road 210 metres ahead of him.

The luminous intensity of two properly adjusted asymmetrical low-beam headlights complying with the regulations is about 1200 cd in the direction of the triangle. This value is determined as follows: the maximum permissible illumination at a distance of 25 metres straight in front of the low-beam headlight ($E_H$) = 0.7 lux. Per lamp this corresponds to $0.7 \cdot 25^2 = 440$ cd. As a warning triangle is placed a little lower than a normal low-beam headlight, a slightly greater luminous intensity has been allowed for per lamp (i.e. 600 cd). In actual use the value may prove less, for instance because the reflector and/or the glass are dirty.
If the warning triangle is 210 metres from the headlamps, the illumination is about $1200/210^2 = 0.027$ lux. For material with a very poor reflective power of 10 cd/m² per lux, the luminance of the triangle would be 0.27 cd/m².

The road surface luminance at this location, with a fairly light material like dry concrete, is about 0.001 cd/m², or 270 times less than the luminance of the triangle.
Even if the warning triangle has a very good (80%) diffuse reflecting white surface for its background, the contrast is *still* very great. This surface would have a luminance of $0.8/\pi \cdot 0.027 = 0.007$ cd/m², which is in any case 40 times less than the luminance of the triangle.
The background luminance thus has a negligible effect on visibility of the triangle because the contrast is always very great.
It is therefore possible to calculate the visibility distance as a function of the amount of light reflected in the observer's direction and the threshold value of the illumination at the observer's eye.




△ = warning triangle
$h_e$ = height of driver's eye relative to road surface (for passenger cars 110 cm, for trucks 150–200 cm
$h_l$ = height of vehicle's headlamp relative to road surface (75 cm)
$\beta$ = angle between direction of observation and direction of illumination (passenger cars 5' to 6'; trucks 10' to 20')

Diagram 3. Sketch of the conditions under which a driver of an approaching vehicle observes a warning triangle on the road 210 metres ahead of him.

The relation between visibility distance D (in metres) and reflective power R (in cd/m² per lux) of the warning triangle could be assessed from:

$$E_\Delta = \frac{I}{D^2}$$

$$L_\Delta = R \cdot E_\Delta$$

$$I_\Delta = L_\Delta \cdot O = R \cdot E_\Delta \cdot O = \frac{R \cdot I \cdot O}{D^2}$$

$$E_o = \frac{I_\Delta}{D^2} = \frac{R \cdot I \cdot O}{D^4} \qquad (4.1)$$

This formula is derived from the law of photometric distance. It has been assumed that the distance that has to be used in the formula relating to this law is identical to the geometrical distance between lamp + observer and reflectorized object. It has also been assumed that a constant figure is applicable for $E_o$.
If $E_o$ is higher than the threshold value of the illumination at the eye, the triangle will be visible. The international criterion for signalling lights is a threshold value of $2 \cdot 10^{-7}$ lux. It has been assumed that this value is also applicable to traffic conditions.
A single asymmetrical low-beam headlight focused at 210 metres has an intensity of about 600 cd. Hence two headlamps have 1200 cd.
The active reflectorized area O of the (open) equilateral triangle, whose sides are 45 cm long and 5 cm wide, is 400 cm². A triangle with the minimum permitted dimensions of $z = z_{min}$ = 400 mm; $b = b_{min}$ = 41 mm, has an area of 454 cm². If the corners are moreover rounded, with a radius of $u = 1/2\ b_{min}$ = 20.5 mm, and if there is also on each side one linear interruption of the maximum width (12 mm), the active reflectorized area will be 428 cm².

The testing requirements (see Annex 1) are that the minimum active reflectorized area must be 400 $cm^2$.
These values entered in (4.1) gives:

$$2 \cdot 10^{-7} = \frac{R \cdot 1200 \cdot 0.040}{D^4}$$

Whence:

$$D = 125 \sqrt[4]{R} \text{ (in m)}$$

For a visibility distance of 210 metres, R would have to be at least about 8 $cd/m^2$ per lux.

### 4.1.3. Visibility distance and glare

A warning triangle with a reflective power of at least about 8 $cd/m^2$ per lux placed on an unlit road and illuminated by the (asymmetrical) low-beam headlights of an approaching vehicle would thus have to be visible to this vehicle's driver from a distance of about 210 metres. If the driver is dazzled by an oncoming vehicle's low-beam headlights, this distance will be reduced. The effect of this glare can be described as the occurrence of an additional veil in the observer's field of vision. The equivalent luminance of this veil can be assessed for a single light source from:

$$L_s = \frac{K \cdot E_o}{\theta^n} \qquad (4.2)$$

When $d \ll D$, $\theta$ can be replaced by $\frac{180}{\pi} \cdot \frac{d}{R}$.

When $\theta > 1.5°$, Hartmann and Moser (1968) find that $n = 2$, $K = 17.7 \pm 2.6$.
Substitution in formula (4.2) of $K = 17.7$ and $n = 2$

$$\theta = \frac{180}{\pi} \cdot \frac{d}{R}$$

$$E_o = \frac{I}{R^2}$$

gives:

$$L_s = \frac{I}{186d^2} \qquad (4.3)$$

With a constant luminous intensity, and if $d \ll D$, the equivalent veiling luminance is therefore independent of the visibility distance.

The equivalent veiling luminance (of the glare) is inversely proportional to the square of the lateral distance between the object observed and the glaring light source, at least if the distal distance is very great compared with this lateral distance (up to a maximum of the distance when $\theta = 1.5°$).

Reduced visibility owing to glare will occur mainly on roads without separate carriageways. The width of such roads is often no more than 2 . 3.6 = 7.2 metres. This means in practice that on such roads (with right-handed traffic) the distance $d_1$ (that between the warning triangle and an oncoming vehicle's right* low-beam headlight) will be about 3 metres; depending on the vehicle's width the distance $d_2$ (that between the triangle and the oncoming vehicle's left* low-beam headlight) will often be 4 to 4.5 metres.

### 4.1.4. Glare and reflective power

What standards must be set for reflective power of the warning triangle in order for it to remain visible far enough away if there are glaring light sources? Formula (4.3) shows that the equivalent veiling luminance $L_s$ depends solely on the oncoming vehicle's lateral position and not on the distal distance between observer and glaring light source.
The angle $\theta$ between the right* (glaring) headlamp and the warning triangle when $d_1 = 3$ metres, and with a distal distance of 210 metres between observer and warning triangle, is about 50'.
Hartmann and Moser (1968) describe experiments concerning disability glare with a very small angle between the direction of view and the source of glare. When $0.25° < \theta < 1.5°$, they found $n = 3.5$ and $K = 50 \pm 6$.

Applied to warning triangle conditions this gives, when D = 210 metres, I = 600 cd per lamp, $d_1$ = 3 metres, $d_2$ = 4.5 metres, for the average equivalent veiling luminance $L_s = L_{s_1} + L_{s_2}$:

$$L_{s_1} = \frac{50 \cdot 600}{210^2 (0.82)^{3.5}} = 1.36 \text{ cd/m}^2$$

$$L_{s_2} = \frac{50 \cdot 600}{210^2 (1.22)^{3.5}} = 0.34 \text{ cd/m}^2$$

$$L_s = L_{s_1} + L_{s_2} = 1.70 \text{ cd/m}^2$$

The minimum difference between the luminance of the warning triangle and the equivalent veiling luminance necessary for visibility can be estimated from Diagram 4 (Adrian, 1965). It must be remembered that the veil spreads over the triangle and over the immediate surroundings. This means that the luminances of the triangle and of the surroundings seen by the observer will both be $L_s$ higher than the intrinsic luminances actually existing at the location of the objects. The intrinsic luminance of the surroundings under the conditions now described may be taken as nil, and therefore the difference between triangle and surroundings luminances is equivalent to the intrinsic luminance of the triangle due to the observer's low-beam headlights.

The dimension $\alpha$ (measured as an angle) of the triangle is taken as the diameter of a circle with the same area as the triangle (0.040 m²). When D = 210 metres, this gives: $\alpha$ = about 4'.

* Seen from the observers point of view

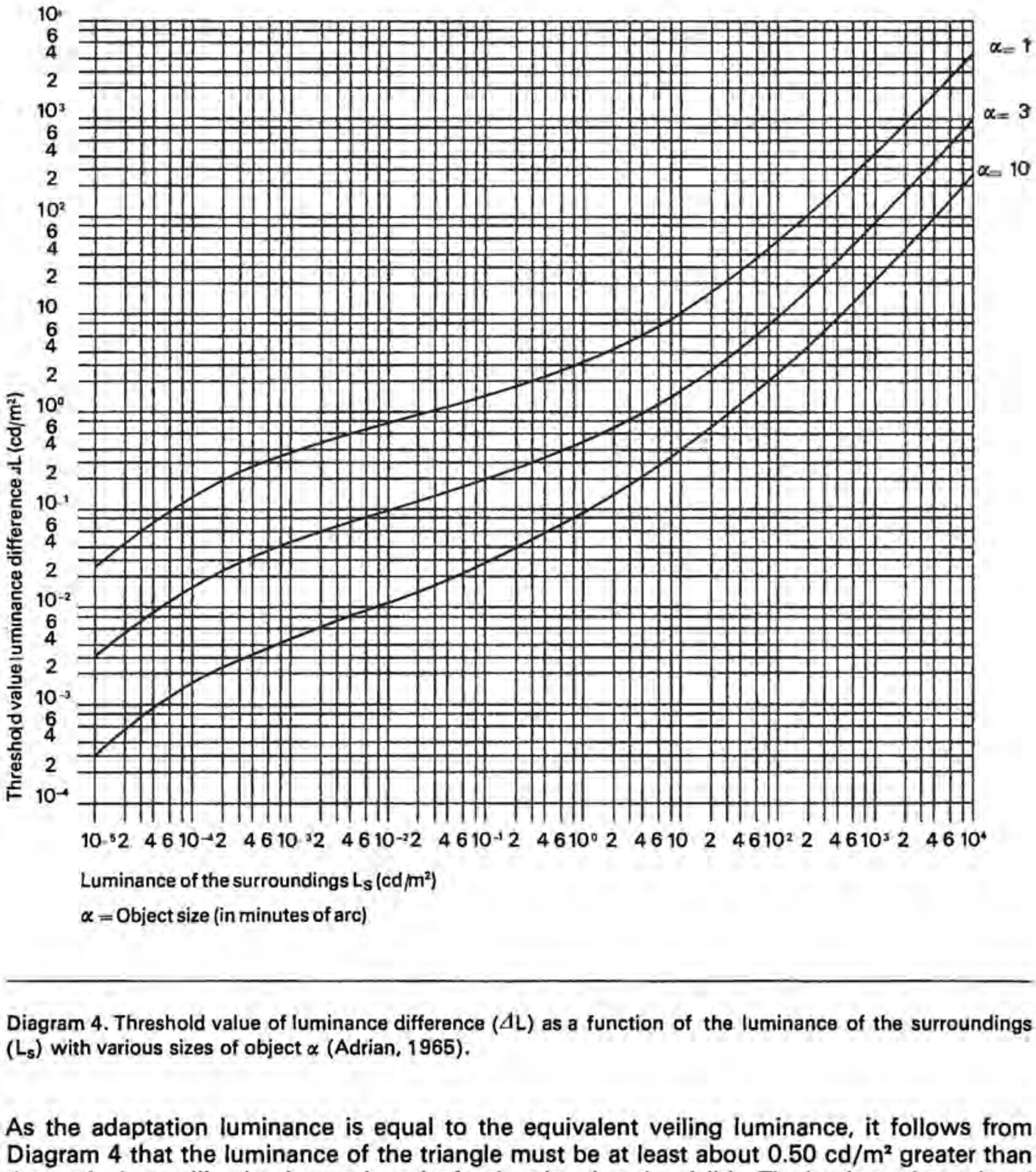



**Diagram 4.** Threshold value of luminance difference ($\Delta L$) as a function of the luminance of the surroundings ($L_s$) with various sizes of object $\alpha$ (Adrian, 1965).

As the adaptation luminance is equal to the equivalent veiling luminance, it follows from Diagram 4 that the luminance of the triangle must be at least about 0.50 cd/m² greater than the equivalent veiling luminance in order for the triangle to be visible. The luminous intensity of two asymmetrical headlamps in the direction of the triangle is about 1200 cd. The illumination on the triangle at 210 metres is then about 0.027 lux. The reflective power of the warning triangle needed for a visibility distance of 210 metres, when the observer is dazzled by the oncoming vehicle's low beam headlights, would then have to be about 0.500/0.027 = 18 cd/m² per lux (luminance of the surroundings taken as nil).

If an oncoming vehicle's low-beam headlights dazzle the observer at lateral distances of 3 metres and of 4.5 metres from the warning triangle, the reflective power of the triangle would thus have to be at least 18 cd/m² per lux for it still to be visible at 210 metres. This will, however, be too little if the distance between the warning triangle and the oncoming vehicle's low-beam headlights is *less* than 3 metres.

With distances $d_1 = 2$ metres and $d_2 = 3$ metres, a reflective power of about 50 cd/m² per lux would be required for the triangle to be visible 210 metres away. Such cases may occur in practice if, for instance, the triangle is placed before a vehicle stationary in a bend at the right and the driver approaching this obstacle is dazzled by an oncoming vehicle's low-beam headlights.

### 4.1.5. Visibility and recognizability

The calculations of the reflective power were based on the criterion of 'visibility'.
For the warning triangle to function effectively, visibility is necessary, but not sufficient. Drivers after all need a danger warning which they recognize as such immediately.
The recognizability distance is determined by the observation of specific details, and also the over-all impression of the object observed.
1. It is assumed that ability to distinguish a circular object 4.4 cm in diameter (the minimum permitted width of the sides of the warning triangle) is a criterion for recognizability of the triangle. The reflective power required for a recognizability distance of 210 metres can be calculated as follows if the observer is dazzled by an oncoming vehicle's low-beam headlights at distances of 3 metres and 4.5 metres from the triangle.
If the size of the object is taken as a circle 4.4 cm in diameter, the dimension $\alpha$ (measured as an angle) at 210 metres will be about 0.8'. If $\alpha = 0.8'$ and $L_s = 1.7$ cd/m² (See page 31): $\Delta L = 4.5$ cd/m². This gives $R > 150$ cd/m² per lux.
2. On the assumption that visibility of one of the corners is a criterion for recognition and if the size of the object is taken as the diameter of a circle with the same area as (a triangle with) 1/3 of the total reflectorized surface of the warning triangle, then $\alpha = 2.5'$. For this value of $\alpha$ and when $L_s = 1.7$ cd/m²: $\Delta L = 1.2$ cd/m² and $R = 1.2/0.027 = 44$ cd/m² per lux.
3. Assuming the over-all impression to be the criterion of recognizability, the necessary reflective power would be equivalent to that needed for visibility of the entire triangle (18 cd/m² per lux).

An estimate of the reflective power required for recognizability at 210 metres with distances $d_1 = 3$ metres and $d_2 = 4.5$ metres between the warning triangle and an oncoming vehicle's two low-beam headlights thus varies between about 18 and 150 cd/m² per lux, depending on which parts of the triangle it is assumed must be visible. On the basis of this it is therefore impossible to indicate standards for the reflective power of warning triangles. *The conclusion is that only empiric research into recognizability can supply the required information.*

## 4.2. Empiric approach

### 4.2.1. Object

The object of the research into the perceptibility of warning triangles was: 'To obtain data on the recognizability distance for warning triangles in daytime, at night and in the dusk, as a function of reflective power and location of the triangle relative to the axis of the road.'

The ultimate object was to arrive at standards for reflective power which the triangle must satisfy for recognizability. The perceptibility research carried out by the Institute for Perception RVO-TNO was not fundamental, for instance it was not aimed at the relationship between recognizability of the triangle and glare affecting the observer. This section summarizes the report on the research. A fuller report is given in IZF Report 1967-C6.

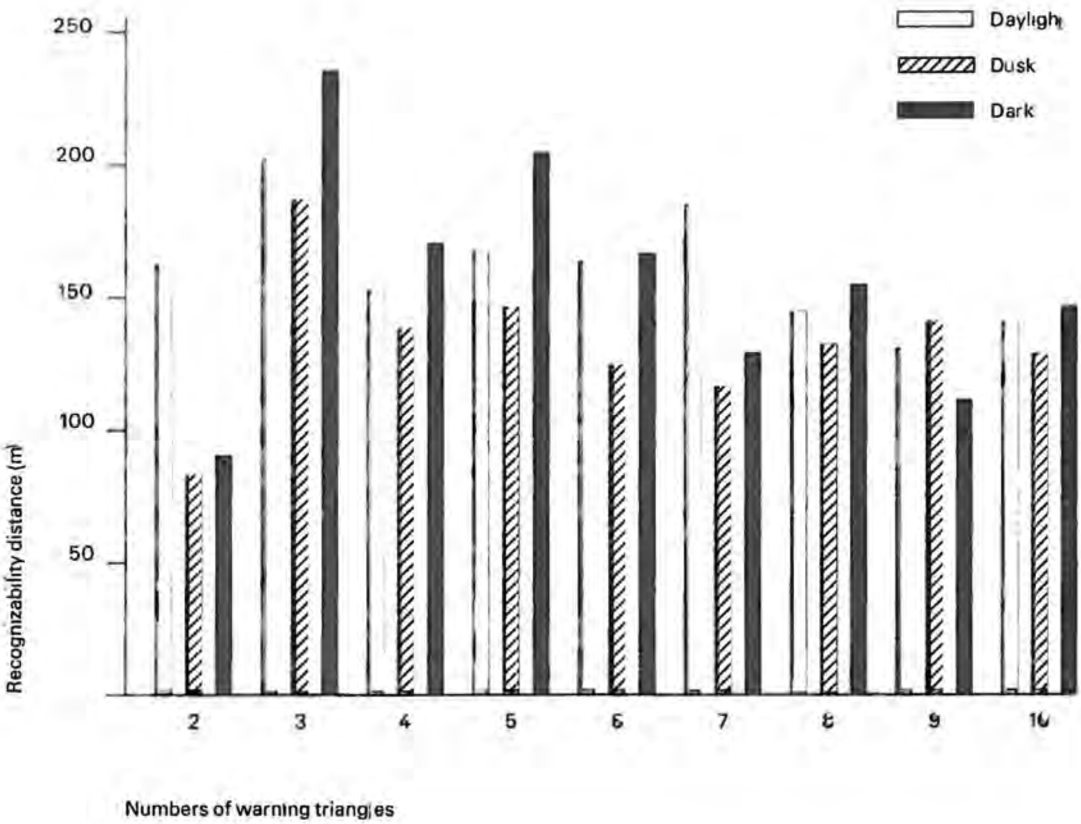



Diagram 5. Recognizability distance of warning triangles in daylight, dusk and after dark (IZF Report 1967. C6).

### 4.2.2. Procedure

The selected test conditions for perceptibility were:

a. daylight;
b. dusk, with an oncoming vehicle using low-beam headlights;
c. after dark (unlit road), with an oncoming vehicle using low-beam headlights.

The tests to determine recognizability distance were made on a stretch of road outside a built-up area.

The warning triangles were placed at three different angles to the axis of the road, i.e. 90°, 80° and 45°. The low-beam headlights of a (pseudo) oncoming vehicle were two stationary lights whose intensity and beams complied with the international standards on the European continent for asymmetrical low-beam headlights (known as E low-beam headlights). The lateral distance d, between the warning triangle and the right light (looked at from the observer's position) was 2.9 metres; the distance d, between the triangle and the left light was 4.1 metres (calculated from the centres of the lamps).
The distance between the two lights and between lights and road surface were comparable with those of low-beam headlights on passenger cars.

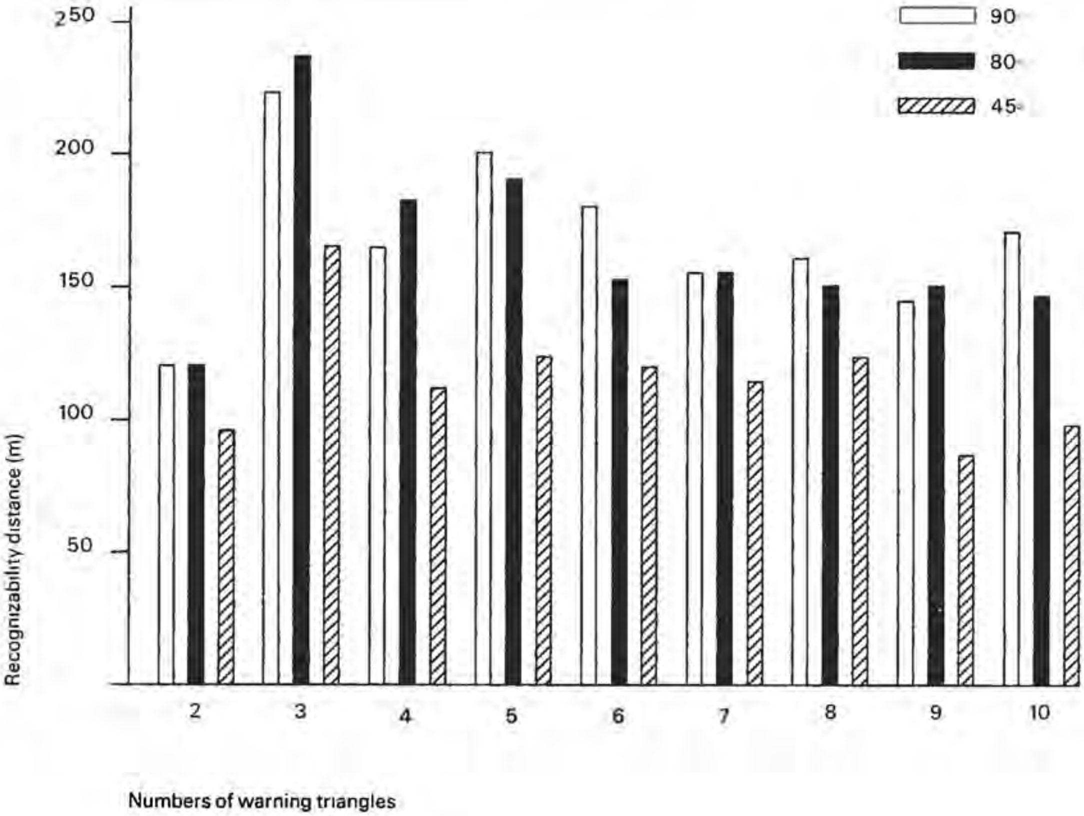



**Diagram 6. Recognizability distance of warning triangles as a function of the angle relative to the axis of the road (IZF Report 1967-C6).**

Nine persons acted as observers in a car which drove over the stretch at a constant speed of 45 km/h. In the dusk and after dark the car had two lighted asymmetrical low-beam headlights. Each triangle was presented to each observer once at nine different points along the road. This was done both in daylight and dusk and after dark.

In this way, nine different warning triangles commercially available in the Netherlands early in 1967 were tested for recognizability distance.

### 4.2.3. Recognizability distance in daylight, dusk and after dark

Six of the nine tested triangles were recognizable further away after dark than in daylight and dusk. Diagram 5 illustrates this.

The recognizability distance in daytime could be increased:
a. by having warning triangles with larger dimensions;
b. by prescribing a still higher reflective power;
c. by using reflectorized material after dark and fluorescent material in daylight and dusk.

Larger dimensions for warning triangles would make them cumbersome, especially because of the greater weight and/or larger dimensions of the base area for obtaining the necessary wind stability (See Section 5).
Where the use of a warning triangle is prescribed, vehicles will usually be on the hard shoulder or the verge.
If the vehicle is stationary on the carriageway a warning triangle or a similar warning system recognizable 210 metres away will not suffice either at night or in the daytime to prevent head-tail collisions between two or more approaching vehicles. Increasing the reflective power and/or using an additional strip of red fluorescent material, specially for use in daytime, therefore seems on the one hand unnecessary and on the other hand not an adequate solution.

### 4.2.4. Location on the road

The research also showed that all tested warning triangles are recognizable at a shorter distance if they are not placed at right angles to the axis of the road. Diagram 6 shows that turning the triangle 10° relative to the position at right angles to the axis of the road has little effect, and there is thus some tolerance. At angles greater than about 30°, there is however an adverse effect upon recognizability distance. It is therefore advisable to instruct road users to place the warning triangle as much as possible at right angles to the axis of the road.

### 4.2.5. Recognizability distance and reflective power

Diagram 7 shows a relationship between the average recognizability distance and the reflective power of warning triangles under conditions when the observer is dazzled by a (pseudo) oncoming vehicle's low-beam headlights at distances of 2.9 metres and 4.1 metres beside the triangle. The tested triangles were found to differ greatly in recognizability distance. These differences correspond to the difference in reflective power.
For a recognizability distance averaging 210 metres (See 4.1.1), Diagram 7 shows a reflective power of about 90 cd/m² per lux to be needed.
Besides differences in recognizability distance between the various triangles, differences per triangle were also found between the various observers. This difference between observers, expressed as a standard deviation, is about 1/3 to 1/4 of the recognizability distance as an average for all persons (See IZF Report 1967- C6). A large part of these differences, however, are likely to be due to differences in decision criteria. This means that with the same degree of visibility (reflective power) of a triangle, observers differ in their criteria for assessing recognizability.

### 4.3. Values of reflective power estimated for visibility and observed for recognizability

With the aid of the formulae described in 4.1.3. calculations were made of the required reflective power expected for a number of recognizability distances. The basic situation in all cases was that of the practical tests as regards distances $d_1$ and $d_2$ (2.9 metres and 4.1 metres respectively) between the warning triangle and the oncoming vehicle's two low-beam headlights. For all recognizability distances the reflective power was calculated for each of the three assumptions regarding the details that have to be visible in order to recognize the triangle:
a. the entire triangle, i.e. the total reflectorized area (0.040 m²). For the calculation (See Diagram 4, page 32) this area was regarded as that of a circle (diameter 0.23 metre);
b. an area equal to one of the three sides of the triangle, i.e. 1/3 of the total reflectorized area. For calculation (See Diagram 4) this area was regarded as that of a circle (diameter: 0.16 metre);
c. an area equal to that of a circle with a diameter equal to the width of the sides of the triangle, i.e. 1/33 of the total reflectorized area (circle diameter: 0.041 metre).

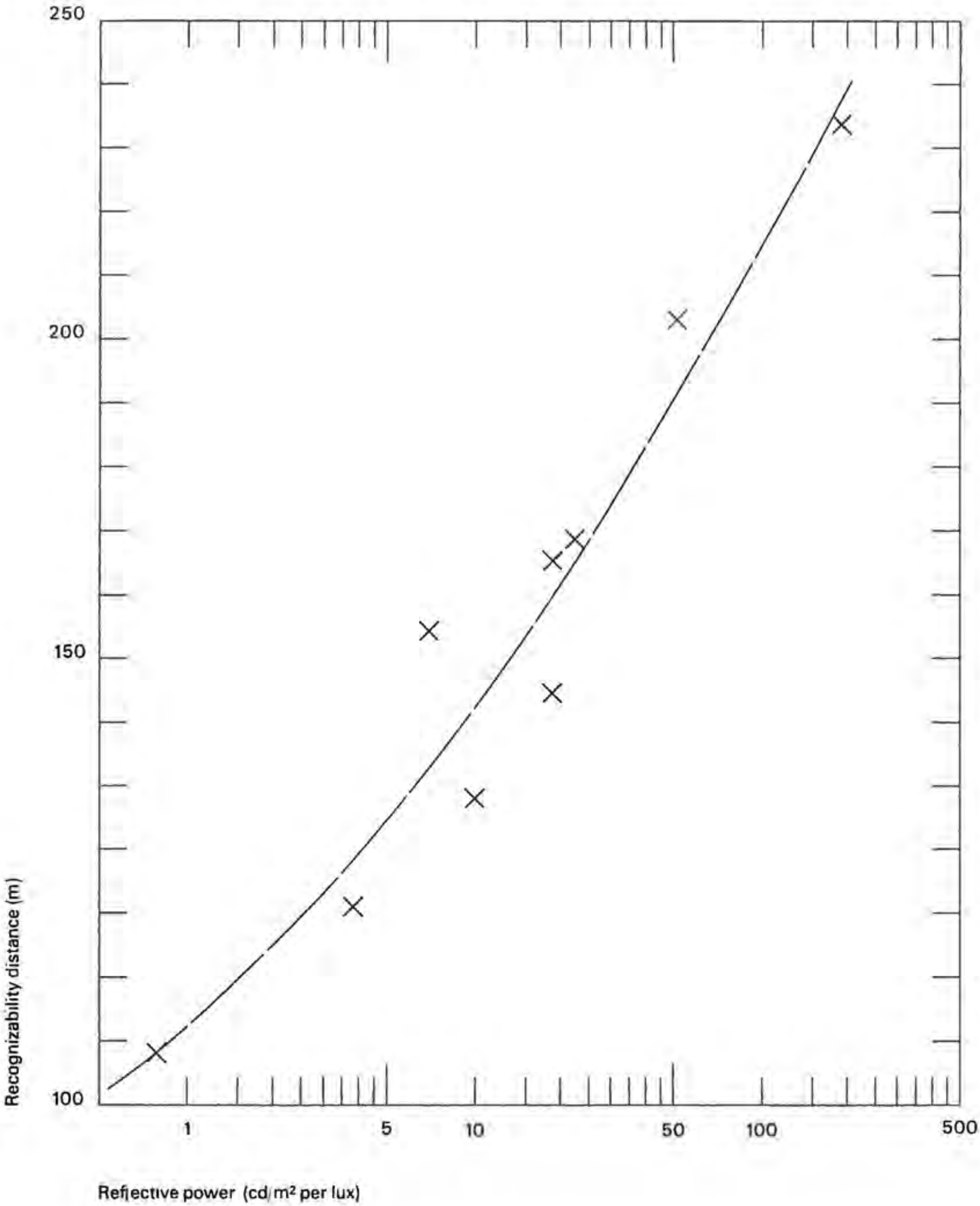



Diagram 7. Recognizability distance after dark as a function of reflective power of the warning triangel. Converted for a standardized measuring procedure

Table 2 lists the resulting values. In interpreting the values given in Table 2, the following should be noted:

1. The 'observed values' were obtained on the basis of the 'best fitting' for the results of the practical tests, owing to which inaccuracies of up to 25% of the stated reflective powers may occur in the recognizability distances of individual triangles.

2. With the stated average recognizability distances allowance must be made for a deviation between the observers which, expressed as a standard deviation, is about 1/3 to 1/4 of the average.

3. The 'expected' reflection values are averages; the relevant deviation is determined by the K and n values taken for formula (4.2).

Based on a number of preliminary assumptions, Table 2 shows that it may suffice, for detecting warning triangles, to distinguish a detail of the triangle with an area greater than 3% and less than 33⅓% of the total.

It can be calculated that the minimum distinguishable detail (depending on reflective power) must have a size (measured as an angle) of 1 to 5 minutes of arc if a triangle with a given reflective power is to be recognizable at the corresponding distance.

Table 3 illustrates this. The $\alpha$ values in this were obtained as follows:

Given D, E and $R_{obs}$; $\Delta L$ then follows from: $R = (\Delta L)/E$, $L_s$ is known.

With the aid of Diagram 4 (page 32), $\alpha$ can be determined from $L_s$ and $\Delta L$.

Table 3 shows that as $\Delta L$ (i.e. the reflective power) is greater, ability to distinguish relatively smaller detail may suffice for detecting the triangle.

If it also is true of the warning triangle that, even with a very large L, distinguishing of details necessitates dimensions of at least ½ minute of arc (See Graham, 1965), the maximum attainable recognizability distance would be about 250 to 300 metres if the observer is dazzled by an oncoming vehicle's low-beam headlights (2.9 metres and 4.1 metres from the triangle) on the assumption that detection of a detail of this size is sufficient to recognize the triangle. An estimated reflective power of 300 to 600 cd/m² per lux would then be needed for this. *With a greater reflective power, the recognizability distance could only be increased by making the dimensions of the triangle bigger.*

## 4.4. Required reflective power

### 4.4.1. After dark

Warning triangles with a reflective power of 90 cd/m² per lux will be recognizable after dark at an average distance of 210 metres if the driver of an approaching vehicle with low-beam headlights is dazzled by a single oncoming vehicle's headlights. But this requires:

1. There must be no other objects apart from the warning triangles to be detected and recognized. Only if this condition is satisfied will the recognizability distance, which is usually shorter than the visibility distance, correspond to the latter.

This condition, however, will not often be satisfied in practice. Hence, the recognizability distance of 210 metres will require a reflective power greater than 90 cd/m² per lux.

2. The lateral distance between the oncoming vehicle's low-beam headlight closest to the triangle and the triangle itself should be at least 3 metres. If the lateral distance is less, the glare which the driver approaching the triangle experiences from the oncoming vehicle's low-beam headlights will increase. A greater reflective power is then required for a recognizability distance of 210 metres.

A lateral distance less than 3 metres is not exceptional, for instance immediately before or in bends. (For this reason alone, vehicles should never be stopped at such places).

3. A distance between (the centres of) the oncoming vehicle's low-beam headlights of at least 1.20 metres. For some narrow vehicles the distance will be less than 1.20 metres, and therefore a warning triangle with a reflective power of 90 cd/m² per lux, located about 3 metres to the side of this oncoming vehicle, will not be visible 210 metres away.

| | | | Part of total reflectorized area | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 100%; ≈ (Ø circle = 0.23 m) | | | 33⅓% ≈ (Ø circle = 0.16 m) | | | 3% ≈ (Ø circle = 0.041 m) | | | |
| D (m) | $L_s$ (cd/m²) | E (lux) | α (minutes of arc) | ΔL (cd/m²) | $R_{exp}$ (cd/m² per lux) | α (minutes of arc) | ΔL (cd/m²) | $R_{exp}$ (cd/m² per lux) | α (minutes of arc) | ΔL (cd/m²) | $R_{exp}$ (cd/m² per lux) | $R_{obs}$ (cd/m² per lux) |
| 234 | 2.37 | 0.022 | 3.5 | 0.70 | 35 | 2.5 | 1.4 | 64 | < 1 | > 5.0 | > 250 | 189 |
| 210 | 2.01 | 0.027 | 4 | 0.55 | 20 | 2.5 | 1.3 | 47 | < 1 | > 4.5 | > 150 | 90 |
| 204 | 1.91 | 0.029 | 4 | 0.50 | 17 | 3 | 0.65 | 22 | < 1 | > 4.0 | > 130 | 75 |
| 200 | 1.86 | 0.030 | 4.5 | 0.45 | 15 | 3 | 0.6 | 20 | < 1 | > 4.0 | > 120 | 70 |
| 150 | 1.21 | 0.053 | 5 | 0.30 | 6 | 3.5 | 0.4 | 9 | < 1 | > 3.5 | > 70 | 14 |
| 100 | 0.66 | 0.120 | 8 | 0.15 | 1 | 5.5 | 0.2 | 1.7 | 1.5 | 1.5 | 12.5 | 1.5 |

Table 2. Reflective power estimated for visibility and observed for recognizability.

| D (m) | E (lux) | R (cd/m² per lux) | ΔL (cd/m²) | $L_s$ (cd/m²) | α (minutes of arc) | Ø (m) |
|---|---|---|---|---|---|---|
| 234 | 0.022 | 189 | 5.76 | 2.37 | 1 | 0.070 |
| 210 | 0.027 | 90 | 2.43 | 2.01 | 1.3 | 0.072 |
| 200 | 0.030 | 70 | 2.10 | 1.91 | 1.5 | 0.078 |
| 150 | 0.053 | 14 | 0.74 | 1.21 | 2 | 0.089 |
| 100 | 0.120 | 1.5 | 0.18 | 0.66 | 5 | 0.140 |

Table 3. Minimum distinguishable detail required for recognizing a triangle object size α (measured as an angle and diameter Ø).

It can therefore be concluded that a reflective power higher than 90 cd/m² per lux is advisable for warning triangles.
In Western Germany the minimum standard is 125 cd/m² per lux. This seems acceptable for the Netherlands too.

### 4.4.2. In daylight and dusk

The recognizability distance of warning triangles in daylight and dusk is less than after dark. This could be improved by increasing the reflectorized area and/or reflective power of the triangle and/or by applying an additional strip of red fluorescent material, for instance connecting with the reflectorized material on the upright sides of the triangle. There does not seem to be much need for this, however, because on the one hand vehicles standing next to the carriageway in daytime (for instance on the hard shoulder or the verge) will mostly be recognized as stationary from their very position. On the other hand, even in daytime a warning system like the triangle will not suffice, when vehicles are standing on the carriageway, to avoid head-tail collisions between vehicles whose brakes are applied when approaching a stationary vehicle.

### 4.4.3. The future

If future vehicle speeds become higher, the present proposed reflective power of warning triangles (125 cd/m² per lux) will give too short a recognizability distance in view of the braking distance required at the higher speed.

# 5. Wind stability of warning triangles

Owing to blasts of wind and/or air turbulence behind passing vehicles, the warning triangle may be moved or blown over. In that case it will not only cease to be effective but may even become a dangerous obstacle. Standards must therefore be formulated for its stability.
These standards can be arrived at from the equation for aerodynamic load of a body placed in a current of air and from those for static equilibrium of a body regarding displacement and/or tipping over.

Meteorological data show that such wind velocities may occur that the stability of the warning triangle cannot be absolutely guaranteed. The stability criterion should therefore be formulated so that the risk of instability is slight enough. A reasonable requirement based on meteorological data is thus that the risk of instability should be limited to weather conditions which do not occur in the country as a whole oftener than once a year on average. According to the information in Table 4 this leads to the condition that the warning triangle must still be stable at the upper limit of wind force 11. (The De Bilt data are more representative of the national average than the Den Helder data).

| Wind force Beaufort scale | Wind velocity in m/sec | Number of strongest blasts in periods of 1 hour (per 10,000 hours) | |
|---|---|---|---|
| | | Den Helder | De Bilt |
| 9 | 20.8–24.4 | 296 | 22 |
| 10 | 24.5–28.4 | 113 | 4 |
| 11 | 28.5–32.6 | 31 | 0.5 |
| 12 | 32.7 and higher | 12 | — |

Table 4. Frequency of occurrence of wind velocities in the Netherlands (observations 6 metres above ground level).

## 5.1. Load on warning triangle owing to air currents

The load on the triangle by air currents can be calculated from the equation

$$W = \frac{C_w \cdot F \cdot \rho \cdot V^2}{2} \qquad (5.1)$$

The frontal area F and the coefficient of air resistance $C_w$ of a warning triangle are determined by the shape and design, which in turn are determined by functional requirements such as detectability and recognizability.
The wind velocity V to be allowed for must be arrived at from available meteorological data and from available aerodynamic knowledge of flow velocities in eddies around bodies in a flowing medium, since no direct measurement data are available.
For air density constance $\rho$ the value may be taken that applies for the standard atmosphere.

### 5.1.1. Air velocity

No information is available on wind velocities in the lowest air stratum up to half a metre above ground level. Meteorological observations are made at fixed measuring points 6 metres above ground level. The resulting data cannot be used for determining stability conditions for warning triangles without correction, because wind velocities are related to height above ground level.
By means of the following considerations, available data permit a reasonable estimate to be made of the air velocity that should be allowed for.

It is known from flow theory that when currents flow past fixed bodies a velocity gradient occurs in the boundary layer of the flowing medium. This is such that in the boundary layer between the flowing medium and the bodies in it there is no sudden increase in velocity. This has also been found to apply in atmospheric currents, for instance close to the earth's surface. With a purely laminar flow the velocity gradient is constant and the velocity of the flow increases in proportion to the distance from the wall. The surface of the earth, however, has many irregularities. These cause local air-flow accelerations, disturbing the linear course of the air velocity. With turbulent currents along walls, there is likewise a velocity gradiant, but this has more influence on the average velocity in the air current than on the extent of fluctuations in velocity.

The upper limit of wind force 11, taken as the stability criterion corresponds to a wind velocity of 32.6 metres/sec (6 metres above ground level).
Civil Air Regulations prescribe strength calculations for gust intensities of 20 metres/sec. These, however, are differences in velocity compared with the movement of the surrounding air. It is reasonable to assume that the measured velocities of 32.6 metres/sec are the sum of an average velocity and a velocity fluctuation of 20 metres/sec (probably much less).
As the average velocity owing to the velocity gradient is considerably reduced and velocity fluctuations also decrease with height (a cautious estimate of these decreases is 80% and 20% respectively), it is reasonable to assume a maximum wind velocity 0.5 metres above ground level of $0.2 \times 12.6 + 0.8 \times 20 - 18.5$ metres/sec.
Based on wind-force frequency, warning triangles will be subjected to a greater force almost exclusively in windy coastal regions, for instance near Den Helder. In exceptional cases (hurricane conditions), higher wind velocities may occur inland.

There have also not been found any results of measurements for velocities that may occur in turbulences caused by passing vehicles. Flow theories, however, show that the effective extent of turbulences in a two-dimensional current around a rigid body is of the same magnitude as the dimensions of the body at right angles to the direction of flow, and with a three-dimensional current are generally much smaller. The average absolute air velocities in such turbulences are much smaller than the air velocity in the undisturbed current.
Air turbulences behind trucks and buses are far more extensive than those behind passenger cars. This is due to the much greater frontal area, greater length and often angular shape of the former. Notwithstanding their lower average speed, trucks and buses therefore disturb air currents more than passenger cars, especially as more attention is paid to streamlining the latter precisely in order to suppress turbulences. Speeds of 30 metres/sec (108 km/h) are still on the high side for many trucks and buses, but are certainly not exceptional.
A reasonable estimate based on the consideration already mentioned is that average turbulent air velocities do not exceed 15 metres/sec.

Allowance must also be made for the possibility of blasts of wind occurring while trucks or buses are driving by. But it would not be correct to superpose the two effects. The increase in turbulent flow round a body in that flow is less according as the turbulence of the undisturbed flow is greater. A minor correction of the calculated wind velocity of 18.5 metres/sec is thus sufficient; 20 metres/sec seems a reasonable assumption. Possibilities of verifying this are dealt with in Annex 2.

### 5.1.2. Frontal area of the triangle

The frontal area F can be calculated from the internationally recommended principal dimensions.
For a closed triangle: (See Annex 1, Diagram a, page 51).
$F_c = 0.0872\ m^2$ if $z = 0.45$ m.

For an open triangle:
$F_o = 0.545\ m^2$ if $z = 0.45$ m and $b = 0.05$ metre.

### 5.1.3. Coefficient of air resistance and air density constant

The Institute for Road Transport Vehicles TNO, measures the coefficient of air resistance $C_w$ for open and closed triangles, with air blasts both frontally and at an angle of 45°. The results are given in Table 5.

For the standard atmosphere the air density constant is equal to: $\rho - 0.125\ kg/m^3$.

### 5.1.4. Calculation of load on triangle

The air forces applied to triangles by a frontal blast $W_0°$ and at an angle $W_{45}°$ can now be calculated. The results are given in Table 6.

## 5.2. Moving and tipping over

A warning triangle may move if the air forces become greater than the maximum reactive forces which the road surface can apply to it by friction. The conditions against movement can be formulated as: $W < \mu \cdot G$ (5.2)

This equation does not incorporate the dimensions of the base. This corresponds to the fact that stability against movement does not depend on the shape and dimensions of the base but purely on the friction properties of the base material relative to the road surface.

| $C_w$ | Air blast | |
|---|---|---|
| | Frontal | Angle 45° |
| Open triangle | 1.6 | 1.3 |
| Closed triangle | 1.06 | 1.00 |

Table 5.

| W | $W_0°$ | $W_{45}°$ |
|---|---|---|
| Open triangle | 2.18 kgf | 1.77 kgf |
| Closed triangle | 2.31 kgf | 2.18 kgf |

Table 6.

| $G_{min}$ | $\mu = 0.3$ | $\mu = 0.5$ | $\mu = 0.8$ | $\mu - 1.0$ |
|---|---|---|---|---|
| Open triangle | 7.3 kg | 4.46 kg | 2.73 kg | 2.18 kg |
| Closed triangle | 7.7 kg | 4.62 kg | 2.90 kg | 2.31 kg |

Table 7.

A warning triangle may tip over if the moment of the air forces against a stay becomes greater than the stabilizing moment supplied by the triangle's own weight as against the stay.
The conditions against tipping over can be formulated as: $W \cdot h \cdot \cos\gamma < G \cdot s$ (5.3)

As regards the dimensions of the base, this equation incorporates only dimension s. This corresponds to the fact that stability against tipping over depends solely upon the location of the corners of the base, but not on the contour. Different base shapes may be qualitatively equal (See, for instance, Diagrams 8 and 10, 9 and 11 respectively).
As stability against movement—vide equation (5.2)—is determined solely by the coefficient of friction $\mu$ and weight G of the triangle, frontal blasts are critical for both open and closed triangles. No data are available regarding the friction coefficients $\mu$ of warning triangles. Based on available friction coefficients for numerous combinations of materials, it can be assumed that the coefficients for warning triangles may range from 0.3 to more than 1. The weight needed to ensure stability against movement can be calculated from equation (5.2) if $\mu$ is known. The necessary weights G are given in Table 7 for several values of $\mu$.
This table shows how important it is to pay attention to the friction coefficient in order to limit the weight. If the base is carefully designed, a value of $\mu = 0.8$ is estimated to be sufficient for any road surface.
If this $\mu$ value and the appropriate G value are accepted, the minimum s value at which the triangle will be stable against tipping over can be calculated with equation (5.3).
The height of the pressure point in a purely homogeneous flow would coincide with the triangle's centre of gravity, i.e. at one-third of the triangle's height. Since there are fluctuations in the air velocity, the pressure point may be higher. In the extreme case this is theoretically half way up the triangle.

Therefore: $4/12\ h_{\Delta} < h_d < 6/12\ h_{\Delta}$.

No major error will therefore be made by assuming that $h_d = 5/12\ h_{\Delta}$.

For the model with the international dimensions this amounts to: h = 0.16 metre.

## 5.3. Examples

Practical application of the stability equations will be illustrated with reference to several types of warning triangle.
An open and a closed triangle with the internationally recommended dimensions and without rounded corners (See Annex 1, Diagram a, page 51) were chosen for this purpose. These triangles were assembled in succession on rectangular and diamond-shaped bases, symmetrically to the base (See Diagrams 8, 9, 10 and 11).
In the case of the base in Diagram 8 or 10, frontal blasts are most critical as regards tipping over. Directions of blast and fall correspond; therefore $\cos\gamma = 1$.
In the case of the base in Diagram 9 or Diagram 11, blasts at an angle of 45° are the most critical for tipping over. Here again directions of blast and fall correspond, and again $\cos\gamma = 1$.
The s values for which stability against blowing over is obtained are given in Table 8.

Diagram 8

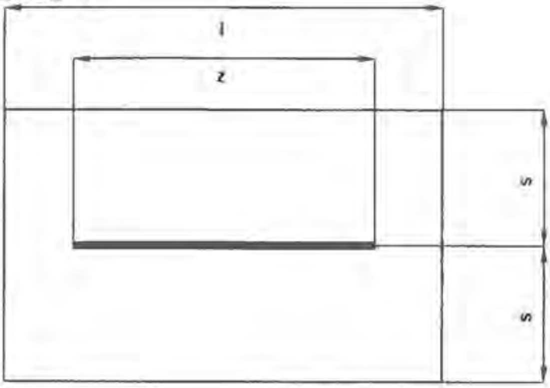



Diagram 9

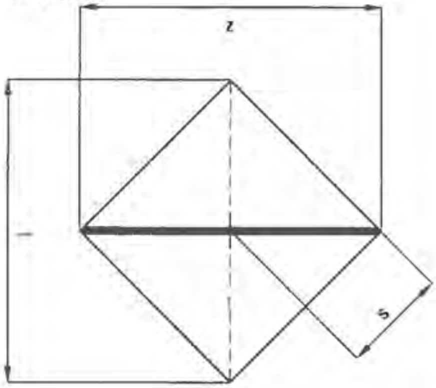



Diagram 10

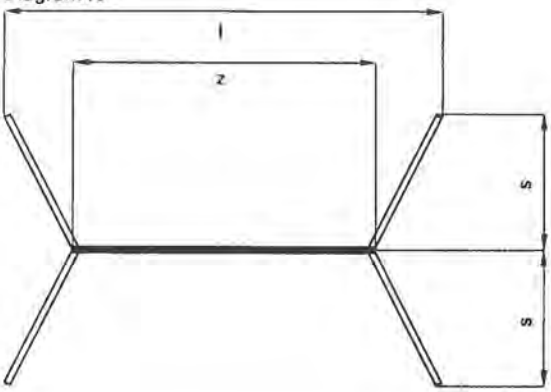



Diagram 11

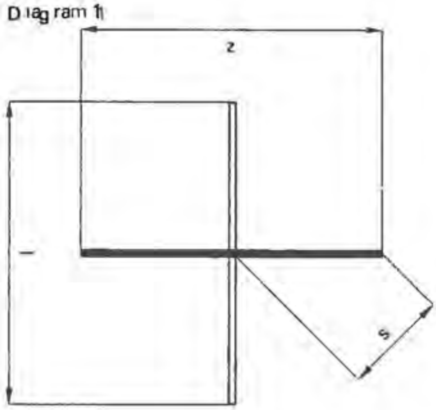



**Diagram 8.** Rectangular base for warning triangle.
**Diagram 9.** Diamond-shaped base for warning triangle.
**Diagram 10.** Base for warning triangle, with stays forming a rectangle.
**Diagram 11.** Base for warning triangle, with stays forming a diamond.

| s | Base | |
|---|---|---|
| | Diamond | Rectangle |
| Open triangle | 0.104 m | 0.128 m |
| Closed triangle | 0.121 m | 0.128 m |

Table 8.

As regards the diamond-shaped bases, it may be added that in practice these will usually be as shown in Diagram 11, the diagonals being of the same length, so that $s = \frac{1}{4} z \sqrt{2} = 0.16$ metre.
If G is sufficient with this type for stability against movement, s is automatically sufficient for stability against blowing over.
For warning triangles with bases different from those mentioned the stability calculations are fundamentally the same. The stability calculation regarding tipping over, however, must then be repeated for every possible kind of stay.

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# Annex to the report Red warning triangles

1. Recommendations for test requirements for warning triangles
2. Notes on stability tests

Prepared in collaboration with the Institute for Perception RVO-TNO, Soesterberg; the Institute for Road Transport Vehicles TNO, Delft; KEMA (N.V. tot Keuring van Electrotechnische Materialen), Arnhem; the Illumination Engineering Society in the Netherlands, Arnhem, and the Paint Research Institute TNO, Delft.

# 1. Recommendations for test requirements for warning triangles

## 1.1. Design

### 1.1.1. Definition of warning triangle

An equilateral triangle which, except for the middle part, consists of red reflectorized material; and which is or is not provided on the outside next to this material with a red fluorescent edging.

### 1.1.2. Types

A warning triangle may be made in the form of:
a. An open triangle.
This is a warning triangle the area of which within the red reflectorized sides is open.
b. A closed triangle.
This is a warning triangle the area of which within the red reflectorized sides is made of a non-reflectorized material.

## 1.2. Dimensions

The dimensions of the red reflectorized part of a warning triangle must comply with the measurements indicated in Diagram a. Dimensions z, b and u determine the contours within which a contribution must be made to the reflectorizing property. Rounding of the corners is permitted, provided the required minimum reflectorized area remains.
Non-reflectorized rectilinear interruptions between adjacent reflectorized parts are permitted, provided the width of any such interruption does not exceed 12 mm; the total effective red reflectorized area of the triangle must be at least 400 cm².

## 1.3. Photometric requirements

### 1.3.1. Colour

a. The colours of the red reflectorized and red fluorescent materials have been established with reference to the colour specification system adopted by the Commission Internationale de l'Eclairage (C.I.E., 1931).
The limits of the colour co-ordinates of the light reflected by the reflectorized material were taken from 'Requirements for motor vehicle reflectors and triangles indicating the length of trailers and articulated trucks', published by the Ministery of Transport and Waterways in the Netherlands. The co-ordinates must therefore satisfy the following conditions:

$y \leqq 0.335$
$z \leqq 0.008$

b. The colour of the red reflectorized material is assessed by illuminating the triangle with a standard light source with a colour temperature of 2850°K and by measuring the colour co-ordinates of the reflected red light at an angle of observation not exceeding 2° and an angle of orientation not exceeding 5° horizontally.

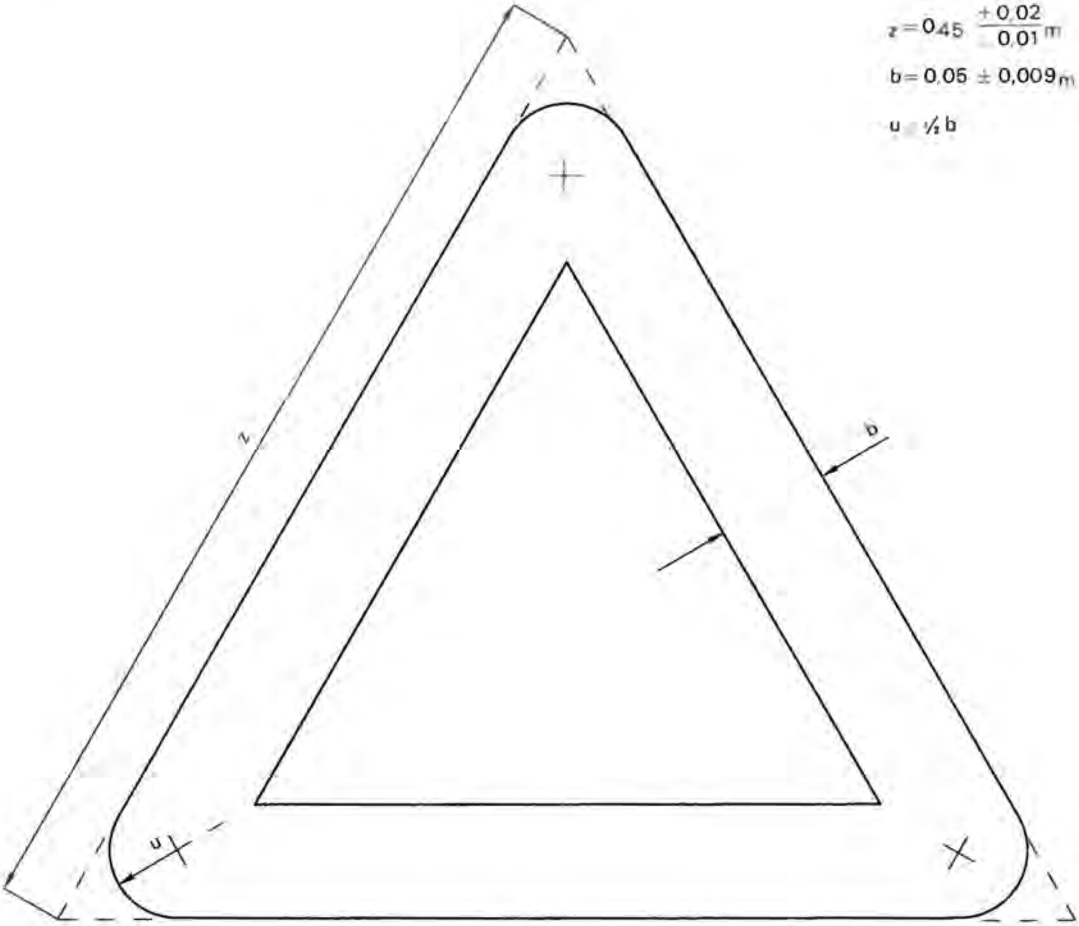


Diagram a

c. If the red reflectorized part of the warning triangle is supplemented at the outside edge with red fluorescent material, the colour co-ordinates of this material must satisfy the following C.I.E. conditions:

$y < 0.290 + 0.080\,x$
$y < 0.088 + 0.429\,x$
$y > 0.313$
$y > 0.213 + 0.165\,x$
$y > 0.830 - x$

d. The colour co-ordinates for fluorescent red apply to diffuse reflected light when illuminating the measurement point, i.e. the part of the material being examined, with standard daylight source C. The angle between the average direction of incident light and the normal at the measurement point must then be 45°, and observation must be made in the direction of the normal at the measurement point.

| Position of triangle | Minimum required reflective power (cd/m² per lux) of reflectorized area upon observation at an angle of 20′ to the average incident light direction[1,2,3] |
|---|---|
| Vertical and perpendicular to average incident light direction (angle of orientation = 0°) | 125 |
| Vertical, using angle of orientation of + and —20° (horizontally) between the normal to the triangle and the average incident light direction | 50 |

1 The reflectorized area to be tested will never be less than 20 cm², while this area must in all cases include the full width of the effective sides.
2 The reflective power relates to reflected red light.
3 The reflective power must be measured by the method mentioned in 'Requirements for motor vehicle reflectors and triangles indicating the length of trailers and articulated trucks'.

Table A

e. The back of the triangle must be of a non-reflecting shade.
f. A support belonging to the triangle must be of a dark colour.
g. The colour of non-reflectorized and non-fluorescent materials or of reflectorized and fluorescent materials of colours other than red will be assessed by visual appraisal.

### 1.3.2. Reflection

a. The reflective power of each part of the red reflectorized material must, when illuminated by a standard light source with a colour temperature of 2850° K, satisfy the requirements of Table A.
b. The diffuse reflection value for red fluorescent material—in conformity with the C.I.E. recommendations referred to in the Road Traffic Signs Standard (NEN 3381)—must be at least equal to 0.35 times the (diffuse) reflective power of a completely diffuse and totally reflectorizing white surface; expressed in the unit used for reflective power in Table A, the diffuse reflection of fluorescent material must be at least 0.112 cd/m² per lux.
Diffuse reflection is assessed under the same conditions as described in 1.3.1. d. on page 51.

### 1.4. Constructional properties

### 1.4.1. General requirements

A warning triangle must be built up in such a way that effective, practical use can be simply and obviously made of it; the construction and design of the triangle must disclose no serious demonstrable effects.
This will be judged during testing and also by setting it up as a trial.

| $C_w$ | Air blast | |
|---|---|---|
| | Frontal | Angle 45° |
| Open triangle | 1.6 | 1.3 |
| Closed triangle | 1.06 | 1.00 |

Table B

### 1.4.2. Stability

The warning triangle must not move and/or tip over owing to blasts of wind with a velocity of 20 metres/sec.
During testing, atmospheric forces may be replaced by a mechanical force, applied to a point at 5/12 of the height of the triangle, calculated with the formula:

$$W = \frac{C_w \cdot F \cdot \rho \cdot V^2}{2}$$

For the coefficient of air resistance $C_w$ the values in Table B can be taken. The frontal area of the triangle F must be measured from case to case. For the standard atmosphere the air density constant $\rho = 0.125\ kg/m^3$. The limit value for the air velocity is $V = 20\ m/sec$.

The stability test must be made for blasts both frontally and at an angle of 45°; in the case of non-symmetrical structures, moreover, for blasts from the front and from behind. The tests must be made on asphalt, concrete and paved road surfaces.

### 1.4.3. Protection against water droplets

The back of the reflectorized material must be protected against penetration of water droplets. The test is made by exposing the triangle in its normal position for 5 minutes to artificial vertical rainfall of 3 mm per minute. After this, the reflective (and fluorescent) power of the triangle must not have decreased substantially, this being assessed visually or, in case of doubt, by measurement, after the front of the triangle has been carefully dried with a cloth.

## 1.5. Material properties

### 1.5.1. Reflectorized material

The reflectorized (and fluorescent) material of the warning triangle must be properly resistant to petrol.
This is judged by wetting the front of the reflectorized (and fluorescent) material of the triangle with a cloth soaked in petrol. The reflective power (and fluorescent properties) must not have decreased substantially after this, which is judged visually or in case of doubt by measurement.

### 1.5.2. Metal parts

a. Corrosion resistance (intended solely for galvanized steel).
Corrosion resistance is determined by degreasing the metal parts and placing them for 15 minutes in a 10% sodium chloride solution at a temperature of (100 ± 5)°C.
Immediately after this, these parts are placed for 15 minutes in a similar solution but at a temperature of (20 ± 5)°C.
Next the parts are rinsed and left to dry. After treatment, the metal parts must not have been visibly corroded.
b. The warning triangle must not be deformed owing to blasts of wind with a velocity of 20 metres/sec to such an extent that the apex of the triangle during such a load is more than 70 mm beyond the vertical plane through the base.
During testing, atmospheric forces may be replaced by a mechanical force as indicated in Section 5.2 of the report Red warning triangles, provided that only the case of frontal blasts against the front need be considered and the test need be made for only one standard road surface.
c. Resistance of paint coating.
If the metal parts are painted, the paint and the undercoat must satisfy the following requirements:
1. The undercoat must be free from rust, any coating caused in rolling the metal and other deposits.
2. The coating of paint must be at least 25$\mu$ thick.
3. The adhesion of the paint must not exceed the value Gt1, as per DIN sheet 53151.

# 2. Notes on stability tests

## 2.1 Testing methods

The testing of warning triangles can be tested in four ways.

### 2.1.1. Practical test

The warning triangle is placed on the road surface. The stability requirement is satisfied if the triangle is not moved or blown over by strong blasts of wind or the suction of heavy vehicles passing at high speed.
One has no control over atmospheric conditions, however, this drawback can be largely overcome by making the stability tests for wind blasts and air turbulences separately.
a. Stability to wind blasts.
The triangle is placed on a base of road surface material, in an open area, where there are no other influences than weather effects and fairly high wind velocities are often recorded.
The test requirement is that after recording the upper limit of wind force 11 at 6 metres above ground level, the warning triangle must not have moved or tipped over.
b. Stability against turbulences behind heavy vehicles.
The warning triangle is placed not more than 1.5 metres from the average driving track, by the side of a road where heavy vehicles pass by at high speeds. The warning triangle must not be moved or tipped over after a number (for instance 100) of heavy vehicles, such as trucks have passed by.

### 2.1.2. Wind tunnel test

Stability requirements are satisfied if the triangle does not move or tip over in the wind tunnel when the air velocity is raised to 20 metres/sec.

### 2.1.3. Load test

The warning triangle is loaded at the pressure point with a force obtained with a steelyard or a weight connected to the triangle with a cord via a pulley. The load is calculated with equation (5.1) (See page 41).
The stability conditions are satisfied if the triangle does not move or tip over with the prescribed load.
The experimental test requirements described in paras. 5.4.1, 5.4.2 and 5.4.3 of the Report, must be repeated for all common types of road surface.

### 2.1.4. Mathematical test

The possible atmospheric loads on the triangle are calculated with equation (5.1). The stability requirements are complied with if formula (5.2) and (5.3) are satisfied.
The mathematical test cannot allow for the possibility of stability against movement being obtained otherwise than by friction.

## 2.2. Comparison of testing methods

In assessing the various testing methods, important factors are reliability, simplicity and the information obtained for improving stability should this prove inadequate.

| Factor | $\mu$ | $C_w$ | $V^2$ | Variance factor | Variance |
|---|---|---|---|---|---|
| Variance | 0.3–1.2 | 75%–125% | 100–900 | | |
| Variance factor | 4 | 1.67 | 9 | | |
| Practical test | — | — | — | 1 | |
| Wind tunnel test | — | — | + | 9 | $\frac{1}{3}$–3 |
| Load test | — | + | + | 15 | $\frac{1}{4}$–4 |
| Mathematical test | + | + | + | 60 | $\frac{1}{8}$–8 |

Table C.

a. The reliability of the testing method is determined by the accuracy of examination. The uncertain factors relating to stability are the air velocity V; the coefficient of air resistance $C_w$ and the friction coefficient $\mu$.
The prescribed blast velocity V = 20 metres/sec is nothing more than a considered estimate with a reasonable chance of V being in the range; 10 metres/sec < V < 30 metres/sec.
$C_w$ shows little variance for flat sheets with various contours. Nevertheless, depending on the way the edge is finished off, there may be deviations of about 25%.
Based on experience with all kinds of combinations of material all that can be assumed as regards $\mu$ is that it will be in the range $0.3 < \mu < 1.2$. The possible effect of these uncertainties on the accuracy of the various test methods is set forth in Table C.

b. The simplicity of a test method is determined by the location where the tests can be carried out and the required measuring equipment.
The *practical test* requires no measuring equipment. The information supplied by the Royal Dutch Meteorological Institute suffices.
For *the wind tunnel test* use must be made of one of the wind tunnels at the National Aerospace Laboratory (NLR).
The *load test* requires only simple test equipment. A pulley with weights is more accurate than a steelyard.
The *mathematical test* requires a rule and a scale.

c. The information obtained from the test relates to the load at which the triangle becomes unstable or starts moving or tipping over. The *practical test* determines the wind force at which the triangle becomes unstable.
If the maximum wind force occurring during the past period is recorded for every observation, the limits of the critical wind force can be determined fairly accurately after a series of observations.
Only relative figures are found, however, and not the actual wind velocity or atmospheric forces. It is not possible, therefore, to determine the coefficient of friction.
In the *wind tunnel test* the blast velocity is exactly known. As the possible variance in the coefficient of air resistance is not so great, the atmospheric force applied to the triangle can be determined with reasonable accurace. Hence the friction coefficient can be ascertained with the same accuracy as $C_w$.
With the *load test* the force applied to the triangle can be determined very accurately. The friction coefficient is therefore also ascertainable very precisely.
In the *mathematical test* the friction coefficient is assumed to be known and no information regarding the friction coefficient is obtained. The various test methods can be classified qualitatively according to each of the three criteria. The results are summarized in Table D.

| | Reliability | Simplicity | Information |
|---|---|---|---|
| Practical test | 1 | 3 | 3 |
| Wind tunnel test | 2 | 4 | 2 |
| Load test | 3 | 2 | 1 |
| Mathematical test | 4 | 1 | 4 |

Table D.

## Conclusions

1. The mathematical test is unsuitable as long as a definite value cannot be guaranteed for the friction coefficient by means of a prescribed design.
2. Except for the practical test, the accuracy of the tests is slight, owing to the uncertainty regarding air velocities.
3. The wind tunnel test is fairly cumbersome and costly.
4. The load test provides accurate information about the friction coefficient by comparatively simple means.
5. By applying the practical test to several representative warning triangles, it can be ascertained whether the estimated wind velocity is sufficiently accurate.

Designed by Cees van Dorland, Krommenie, The Netherlands
Printed by Meijer Wormerveer n.v., The Netherlands