ANNEX VI
to SWOV report
Safety effects of road design standards
R-94-7

Road cross-section

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R-94-7 VI
Published by: SWOV Institute for Road Safety Research, Leidschendam, The Netherlands

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Notice to the reader

This volume is one of the annexes to a main report on safety effects of road design standards which was compiled by SWOV in collaboration with other European partners, in 1993-1994.

The project was carried out with financial support of the Commission of the European Union. However, no authority of the European Union has responsability for the contents of this publication.

The main report is a composition of contributions from various authors, edited by SWOV and published in both English and French. The annexes were not re-edited but were published in the form in which they were furnished by the authors. SWOV is not responsible for the contents of annexes that were produced by authors from outside the institute.

The full publication consists of the following volumes.

Main report: Safety effects of road design standards
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Annex I: Road classification and categorization
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Annex II: Assumptions used in road design
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Annex III: Methods for investigating the relationship between accidents, road user behaviour and road design standards
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Annex IV: International organizations and road design standards
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Annex V: National road design standards
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1. Introduction

The importance of properly analyzing roadway width standards requires systematic consideration of numerous variables. The dimensions requiring investigation should include a study of present professional experience in road design, historical review of the evolution of width standards and an evaluation of safety, operational, environmental and cost aspects of width elements.

The main objective of the project was the analysis of cross-section dimmensions established in national standards, basic criteria and safety effects of lane widths and shoulder widths. Three sources were taken into consideration:
- the knowledge relating to relationships between road geometry and operational, economical and safety aspects,
- conclusions from the comparison of dimensions provided in different standards,
- facts and assumptions presented in national guidelines.

The following road types were compared:
- Rural Motorways,
- Rural Non-Motorway Divided Roads (including Dual Carriageway Expressways),
- Undivided Roads (including Single Carriageway Expressways and Ordinary Roads with the Design Speed higher than 60 kmph).

In the evaluation of cross-section dimensions, national and international standards were compared:
- standards used in The Netherlands (Ref. 1, 2), France (Ref. 3, 4), Belgium (Ref. 5, 6), United Kingdom (Ref. 7, 8, 9), Germany (Ref. 10, 11), Italy (Ref. 12), Ireland (Ref. 13), Danemark (Ref. 14), Spain (Ref. 15); original figures of cross-sections from some guidelines are shown in Appendix 1.
- Revised Text of Annexes II and III of The European Agreement on Main International Traffic Arteries - AGR (Ref. 16),
- Road Typology in The Trans-European Road Network, Non-Motorway Link - START (Ref. 17),
- Trans-European North-South Motorway - TEM, Standards and Recommended Practice (Ref. 18).

Comparisons carried out in Technische Hochschule Darmstadt (Ref. 19) and in University College Cork (Ref. 20, 21) were the only source of road design standards in other EFTA countries and the starting point for evaluation of road design standards.

The direct comparison of all available information is unfortunately difficult because:
- a number of countries do not use certain categories of road or use for example undivided motorways and semi- motorways,
- the design speed does not always mean exactly the same criterion in all countries,
- road design guidelines contain a different range of specifications, facts and assumptions related to cross-section dimmensions.

In order to compare standard dimensions, the following definitions of cross-section elements were assumed (see Figure 1):

PLATFORM consists of carriageways, shoulders and central reservation.
PAVED WIDTH means the sum of carriageway width and paved shoulder width.
CARRIAGEWAY consists of traffic lanes (including centre line).
SHOULDER may consist of paved shoulder and soft/grass verge.
CENTRAL RESERVATION may consist of inner paved shoulders and median strip (verge).
PAVED SHOULDER comprises also EDGE STRIP and EMERGENCY STOPPING LANE.

In Chapter 2 the overview of general findings from European and American literature is presented. The Chapter 3 concerns investigated standards and elaborations relating to these standards.

2. Factors effecting the cross-section width

The factors effecting the cross-section width 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 typical personal car and heavy vehicles, number of pedestrians, cyclist volume,
- road factors: alignment, drainage, construction practice, maintenance procedures, temporary changes of traffic regulations in work and congestion areas,
- human factors: drivers' behaviours in speed and lateral placement, behavioural adaptations, safety filling,
- environmental factors: landscaping, access requiments, aesthetics, protected area,
- safety considerations: accidents rates, severity of accidents, costs,
- operational requirements: demanded level of service, capacity, delays,
- benefit/cost analysis: construction, maintenance, accident and operational costs.

Some of the variables are universal in nature, for European countries as speed, driver's behaviour under conflict situations, accidents related to geometry, vehicles characteristics. Other variables may have specific character, for example type of terrain, costs of building and maintaning.
In methodology for analysis of rural element widths, factors mentioned above should be taken into consideration in base values analysis and benefit/cost analysis to provide optimal dimensions. A systematic approach to the evaluation cross-sectional width was developed (Fig. 2).

2.1 Historical progression of design standards

The investigation of sources indicates the evolution of roadway design standards over the last 40 years. In 1921 in the USA an 18-foot carriageway was indicated as a minimum on two-lane roads. Studies in 1937-1943 produced the popular set of minimum dimensions of 20, 22 and 24 feet. Shoulder width standards have remained fairly constant since 1940. Recent policy recognized both the importance of carriageway width and the occasional cost and right-of-way constraints which occur. As a result, shoulder widths range from 2 to 10 feet for all average running speeds (Ref. 22). These changes certify the professional growth in knowledge and response to changes in vehicles speeds, sizes and volumes in the beginning of the motorization era. Recently changes in some European standards certify first of all the intention to optimalise cross-section width taking into consideration benefit/cost analysis. In the period from 1956 to 1982 in German standards new types and dimensions of cross-section elements appeared (Ref. 23). For rural divided roads

- three-lane carriageway and narrow type of two-lane carriageway with lane width of 3.5 m and emergency stopping lane of 2.0 m (RAS-Q 1970/74), and
- narrow type of two-lane carriageway with lane width of 3.25 m and without emergency stopping lane (RAS-Q 1982)

were admitted.

With reference to rural undivided roads, the emergency stopping lane was removed from all types of single carriageway roads, remaining one cross-sectional type with paved shoulder of 1.5 m and four ordinary cross-sections with lane width ranging from 2.75 m to 3.75 m.

The guidelines considered in this report were edited in the period of least 16 years. Changes in different factors effecting the choice of optimal cross-section width, especially cost relations (construction, energy, accidents, environment) should be taken into consideration by guideline users in consequence calculations.

2.2 Operational effects

A traffic lane is that part of carriageway set aside for the normal movement of a single stream of vehicles. In case of shoulders, the problem is more complex. On motorways, stabilized and paved shoulders, if there are, fulfil the role of emergency stopping lanes. Their width depends mainly on a width of typical heavy vehicle and type of terrain. In case of undivided road, shoulders serve a variety of functions, and it is not always clear, which of these should provide the basis for shoulder standards. Depending on the type of road, type and width of shoulder (paved, sealed, grassed), the major function can be (Ref. 24):

- lateral support to the traffic lanes,
- to drain water away from pavement,
- to increase the "effective" width of traffic lanes,
- to provide space for slower vehicles to allow faster vehicles to pass,
- to enable a stopped vehicle to stand clear of the traffic lanes,
- to provide a recovery area for errant vehicles,
- to provide the possibility to make a tracking correction.

Functions mentioned above do not refer to any berm, verge or extra width provided to accomodate barriers, fencing, post, guide etc.

Operational effects of lane and shoulder width can be considered in some topics:
- use of lanes by different type of vehicles,
- use of shoulder by moving and stationary vehicles,
- lateral placement,
- running speed of vehicles,
- manouevre freedom
- operating costs.

Results from British surveys (Ref. 25) indicate one stop every 33,000 vehicles kilometres for light vehicles and one stop every 10,000 vehicles kilometres for heavy vehicles. On Dutch motorways (Ref. 1), observations indicate 0.3 stop per per day per kilometre. This rate of emergency stops is sufficient to change for worse safety and operational characteristics, if stationary vehicles occupy a part of the traffic lane.

American studies (Ref. 24) suggest that paved shoulders improve the lateral separation between oncoming vehicles. This separation depends on width and type of shoulders. The distance from the centreline on single carriageway road is greatest on section with no distinctions between shoulders and traffic lanes. On roads with 1.2 m shoulders vehicles were placed approximately 1.1 m nearer to centre line than on roads with 2.4 m shoulders. The reduction of shoulder width from 1.2 m to 0.9 m caused no further change in placement. German analysis of the lateral distance (Ref. 26) shows that drivers make their driving behaviour dependent primarily upon the presence of an emergency lane, the width of traffic lanes, the speeds and the volume of traffic on the lanes. The lateral distance between overtaking depended above all on the distance of the vehicle overtaken to the centreline. This distance is similar (173-184 cm) for 3.25 m traffic lane with emergency stopping lanes (ESL) and 3.5-3.75 m traffic lanes without ESL. For 3.25 m traffic lane without ESL, lateral distance between overtaking is lower than 30 cm, for 3.75 m traffic lane with ESL, this distance is higher than approx. 50 cm. According to these findings, cross-section of RQ 26 (see Appendix 1) was suggested as sufficient for design speed to 120 kmph.

The running speed can have measurable impact on the level of service and operating costs. A review of research efforts indicates that narrow pavement widths have some effect on vehicle speeds on low volume rural road (Ref. 22). Speed differencies between two lane highways with and without paved shoulders at traffic volume greater than 250 vehph were of the order of 8 kmph (Ref. 24). As traffic volume increases the operational benefits derived from a full-width paved shoulder increase. They are significant at volumes greater than about 200 vehph, when paved shoulders appear to increase the average speed on the roadway by at least 10 percent and limit the number of the vehicles that are in platoons to less than 20 percent (Ref. 27).

In German study it was found that up to a traffic volume of 1200 vehph in one direction the average speed of trucks on sections without ESL showed a reduction of 7 kmph when the width of lane was less than 3.5 m.

From analysis of wide edgeline painting effects on lateral placement and speed (Ref. 28) it can be concluded there were no statistically signifficant differences between the 10 cm and 20 cm wide edgeline.

All mentioned above operational characteristics result in the road capacity. Citing the HCM-85 (Ref. 29),a reduction of lane width from 3.6 m to 2.7 m causes capacity reduction of 19 percent, but reduction from 3.5 to 3.25 m causes very little reduction of capacity.

2.3 Traffic safety

Accident experience on all rural roads is a complex function of many factors. To compare accident occurrences for various lane and shoulder width, two different procedures may be used (Ref. 30, 31):

- comparative analysis allowing for a large data base without relying on improved road section; the results of these studies must be considered with caution, because it is difficult to control all the co-variables,
- before and after analysis for road sections that were widened; these analysis may be difficult because of limited sample size, effects of other improvement, additional traffic.

The conclusions of studies related to the effect of pavement width, lane width, shoulder width and shoulder type on accidents especially on two-lane rural roads were often not only inconsistent, in many cases contradictory. But considering the most solid studies the results are more clear.

Taking into consideration American prior studies, general effects of lane and shoulder width on accidents can be summarized as follow (Ref. 31, 32, 33):

- accident rates generally decrease as lane and shoulder widths increase,
- lane and shoulder conditions directly affect run-of-road and opposite-direction accidents (these accident types represent over 50% of the total); other accident type are not directly affected by these elements,
- rates of r-o-r and o-d accident decrease with increasing lane width; however marginal effect of lane -width increments is diminished as either the base lane width or base shoulder width increases; the unadjusted accident rates are approximately the same (or slightly higher) for 3.6 m lanes as for 3.3 m lanes, possibly indicating in part the limit beyong which further increases in lane width are ineffectual (Fig. 3),
- rates of r-o-r and o-d accident decrease with increasing shoulder width; however the marginal effect of shoulder width increments is diminished as either the base lane eidth or base shoulder width increases; before-after studies show also a significant reduction (12% - 27%) for the total accident rate, when adding or widening paved or stabilized shoulders on two-lane roads; it should be noted there was a slight increase in rate for shoulders 3.0-3.7 m wide (Fig. 3),
- lane width has a greater effect on accident rates than shoulder width (Table 1).

On the basis of the results of prior studies, comprehensive models have been developed (Ref. 32).

Table 1. Percentage Reduction in Accidents due to lane widening, paved shoulder widening and Unpaved shoulder widening (Ref. 34)

Total amount of lane or shoulder widening (m) Total	Per side	Lane widening	Paved shoulder widening	Unpaved shoulder widening
0.6	0.3	5	4	3
1.2	0.6	12	8	7
1.8	0.9	17	12	10
2.4	1.2	21	15	13
3.0	1.5		19	16
3.6	1.8		21	18
4.3	2.1		25	21
4.9	2.4		28	24
5.5	2.7		31	26
6.1	3.0		33	29

The evaluations of the accident reports from the stretches in Germany (Ref. 26) led to the result that the frequency of accidents due to "errors in overtaking, being overtaken, and changing lanes" was higher than average on stretches with narrow traffic lanes (3.25 m).
Comparison of accident rates and accident cost rates for German rural roads (Ref. 35) shows that

- type d2 (RQ 10 with 3.25 m traffic lane, 0.25 m edge strip and 1.5 m paved shoulder) and type e2 (RQ 10 with 3.0 m traffic lane with 1.5 m verge) have the highest accident rates,
- type e2 (RQ 10) and b2u (RQ 11 in RAS-Q 74 with 5.25 m traffic lane and 0.25 m edge strep) have the highest accident cost rates, - type b2+1 (RQ 12 with 3.5-3.75 m traffic lanes, 0.5 m double centreline and 0.25 edge strip) has the lowest accident rates and accident cost rates,
- paved shoulder on non-motorway divided roads (4m, 4ms) does not cause significant improvement in accident rates, but the lack of central reservation causes double increase of accident cost rates,
- increase of number of lanes on motorways cause a slight decrease of accident rate, but accident cost rates are constant.

These findings are presented on Fig.4 and 5. It should be noted that type c2 with 3.25 m lane width (eliminated from RAS-Q 82) has the accident cost rate lower of 27 percent than b2 type with 3.75 lane width.
German comparative studies concerning motorways (Ref. 36) show that for the same lane number and lane width the motorways with an emergency stopping lane (often 3.0 m wide) has a total accident rate which is reduced of more than 15% relatively to the rate on motorways with narrow paved shoulders.

A study undertaken in Denmark (Ref. 37) found that for road

widths of under 6 m there was an increase in the risks of both injury accidents and severe injury accidents. However, recent Swedish work concluded that it was not possible to detect any statisicall significant differences in accident rates between wide and narrow roads. Of the three road width classes used (6-8.5, 9 and 10-13 m), the 9 m roads had a higher accident rate irrespective of the decade of construction.(Ref. 21).
Results of safety research carried out in Switzerland show that increasing the single carriageway width to 8.5-10.0 m decreased accident rate as well as the victim rate, but for the widths between 12 m and 14.0 m both rates increased again. These and other findings question the validity of the undoubted hypothesis "the wider the road, the safer it is" (Ref. 38). Polish findings show that the widening of road pavement from 9-10 m to 10.5-11 m caused the increase of accident cost rates (Ref. 39). That suggests the importance of futher solid investigation in this field in European countries.

2.4 Costs relationships

The analysis of total economic consequences of the choice of road cross-section and its optimal dimensions requires the inputs of some costs components into the calculation (Ref. 40):
- construction costs,
- vehicles operating costs,
- accident costs,
- maintenance costs.

From practice point of view, entry parameters can be divided into three groups:
- parameters independent on the road: length of time period in question, opening year, traffic development, percentage of heavy vehicles,
- parameters dependent of the road: capacity, volume/speed relationships, accident rates, construction costs, maintenance costs,
- price level: price per accident, hourly price for cars and heavy vehicles, driving costs, discount rate.

The results of the benefit/cost calculations for two-lane roads in USA show that (Ref. 22):
- the relatively high cost of providing full pavement width and wide shoulders against the expected safety benefits for very low volume is evident,
- there are optimum widths
  - for low device standard (ADT less than 100) 2.7-3.0 m lane width with 0.6 m shoulder width,
  - for intermediate device standard (ADT from 200 to 400) 3.0-3.3 m lane width and 0.9 m shoulder width,
  - for high device standard (ADT from 400 to 1200) 3.3-3.6 m lane width and 1.2 m shoulder width.

The Australian studies (Ref. 38) concluded that some particular areas where costs may be reduced are in pavement and shoulder width as show in Fig. 6

In Danish practice (Ref. 14), economic optimal annual daily traffic is determined for different type of single carriageway, for example:
- 0-2000 pcuph for 6 m carriageway,
- 2000-5000 pcuph for 7 m carriageway,

- 5000-7000 pcuph for 8 m carriageway,
- 7000-14000 pcuph for 15 m carriageway.

Economic reasons induce to searching of intermediate cross-sections for minimising the area requirement for road development, especially for average daily traffic between 7000-20000. Intermediate cross-sections according to the present German guidelines are presented on Fig. 7 (Ref. 41).
In Sweden (Ref. 40) a benefit/cost method is used to select between different investment alternatives. There is no standard model for quantitative socio-economic evaluation. The determination of the most suitable cross-section is based on the principle that the total costs for society should be minimised (Fig. 8).

3. Cross-section dimensions and assumptions in investigated standards

3.1 Subject of guidelines in cross-section aspects

Studied standards indicate the varying design philosophies (Ref. 20). It concernes main factors determining road alignment and and cross-section, definitions and importance of design speed, possibilities of departures from standards as well as the role of guideline users in the designing process. Therefore standards documents contain
- cross-section dimentions for some type of roads; usually the modification of standards are to be avoided, or
- cross-section dimentions and the basis for justifying those dimensions is also given, or
- cross-section dimensions and procedures for the choice of optimal cross-section or for the consequence determination of the departure from the standards.

Analysis of basic criteria on the base of national standards and, if there are, additional elaboration related to standards is very limited. As it is presented in Table 2 there are few considered standards which give explanations on admitted width of cross-sectional elements. The background for cross-sectional dimensions of undivided motorways is presented very rarely.

3.2 Design speed ranges

For the purposes of comparing cross-section dimensions, the cross-section elements for different countries are compared by design speed in spite of different design speed concepts and definitions used in these countries.

In the group of EU countries the motorway design speed range is from 80 kmph to 140 kmph (Table 3), and so
- speed of 80 kmph is used in France (for type of 2x2, 2x3, 2x4) and in Ireland (for type 2x2, 2x3),
- speed of 90 kmph is used in Belgium and the Netherlands (urban motorway),
- speed of 100 kmph is used in Germany, United Kingdom, France, Italy and Ireland,
- speed of 120 kmph is used in all countries particularly for type of 2x2 and 2x3,
- speed of 140 kmph is used in Spanish (for type of 2x2), Belgian and Italian (for type of 2x2, 2x3) standards.

Table 2. Guideline contents refering to cross-section

Problem	Countries											
	B	DK	F	G	UK	GR	I	IR	L	NL	SP	P
classification of roads	MR	MR	M	MR	MR		MR	MR		MR	MR	
road functions		MR		MR	MR					MR	MR	
design speed	MR	MR	M	MR	MR		MR	MR		MR	MR	
design flow	MR	MR	M	MR	MR			MR		MR	MR	
typical vehicles		MR		MR						MR	MR	
traffic lane dimensions	MR	MR	M	MR	MR		MR	MR		MR	MR	
shoulder dimension	MR	MR	M	MR	MR		MR	MR		MR	MR	
departures from standards			M		R							
road safety		MR		MR						MR		
economic reasons		MR		MR								
operational reasons		MR	MR	MR						MR		
maintenance			MR	MR								
construction							MR					
environment												
optimalisation procedures		MR			MR							
markings		MR	MR				MR			MR		

*"M"- motorways,"R"- other roads,

All countries of EFTA used motorway standards for design speed of 120 kmph. The international agreements (AGR, TEM) anticipate the design speed from 80 to 140 kmph, but in case of TEM the type of 2x4 is not taken into consideration.

In case of rural non-motorway divided roads it was found that this road type is not generally specified in the standards of the Netherlands. Design speeds range from 60 kmph (B,IR,I,UK) to 140 kmph (SP). Seven EU countries (without NL and I) prove speeds of 90-100 kmph. Three EU countries use speeds of 80, 100 and 120 kmph (Table 4).

Rural undivided roads have the widest range of design speed due to different functions performed in the network. Taking into consideration roads with a design speed of at least 60 kmph, in EU countries speeds range from 60 kmph to 120 kmph (Table 5).

Table 3. Design speed of motorways in EU countries

Country	Design speed														
	80			90			100			120			140		
	Number of lanes														
	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
B				x	x					x	x		x	x	
DK										x	x				
F	x	x	x				x	x	x	x	x	x			
G							x	x		x	x				
UK							x	x		x	x	x			
GR *															
I							x	x		x	x		x	x	
IR	x	x					x	x		x	x	x			
L *															
NL				x	x	x				x	x	x			
P *															
SP										x			x		
All	2			2			5			9			3		
AGR	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
TEM	x	x		x	x		x	x		x	x				

Table 4. Design speed of non-motorways divided roads in EU countries

Country	Design speed							
	60	70	80	90	100	110	120	140
B	x			x			x	
DK					x			
F					x			
G			x	x	x		x	
UK	x	x			x			
GR *								
I					x			
IR	x		x		x		x	
L *								
NL								
P *								
SP			x				x	x
All	3	1	3	2	6		4	1

Table 5. Design speed of undivided roads in EU countries

Country	Design speed							
	60	70	80	90	100	110	120	140
B	x			x				
DK	x		x		x			
F	x		x		x			
G	x	x	x	x	x			
UK	x		x		x			
GR *								
I	x		x		x			
IR	x		x		x			
L *								
NL	x		x		x			
P *								
SP	x	x	x		x		x	
All	9	2	8	2	8		1	

* data uncompleted

3.3 Ranges of used cross-section widths

3.3.1 Motorways

Two-, three- and four-lane motorways with design speed of 80-140 kmph were compared (Fig. 9). The width range for all cases is from 3.25m to 3.75 (edge line excluded).

In relation to design speed ranges, the width varies
- for 80 kmph from 3.5 m (F,TEM) to 3.75 m (IR),
- for 90-100 kmph from 3.25 m (NL) by 3.5 m (F,B,AGR,TEM) to 3.65-3.75 (all other countries),
- for 120 kmph from 3.5 m (NL) to 3.75 m (G,GB,I,IR) country),
- for 140 kmph from 3.5 m (B) to 3.75 (I,SP).

In Italian and TEM standards for three lane carriageways, the width of right lane is reduced by 0.25 m.

The width of shoulder (paved shoulder plus verge) varies from 2.75 m (F) to 6.75 m (IR) (Fig. 10).
In relation to a design speed, the shoulder width is
- for 80 kmph from 2.75 m (F) to 5.25 m (IR),
- for 90-100 kmph from 2.75 m (F) to 5.70 m (NL) and 5.75 m (IR); six countries use a with of 3.0-5.0 m,
- for 120 kmph fron 2.75 m (F) to 6.75 m (IR); eight countries use a width of 3.0-5.0 m,
- for 140 kmph from 3.75 m (I) and 4.05 m (F) to 4.5 m (SP).

The AGR and TEM standards anticipate shoulder width in a range of 3.25-3.75 m.

The width of paved shoulder varies from 0.5 m (DK) to 3.75 m (IR,NL). Values between 2.5 m and 3.0 m are the most frequent for all design speeds. AGR and TEM standards recommend at least 2.5 m in width (Fig. 9).
The comparison of paved shoulder width and verge width is shown

in Figures 9 and 10.

The pavement widths with two traffic lanes range
- for design speed range of 80-100 kmph from about 10.5 m (F,NL) to 11.0-11.5 m (I,G,IR),
- for design speed of 120-140 kmph from 8.0 m (DK) to 12.0 (NL,B).

The comparison of pavement widths with two-, three- and four-lanes is shown in Figure 11.

3.3.2 Non-motorway divided roads

Two- and three-lane dual-carriageway non-motorways were compared (Fig. 12). In relation to design speed ranges, the lane width are provided
- for 60 kmph of 3.5 m (IR,B),
- for 70-80 kmph from 3.25 m (G) to 3.50 m (IR,SP),
- for 90-100 kmph from 3.25 (G) and 3.5 m (G,I,B,F,SP,DK) to 3.75 m (IR),
- for 120 kmph from 3.5 m (G,B) to 3.75 m (IR,SP),
- for 140 kmph of 3.75 m (SP).

The typical value provided in seven EU's countries is 3.5 m. In AGR standards, traffic lanes on a straight alignment should have a minimum width of 3.5 m.

Shoulder width (paved shoulder plus verge) ranged from 2.25 m (I) and 2.5 m (DK) to 4.3 m (B).
In relation to a design speed, the shoulder width is (Fig. 13):
- for 60 kmph from 3.0 m (IR) to 4.3 m (B),
- for 70-80 kmph from 2.0 m (G) to 4.0 (IR),
- for 90-100 kmph from 2.25 m (I) to 4.0 m (IR,DK,G),
- for 120 kmph from 3.0 m (SP) to 4.3 m (B),
- for 140 kmph 3.0 m (SP).

Values for outer paved shoulders (edge strip, emergency stopping lane) ranged from 0.5 m (D,DK) to 3.0 m (IR,SP). The majority of countries don't provide a width wider than 2.5 m (Fig. 12).

The pavement width in case of two-lane carriageways ranges from 7.5 m (G) to 11.0 m (IR) for design speed lower than 100 kmph, and from 7.5 m to 11.5 m for design speed of at least of 100kmph (Table 6).

3.3.3 Undivided rural roads

There is a wide variation in the lane width (Fig. 14). Generally, it ranges from 2.75 (NL) to 5.0 m (DK). In relation to design speed ranges, the lane width is
- for 60 kmph from 2.75 m (NL) to 3.75 m (IR),
- for 70-80 kmph from 3.0 m (DK) to 3.75 m (IR,I,D,UK),
- for 90-100 kmph from 3.5 m (D,NL,DK) to 5.0 m (DK),
- for 120 kmph 3.75 m (SP).

There are large differences between standards for shoulder width, paricularly for verge widths. The shoulder width varies from 1.5 m (G) to 6.0 m (IR) and 6.45 m (NL). The paved shoulder width range from 0.0 (DK) to 3.0 m (IR). Verge width ranges from 0.75 m (F) to 6.0 m (NL) (Fig. 14 and 15).

Table 6. Pavement width of non-motorway divided roads (one direction, two-lane carriageway)

Country	Pavement width	Conditions	Design Speed
B IR	9.5 8.5		60
G IR SP	7.5 8.5 11.0 9.5	c4m regional national	80
B G	9.5 7.5 10.0	 c4m b4ms	90
DK F G UK I IR SP	8.0 10.0 7.5 10.0 9.3 8.95 10.5 11.5 9.5	 c4m d4ms regional national	100
B G IR SP	9.5 10.0 11.5 10.5	 national	120
SP	10.5		140

Pavement width of undivided roads ranges
- for 60 kmph from 6.5 m (IR) to 8.0 m (G),
- for 70-80 kmph from 6.0 m (DK) to 12.0 m (SP),
- for 90-100 kmph from 7.0 m (G) to 11.5 m (IR). Higher values of width are caused by using wide traffic lanes (5.0 m) or wide paved shoulders (Figure 16).

3.3.4 Conclusion

In regards to motorways, seven EU countries (F,IR,G,I,B,UK,SP) use one width of traffic lane for all design speeds. In Dutch and TEM standards, the lane width depends on design speed, in Danish standards the lane width depends on economic reasons (wide and narrow cross-section). Generally, the effect of design speed on used lane widths is unnoticed.

Paved shoulder width for motorways in French standards depends on design volume or special economic conditions, in Irish standards this width depends on design speeds, in Dutch standards it depends on number of lanes, in Danish standards depends on economic requiments. Only two motorway standards (F, DK) provide outer paved shoulder width below 2.5 m admitted by AGR. On the average, widths for speed of 100-120 kmph are a little higher than for 80 kmph.

Pavement width ranges from 8.0 to 12.0 m in case of two traffic lanes in one direction.

On non-motorway divided roads a lane width ranges from 3.25 to 3.75. Width of 3.75 appears for design speed of 100-120 kmph. There is a total disagreement in outer paved shoulder width and outer verge width. These types of roads are used with or without wide paved shoulder, so the width of pavement ranges from 7.5 m - to 11.5 m. Paved shoulder width for non-motorways in Irish standards is connected with road class. Only some standards explain the function of used paved shoulders. There are not explications on shoulder dimensions for non-motorways divided roads.

On rural undivided roads, traffic lane widths range from 2.5 m (DK) to 3.75 m. On the average, traffic lane width and shoulder width increase when design speed increases. But there are considerable differences in dimensions of shoulder elements. In Irish standards wide paved shoulders and wide verge, in Dutch and Danish standards narrow paved shoulders and wide verge, in Spanish wide paved shoulders and narrow verge are admitted. In Irish, Danish and Dutch standards shoulder width is connected with design speed. Wide shoulders admitted in Dutch standards have the substantiation in American accident research which confirms that 80-90 % of out-of-road accidents occure less than 10 m from a carriageway. In five standards (IR,I,G,DK,NL) reduction of lane width is connected with design speed decrease. A width lane in British standards relates to design flow. Italian and TEM standards recommend the width of 3.50 m for right traffic lane of three-lane carriageway while remaining two lanes have width of 3.75 m. In these cases it has been admitted that the margins between passing vehicles were sufficient because of paved shoulder and movement of vehicles nearer edge line. Finally, pavement widths of 6.0-12.0 m are used in design standards.

3.4 Design vehicle and dynamic space

Minimal width of traffic lane and paved shoulder results first of all from design width of vehicles (95th percentile width of all vehicles) and design side margins (85th percentile distance) determined by lateral placement and dynamic space of moving vehicles. Design vehicles widths found in Dutch, German and Spanish standards are presented in Table 7 (see also Fig. 17 and 18).

For rural roads the width of typical heavy vehicles is admitted. In German standards, minimal lane width results is the sum of 2.5 m heavy vehicle width, 0-1.25 m side margin and 0.25 m additional space strip, if there is opposing traffic lane. It creates traffic lane width from 2.75 to 3.75 m (Table 8). Side margins depend on speed limits as is shown in Table 9.

In Dutch standards it is stated that lateral movements depend on the difference between lane width and vehicles width. This rest width effects level of actual speed and safety. Both too small and two big rest width may cause unsafe situations. Austrian studies (Ref. 42) conclude that 85 % of personal cars run not faster than 120 kmph when rest width is 1.6 m, and not faster than 90 kmph when rest width is 1.1 m. Also 85 % of lorries run not faster than 80 kmph when rest width is 0.60 m. For max. personal car width of 1.75 m and max lorry width of 2.60, this would result in a lane width of

3.35 m for design speed of 120 kmph,
2.85 m for design speed of 90 kmph,
3.20 m for lorry speed limit of 80 kmph.

Taking into consideration safety margin between users depends on design speed (see Table 10), Dutch traffic lane width ranges from 3.35 m to 3.50 m for motorways and from 2.75 m to 3.25 m for single carriageway roads (see Table 11).

Table 7. Width of design vehicles

Country	Type of vehicles		
	heavy	personal	autobus
NL	2.6	1.75	
G	2.5	1.75	2.5
SP	2.5	1.85	2.5
DK	2.5	2.00	2.5

Table 8. Dimensions of cross-section in German standards

Type of cross sect.	Number of lanes	Design vehi-cle width	Side margin width	Extra width	Total lane width	Edge strip	ESL or paved shou-lder
a	6	2.5	1.25	-	3.75	1.00	2.50
	4	2.5	1.25	-	3.75	0.50	2.50
b	6	2.5	1.00	-	3.50	0.50	2.00
	4	2.5	1.00	-	3.50	0.50	2.00
	2	2.5	1.00	0.25	3.75	0.25	1.50
c	4	2.5	0.75	-	3.25	0.50	-
	2	2.5	0.75	0.25	3.50	0.25	-
d	4	2.5	0.50	-	3.00	0.25	-
	2	2.5	0.50	0.25	3.25	0.25	-

Table 9. Side margin widths in German standards

Permited speed	Margin width
> 70 kmph	>= 1.25
<= 70 kmph	>= 1.00
<= 50 kmph	>= 0.75

Table 10. Side margin widths in Dutch standards

Design speed kmph	Lane width	
	dual carriageway	single carriageway
120	1.50	
100		1.50
90	1.00	
80		1.00
<= 60	1.00	

Table 11. Traffic lane widths in Dutch standards

Design speed kmph	Lane width	
	dual carriageway	single carriageway
120	3.50	
100		3.25
90	3.00	
80		3.10
<= 60		2.75

3.5 Widened cross-section cases

Pavement width results from all mentioned above factors, first of all design vehicle width, margins between moving or standing vehicles, type and function of shoulders. The choice of typical pavement width in standards depends on economical, operational and safety reasons. One of the important factors is the maintenance reason conserning traffic management in road work areas on motorways. The use of the 4-0 system (one carriageway of motorway is temporarily used as a two-way carriageway) needs widest pavement width. In some cases it may cause economical hesitations.

In German practice (Ref. 11) the pavement width of RQ29 type cross-section is changed from 11.0 m to 11.5 m by widening of emergency stopping lane from 3.0 m to 3.5 m or widening of inner edge strip from 0.5 m to 1.0 m.

In Dutch motorway standards a pavement width of 12.0 m is recommended. This width may be divided by concrete barrier on two two-lane carriageways. In this case a left lane of 2.50 m is intended for personal cars only (Fig. 19).

3.6 Reduced cross-section width

It is stressed in some standards that designer will have to choose the road types according to the criteria dictated by economic analises. Sometimes economic conditions inadequancy of area, size of earthworks provokes the reduction of cross-section width. French guidelines proposes certain succesion of reductions
- first of all - reduction of central reservation, then ESL depending on obstacle presence,
- last step - reduction of lane width.

Danish standards propose the narrow type of cross-section for dual carriageway roads. Also British standards use special cross-sections with restricted width.

4. Conclusions and recommendations

1. The considered standards and guidelines present different approach to the design process offering different range of facts, assumptions, explanations, rules and recommendations. Dutch, German, Danish and British guidelines have some elements which can be recommended as a "best practice".
It is necessary
- to create national methodological documents for designers and planners with guideline references for road safety,
- to agree fundamental facts, assumptions and definitions (e.g. design and running speed, cross-section elements, design vehicles dimensions).

2. The safety aspect is one of some factors effecting cross-section dimensions. This aspect should be peculiarly important in design practice. Safety conscious design requires that designers know the safety repercussions of their decisions.
It is necessary
- to indicate in guidelines both the cost optimal range of cross-section dimensions and indispensable values from safety point

of view,
- to create clear procedures for economic calculations and safety benefits evaluations making possible the consequence determination of departure from safety standards,
- to determine savings due to accident reductions dependent on lane and shoulder width before and after widenigs.

3. Cross-section type and its dimensions together with other geometrical features determine road character. Critical review of the available literature dealing with the safety effects of cross-section standards indicates inconsistent or in many cases contradictory conclusions. Accident data are often insufficient to establish scientifically defensible relationships between road geometry and safety or to deternine the part of cross-section features in the accident causation. Prior research has established that lane and shoulder conditions directly affect run-of-road and opposite-direction accidents. Generally, accident rates of accident decreased steadily as lane or paved shoulder width increased.
It is nesessary
- to undertake in Europe futher national and international studies to create the most likely relationships between accident experience and lane width, shoulder type and shoulder width for different cross-section type, traffic conditions and accesibility, environmental features; it should be noted that North-American and European practices concerning shoulders are different,
- to undertake the research which will assist in understanding behavioural adaptation to consider the potential negative safety implications of behavioural adaptation resulting from design activities.

4. The comparison of motorway cross-section width shows relative great agreement of standards. The majority of EU countries uses lane width of 3,75. The width of 3.25 m is rarely used and only for a design speed of 90 kmph. In case of paved shoulders, only two countries use a width below 2.5 m recommended by AGR. Pavement width ranges from 8.0 m to 12.0 m for one direction. From safety point of view one can state that
- widening of lane over 3.5 m for traffic lane and 2.5 m for emergency stoping lane admitted in AGR causes a slight changes of accident rates, so lane width of 3.5 m can be recommended,
- safety effects of 3.25 m lane width for urban motorway should be investigated in different countries in order to determine safety consequences and using conditions,
- total carriageway pavement width (11.5-12.0 m) for 2x2 lane motorways may result from maintenace requirement to make possible temporary use of one carriageway as a four-lane two-way road section, however the safety effects in this case should be investigate.

5. Non-motorway divided roads as a type of roads with motorway cross-section and other non-motorway features have high accident rates. The use of wide paved shoulders on these roads in different countries depends on some additional factors like road network structure, landscaping and multifunction of road link. Even if wide paved shoulders can have some advantages for safety, the possibility of emergency stopping gives only inessential

benefits, then a paved shoulder of a width comparable to the emergency stopping lane width seems not necessary.

6. Undivided rural roads have considerable different dimensions of traffic lane and shoulders. In many cases two-lane cross section with wide paved shoulder are used like four-lane roads. Basing on safety finding one can conclude

- cross-section dimensions with invironmental features should make the impression of "narrow cross-section" being simultaneously a wide "soft" road space,
- four-lane undivided roads should be avoided in rural areas,
- in many cases tree-lane (2+1) type of cross-section is far more safe than wide two-lane cross-section,
- wide paved shoulder on two lane roads can have width of 1.8-2.0 m on higher speed single carriageway road; a different colour of paved shoulders could stress special functions of these lanes, different than functions of main lanes,
- using of emergency lay-bays every one kilometre and wide verges can be recommended to design practice.

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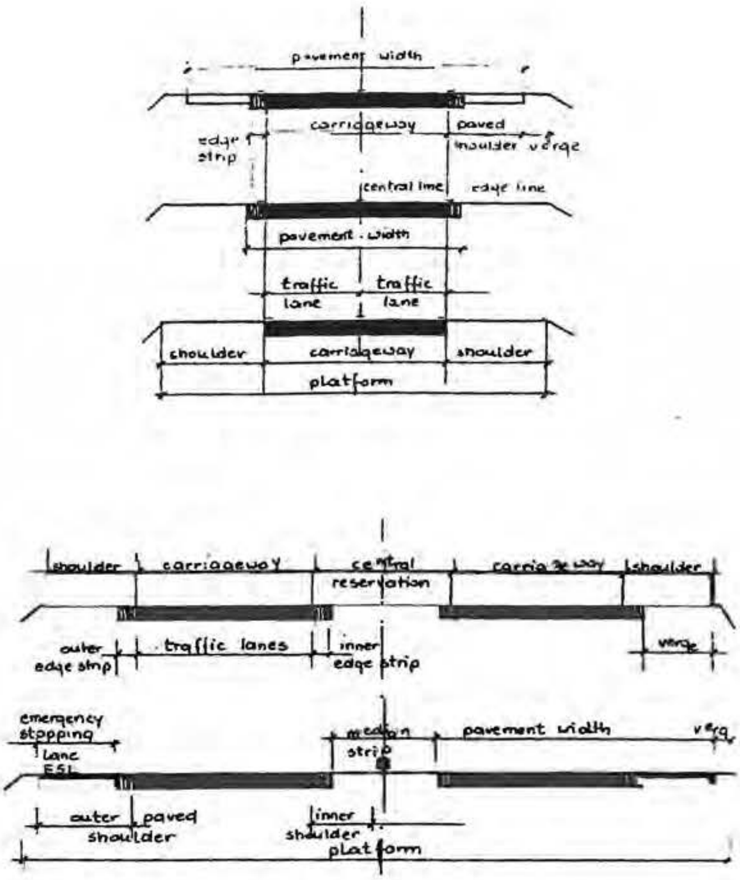


Figure 1. Elements constituting a standard cross-section

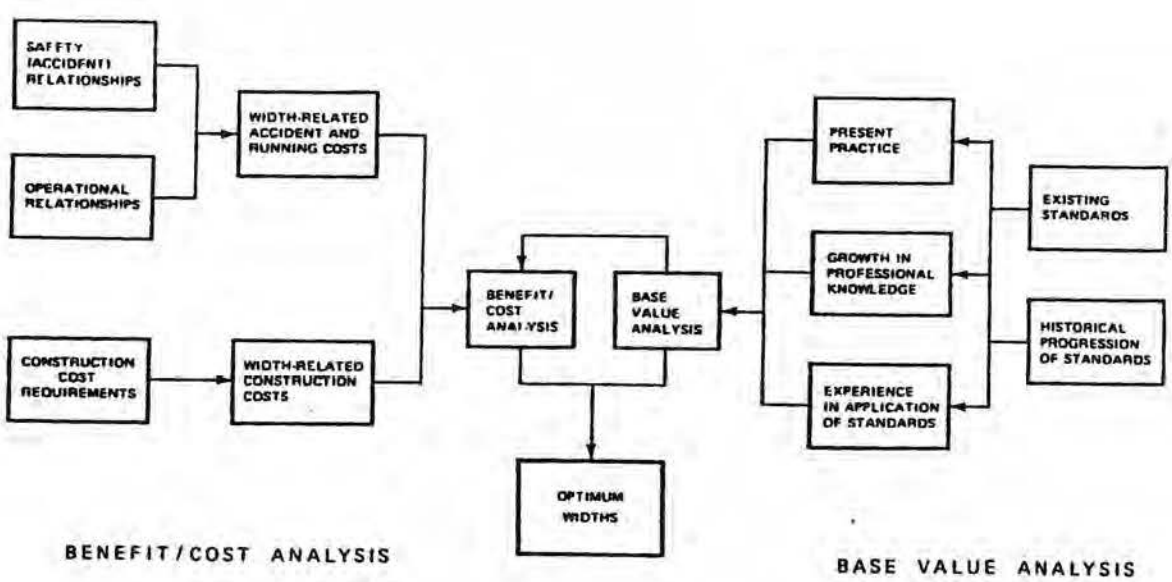


Figure 2. Methodological approach to evaluation of cross-section width

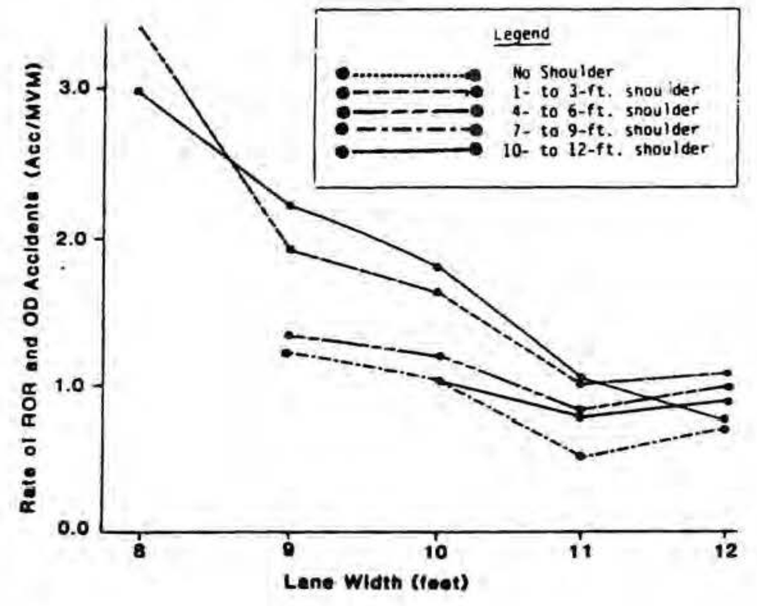


Figure 3. Relationship between accidents and lane and shoulder width (Ref. 32)

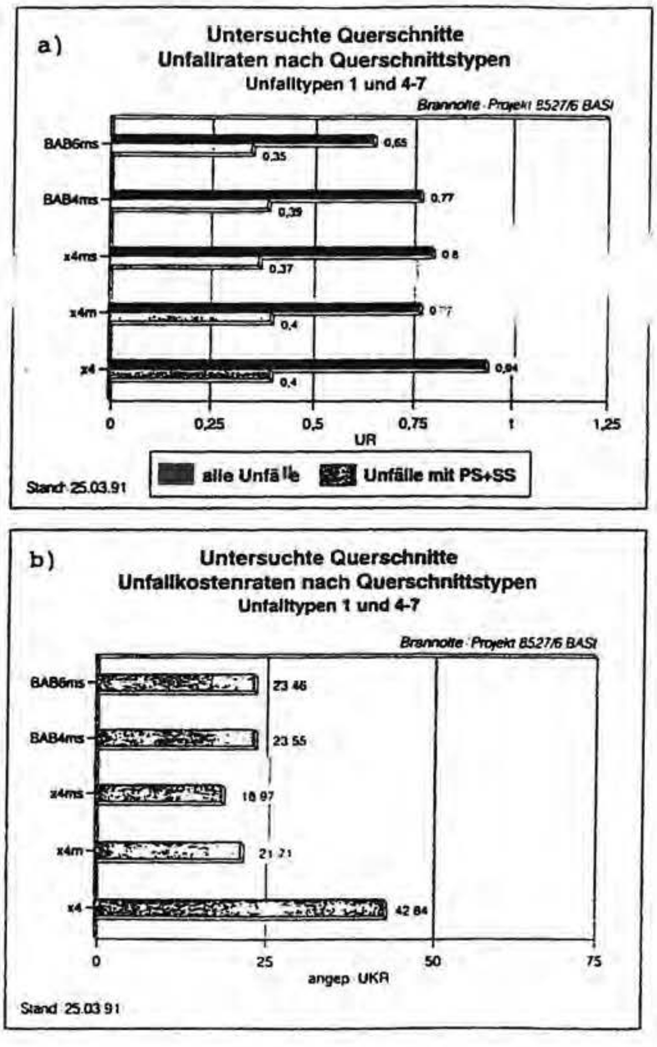


Figure 4. Accident rates (a) and accident cost rates (b) for four- and six-lane cross-sections (Ref. 23)

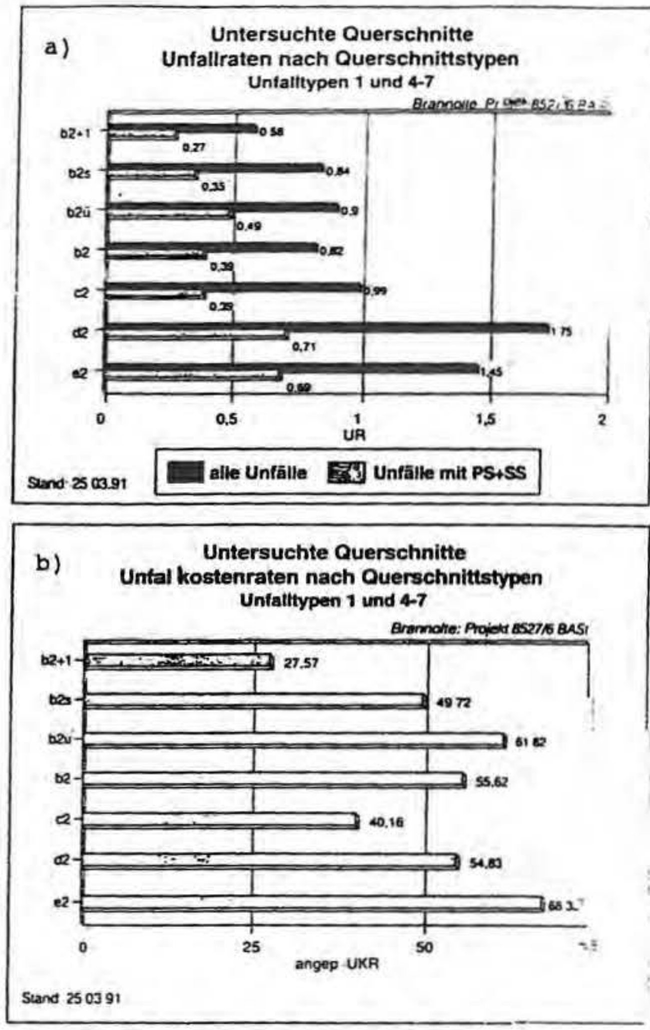


Figure 5. Accident rates (a) and accident cost rates (b) for single carriageway cross-sections (Ref. 23)

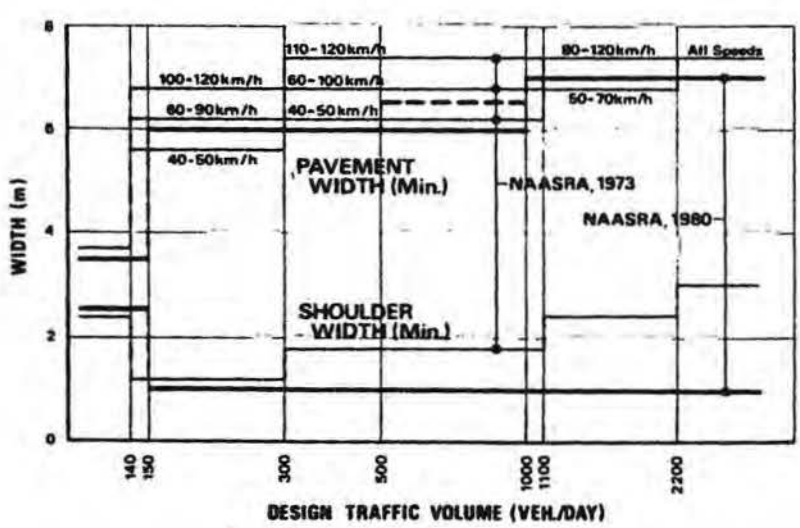


Figure 6. Minimum pavement and shoulder width (Ref. 38)

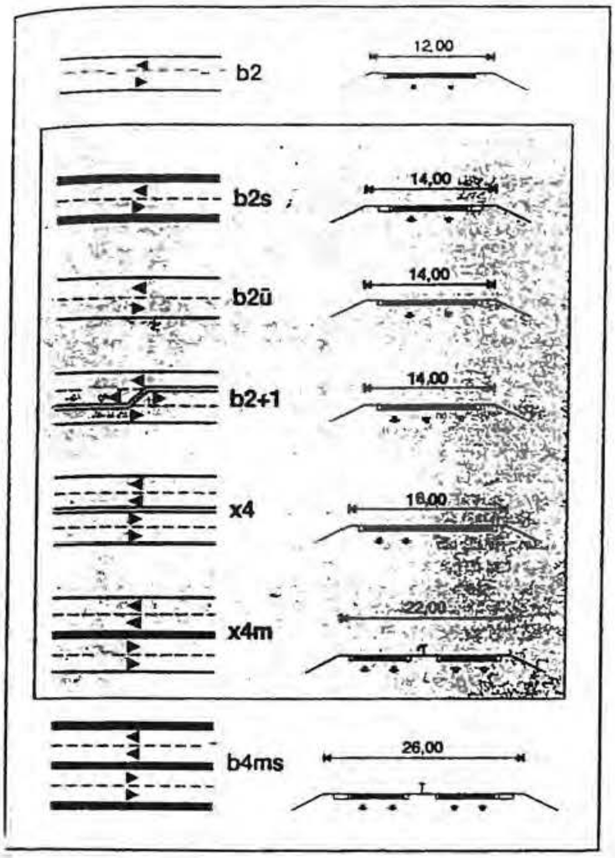


Figure 7. Intermediate cross-sections in German guidelines

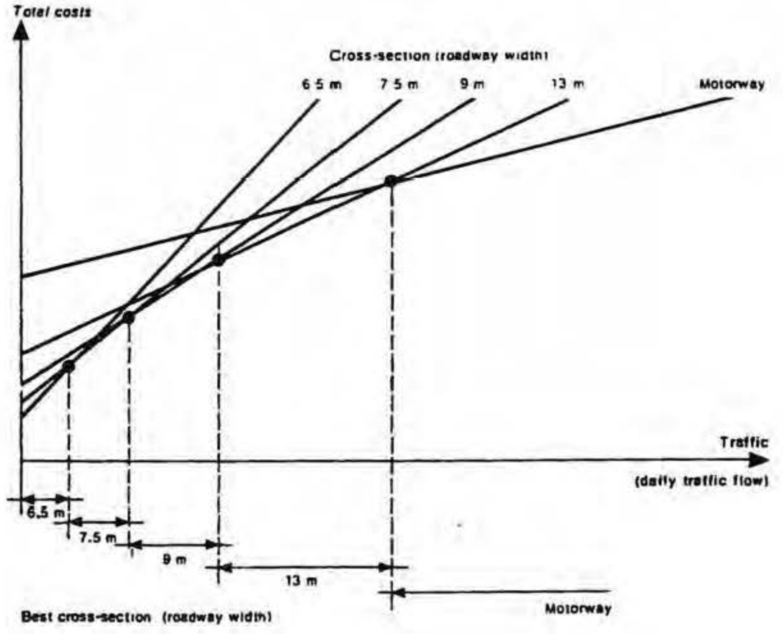


Figure 8. Selection of the best cross-section by minimizing the total costs in Sweden (Ref. 41)

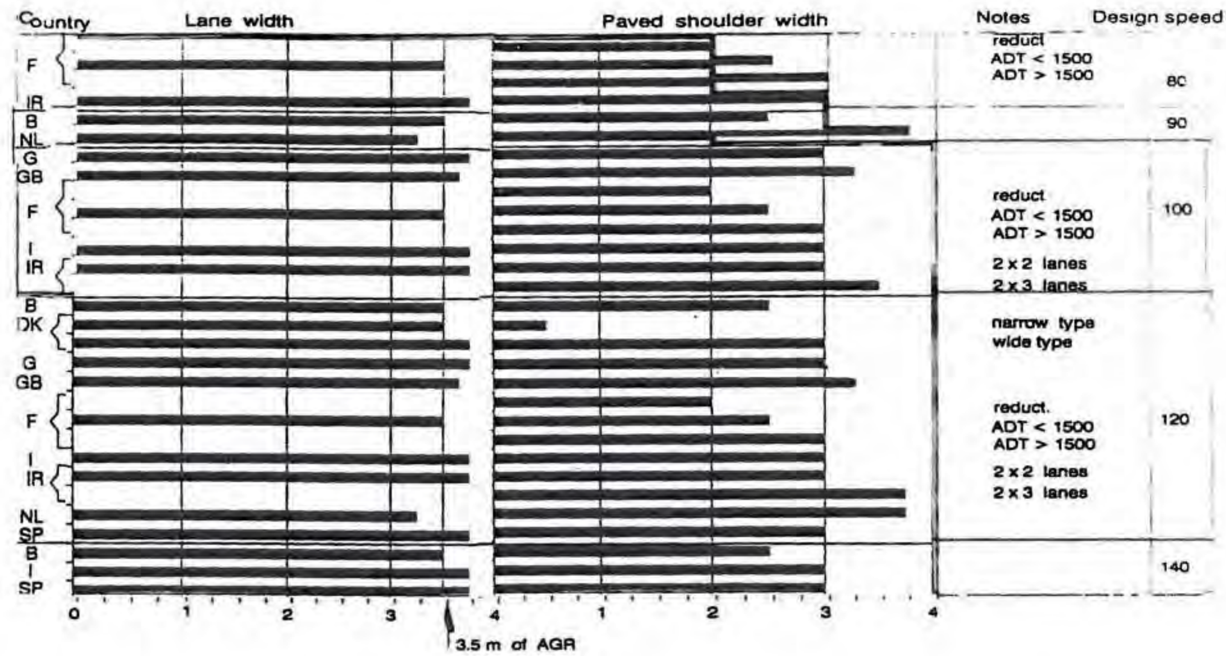


Figure 9. Traffic lane and paved shoulder width for motorways

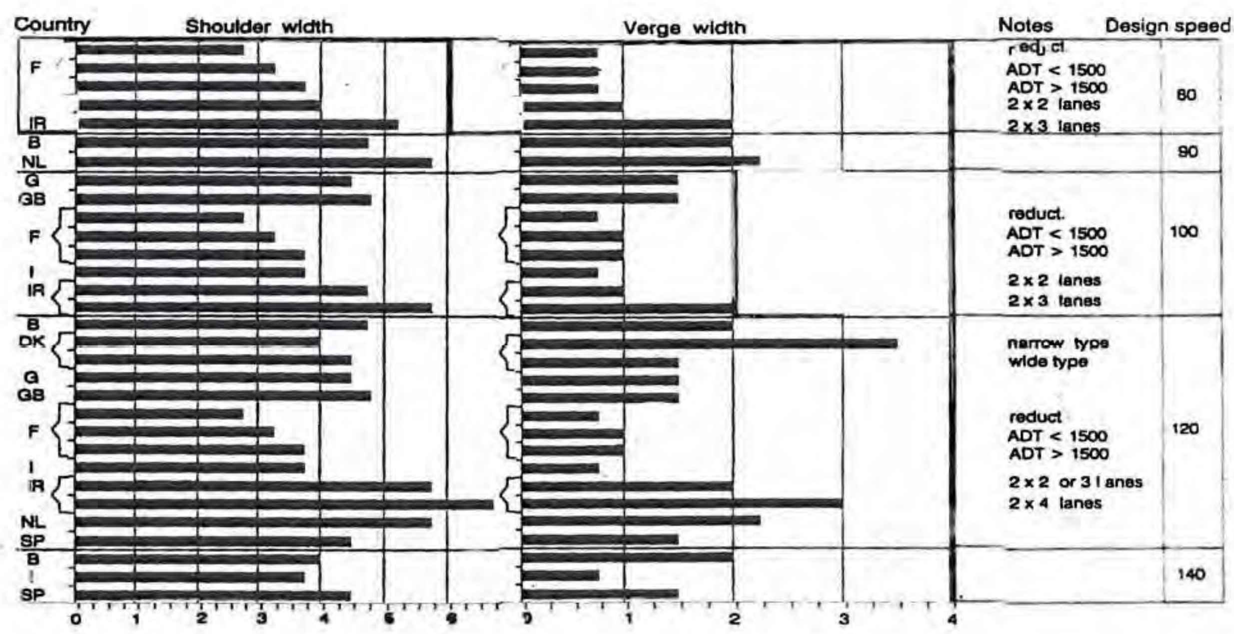


Figure 10. Outer shoulder and verge width for motorways

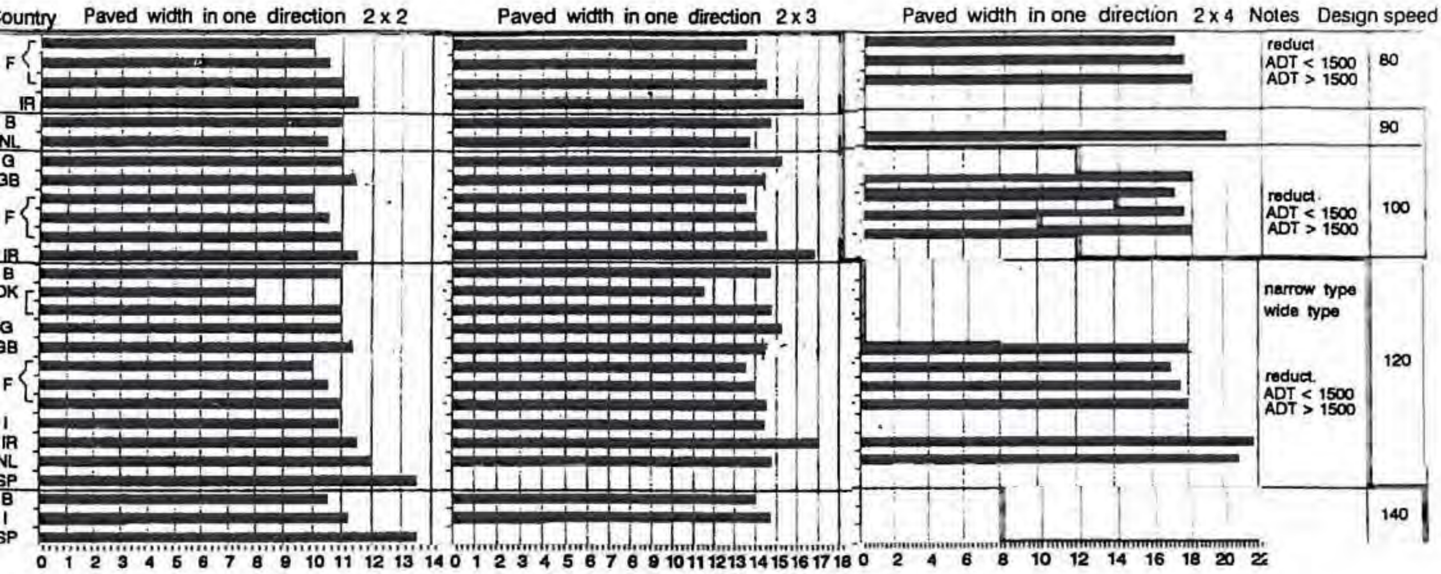


Figure 11. Pavement width of motorways

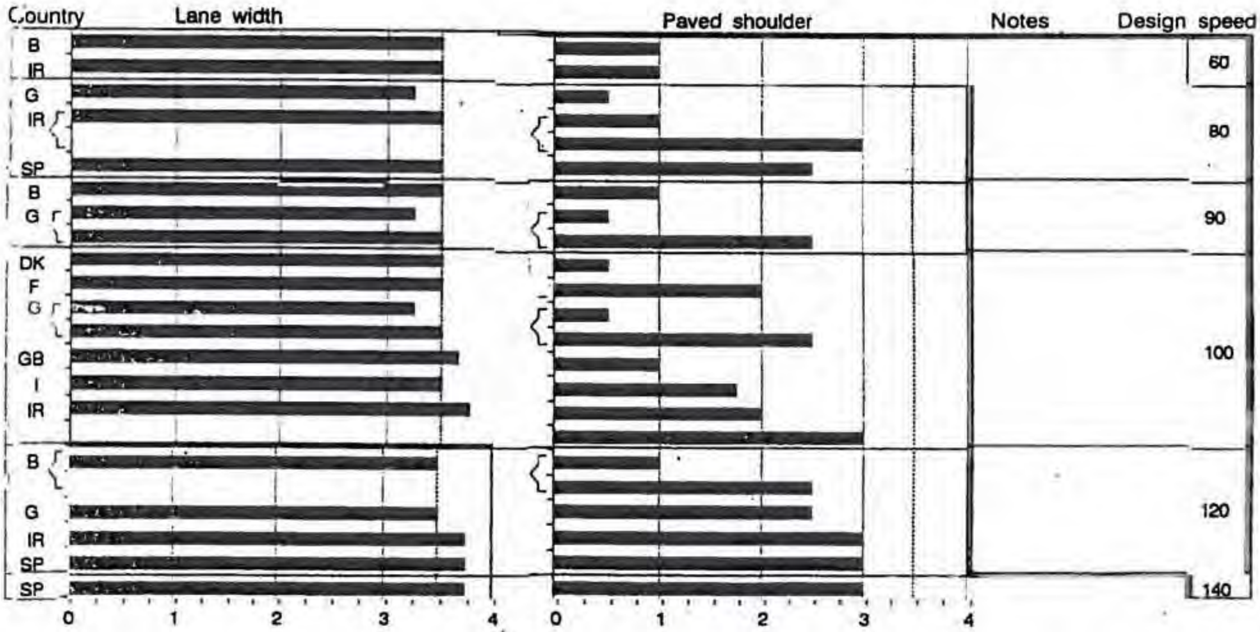


Figure 12. Traffic lane and paved shoulder width for non-motorway divided roads

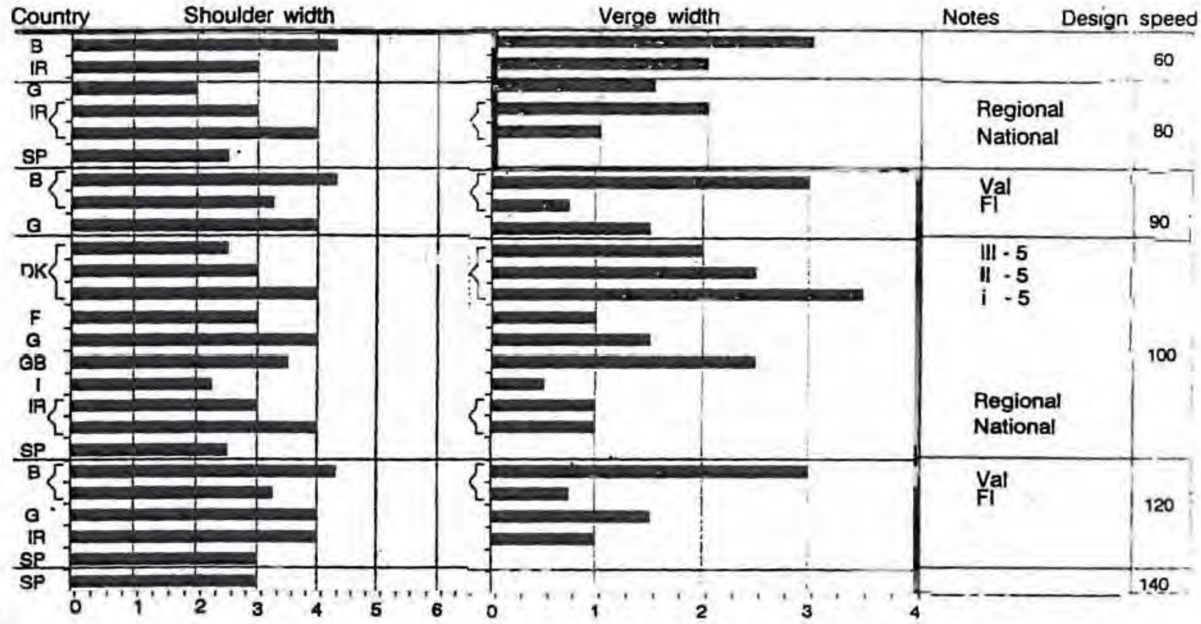


Figure 13. Outer shoulder and verge width for non-motorway divided road

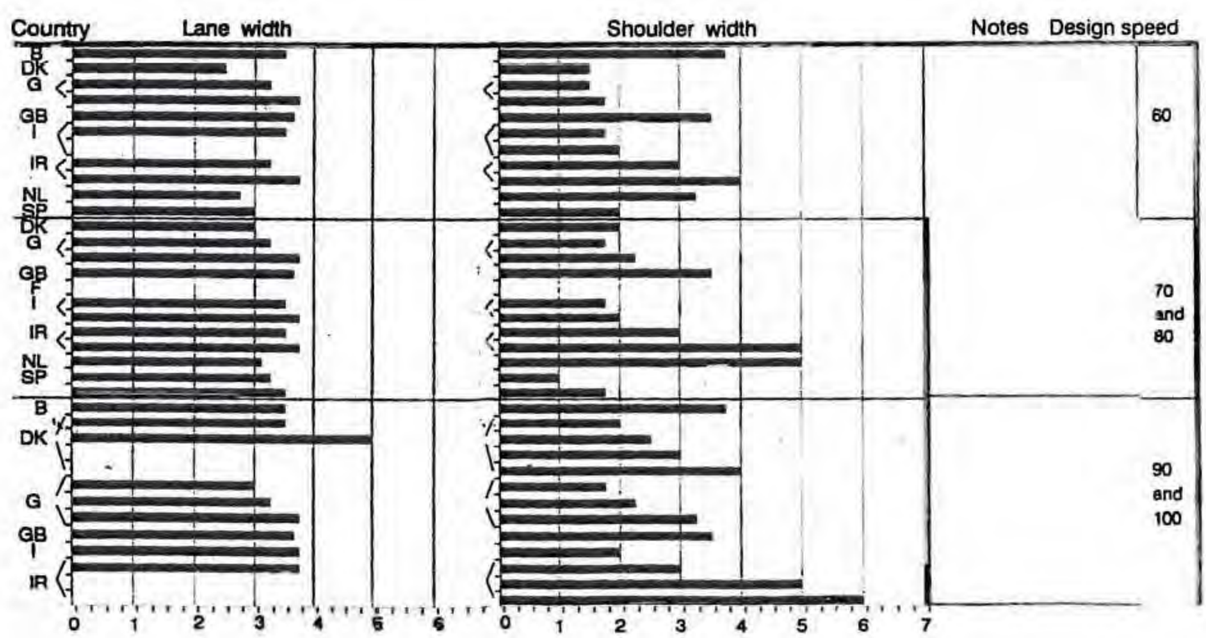


Figure 14. Traffic lane and shoulder width for undivided roads

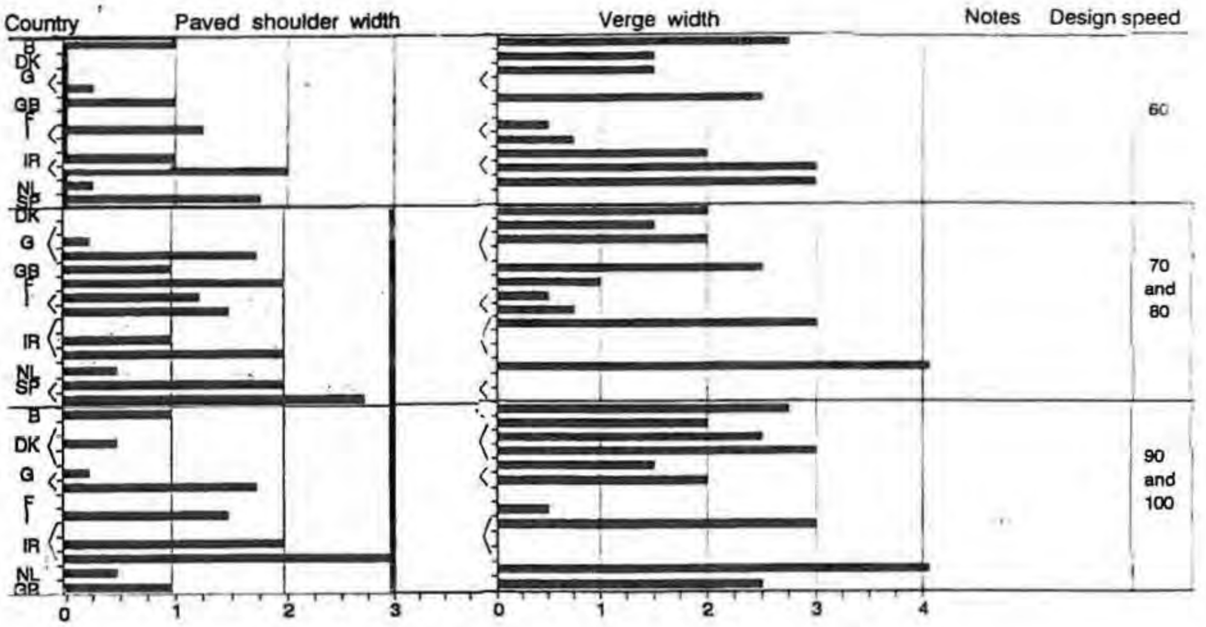


Figure 15. Shoulder and verge width for undivided roads

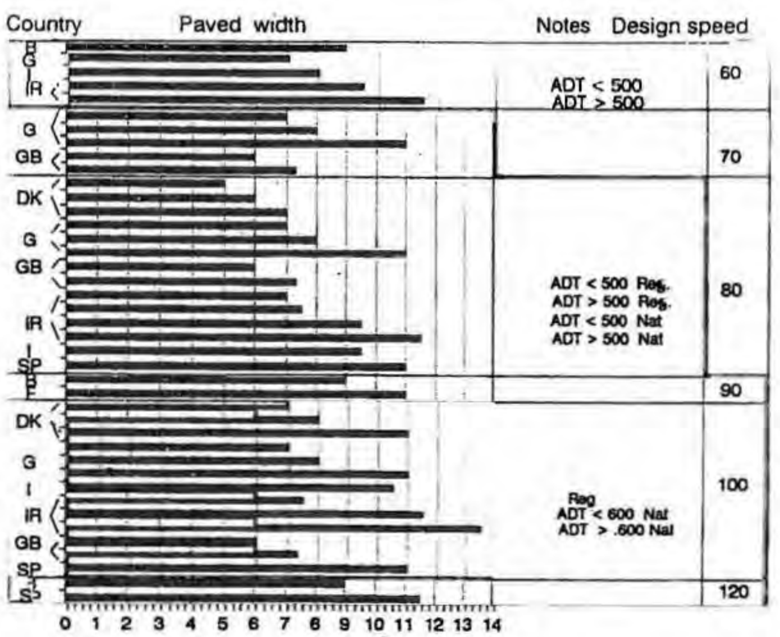


Figure 16. Pavement width of undivided roads

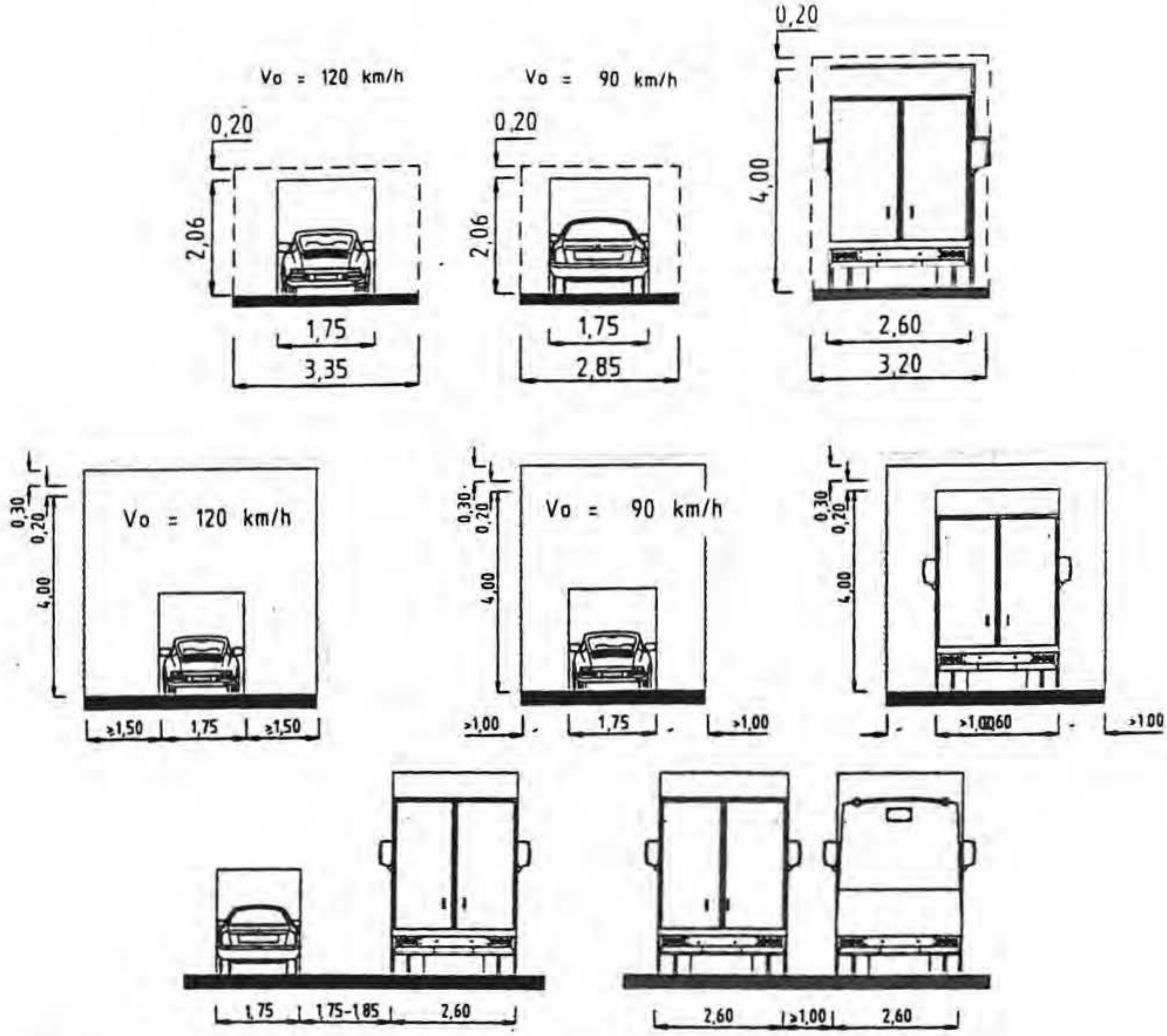


Figure 17. Calculation of cross-section width in Dutch standards

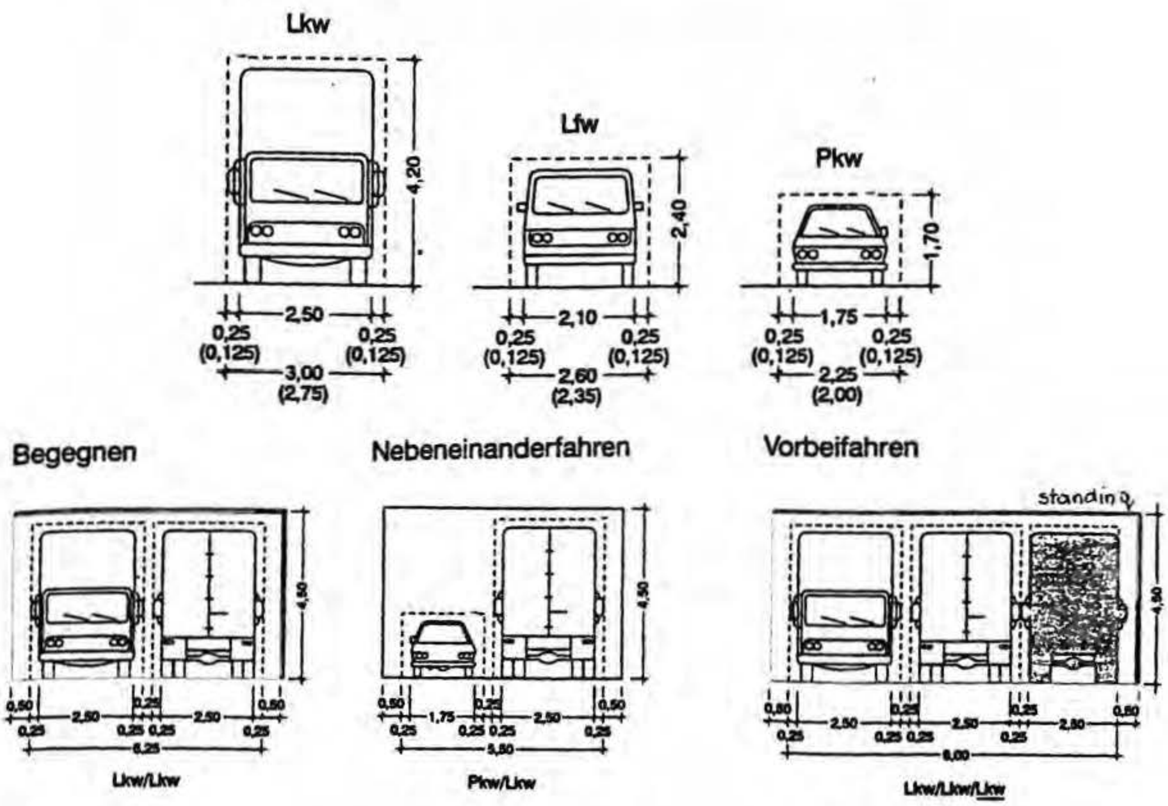


Figure 18. Calculation of cross-section width in German standards

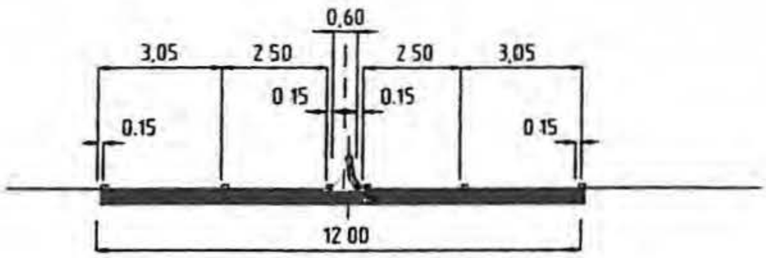


Figure 19. The 4-0 system on one carriageway of 2x2 motorway in Netherlands

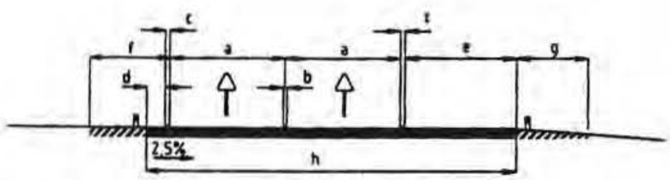
Appendix 1

Original standard figures of cross-sections

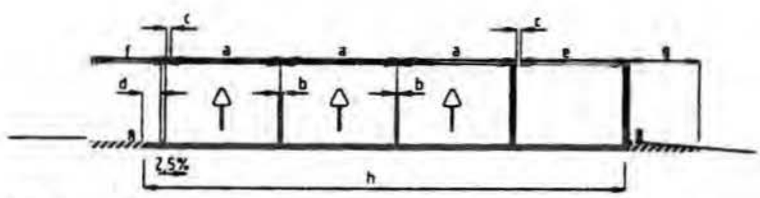
Figuur 13

AARDEBANEN

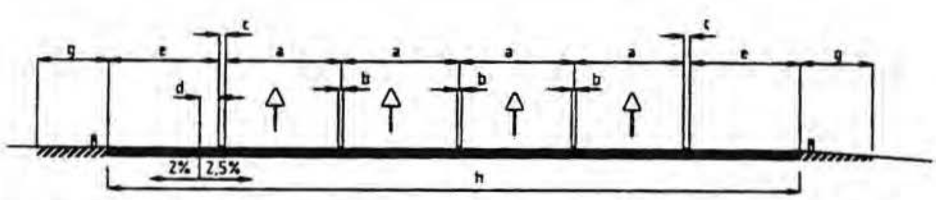
NORMAAL-DWARSPROFIELEN VAN HOOFDRIJBANEN



2x2-strooks hoofdrijbaan 13.1



2x3-strooks hoofdrijbaan 13.2



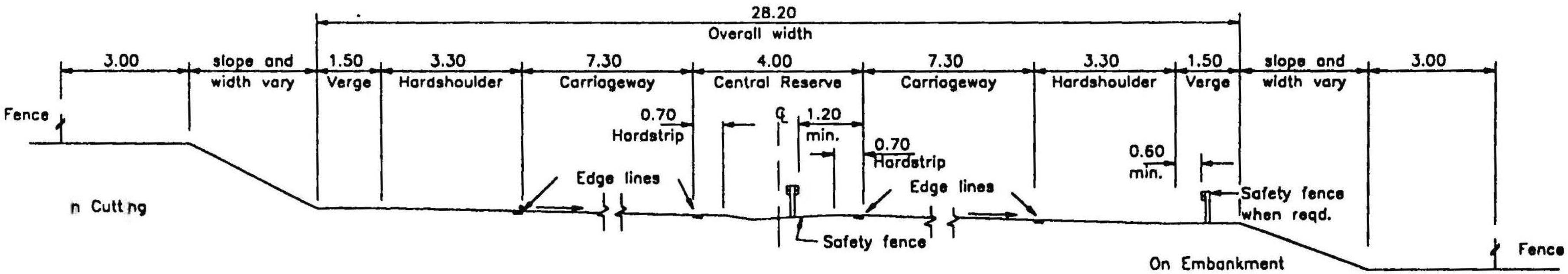
2x4-strooks hoofdrijbaan 13.3

	Vo=120 km/h	Vo= 90 km/h
a rijstrook	3,50 m	3,25 m
b deelstreep		
2x2 / 2x3 / 2x4	0 15 m	0,15 m
c kantstreep		
2x2 / 2x3 / 2x4	0 20 m	0 20 m
d redresseerstrook		
2x2	1.10 m	0,30 m
2x3	0 60 m	0,30 m
2x4	0,60 m	0 30 m
e vluchtstrook		
2x2	3 50 m	3,25 m
2x3 / 2x4	3 25 m	3,25 m
f bergingszone	2 45 m	2 45 m
g vluchtruimte	2 25 m	2 25 m
h verhardingsbreedte		
2x2	12 00 m	10 45 m
2x3	14 75 m	13 70 m
2x4	20 90 m	19 90 m

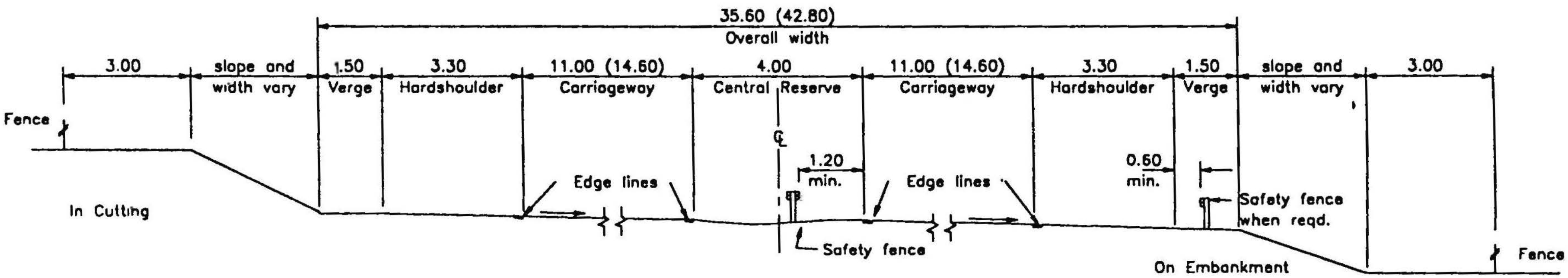
draagkrachtige grond

maten in m

Append 1



DUAL 2 LANE MOTORWAY (D2M)



DUAL 3 LANE MOTORWAY (D3M)

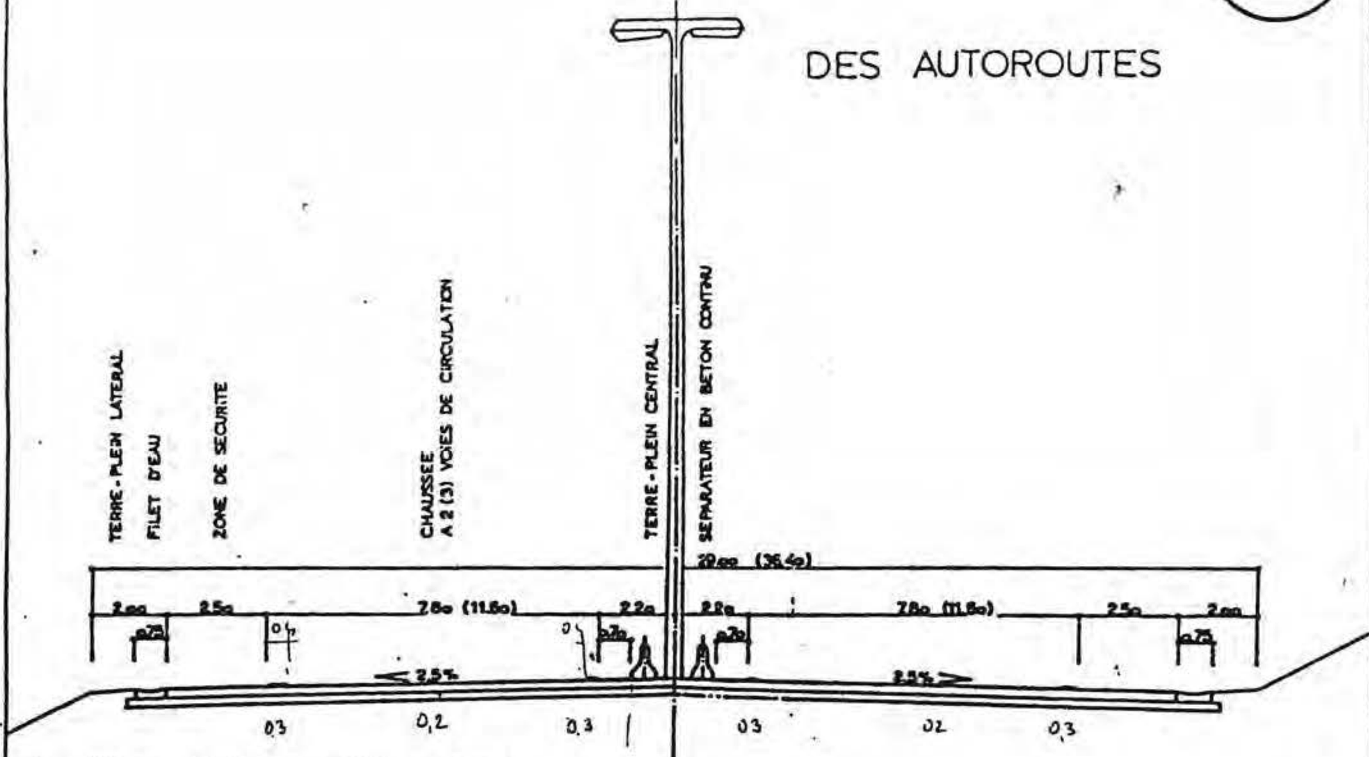
DUAL 4 LANE MOTORWAY (D4M)
As D3M but with dimensions in brackets for carriageway and overall width

NOTES
1. ALL DIMENSIONS ARE IN METRES.
2. The cross sections shown are typical only.
3. Normal crossfall on balanced carriageways shall be 2.5%
4. Permanent fence lines may vary from the position shown and the Contractor shall erect the fences in the positions indicated on the layout drawings.
5. See Drawing No A11 for edge and lane line details.

HIGHWAY CONSTRUCTION DETAILS	HIGHWAY CROSS SECTIONS	A Issue	DEC 91 Date	RURAL MOTORWAYS	Drawir[illegible] 6B

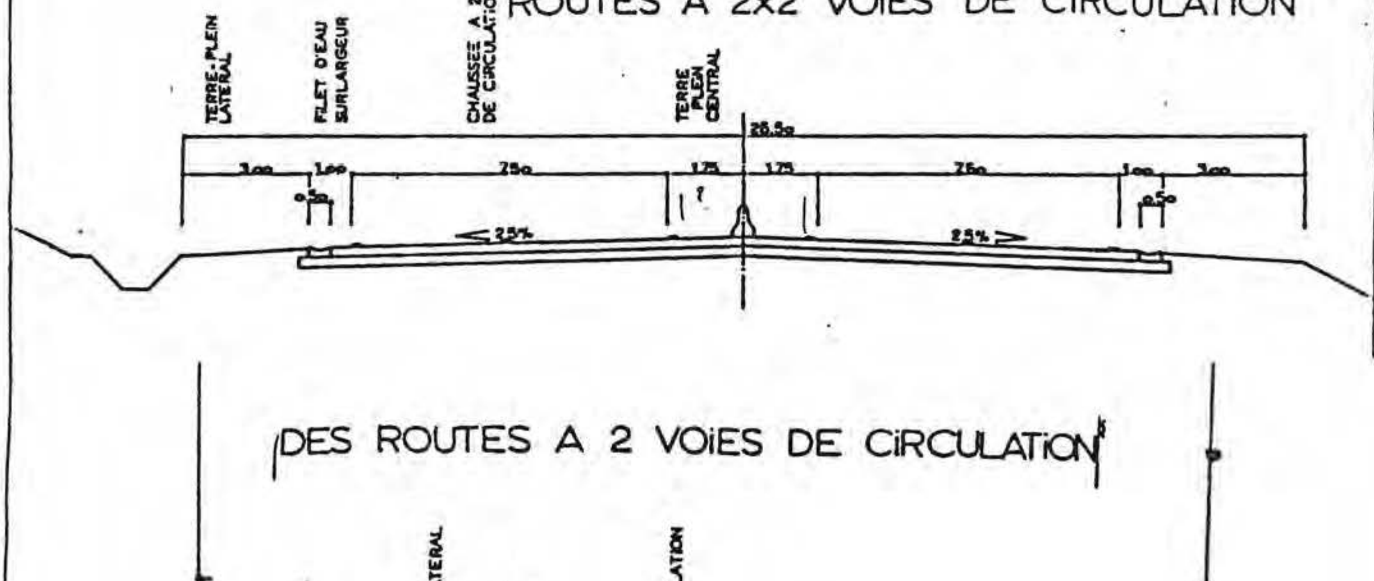
B

DES AUTOROUTES

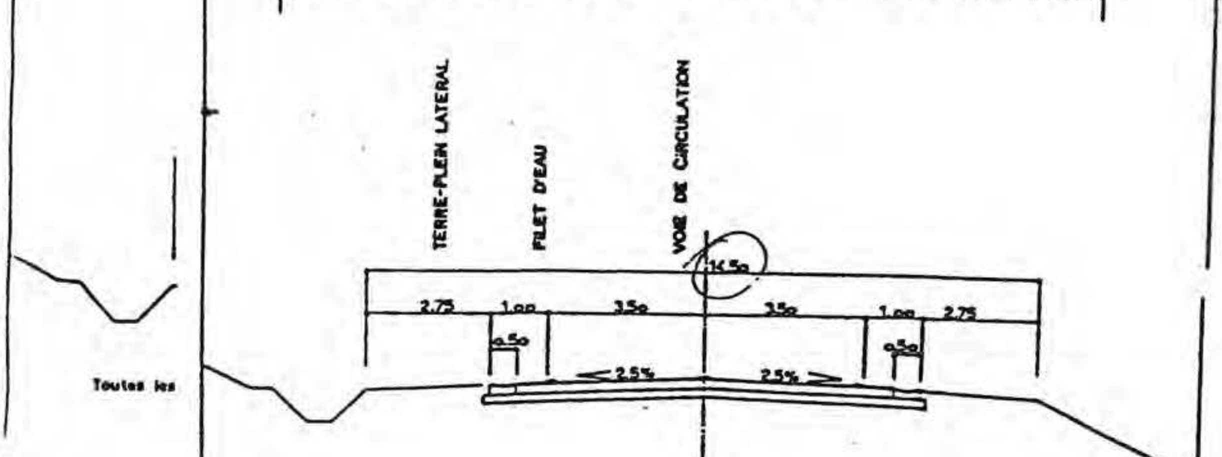


N.B. Les chiffres entre parenthèses correspondent à deux chaussées à trois voies de circulation
Toutes les cotes sont exprimées en m.

PROFIL EN TRAVERS TYPE DES ROUTES A 2x2 VOIES DE CIRCULATION



DES ROUTES A 2 VOIES DE CIRCULATION



Toutes les

ROAD TYPES

STRADE TIPO

SINGLE CARRIAGEWAY ROADS

	TIPO DI STRADA	INTERVALLO DI VELOCITA' (Km/h)	PIATTAFORMA (metri)
Strade a carreggiata unica	IV°	80 < V_p < 100	1.50, 3.75, 3.75, 1.50 — 10.50
	V°	60 < V_p < 80	1.25, 3.50, 3.50, 1.25 — 9.50
	VI°	40 < V_p ≤ 60	1.00, 3.00, 3.00, 1.00 — 8.00

Tab. 2.2.1.b

ROAD TYPE

STRADE TIPO

MOTORWAYS

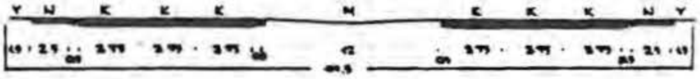
DIVIDED CARRIAGEWAY ROADS

	TYPE OF ROAD TIPO DI STRADA	SPEED RANGE INTERVALLO DI VELOCITA' (Km/h)	CROSS-SECTION (m) PIATTAFORMA (metri)
Strade a carreggiate separate	I° M/WAY	110 < V_p ≤ 140	a) 3.00, 3.75, 3.75, 4.00, 3.75, 3.75, 3.00 — 25.00 b) 3.00, 3.50, 3.75, 3.75, 4.00, 3.75, 3.75, 3.50, 3.00 — 32.00
	II° M/WAY	90 < V_p ≤ 120	a) 3.00, 3.75, 3.75, 2.00, 3.75, 3.75, 3.00 — 23.00 b) 3.00, 3.50, 3.75, 3.75, 2.00, 3.75, 3.75, 3.50, 3.00 — 30.00
	III°	80 < V_p ≤ 100	1.75, 3.50, 3.50, 1.10, 3.50, 3.50, 1.75 — 18.60

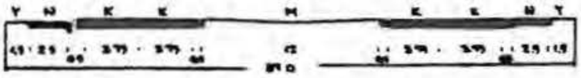
Tab. 2.2.1.a

DK

I-1 6-lane motorway, wide cross section



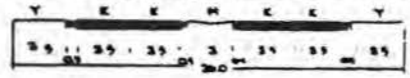
I-2 4-lane motorway, wide cross section



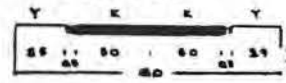
I-3 6-lane motorway, narrow cross section

I-4 4-lane motorway, narrow cross section

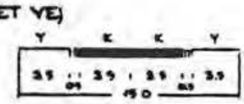
I-5 4-lane road, central reserve



I-6 Wide 2-lane road

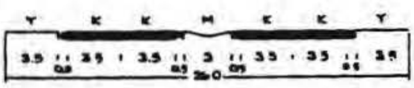


I-7 2-SPORET VEJ

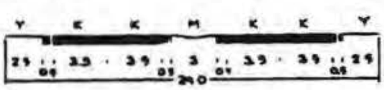


II-3 6-lane motorway, narrow cross section

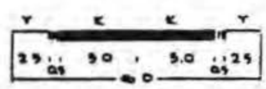
II-4 4-lane motorway, narrow cross section



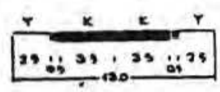
II-5 4-lane road with central reserve



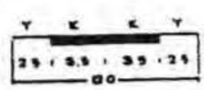
II-6 wide 2-lane road



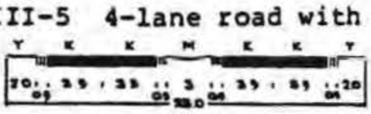
II-7 2-lane road



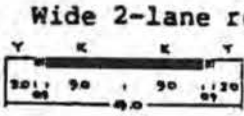
II-8 2-lane road



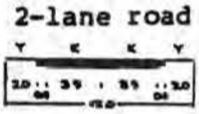
III-5 4-lane road with central reserve



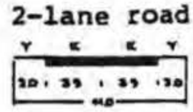
III-6 Wide 2-lane road



III-7 2-lane road



III-8 2-lane road



III-9 2-lane road