Safety standards for express roads

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Research in the framework of the European research project SAFESTAR, Workpackage 3.4

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Summary

The objective of the SAFESTAR project is the formulation of design standards or recommendations exclusively based on safety arguments. Workpackage 3 (WP3) of SAFESTAR, of which this report is the concluding report, should result in design recommendations for single and dual-carriageway express roads of the Trans European Road Network (TERN).
The objective was to formulate the design recommendations on the basis of an extensive accident analysis (WP3.1), a description of decision-making processes in EU member states (WP3.2), the conclusions and findings of a workshop (WP3.3), and a literature review.
The main conclusion of this Workpackage (WP3.4) is that the amount of information and knowledge on safety effects of design parameters of express roads is very limited. The reports of WP3.1 to WP3.3 and of the literature review conducted in WP3.4, could therefore not result in design recommendations or safety standards. To be able to give design recommendations for express roads, elaborate research on the safety effects of the different design parameters yet has to be carried out.
In contrast with the situation for express roads, extensive research on safety effects of design characteristics has been carried out on motorways and on rural two-lane roads. Because function, design, and use of these particular road-types differ too much from express roads, this research information however cannot be simply translated to the situation on express roads. Some of the information of this research on road-categories just above and just below the express road category can however give some indication of possible effects. These indicators can therefore serve as a guide in future research on express roads.

It is recommended to restrict use of express roads to high speed motorised traffic exclusively and to limit the number of access points as much as possible.
The horizontal alignment has to be consistent and allow for a constant design speed along the entire road section. In order to distinguish clearly between situations where overtaking is, or is not, possible, intermediate curve radii (between approximately 800 m and 2,000 m) must be avoided. The distance between two successive curves or between a straight section and a curve should be large enough to judge and interpret the situation (a recommendation is expected to be around 3 seconds driving time).
Narrow curves should be avoided because of the proven increase in accident rates (510 m could be used as an indication for the minimum curve radius).
Research indicates a probably positive effect on traffic safety of transition curves . Because of some contradicting results however, further research is advised.
Super-elevation values larger than approximately 8 % are not recommended.
Research indicated 3.5 m as an optimum value for lane width on express roads. An unequivocal value for the optimum shoulder width on express roads could not be given on the basis of past research.
Because of their considerable improvement of traffic safety, climbing lanes must be recommended on upgrade sections on two-lane express roads.
Minimum values for obstacle-free zones on express roads probably vary between 3.5 and 5 metres.

Research on motorways and two-lane rural roads indicate a maximum sideslope of 5:1. Steeper slopes have to be considered as dangerous areas, and should therefore be protected with guard rails.

Contents

1. Introduction

The overall objective of SAFESTAR is the formulation of safety arguments for selecting certain design elements or for recommending certain dimensions. Workpackage 3 should result, if at all possible, in recommendations for minimum design standards for road sections and intersections of both single and dual-carriageway express roads of the Trans-European Road Network (TERN).
For non-TERN express roads in individual Member States, these recommendations could be considered as 'good practice guidelines'.

The general characteristics of express roads as described by the Motorway Working Group Action Start in 'Standardisation of Typology on the Trans-European Road Network' (Motorway Working Group, 1994) will be used as a basic assumption in this report. The Working Group recommends that express roads should:

- have no urban sections;
- have no private access;
- have a minimum lane width of 3.5 m;
- have edge line and central markings;
- have a head clearance of 4.5 m;
- provide for emergency calling points;
- provide for service area's at a maximum distance of 100 km, directly accessible from the road, and with 24 hours refuelling possibilities;
- have an average daily traffic for single-carriageway express road of 5,000 vehicles per day; for dual-carriageway express roads of 10,000/15,000 vehicles per day;
- not permit parking and stopping on the carriageway;
- not permit slow moving vehicles, bicycles, pedestrians or animals.

High volume and high speed are the main characteristics of the express roads as described by the Working Group.

Although express roads exist, and will continue to exist, in most EU member states, partly due to the used definition of express roads, there is very little research information on this road type.
The study that complies most with the SAFESTAR definition of express roads is a study carried out by the British Foundation for Road Safety Research (Hughes & Amis, 1996; Hughes, Amis & Walford, 1997), on the safety of single and dual-carriageway 'A-class' Roads. On this road type however, slow moving traffic (e.g. bicycles) are allowed. Because bicycle volumes on the selected roads proved to be (very) low, this deviation from the SAFESTAR definition was judged to be of minor importance.
In many other studies car-volumes of studied road sections were low or very low, which - given the great influence of car-volumes on traffic safety - was considered to be a greater deviation from the SAFESTAR definition of express roads. Other major deviations from the definition of express roads in SAFESTAR in existing literature were the presence of urban sections, private access, and lane widths under 3.5 m
In the original Workpackage plan the contents of the safety standards (WP3.4) would have to be based mainly on the results of WP3.1 (accident

analysis), 3.2 (Description of decision making processes) and 3.3 (Workshop on express roads).
These preceding Workpackages however did not result in detailed information on relationships between geometric design features and accident rates. For detailed information of effects of design parameters on traffic safety, the number of (Portuguese) express roads as well as the number of accidents included in the study proved to be too small. The analysis of decision making processes described very diverse processes in which safety arguments hardly played a role of importance. The workshop on express roads did not give new information or study-results on the effects of design parameters.

O'Cinneide (1995) also concluded that very few studies have related detailed geometric standards to accident rates over entire road networks. It is therefore difficult to draw reliable conclusions except in broad terms. However, O'Cinneide stated that, despite the differences, there seems to be broad agreement on the general relationships between geometric design elements and accident rates. Consequently, for the purposes of evaluating the safety impacts of lower physical design standards or for comparing safety of alternative route alignments, the available information should provide a reasonable indication of the likely *differences* in expected accidents.
Within the road category 'express road' there proved to be a wide range of different designs and regulations. Safety effects of design variations however sometimes proved to be comparable for the different road types. Valuable information for the design of express roads can therefore be derived from other, more or less comparable, road types. Though scientifically not very accurate, the problem of the lack of studies on SAFESTAR-type express roads can be dealt with in this manner.
Though not accurate and specific enough to use as a basis for the formulation of design recommendations or standards, the information can give some insight on possible safety effects, probable direction of effects, and estimates on the strength of the effects.
In fact the lack of specific information on safety effects of design parameters on express roads stresses the need for further research. The information gathered in this report based on research on other (more or less comparable) road-types can be seen as a guide for this future research.

Based on the existing literature, the following design parameters can be given:
- choice of road type;
- access;
- alignment;
- cross-sections;
- intersections;
- road-side design.

As indicated in the technical annex of SAFESTAR, motorists can usually identify motorways and single carriageway ordinary roads as two distinct road types, each requiring different driving behaviour.
Most countries also know road types, which do not fulfill the design criteria of a motorway, but which are of a higher order than the ordinary single-carriageway roads. These intermediate types of roads (Express roads, A-level roads or Arterial highways) are more difficult to define and identify.
Because of their mixed functions, safety performance indicators of these types of roads are not positive.

As an aid to solving the contradictions between functions, and to nevertheless enable the roads to fulfill their various roles satisfactorily, road classification is generally introduced. Road classification means that the geometrical characteristics of a road are related to its functions. The main purpose of road classification should be that the function of a road is made clear to the road users by means of distinct features.
It should be noted that road classification systems in use have several drawbacks. First, road classification is often used by road administrators as an aid to distinguish between roads for reasons other than improvement of road safety. In addition, many roads do not comply with the requirements associated with the various road classes in existing classification systems. Road classification can be valuable for safety, provided that the classification system has been well designed (concentrated on safety) and implemented consistently.
There is another shortcoming of most road classification systems. Because more than one aspect of the traffic function may occur on the same road, the difference between the subsequent classes often tends to be only slight, especially if the number of classes is relatively large. Expressing all these differences by introducing distinctions in the geometrics of the roads is then becoming somewhat artificial.

A fundamentally better situation may be reached by adopting the approach of the so called 'sustainably safe' road system, developed in the Netherlands. According to this approach, every road should have only one of the elements of the traffic function, i.e. either of flow function, a distributor function, or an access function.
This new concept comes down to the removal of all function combinations by making all roads monofunctional.

According to Michalski (1994) the research results pointing out the effects of individual design elements can have many weaknesses. The results are usually based on large-scale comparison of different road environments, the so called cross-sectional approach, and less frequently on before-after experiments with control sites.
The cross-sectional approach, usually in the form of accident modelling, is suitable for determining the effect of many variables acting together. However the conclusions for the effects of individual factors should be evaluated with care. Examining the relationships between single design factors and accidents without considering the interactive effect with other parameters can yield biassed or masked relationships.
Most of the studies quoted in this report are cross-sectional approach studies.

Based on an accident analysis on Portugese express roads, Cardoso &Costa (1998) conclude that single and dual carriageway express roads have entirely different safety problems, and should therefore be considered separately.

2. Choice of road type

Proper road design is crucial to reduce human errors in traffic, and less human errors will lead to less accidents. Three safety principles have to be applied in a systematic and consistent manner to prevent human errors:

- *Prevent unintended use of roads and streets*, after having defined the function of a road; flow or through function (rapid processing of through traffic), distributor function (rapid accessibility of residential and other areas) and access function (accessibility of destinations along a street while making the street safe as a meeting place).
- *Prevent large discrepancies in speed, direction, and mass* at moderate and high speeds, i.e. reduce in advance the possibility of serious conflicts in advance.
- *Prevent uncertainty amongst road users*, i.e. enhance the predictability of the road's course and people's behaviour on the road.

Implementation of these three principles will lead logically to a road network with three functional road categories: roads and streets with a flow function, a distributor function, or an access function. This categorisation is applicable to roads both inside and outside built-up areas. The frequency of properties alongside and in the immediate vicinity of the road, does determine its design. So do traffic volumes of course, specifically with regard to the cross-section of the road. Depending on the frequency of properties and on traffic volumes, several road types can be distinguished within one road category. Despite differences in design, roads should have only one clearly recognisable function. (Wegman & Slop, 1995).

Outside urban areas, two road types with flow function can be identified, namely motorways and express roads.
From a traffic safety point of view, motorways should be preferred for road-network sections with a flow function. Workpackages 3.2. and 3.3. however demonstrated that financial considerations in most European countries can lead to the choice for the sub-standard express roads, and will lead to this choice in the future for the same reason.

3. Access control and road use

3.1. Access control

Generally, access control reduces the variety and spacing of events to which the driver must respond, which results in improved traffic operations and reduced accident experience. Cirillo (1992) describes full access control as the most important single design factor for accident reduction. Data in this study show accident and fatality rates on facilities with full control of access to be 1/2 that of rural highways with no access control, and 1/3 that of urban highways of similar design. In this study (Cirillo, 1992), access control is described as some combination of at-grade intersections, business driveways, private driveways, and median crossovers.

Although the road-type studied in this research (mainly low-volume, two-lane highways) is not fully comparable with the express roads as described in the SAFESTAR study, it can safely be concluded that an increase in the number of access points on express roads causes an increase in the number of accidents. The exact strength of the increase is probably strongly dependent on exact design and use, and can therefore not be given for express roads.

In a study of British trunk roads, Walsmley & Summersgill (1998) found that an extra access to a typical single-carriageway scheme would only have a small effect (less than 1 per cent) on the number of accidents.
Adding an extra access to a typical dual-carriageway scheme caused an increase in accidents of 2 to 3 per cent (Walmsley & Summersgill, 1998).

3.2. Road use

One of the requirements of an express road, as mentioned in the general description of express roads (chapter 1), is that slow moving vehicles, bicycles, pedestrians, and animals are not permitted to use the express road. This restriction however is not adopted in all EU countries. In the UK for instance non-motorised traffic is allowed to use express roads ('A-class' roads).

It is commonly accepted that the exclusive use by high-speed motorised traffic is one of the most important safety requirements on roads with an important traffic flow function.

Recommendations
Based on research findings and common practice, it can be recommended to restrict use of express roads to high speed motorised traffic exclusively. Slow moving vehicles and vulnerable road users should be banned from the express roads at all times. In this way differences in driving speeds can be limited and dangerous conflicts with vulnerable road users can be avoided.
Furthermore the number of access points should be limited as much as possible. With the introduction of additional access points on express roads, road safety implications should be considered and weighed carefully.

4. Alignment

The design of roads primarily involves three geometric design elements: vertical alignment, horizontal alignment, and cross-section design.
Design speed controls the vertical and horizontal alignment of a road, which is based partially on safe stopping sight distances. Therefore, vertical and horizontal alignment control sight distance and the safe operating speed of the road. The correct combination of vertical and horizontal alignment promotes uniform speed for motorists and thus contributes to a safe design (Zegeer et al., 1992).
Zegeer et al. (1992) conclude that although each element may be designed separately, the effect that vertical and horizontal alignment have on each other in combination should be carefully considered in highway design. It is desirable that they increase safety and encourage uniform speed along a highway section. Poorly designed vertical and horizontal alignment combinations can detract from the desirable features and aggravate the deficiencies of each. Instead, vertical and horizontal components should complement each other.

4.1. Horizontal alignment

In general accident studies indicate that horizontal curves experience a higher accident rate than tangents, with rates ranging from 1.5 to 4 times greater than the tangent sections (Zegeer et al., 1992).

In a 1996 study of 'A-class' roads in the UK, the relation between road design characteristics and the occurrence of accidents was analysed for both single and dual-carriageway A-class roads (Hughes & Amis, 1996; Hughes, Amis & Walford, 1997).
For dual-carriageway sections, links with bendiness characteristics falling within the range of 25 to 70 degrees per kilometre were found to correlate, on average, with 22 per cent more accidents than those with bendiness characteristics of less than 25 degrees per kilometre.
Links with bendiness characteristics falling within the range of 70.1 to 90 degrees per kilometre were associated, on average, with 260 per cent more accidents than those sections with bendiness characteristics of less than 25 degrees per kilometre.
In this study (Hughes, Amis & Walford, 1997) an increase in link bendiness of 10 degrees per kilometre is associated, on average, with a 10 per cent reduction in the odds of a rear-end accident, but a 14 per cent increase in the odds of a loss of control type accident.

For single-carriageway sections this same study found comparable results. Within the bendiness range considered in the model (0 to 163 degrees per kilometre) an increase in bendiness of one degree per kilometre is related to a one percent increase in accidents.
Bends were generally associated with an increase in the odds of a loss of control type accident.
Bends with radii less than 510 metres were associated with a 40 percent reduction in the odds of a KSI (killed + serious injury) accident.

Other studies found comparable effects of changes in bendiness on traffic safety. Although the studied road sections are not completely similar to the sought after 'express roads', their results are presented here.

Both Brenac (1994) and Slop et al. (1996) derived from several statistical studies that the accident rate (accidents per vehicle kilometre) is high for small radius curves and decreases when radii increase. Although this general trend is clear, it covers large differences in safety records between curves with similar radii. These differences are caused by the effects of other design variables, such as the features of the alignment leading up to the curve.
Long straight or nearly straight sections facilitate overtaking on single carriageway roads. It is advisable to design, whenever possible, alignments which include more than 50% of sufficiently long straight sections or large radius curves, to ensure opportunities for overtaking under good conditions, and also to properly locate intersections.
However, straight sections greater than 5 km in length are generally avoided because they are believed to encourage drivers' drowsiness. Long straight sections, especially with constant non-zero gradients, also make the estimation of distance and speed of oncoming vehicles more difficult.
There is an obvious conflict between the advantage of providing more overtaking opportunities and the assumed disadvantages mentioned in the case of long straight sections. Since neither the arguments in favour nor those against long straight sections are strongly supported by research so far, decisions should be based on the relative importance of the different arguments in a specific situation.

According to Slop et al. (1996), statistical studies also show that the situation of a curve within the total alignment is an important factor. The accident rate of small radius curves is very high if the overall horizontal alignment is relatively straight, but is more moderate if the alignment is relatively bendy.

Though studied road-types are not completely comparable with the express road-type, the general conclusion that an increase in bendiness as well as a decrease in curve radii cause a increase in accident rates, can be adopted for express roads. This relationship proved to be comparable for all studied road-types.
Information on the exact strength of the relationships cannot be derived from the quoted research.

Wider lanes and shoulders on curves are also associated with a reduction in curve-related accidents. Zegeer et al. (1992) found the following accident reductions in improvements involving widening lanes and/or shoulders on horizontal curves in two-lane rural highways (see *Table 1*).

Total amount of lane and shoulder widening (feet)		Percent accident reduction		
Total	Per side	Lane widening	Paved shoulder widening	Unpaved shoulder widening
2	1	5	4	3
4	2	12	8	7
6	3	17	12	10
8	4	21	15	13
10	5	--	19	16
12	6	--	21	18
14	7	--	25	21
16	8	--	28	24
18	9	-	31	26
20	10	--	33	29

Table 1. *Percentage reduction in accidents due to lane and shoulder widening (Zegeer et al., 1992).*

It is plausible that a similar effect can be found on express roads (positive safety effect of lane widening in curves). Because the research described is limited to research on two-lane rural highways however, this information is not directly applicable to express roads without thorough research.
Transition curves (or spiral transitions) are used to link a straight section to a circular curve and/or two circular curves of opposite curvature.
According to Slop et al. (1996), a transition curve must allow:

- an adequate transition of the straight section crossfall to the amount of super-elevation in the circular curve;
- a progressive increase of the centrifugal force;
- good visual guidance.

Zegeer et al. (1992) state that adding transitions to highway curves dramatically reduces the friction demands of the critical vehicle traversals. Transition curves were found to reduce curve accidents by 2 to 9 percent, depending on degree of curve and central angle. An accident reduction of 5 percent of total accidents was found to be most representative of the effect of adding transition curves on both ends of a curve, on two-lane rural highways.
In marked contrast with these results are the results of some studies quoted by O'Cinneide (1995), which concluded that transition curves are dangerous because of driver underestimation of the severity of the horizontal curvature. In a California Department of Transportation study, a comparison of over 200 bends, both with and without transition curves, was made. Bends with transitions had, on average, 73 percent more injury accidents. For this reason the Department's report "Accidents on spiral transition curves in California" recommends against any use of these transition curves.
In spite of some contradicting results, most studies indicate a positive safety effect of the presence of transition curves. The use of transition curves can therefore be recommended in the design of express roads, though further

research to clear the existing uncertainties and contradictory findings must be advised.

A super-elevation of the carriageway improves visual guidance and compensates for a part of the centrifugal force. There is a general agreement that the use of curves (below a certain radius) that are not super-elevated should not be recommended, because they cannot compensate for the centrifugal force, leading to many accidents.
According to Zegeer et al. (1992) a 10 percent reduction in total curve accidents on two-lane rural highways could be obtained if proper super-elevation is provided to the horizontal curve.
In a study of Zegeer et al. (1992) no adverse effects of too much super-elevation were found based on available data. Current design policy is implemented with an assumed upper limit on super-elevation for areas with snow and ice. The presumption is that excess super-elevation produces sliding down the curve under low-speed conditions, and hence increases accident potential. While this condition could theoretically occur at low-speed curve locations with sharp curvature at a high rate of super-elevation, no evidence was found of any such significant adverse safety effects.

A positive safety effect of super-elevation in horizontal curves for express roads is very plausible. The exact strength of this effect however cannot be estimated on the basis of research on two-lane highways.

Recommendations
The most important for a safe design is a logical succession and linking of the different design elements. Within the horizontal alignment the succession of curves, straight sections, and transitions should also be logical and consistent in order to allow for proper anticipation, and to avoid unexpected situations. Since express roads are described as 'high speed, high volume' roads, the design speed should be guaranteed along the entire length of the road, including the curves. Speed reducing measures or curves that require lower driving speeds should be avoided where possible. Like on motorways, drivers on express roads should not have to decide or estimate the safe driving speeds on curves, but should be able to maintain their original driving speed. If this is not possible, the safe 'advisory' speed for curves should be indicated. Situations where overtaking is possible should be clearly distinguished from those where it is not. Dilemma situations could occur in intermediate curve radii (between approximately 800 m and 2,000 m). These intermediate curve radii should therefore be avoided (Slop et al., 1996).

Because of the proven increase in accident rates on curves with radii under 510 m, these narrow curves should be avoided. Because of the requirement of maintaining constant design speeds (also on curves) these narrow curves should also be avoided for this reason.

It is recommended to use the following method for determining safely and comfortably traversable curve radii.

$$R_h \geq \frac{V_0^{\,2}}{127(f_z + i/100)}$$

where:

R_h = curve radius in m;
V_0 = design speed in km/h;
f_z = side friction coefficient;
i = super-elevation in %.

For determining the minimum radius for a given design speed, the side friction coefficient is given in the following table. The friction coefficients in the following table are based on driving-comfort:

V_0	50	70	90	120 km/h
f_z	0.18	0.16	0.13	0.10

The use of straight sections longer than 5 km is generally advised against, because of the risk of encouraging drivers' drowsiness

Although there have been some contradictory results, the general conclusion is that the use of transition curves on high-speed roads have a positive effect on traffic safety, and can therefore be recommended.
The use of super-elevation in curves also has a positive effect on accident rates. Though maximum values are depending on local factors (i.e. winter conditions, traffic conditions) values larger than 8% are generally not recommended.

4.2. Vertical alignment

No research results on the safety effects of the vertical alignment on express roads were available. Results discussed in this chapter are based on research on two-lane rural highways and interurban roads.

Research on two-lane rural highways in the US (Zegeer et al., 1992) has shown that the accident rate for downgrades is 63 percent higher than for upgrades. Downgrade accidents proved not only more frequent, but also more severe than upgrade accidents.
Slop et al. (1996) found that generally there is a decrease in safety with increasing gradients. Accident studies have shown that the accident rate increases only slightly up to a gradient of 6 to 7 percent but much more rapidly beyond. This increase is especially significant downhill.
Slop et al. (1996) conclude furthermore that resulting (speed and) safety impact depends on the combination of gradients used and the total height difference to be negotiated. It could sometimes be a better solution for safety to use a steep gradient over a shorter distance for negotiating a height-difference, rather than a moderate gradient over a longer distance.
The accident rate increase on steep gradients is especially severe when the horizontal alignment is relatively bendy (curve radii < 400 m). The length of

the gradient, its character (a succession of relatively high or low gradients, particularly in conjunction with a bendy horizontal alignment) can have unfavourable consequences on accident risks involving heavy vehicles. Though the exact magnitude or strength of effects cannot be adopted for express roads, similar relationships as described seem plausible for express roads.

A specific effect of vertical alignment is a blind effect caused by a convex curve as shown in *Figure 1*. This blind effect affects sight distances considerably.

Figure 1. *Blind effect in a convex curve. (Slop et al., 1996).*

Unlike other alignments aspects, convex curves have not yet been the subject of many studies which would clearly show their impact on safety.
For the determination of the radius of a (convex) vertical curve, Slop et al. (1996) give the following relation:

$$R_v = \frac{0.5 S_a^2}{(h_e^{0.5} + h_0^{0.5})^2}$$

where:
R_v = radius of vertical curve (convex);
S_a = actual sight distance;
h_e = eye height;
h_o = object height.

The value to be substituted for S_a depends on what the designer wishes to offer to the road user. The minimum requirement is the stopping sight distance.

Since the blind effect can not appear in a concave curve, there is no need for large radii for that reason. A certain minimum value is nevertheless required because of two other reasons:

- Concave curve radii of 1,000 m to 1,200 m at least are recommended to give a maximum acceptable value for the vertical acceleration.
- A minimum value of approximately 3,000 m is preferred to avoid, at nighttime, dipped headlights providing insufficient sight distance.

Recommendations

A general recommendation is to carefully combine horizontal and vertical alignment, because of the considerable effect on safety in case of unfortunate combinations.

Convex (top) curves should be based on the required stopping sight distance.

Concave (sag) curves should have a minimum value of 3,000 m

5. Cross-section

The factors that determine the cross-section are:
- road network factors: road function, design speed, average trip length of vehicles;
- traffic factors: traffic volume, type of vehicles using the road, width of passenger cars and heavy vehicles, number of pedestrians, volume of cyclists;
- road factors: alignment, drainage, number and function of traffic lanes and shoulders, construction practice, maintenance procedures;
- human factors: drivers' behaviour in speed and lateral position, behavioural adaptations, feeling of security;
- environmental factors: landscaping, access requirements, aesthetics;
- safety considerations: accident rates, severity of accidents, accident costs;
- operational requirements: required level of service, capacity, delays;
- cost-benefit analysis: construction, maintenance, accident and operational costs.

The most important elements of the cross-section design are:
- carriageway width:
  - lane width;
  - shoulder width;
  - climbing lanes;
- medians;
- roadside design and obstacle-free zones.

Roadside design and obstacle free zones will be discussed in chapter 6.

5.1. Lane width

Minimal width of traffic lanes and paved shoulders depends first of all on the design width of vehicles and side margins determined by lateral position and dynamic space of moving vehicles. Usually the width of the European 'design heavy vehicle' is 2.5 m; in the Netherlands 2.6 m.
In German standards, minimal lane width results from the sum of 2.5 m heavy vehicle width, 0 - 1.25 m side margins and 0.25 m additional space strip if there is opposing traffic. It creates a traffic lane width from 2.75 m to 3.75 m Side margins depend on speed limits. In Dutch standards, as a result, traffic lane width ranges from 3 25 m to 3.59 m for motorways and from 2.75 m to 3.25 m for single carriageway roads.

In a study of accidents on A-class roads in Great Britain (comparable to express roads as defined in SAFESTAR), the effects of variations in carriageway width were studied (Hughes & Amis, 1996; Hughes, Amis & Walford, 1997).
For dual-carriageway sections, an increase of one metre in main carriageway width was associated with a decrease of 56 % in the odds of an accident involving a vehicle joining the main road from an on-ramp.
For single-carriageway A-class roads, within the carriageway width considered in the model (7.0 - 21.2 m), a one metre increase in carriageway width at a junction was associated with an estimated accident reduction of 5 %.

For sections between junctions on single-carriageway A-class roads, a one metre increase in carriageway width is connected with a 19 % decrease in accidents (range considered in the model was 7.1 - 11.5 m).
The authors stress that the observed effects are not linear and that they are only applicable within the range of the model.

Another study of trunk roads (A-class roads) in Great Britain (Walmsley & Summersgill, 1998), showed similar results. In summary, the authors found that wider single-carriageway trunk roads, and probably wider dual-carriageway trunk roads are safer. Wide single-carriageway roads (10 m wide) had about 22 percent fewer accidents than roads with a standard width (7.3 m), other things being equal.

Based on the analysis of accidents on two-lane rural highways, Zegeer et al. concluded that accident rates generally decrease with increasing lane and shoulder width (Zegeer, Deen & Mayes, 1981; Zegeer & Deacon, 1987). Lane and shoulder width directly effect run-of-the-road accidents and opposite-direction accidents. Other accident types proved not to be directly effected by these elements. The accident rates Zegeer found were approximately the same for 3.6 m lanes as for 3.3 m lanes, possibly indicating that the limit beyond further increase in lane width are ineffectual. Lane widths proved to have a greater effect on accident rates than shoulder width.
The evaluation of traffic accidents in Germany by Oellers (1976) led to the result that the frequency of accidents due to errors in overtaking, being overtaken, and changing lanes was higher on stretches with narrow traffic lanes (3.25 m).

Zegeer & Council (1992) quantified the safety effects of lane widening in *Table 2*.

Amount of lane widening	Percent reduction in related accident types
30.5 cm	12 %
61.0 cm	23 %
91.5 cm	32 %
122.0 cm	40 %

Table 2. *Safety effects of lane widening (Zegeer & Council, 1992)*

The relationship of *Table 2* is also very plausible for express roads, though the exact reductions as described cannot be used for express roads because of differences in design and use. Research on express roads is needed for an exact description of the effects and their strength.

Hadi et al. (1995) estimated the effects of cross-section design elements on total, fatality, and injury crash rates for various types of rural and urban highways at different traffic levels.
They concluded that significant relationships could be found between lane width and crashes for undivided highways and urban freeways. For other highway types, no such relationship could be identified. They indicate that for

two-lane rural, two-lane urban, four-lane urban undivided, and urban freeways widening lane width up to 4.0 m, 3.7 m, 4.0 m and 4.3 m respectively could be expected to decrease crash rates. They furthermore indicate the highest benefits due to lane widening were estimated for urban freeways, followed by four-lane undivided urban highways, followed by two-lane rural highways. For two-lane urban highways there was a greater relationship between pavement width (lane width plus paved shoulder width) and crash frequency than between lane width and crash frequency when continuous representations of variables were used. The effect of lane width on crash rate for this highway type was lower than for other highway types.
Accident analysis on express roads in Portugal by Cardoso & Costa (1998) showed that single carriageway express roads with lane widths greater than 3.50 m had better accident records than roads with lane widths below or equal to 3.50 m.

From the above-mentioned results one could get the impression that 'the wider a road is, the safer it is'. Michalski (1994) questions the validity of this hypothesis, based on safety research carried out in Switzerland. Results showed that increasing the single carriageway width between 8.5 m and 10.0 m decreased accident rates as well as the victim rates, but for widths between 12.0 m and 14.0 m both rates increased again. For motorways, widening a traffic lane over 3.5 m causes no significant further improvement of the accident rates. The lane width of 3.5 m can therefore be indicated as an optimum for motorways.

Recommendations
For both single- and dual-carriageway express roads, a lane width of 3.5 m can be recommended.
Research on the effects of lane width on motorways and low volume highways resulted in an optimum lane width of 3.5 m to 3.6 m With similar results for road categories just above and below the express road category, it can be safely assumed that this value will also be a safe standard for express roads.

5.2. Shoulder width

A road shoulder serves several functions with both operational and safety purposes. A road shoulder:
- increases the effective width of the traffic lanes and so increases lateral clearance;
- provides a recovery area for stranded vehicles;
- provides space for use by emergency vehicles.

Although reliability of cars has improved over the years, a 1978 study by McLean (1978) indicates one stop every 33,000 vehicle kilometres for light vehicles and one stop every 10,000 vehicle kilometres for heavy vehicles.
On Dutch motorways (ROA, 1992/1993) observations indicate 0 3 stops per day per kilometre.
The rate of emergency stops is sufficient to cause unsafe situations and operational characteristics if stationary vehicles occupy a part of the traffic lane.
Australian studies (Armour & McLean, 1983) suggest that paved shoulders improve the lateral separation between oncoming vehicles.

German analysis of the lateral distance (Oellers, 1976) shows that drivers adjust their driving behaviour to the presence of an emergency lane, the width of traffic lanes, and the speeds and volumes of traffic on the lanes. The lateral distance between overtaking vehicles depended above all on the distance of the vehicle overtaken to the centre line.

No research results on the quantitative safety-effects of shoulder width were found referring directly to express roads as described in the SAFESTAR project. A selection of information on shoulder width on more or less comparable road types will be presented.

Several studies (Hedman, 1990; Zegeer et al., 1988) show a decrease in accidents with an increase in shoulder width.
As noted by Hedman (1990), recent studies show a decrease in accidents with an increase in width from 0 to 2 m Additional benefits for widths above 2.5 m proved to be very small.
Several authors have furthermore concluded that the effect of lane width on accident rates is greater than the effect of shoulder width.
Zegeer et al. (1988) concluded that non-stabilized shoulders, including loose gravel, crushed stone, raw earth and turf, exhibit greater accident rates than stabilized or paved shoulder. The same conclusion was drawn by Armour (1984) who found that the accident rate of roads with unsealed shoulders was between three and four times the accident rate for roads with sealed shoulders. This was true for straight road sections and for road sections with a curve or grade. An examination of accident description showed that losing control of the vehicle in the gravel shoulder was suggested as a contributing cause in about 17 % of fatal accidents.

Zegeer & Council (1992) described the quantitative effects of shoulder widening in *Table 3*.

	Percent reduction in related accident types	
Shoulder widening per side	Paved	Unpaved
61 cm	16%	13%
122 cm	29%	25%
183 cm	40%	35%
244 cm	49%	43%

Table 3. *Safety effects of shoulder widening (Zegeer & Council, 1992).*

German comparative studies concerning motorways (Brühning, 1977) show that the motorways with an emergency stopping lane (often 3.0 m) reduced the total accident rate by more than 15 %, when compared to rates on motorways with narrow paved shoulders.

Hadi et al. (1995) concluded that using *inside* paved shoulders of 1.2 m to 1.8 m wide was found to be very effective in decreasing crashes on rural freeways. It was found that using a 1.8 m shoulder width could decrease crash rates by 15.7 %.

As in the previous paragraph, there were no research results available on the effects of median design on express roads as described in chapter 1. Results of research on other road types will therefore be presented.

Zegeer & Council (1992) describe a comparison of the safety of a raised (mound) median design vs depressed (Swale) medians in a 1974 Ohio study by Foody & Culp (1974). Using a sample of rural Interstates, all having 26 m wide medians and other similar geometrics, accident experience was compared between the two median designs. The typical median cross-sections for the sample mound and Swale medians used in the study are shown in *Figure 2.*

No differences were found in the number of injury accidents, rollover accident occurrence, or overall accident severity between the raised and depressed median designs. However, a significantly lower number of single-vehicle median involved crashes were found on sections with depressed medians compared to raised medians. The authors concluded that this may indicate that mildly depressed medians provide more opportunity for encroaching vehicles to return safely to the roadway.

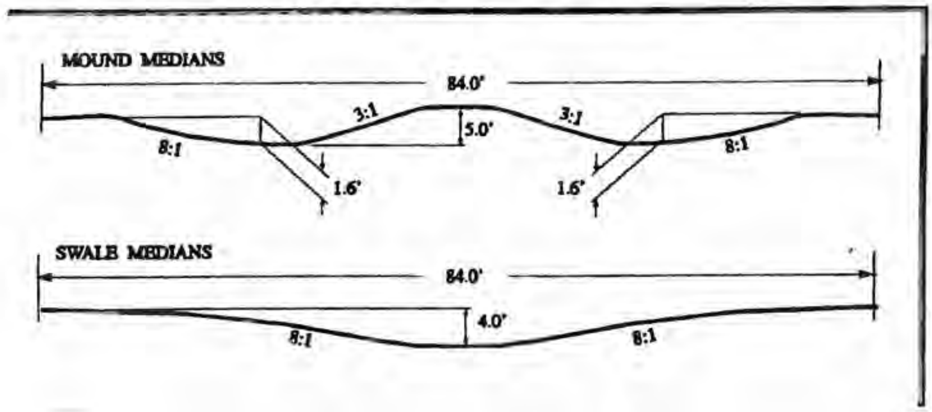

Figure 2. *Typical median cross-sections. (Zegeer & Council, 1992).*

A 1973 study by Garner & Deen in Kentucky compared the crash experience of various median widths, median types (raised vs depressed), and slopes on Interstate and turnpike roads in Kentucky (Garner & Deen, 1973). Highways with at least 9 m wide medians had lower accident rates than those with narrower median widths. For wider medians, a significant reduction was also found in the percentage of accidents involving a vehicle crossing the median. Median slopes of 4:1 or steeper had abnormally high accident rates for various median widths, while a higher crash severity and higher proportion of vehicle overturn accidents were found for medians which were deeply depressed. For median widths of 6 m to 9 m, the use of a raised median barrier was associated with a higher number of accidents involving hitting the median and losing control. (Unfortunately no information was given on the severity of the accidents).

Recommendations
The separation of opposing traffic with a median strongly improves traffic safety. The usually very severe head-on accidents are fully excluded.

In contradiction with these results however, the NCHRP Report 197 (TRB, 1978) concludes that on multi-lane divided highways, accident rates increase with an increase of the median shoulder width.

Walmsley & Summersgill (1998) found that on both single-carriageway and dual carriageway trunk roads in Great Britain, accident rates on roads with hard shoulders were consistently lower than on roads without shoulders.
On dual-carriageway trunk roads with shoulders, the number of accidents proved to be around 16 smaller than on roads without shoulders. For single-carriageway trunk roads, this accident reduction due to the presence of shoulders proved to be 18 per cent.

Recommendations
Though the positive effect of lane width is greater than the effect of shoulder width, several studies have concluded that the presence of shoulders contribute significantly to traffic safety. The presence of paved shoulders can therefore be recommended for both single and dual-carriageway express roads.
Research however does not indicate an unequivocal value for the optimum shoulder width. Recommendations on the exact shoulder width can therefore not be given in this report. Local situation and traffic behaviour as well as shoulder widths differ widely in various European countries.
Michalski (1994) indicates that wider shoulders on two-lane roads can stimulate drivers to use shoulders as a traffic lane. Though this expectation is not found in other studies, this and other considerations can play a role in selecting the shoulder width for a particular road section.

For determining the shoulder width, the method used in the Dutch guidelines (ROA, 1992/1993) seems valuable. Based on the dimensions of a the width of a truck of 2.5 m, a shoulder width of 3.0 m to 3.5 m is recommended.
A stationary truck on the shoulder can be passed safely and without influencing traffic operations seriously. Given the lack of empirical data and equivocal conclusions, these dimensions can be seen as 'best practice'.

Further research must be advised to determine the optimum shoulder width for express roads.

5.3. Medians

A median separates the traffic lanes in opposite direction, thus creating two separate carriageways. Elements of median design which, according to Zegeer & Council (1992), may influence accident frequency or severity, include median width, median slope, median type (raised or depressed), and presence or absence of a median barrier. Wider medians are considered desirable in that they reduce the likelihood of head-on crashes between vehicles on opposing directions. Median slope and design can effect rollover accidents and also other single-vehicle crashes (fixed object) and head-on crashes with opposing traffic. The installation of median barriers typically increases overall accident frequency due to the increased number of hits to the barrier, but reduces crash severity, resulting from a reduction or elimination of head-on collisions with opposing traffic.

The width of the unpaved median is dependent on the location on the median crash barriers. Crash barriers are not essential if there is no risk that the median may be crossed. This width is assumed to be approximately 20 m Because such a width will generally not be feasible in practice, medians are normally equipped with crash barriers.
Safety generally improves with widening of the median. The greater the distance from carriageway edge to median barrier is, the greater the possibility will be that an off-road driver can recover safely (without hitting the median barrier).
Slopes and obstacles in the median should be avoided (or protected).

5.4. **Climbing lanes**

A climbing lane is an extra traffic lane provided on uphill gradients for slow moving vehicles.
The presence of a climbing lane on a two-lane (single-carriageway) section can reduce the number of catastrophic overtaking accidents that occur due to the presence of opposing vehicles during the overtaking manoeuvre. Such accidents normally involve high-speed head-on or run-off-the-road accident types. On dual-carriageway sections the purpose of climbing lanes is mainly the improvement of traffic operations. Safety effects are generally caused by the minimizing of speed differences on the adjoining lanes and thereby reducing the odds of rear-end accidents.

Hedman (1990) quotes a Swedish study which concluded that climbing lanes on rural two-lane roads reduced the total accident rate by an average of 25 %. 10 % to 20 % on moderate up-gradients (3 % to 4 %) and 20 % to 40% on steeper gradients. It was also observed that additional accident reduction can be obtained within a distance of about 1 km beyond the climbing lane.
Martin and Voorhees Associates (1978) found an overall reduction of accidents of 13 % due to the presence of climbing lanes in the UK.

Harwood, Hoban & Warren (1988) quote a California study by Rinde (1977) at 23 sites in level, rolling and mountainous terrain where accident rate reductions due to the passing lane installation, of 11 % to 27 % were found, depending on road width. When the sites in mountainous terrain were excluded from the analysis, accident reductions of 42 % were found for the level terrain sites as well as for the rolling terrain sites.

Because the studied road sections in the described studies are not completely comparable with express roads, the accident reduction found cannot be used. It is however very plausible that the provision of climbing lanes on uphill gradients of express roads have a positive effect on traffic safety.

Recommendations
Because of the considerable improvement of traffic safety, climbing lanes must be recommended on upgrade sections on single carriageway express roads. Even on moderate upgradients (3 % to 4 %), climbing lanes can reduce the accident rates.
On dual-carriageway express roads the provision of climbing lanes is dependent on the steepness of the gradient, the number of heavy trucks, and the possibility of slow moving trucks reducing speeds of other vehicles.

6. Intersections and interchanges

Though intersections and interchanges constitute a very small part of express roads, they are implicated in a substantial part of the accident rates on this road type. Analysis of accidents on express roads in Portugal (Cardoso & Costa, 1998) proved that on dual-carriageway express roads, 11 % of the accidents was located at intersections; on single carriageway express roads 20 % of the accidents was located at intersections.

On express roads, junctions can be both at grade and grade-separated. Dual carriageway express roads with grade-separated junctions are expected to be upgraded to motorway standards within a reasonable period (with exceptions only if this is clearly not possible, for example at mountain passes).

The amount of available research on safety effects of intersection design in express roads proved to be very limited.
Whereas in chapter 4 to 6 information from research on comparable road types could be used, this method could not be used for intersection and interchange design. Available information on safety effects of the design of intersection and interchanges is obtained from research on motorways (freeways) and on (very) low volume highways or rural roads. Traffic characteristics and road-function have large implications for the design of intersections and interchanges. Differences are in fact so substantial that the available literature on freeways and low volume highways cannot possibly be used to estimate possible effects of design variations in intersections on high volume express roads.

In a UK study on single and dual-carriageway 'A-class' roads (Hughes & Amis, 1996; Hughes, Amis & Walford, 1997), the interaction between the road environment parameters and accident frequency and types were examined.
For single-carriageway sections all studied junctions were T-junctions. For single-carriageway sections, 72 explanatory variables were considered, of which the following variables were found to have a significant association with the occurrence of accidents at public road junctions (Hughes & Amis, 1996):

1. major road traffic flow. Within the major traffic flow range considered in the model (4,500 to 17,400 vehicles per 16-hour day), an increase of 1,000 vehicles per day is associated with a 6 % increase in accidents.
2. minor road traffic flow. An increase in minor traffic flow from one categorical level to the next results in an increase in accident frequency of 87 %. (levels: 0-1,000 veh., 1,000-2,500 veh., 2,500-4,000 veh., and 4,000-5,000 veh. per 16-hour day).
3. carriageway width. Within the carriageway width range considered in the model (7 0 m to 21.2 m), a one metre increase in carriageway width at a junction is associated with an estimated accident reduction of 5 %.

For dual-carriageway sections the same study (Hughes, Amis & Walford, 1997) revealed the following effects:

Grade separated junctions, on-ramps

1. minor road traffic flow. A 1,000 vehicle increase in the number of vehicles entering the main road from the minor road is associated with a 16 % increase in accidents.
2. vertical alignment of on-ramp. Compared to an on-ramp arrangement where the vertical alignment is level, on-ramps with positive vertical alignment and negative vertical alignment are associated with increases in accident frequency of 350 % and 250 % respectively. On-ramps with a sag or crest profile are associated with 500 % more accidents than those with level alignment.
3. distance to next junction. As the distance to the next junction increases, accident frequency at the preceding junction decreases. A one kilometre increase in inter-junction distance is associated with a 26 % decrease in accident frequency.
4. verge width on offside of on-ramp. The presence of a wide verge on the offside of the on-ramp is associated with a 90 % reduction in accident frequency (compared to a narrow verge).
5. on-ramp merging length. Accident frequency decreases as the length of the merging lane between the end nosing and the end of the on-ramp increases. A 100 m increase in merging length is associated with a 6 % decrease in accident frequency.

Grade separated junctions, off-ramps

1. exit traffic flow. A 1,000 vehicle increase in the number of vehicles leaving the main road onto the minor road is associated with a 13 % increase in accidents.
2. vertical alignment of off-ramp. Compared to an off-ramp arrangement where the vertical alignment is level or negative, off-ramps with positive or crest vertical alignments are associated with an increase of 124 % in accident frequency.
3. distance to next junction. As the distance to the next junction increases, accident frequency at the preceding junction decreases. A one kilometre increase in inter-junction distance is associated with a 61 % decrease in accident frequency at the off-ramp.
4. verge width on offside of off-ramp. The presence of a wide verge on the offside of the off-ramp is associated with a 79 % reduction in accident frequency (compared to a narrow verge).

T-junctions

1. minor road traffic flow. An increase of 1,000 vehicles per 16 hour average annual weekday flow entering the dual carriageways from the minor road is associated with an increase of 120 % in accidents at the junction.
2. gap in central reservation. T-junctions served by a gap in the central reservation are associated with 270 % more accidents than T-junctions having no gap.
   The larger amount of accidents in this situation is explained by the presence of vehicles turning left from the side road to the express road (turning right in the British situation). This relatively high-risk traffic stream is excluded in the situation where there is no gap in the central reservation.

3. traffic using gap in central reservation. A 10 % increase in the proportion of minor road traffic flow using a gap in the central reservation is associated with a 9 % increase in accidents at the junction.

Due to the relatively small amount of studied road sections and intersections in this study (Hughes, Amis & Walford, 1997), and the large amount of interrelated variables, of which relations and mutual influences are not discussed, the results of this study are questionable and should be used with care.
Since no other research findings could be used on this subject, no recommendations can be given on the design of intersections and interchanges on express roads.

In a UK study of trunk roads in Great Britain by Walmsley & Summersgill (1998), the presence of junctions was found to be a major determinant of the number of accidents.
On a typical dual-carriageway trunk road, each major junction was found to contribute about 22 per cent increase in accidents. On a typical single-carriageway trunk road, this increase was 11 per cent.

7. Roadside design

The condition of the roadside is one of the design characteristics which most affects crash frequency and severity. In most European countries approximately one quarter of all casualties are killed in accidents with obstacles. Providing a more 'forgiving' roadside relatively free of steep slopes and rigid objects, or protection by means of a crash barrier, will allow many of these run-off-road vehicles to recover without resulting in a serious crash.

For a strategy with respect to the design of verges, three general principles can be distinguished, which are applicable to both divided and undivided roads (Schoon, 1994). These are listed below, in order of preference:

- In the first design, an *obstacle-free zone* is regarded as the safest solution. There are no hazard areas or obstacles. Vehicles leaving the road can go on running freely or perhaps can be brought under control.
- In the second type, *a zone with single obstacles*, fixed roadside objects and single rigid obstacles are present. Roadside equipment like lamp posts and traffic signs have to be designed in a way that, if hit by a motor vehicle, they do not endanger the drivers and passengers. The rigid objects, if there is no way to remove them, will have to be protected separately (i.e. with a crash barrier of short length or with an impact attenuator).
- The relatively least safe area, a *full protected zone*, has a hazard area too close to the carriageway. This should be protected along the full length by a crash barrier.

In both German and Dutch standards, it is stated which obstacles must be shielded by a crash barrier. Some of the most important are:

- water;
- noise screens;
- trees, poles, large signs, alarmposts (unless the alarmposts have a special constructions which will bend relatively easy at ground level in case of an accident);
- walls of buildings;
- special constructions (bridges, viaducts);
- downward slopes;
- upward slopes.

The relative hazard of the roadside may be described in terms of several characteristics, including (Zegeer & Council, 1992):

- roadside recovery distance (or roadside clear zone);
- sideslope;
- presence of specific roadside obstacles (e.g. trees, culverts, utility poles, guardrails).

7.1. Roadside recovery distance

The roadside recovery distance is a relatively flat, unobstructed area adjacent to the travel lane (i.e., edgeline) where there is a reasonable chance for an off-road vehicle to recover safely. The recovery distance therefore is the distance from the outside edge of the travel lane to the nearest rigid obstacle, steep slope, non-traversable ditch, or other threat to errant motor vehicles; and consists of the shoulder width + verge width (Zegeer & Council, 1992). According to Zegeer & Council (1992), single-vehicle accidents per mile per year are highest for roads with a non-clear zone, next highest for a 4:1 clear zone (i.e. same clear area with a 4:1 sideslope), and lowest for a 6:1 clear zone for various ADT's (see *Figure 3*).

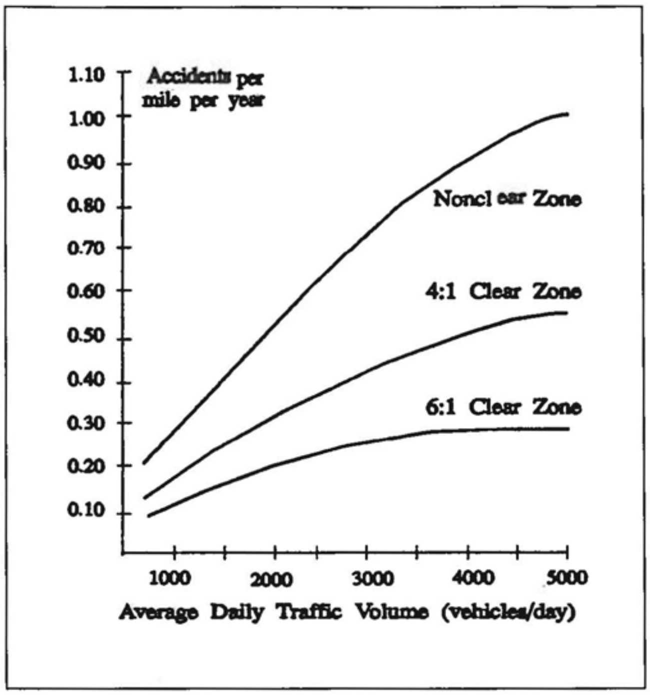

Figure 3. *Relationship between single-vehicle, run-off-road accidents per mile per year, and ADT for two-lane highways. (Zegeer & Council, 1992).*

For roadways with a limited recovery distance (particularly less than 3 or 4.5 m) where roadside improvements are proposed, Zegeer gives the following accident reduction factors (see *Table 4*).

Amount of increased roadside recovery distance	Percent reduction in related accident types
1.5 cm	13 %
2.5 cm	21 %
3.0 cm	25 %
3.5 cm	29 %
4.5 cm	35 %
6.0 cm	44 %

Table 4. *Safety effects of increasing the roadside recovery distance (Zegeer & Council, 1992).*

Because design and use of the studied road sections differ from the characteristics of express roads, these figures should merely be seen as an indication of the relationship and as a rough estimate of possible effects.

In a Dutch accident study dating from 1983 (Schoon & Bos, 1983), the relation is determined between the number of accidents with trees and the distance of the trees to the edge of the pavement. The tree accidents (and in fact all fixed object accidents) are related to the total number of accidents. As variable, the motor vehicle volume (ADT) was used.
Based on this study. Dutch guidelines recommend widths varying from 10 m for motorways, to 6 m for single carriageway roads with a design speed of 100 km/h, and 4.5 m for single carriageway roads with a design speed of 80 km/h. (measured from the edge line of the traffic lane). Wider recovery areas do not substantially reduce accident rates any further.
If a sufficient recovery distance cannot be provided, the obstacles within the verge should be protected by guardrails. It has to be considered that guardrails should be regarded as obstacles themselves. However, the severity of crashes with guardrails is much lower than of crashes with other rigid obstacles.

Recommendations
The recommended values for the minimum obstacle-free zone differ largely between countries and are based on a very limited amount of empirical data. In some countries the minimum value is fixed, in other countries the minimum value is made dependent on road category, design speed, and/or traffic volume.
Based on current practice in EU Member States, and on available research data, Schoon (1994) comes to a 'best practice value' for obstacle-free zones of at least 5 m for rural non-motorway divided roads and rural undivided roads with a design speed of 100 km/h; and 3.5 m for undivided primary rural roads with a design speed of 80 km/h.

7.2. Sideslope

The steepness of the roadside slope or sideslope is a cross-sectional feature which affects the likelihood of an off-road vehicle rolling over or recovering back into the travel lane.
Zegeer et al. (1987) developed relationships between single-vehicle crashes and field-measured sideslopes from 2:1 to 7:1 or flatter, in Michigan, Alabama, and Washington. As shown in the following figure, single-vehicle accidents (as a ratio of accidents on a 7:1 slope) are highest for slopes of 2:1 or steeper, and drop only slightly for 3:1 slopes. Single vehicle accidents then drop linearly (and significantly) for flatter slopes.
The use of flatter slopes not only reduces the accident rate, but it may also reduce rollover accidents, which are typically quite severe. Zegeer concludes that sideslopes of 5:1 or flatter are needed to significantly reduce the incidence of rollover accidents.

Recommendations
Research proved that on slopes steeper than 5:1 there is a risk of roll-over accidents, especially when drivers undertake emergency steering or braking manoeuvres. It is believed that most drivers make those steering or braking manoeuvres while running off the road.

Most countries recommend maximum side slope gradients considerably steeper than 5:1, sometimes based on the presumption drivers do not take evasive actions while going off the road. Because this seems very unlikely, a maximum sideslope of 5:1 should be recommended. Steeper slopes have to be considered as dangerous areas and should therefore be protected with guard rails.

Because the amount of research focussed directly on express roads is very limited, further research on the exact effects and on recommended dimensions is advised.

8. Discussion

One of the main findings of this study is that the amount of research on safety effects of design parameters on express roads is very limited and insufficient to use as a basis for design standards.
Extensive research on safety effects of design characteristics has been carried out on motorways and rural two-lane roads (highways), but because effects and recommended standards are highly dependent on function, design, and use, this information cannot be simply adopted for the situation on express roads. Although this information on the road categories just above and below the express road category can sometimes give an indication of possible safety effects, further research focussed on express roads is needed to give reliable design recommendations.

During this study the need for design standards for express roads proved to be great. Express roads throughout Europe show a wide variety of different designs, whereas possible (positive or negative) effects of those differences are not known. To improve the poor safety record of express roads, uniform design recommendations are considered very important.
In an interview with a Netherlands national road administrator, conducted in Workpackage 3.2, there proved to be several experiments in the Netherlands in improving the design of express roads. These experiments were not based on research results and thorough before/after studies were not used.
The most commonly used strategy in the design experiments is the introduction of 'motorway design characteristics' in the design of the express road. The idea is that the use of design elements of a safer road type improves the safety of the express road. This approach however is controversial. The use of motorway design characteristics in other road types is strongly advised against in numerous guidelines because of possible adverse safety effects. According to this theory, the motorway design characteristics could cause road users to think (falsely) that they are driving on a motorway, leading to possible misjudgements on other sections of the road. Although this theory is very plausible, it is not known if this misjudgement effect truly causes higher accident rates. The positive effect of the introduced (motorway) design element could very well be stronger than the possible negative effect of misjudgement problems.
Further research is important to support the search for safer design of express roads. Since road administrators are already undertaking the abovementioned experiments, it is important to gain more insight in possible effects in the short term.

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