# GUIDELINES FOR ROAD DESIGN, CONSTRUCTION, MAINTENANCE AND SUPERVISION

## VOLUME I: DESIGNING

## SECTION 1: ROAD DESIGNING

### Part 3: GEOMETRICAL ROAD ELEMENTS

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# CONTENTS

# 1  TRAFFIC

This section consists from three main parts:

- factors in the driver-vehicle-environment system,
- traffic data,
- traffic demand and traffic volume.

This guideline is based and accordant with the Law of Public Roads, rule-books and technical standards valid on the territory of Bosnia & Herzegovina and with several EU Directions which directly influence to the acceptance of the terms for the intensifying of the efficacy of the roads to be capable to form a part of European road network, for the increasing of traffic safety on the roads, and for the reconciliation of measures by protecting the environment.

## 1.1  DRIVER-VEHICLE-ENVIRONMENT SYSTEM

### 1.1.1  Traffic participants

Traffic participants on the road are:

- Drivers of motor vehicles and passengers in vehicles;
- Cyclists;
- Pedestrians; and
- Other participants (tractors and non-motor vehicles).

Particular participants may use the same or separate traffic areas. Use of the same or separate traffic areas is defined by attributes, characteristic for a particular road category, stemming from its primary traffic function.

In case a road is built with separate traffic areas for different participants, crossings between such areas should be particularly thoroughly planned and the parallel management should take into account adequate distances depending on the speed of vehicles on the roadway (protective/safety width).

### 1.1.2  Traffic functions

Traffic functions of the road:

- Long-distance connections;
- Connections;
- Collection;
- Providing access.

In various types of the traffic function participants on the roadway are drivers of motor vehicles, which have:

- Different psychophysical condition (tiredness, reaction time);
- Different knowledge of the road and road conditions with regard to frequency of use (one time, occasional and frequent); and
- Different attitude to use of the road (foreigners, local population).

In order to provide rational selection of road elements roads with different traffic function should be dimensioned by taking into account differences between users. Characteristics are specified in Table 1.

The following should be taken into account in determining the comfort level of drivers and passengers:

- *Field of view* shall be the area seen by the driver in a single view, borders are set by width (angle) and depth (length) of view, which change during motion.

The following areas are distinguished in the sight field:

- o Sharp visibility (angle $\alpha$=3-5°);
- o Relative visibility (angle $\beta$=10-15°); and
- o Peripheral visibility (angle $\gamma$=120-180°).

Normal sharp visibility – sight distance $L_\alpha$ [m[1]] shall be defined by the following equation:

$$L_\alpha = t_\alpha \cdot v \approx 4 \cdot V$$

where:

$t_\alpha$ [s]     ..... Time of driving with the largest sharpness (12-14 s);

v     ..... Driving speed in [m/s];

V     ..... Driving speed in [km/h].

- *Reaction time $t_r$,* shall equal between 0.7 and 2.5 seconds and shall be taken into account notably in dimensioning of stopping visibility. The following values should be taken into account in road planning with regard to the type of typical users:
    - o Normal                                   ..... 2.0 s;
    - o Acceptable                             ..... 1.5 s;
    - o Exceptional                           ..... 1.0 s.

    The reaction time taken into account may be shorter or may even be excluded in cases of roads where drivers are frequent users ($t_r$ = 1.5 s), with permanently placed obstacles (crossroads, crossings, other physical obstacles) to which the driver is warned with traffic signs.
- *Lateral acceleration $a_R$,* conditioning the comfort of driving, equals:
    - o For comfortable driving            ..... up to 2.5 m/s²;
    - o For acceptable driving             ..... up to 3.0 m/s²;
    - o Upper limit value                    ..... 3.5 m/s².
- *Lateral thrust $x_{Ri}$* (change of acceleration) [m/s³] shall be taken into account in the range between 0.30 ≤ $x_{Ri}$ ≤ 0.95, with the mean value equalling 0.5 m/s³.
- *Longitudinal acceleration $a_T$,* conditioning the comfort of driving, equals:
    - o For comfortable driving            ..... up to 2.65 m/s²;
    - o For uncomfortable driving        ..... up to 3.45 m/s²;
    - o For exceptional driving conditions     ..... 4.25 m/s².
- *Longitudinal thrust $x_{Ti}$* (change of acceleration) shall be limited by value $_{max}x_{Ti}$ = 2.5 m/s³.

**Table 1: Psychophysical factors and physiological limitations of drivers and the impact on elements**

| Factor type | Project elements of the road |
|---|---|
| Field of view | Length of straight section, signs |
| Reaction time | Braking distance |
| Lateral acceleration | Minimal horizontal elements |
| Lateral thrust | Minimal length of the transition curve |
| Longitudinal acceleration | Changes of speed |
| Longitudinal thrust[*] | Free braking |

[*]* Longitudinal thrust (intensive braking) is not taken into account in calculation of braking distances.

### 1.1.3 Motor vehicles in road traffic

Motor vehicles are because of the purpose of use and driving dynamics requirements relevant for determining road dimensions and its additional arrangements.

Main characteristics of motor vehicles are as follows:

- Dimensions of vehicles, determining widths of traffic lanes and widening in curves;
- Manoeuvrability determining the outer turning circle;
- Driving speed, which conditions the size of geometric and technical elements of the roadway;
- The system for changing speed of vehicles i.e. for engine acceleration and engine and braking deceleration and gripping on the roadway (sliding friction coefficient).

#### 1.1.3.1 Dimensions of Motor Vehicles

Dimensions of motor vehicles and the size of the outer turning circle (radius) are as follows (Table 2):

**Table 2: Dimensions of vehicles and their manoeuvrability**

| Means of transport | Dimensions of the vehicles [m] | | | Outer turning circle (radius) $R_{zu}$ [m] |
|---|---|---|---|---|
| | Length | Width | Height | |
| Bicycles with motors | 1.80 | 0.60 | 1.00[1] | 3.00 |
| Motorcycles | 2.25 | 0.70 | 1.00[1] | 3.00 |
| Typical cars | 4.70 | 1.75 | 1.50 | 5.80 |
| Small cars | 3.80 | 1.60 | 1.40 | 5.30 |
| Large cars | 5.15 | 1.90 | 1.60 | 6.00 |
| MPVs | 4.70 | 2.10 | 1.70 | 5.80 |
| Combined vehicles | 5.00 | 2.10 | 2.30 | 6.20 |
| Freight vehicles Smaller freight vehicles | 6.00 | 2.10 | 2.30[2] | 6.20 |
| Typical two-axial | 8.50 | 2.50[3] | 3.00[2] | 9.60 |
| Typical three-axial | 10.00 | 2.50[3] | 3.00[2] | 9.80 |
| Freight vehicles with trailers | 16.00 | 2.50[3] | 4.00 | 12.50 |
| Semi-trailer, trailer vehicles | 16.50 | 2.50[3] | 4.00 | 12.00 |
| Waste removal vehicles Typical two-axial | 7.70 | 2.50 | 3.30[2] | |
| Typical three-axial | 10.50 | 2.50 | 3.30[2] | |
| Fire-fighting vehicles | 6.80 | 2.50 | 2.80[2] | 9.25 |
| Fire-fighting vehicles with ladder | 12.0 | 2.50 | 3.50 | 10.50 |
| Typical bus I | 11.00 | 2.50[3] | 2.95 | 10.25 |
| Typical bus II | 11.50 | 2.50[3] | 2.95 | 11.00 |
| Typical interurban buses | 12.00 | 2.50[3] | 3.10/3.45[4] | 11.40 |
| Typical bending buses | 18.00 | 2.50[3] | 2.95 | 12.00 |
| Tractors with trailers | 9.20 | 1.80 | 3.50 | 4.50 |

[1]  Together with driver and passenger 2.0 m

[2]  Height of the driver's cabin

[3]  2.95 m with the outer mirror

[4]  Double deck buses

The freight vehicle of 2.50 m in width and 4.00 m in height is used for determining the standard width of traffic lanes and the height of the road profile on public roads. Widening of traffic lanes is

set with regard to inter-axis distance of vehicles on a particular road being the typical users on the road in question. The largest vehicles typical for that road are taken into account for low traffic roads and special purpose roads (non-standard roads).

## 1.1.3.2 Speed

Speed V [km/h] is a driving dynamics quantity on which driving comfort and road traffic safety depend. The following speed types are distinguished with regard to road planning:

- *driving speed* ($V_{dri}$) is the actual speed of a vehicle on the carriageway;
- *design speed* ($V_{des}$) is any speed assumed to assess or calculate road technical elements;
- *admissible driving speed* ($V_{adm}$) is the speed directed on a road or a road section by a law or administrative restriction;
- *travelling speed* ($V_{tra}$) is the mean driving speed of vehicles on particular road;
- *conceptual speed* ($V_{con}$) is the design speed specified for an individual road category with regard to its traffic function and spatial conditions; dimensions of road geometric and technical elements are assessed on the basis of this speed;
- *free flow speed* ($V_{free}$) is the driving speed in a free traffic flow on a clean and wet carriageway; it is also called $V_{85\%}$ and is enabled by individual geometric and technical elements of either designed or existing road; it is used as design speed for traffic safety analyses, and for corrections of individual road technical elements;
- *transverse speed* ($V_{rad}$) is the radial speed of vehicle by moving to neighbour traffic lane.

## 1.1.3.3 Values Regarding Changes of Vehicle Speed

The following average values are taken into account in changes of vehicle speed:

- *Acceleration:*
  - Personal vehicles:               0.50 – 1.50 m/s$^2$;
  - Freight vehicles:                0.30 – 0.75 m/s$^2$;
- *Passive braking (braking with engine):*
  - Personal vehicles:
    - 0.50 – 0.82 m/s$^2$;          for $V_{dri}$ = 60 - 100 km/h;
    - 0.66 m/s$^2$ on average      for $V_{dri}$ = 80 km/h;
- *Active braking (braking with brakes):*
  - Personal vehicles:
    - 3.75 – 2.94 m/s$^2$;          for $V_{dri}$ = 60 - 100 km/h;
    - 3.31 m/s$^2$ on average      for $V_{dri}$ = 80 km/h;
  - Freight vehicles:
    - 1.50 m/s$^2$.

These values are only approximate and are intended foremost for testing admissibility of quantities, calculated for individual cases by using different bases (for traffic safety analyses).

Whereby it is permitted to use, as the upper limit of these values, the value stemming from skidding resistance between the roadway and tyres (SFC sliding friction coefficient) with regard to the design (preliminary) speed or project speed or the value resulting from SFC's value measured on the roadway, when actual conditions on the roadway are being determined. It is determined by:

$$a_{dej} \leq f_{t\,adm} \cdot g$$

where:

$a_{dej}$    [m/s$^2$]  The actual / used part of acceleration;

$f_{t\,adm}$  [-]    Maximum permitted SFC value with regard to speed;

$g$     [m/s$^2$]  Gravitational acceleration (9.81 ms$^{-2}$).

## 1.1.3.4 Gripping on Asphalt Roadway – Skidding Resistance

Gripping on the roadway is expressed with the sliding friction coefficient (SFC or $\mu_g$) between the roadway and tyres. When dimensioning road elements, SFC, which provides traffic safety for 95% sample of asphalt roadways and vehicles on clean and wet roadway, should be taken into account. This value has been empirically determined with a tyre approved by the PIARC and is expressed with the following equation:

$$f_{t\,dop} = \mu_g = 0{,}2 \cdot \left(\frac{V}{100}\right)^2 - 0{,}629 \cdot \left(\frac{V}{100}\right) + 0{,}637$$

**Figure 1: SFC values in line with PHOENIX with included 95% line in line with PIARC**
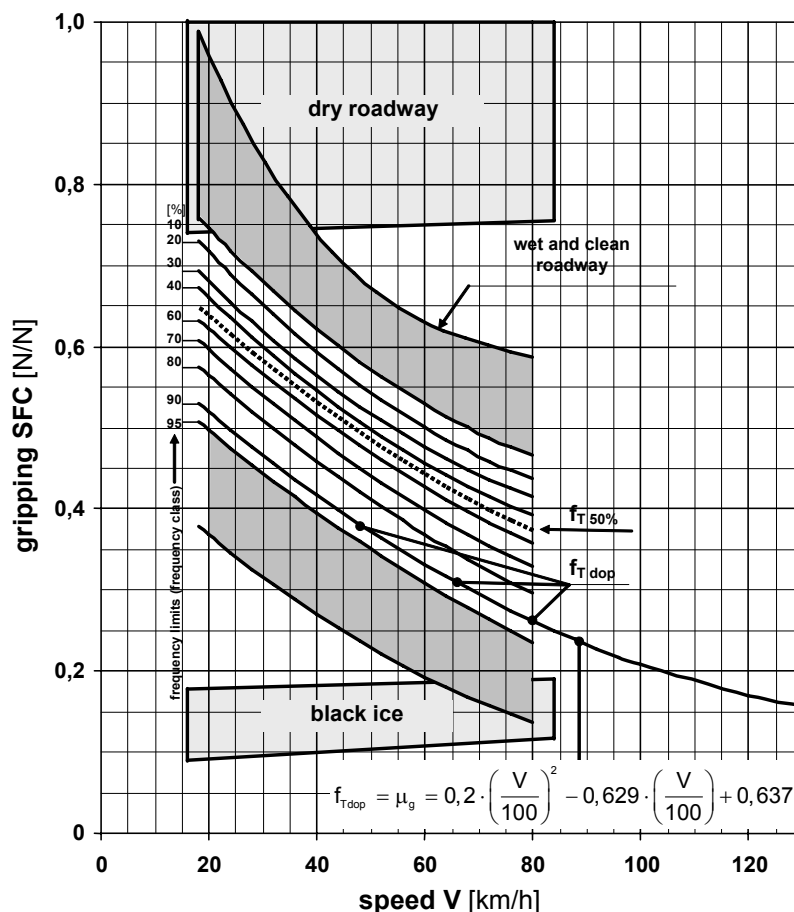


On a dry asphalt roadway, the approximate minimum value of SFC or $\mu_g$ = 0.75 [-], on iced roadway the respective value equals between 0.08 ($V_{dri}$ = 40 km/h) and 0.11 ($V_{dri}$ = 80 km/h). Empirical values of SFC are presented in the figure 1. When other materials are used for the wearing course, appropriate different characteristic values of SFC should be taken into account, as defined in professional literature or on the basis of actual measurements.

The value of the sliding friction coefficient is foremost influenced by the following:

- The speed of vehicle's movement;
- Wetness and temperature of the roadway;
- Wearing-blocking course of the roadway construction (texture of the surface, type of stone grains, quantity of tack coat);
- Profile and material of tyres of the vehicle.

SFC is a vector quantity, which is in use for various purposes regarding dimensioning of elements divided into transversal ($f_T$) and radial ($f_R$) elements. The following relationships apply for the maximum value of SFC in both right-angled directions:

$$f_{T\,max} = f_{t\,max} \quad \text{and} \quad f_{R\,max} = n \cdot f_{t\,max}$$

where the quotient "n" depends on speed and the following equation applies:

$$n = 0,873 + 10,3 \cdot 10^{-4} \cdot V$$

A different value of $f_{Rmax}$ may be established in special cases (analyses) by using appropriate expert assessment. Generally, it is permitted to use the quotient of n = 0.925 for determining $f_{Rmax}$ which corresponds to driving speed of 50 km/h.

The following applies to the resultant of both components of SFC:

$$f_t^2 = f_T^2 + f_R^2 \quad \text{and} \quad 1 = \sqrt{\left(\frac{f_{Tmax}}{f_{tmax}}\right)^2 + \left(\frac{f_{Rmax}}{f_{tmax}}\right)^2}$$

### Figure 2: Interdependence of utilisation of SFC by normal component
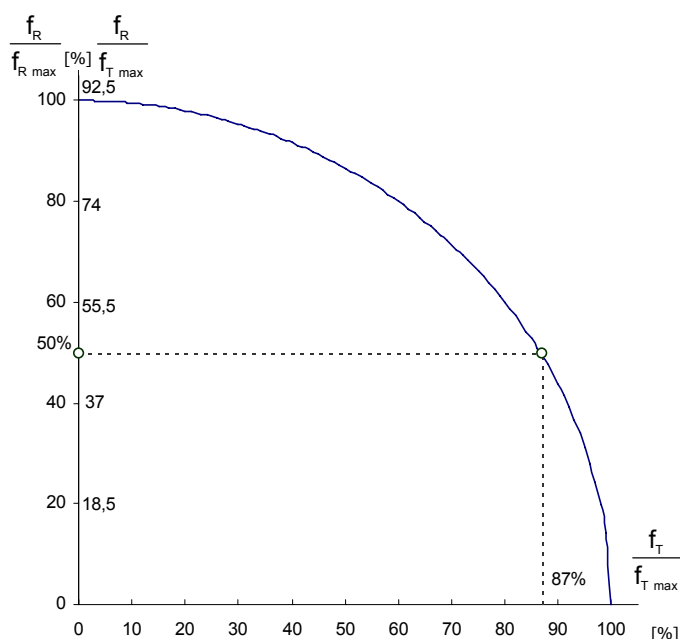


Utilisation of SFC in transversal direction is permitted only to the extent ensuring that its remaining value presents no danger to traffic safety with regard to braking on the same geometric element of the road. The utilisation level $f_{R\,maxadm}$ is also limited by limit values of typical characteristics of road users (drivers and passengers in vehicles), and may vary in different conditions (e.g. speed).

$f_{T\,maxadm}$ may be fully used for calculation of braking distances.

## 1.1.4 Cyclists, pedestrians and means of transportation for disabled persons

For determining dimensions of the cyclist area required by cyclists for driving, the length of 2.00 m, width of 0.75 m and height of 2.25 m with the average speed of movement equalling 12 km/h are taken into account.

For determining dimensions of the pedestrian area, profile of width equalling 0.75 m and height of 2.25 m with the average speed of walking equalling 4.3 km/h are taken into account for walking.

As regards dimensioning of pedestrian areas, dimensions for prams of length equalling 1.10 m, width of 0.55 m and height of 1.00 m and for wheelchairs dimensions of length equalling 1.50 m, width of 1.20 m and height of 1.50 m are additionally taken into account.

Minimal dimensions of means of transportation are defined in Table 3.

**Table 3: Dimensions of non-motor means of transportation and their manoeuvrability**

| Means of transport | Dimensions of the vehicles [m] | | | Outer turning circle (radius) $R_{ZU}$ [m] |
|---|---|---|---|---|
| | **Length** | **Width** | **Height** | |
| Prams | 1.10 | 0.55 | 1.00[1] | 1.00 |
| Wheelchairs | 1.25 | 0.85 | 1.10[1] | |
| Bicycles | 1.85 | 0.60 | 1.00[1] | 3.00 |

[1] Together with driver and passenger 2.0 m

## 1.1.5 Road environment (the road and its surroundings)

The road environment consists of the roadway and road surroundings with drainage facilities, natural or built slope, traffic equipment and service areas.

The following is distinguished with regard to the loading and land use of the area through which a road passes:

- Urban area (dense building);
- Suburban and rural areas (rare buildings, individual buildings, business facilities, etc); and
- Other areas (mostly non-built areas, forests, farmland, parks, etc.).

In passing of a road through areas with different land use, the same road section may be – providing the conditions for ensuring functionality allow it – implemented for a changed structure of users. The road's technical and geometric elements may also change. Each transitional part of such road section shall be technically particularly carefully planned and special traffic signs should be envisaged if necessary. Planning should be particularly careful for those parts of the road where the speed limit, size of geometric elements and normal cross section (composition and size of elements) change.

### 1.1.5.1 Roadway

The roadway is a part of the road area between inner edges of natural or built slopes of the cut or embankment and consists of the following:

- Carriageway (traffic and border lanes);
- Traffic lanes for non-motorised participants (cyclists, pedestrians, other);
- Non-traffic lanes (separation lanes between directional carriageways or between the carriageway and other traffic lanes and lanes intended for still traffic);
- Longitudinal areas for protection of the carriageway (verges);
- Longitudinal facilities for drainage, except longitudinal ditches; and
- Longitudinal areas for protection and providing functionality to the roadway (berms).

### 1.1.5.2 Road surroundings

Road surroundings encompass areas required for building, operations and maintenance of the road. Road surroundings consist of:

- Roadway;
- Longitudinal ditches along the roadway;
- Natural or built slopes;

- Longitudinal ditches along the outer edge of slopes; and
- Both-sided protective width along the outer edge of slopes, longitudinal ditches or the roadway.

Unless an administrative decision (spatial planning regulations) or project design specify otherwise, the width of the protective layer shall be:

- Along local roads          0.50 m;
- Along regional roads        1.00 m;
- Along major roads          2.00 m.

As regards roads intended exclusively for motor traffic (motorways, highways) having protective fence on both sides, the protective width shall be on the outer side of protective fences. In such cases, the protective width may be increased and determined with regard to requirements of functionality and maintenance of fences.

# 1.2  TRAFFIC DATA

## 1.2.1  Traffic volume

The standard form for keeping records on traffic load on roads is the annual average daily traffic (AADT), which refers to the co-called traffic section of the road. If a particular road was not in use for a certain number of days in a year, the average shall be calculated for the period when the road was in use (ATD). The AADT shall be determined by counting or by a traffic study.

The AADT does not present the characteristic changes in traffic volumes during a year, month, week, day or hour. Therefore, traffic quantities related to a particular time interval and representing typical characteristics of the traffic flow are used for planning roads and dimensioning elements.

Data required for planning and operation of a road shall be obtained by:

- For roads:
  - counting traffic on selected points of the road (counting points) in consecutive hours (automatic or between 6 a.m. and 10 p.m. or during selected hours);
- For crossroads:
  - counting traffic at crossroads (in 15 minute intervals, by individual direction);

Records on counting data shall be kept.

## 1.2.2  Use of traffic data

Use of data regarding AADT, ATD:

- Determining needs and priorities regarding road maintenance;
- Determining priorities in reconstructions of the existing road network (roadway management);
- Activities related to road network planning and searching for optimal routes of new roads;
- Determining the needs and requirements for new roads; and
- Determining measures regarding traffic management.

Data on traffic loads, including traffic structure: proportion and types of motor road traffic, number of axes, weight and dimensions of heavy vehicles shall be used for:

- Design of traffic areas with regard to technical conditions and minimal dimensions of geometric elements (minimal horizontal radius, inclination…);
- Construction of roadway structures and bridging facilities;
- Analysing the impact of heavy vehicles on road permeability;
- Establishing the traffic regime; and
- Setting traffic limitations.

Data obtained by counting on an open road section or a section in urban area shall be used for determining:

- Traffic loads in individual directions;
- Traffic loads during the day; and
- Distribution of vehicles to particular categories (structure of vehicles).

Data on traffic distribution by direction and vehicle structure shall be used for analyses of permeability, planning traffic regimes (one-way streets or roads, traffic limitations, etc.), determining needs for parking spaces and determining the efficiency of particular measures on roads and crossroads.

Data on traffic obtained by counting traffic at crossroads shall be used for determining:

- Traffic entering the crossroads area;
- Traffic flowing in a particular direction through the crossroads;
- Traffic quantity during particular intervals in the day; and
- Traffic structure (classification).

Data on traffic related to time intervals shorter than one hour shall be used in:

- Analyses of changes in traffic during the peak hour;
- Establishing the reduced permeability of traffic areas;
- Determining traffic characteristics during the peak hour.

Traffic load during the peak hour is used in:

- Determining permeability of a particular road;
- Establishing needs, planning and accurate determining of types and positions of individual types of equipment of traffic areas;
- Determining the needs for parking, turning and stopping;
- Design of roads: determining the number and width of traffic and other lanes, needs for additional measures (canalising of traffic flows, etc.).

Data on traffic loads during the whole year are used in:

- Traffic prognosis;
- Economic analyses (traffic work and calculations of costs);
- General traffic safety analyses;
- Solving specific problems related to traffic loads.

## 1.2.3 Vehicle classification

Structure of vehicles in traffic with regard to counting and statistic processing in accordance with the EC Directive:

| | |
|---|---|
| MC | Motorcycles; |
| PV | Personal vehicles with and without trailers; |
| BUS | Buses with and without trailers, bending buses; |
| LF | Light freight vehicles with and without trailers (up to 3.5 t); |
| MF | Medium freight vehicles (between 3.5 t and 8 t); |
| HF | Heavy freight vehicles (over 8 t); |
| FT | Heavy freight vehicles with trailers; |
| HFT | Tractors i.e. heavy freight vehicles with semi-trailers; |
| | and additional (statistically optional): |
| TR | Farming tractors; |
| CY | Cyclists. |

As regards traffic dimensioning of roads, vehicles in the traffic flow are classified only as personal vehicles (P), buses (B), light lorries (LL) and heavy lorries (HL). Their number and proportion is determined. In case the traffic dimensioning uses only the term "heavy vehicles" instead of broken down structure of heavy vehicles, all freight vehicles and buses shall be included in this category.

As regards traffic dimensioning of crossroads, vehicles in the traffic flow are classified only as personal vehicles (P), buses (B), freight vehicles (F) and tractors and freight vehicles with trailers (T).

Traffic volume is expressed in units of personal vehicles per hour (pc/h). The standard weight value for personal vehicles is 1, buses and lorries 2, and tractors and lorries with trailers 3.5. These weights apply for analyses of crossroads whereas in other cases the calculation of equivalent traffic volume by the HCM (Highway Capacity Manual - USA) methodology is used.

## 1.3 TRAFFIC DEMAND AND TRAFFIC VOLUME

### 1.3.1 Design traffic volume

#### 1.3.1.1 General conditions for establishing design traffic volume

For traffic dimensioning of roads the following has to be considered:

- design-hour volume for road dimensioning $Q_{h\,mer}$ and
- design flow rate during peak 15-minute period for crossroads dimensioning $Q_{15mer}$.

In both cases the relevant traffic load is expressed either as the number of vehicles per hour or the number of personal car equivalents per hour (pc/h). The suitable peak hour factor (PHF) has to be taken into account, which represents the fluctuation in the traffic flow within the peak hour. For roads with unhindered or partly hindered traffic flow, the PHF is from 0.80 to 0.95. Lower values are characteristic of roads outside urban areas and represent high fluctuations in throughput within the peak hour. High values are typical of urban roads and roads near cities, representing high traffic loads. In the case of counting, the PHF is calculated for each direction separately (branch, lane, crossroads).

The methods for acquiring traffic data and the source of data have to be specified in the project task. The following is acceptable:

- counts and measurements (manual, automatic),
- traffic study and/or computer simulation,
- expert assessment.

If the method for acquiring data about traffic load is not set in the project task, the $Q_{h\,mer}$ depending on the road function is used as % of AADT as stated in Table 4. The values given in the table below are experiential and have to be applied on a case by case basis in accordance with the expert assessment. The percentage value is called design factor. The expert assessment and its justification are constituent parts of the reports included in project documentation.

**Table 4: Typical values of the design factor**

| Road function | Design factor [% AADT] |
|---|---|
| Long distance road | 12-16 |
| Connecting road | 10-14 |
| Collector road | 9-11 |
| Estate road | 8-10 |

On roads with a different (characteristic) annual and daily fluctuation in traffic $Q_{h\ mer}$ has to be specifically expertly set within the scope of the project (seasonal traffic, tourist roads, streets).

### 1.3.1.2 Roads with typically seasonal variations

On roads with particularly pronounced seasonal traffic (when the seasonal traffic volume exceeds the average by more than 50%) it is recommended that the traffic data and the road throughput calculation are provided separately for seasonal and off-seasonal traffic volume.

In such case it is on account of construction rationality recommended that for the seasonal period a lower level of service is taken into account or 10-20 km/h lower average travel speed than planned on a particular road of a certain category.

The above recommendation cannot be applied to multi-lane roads with separate carriageways.

## 1.3.2 Service flow rate, level of service

Service flow rate is the maximum quantity of traffic flow at which a certain level of service is provided by a certain road type.

The service flow depends on:

- factors resulting from road impacts,
- factors resulting from traffic impacts,
- the influence of the method of traffic control and management as well as technology.

The HCM (Highway Capacity Manual) is used for analysing the capacity and level of service. The criterion of road traffic performance is constituted by the level of service (LOS) defined according to the hindrance of vehicles in traffic flow (concentration of the traffic flow) and in line with the average travel speed (spatial speed). The LOS is classified into 6 units: from A to F. Unit F represents an unacceptable level of service.

The road capacity (bordering between LOS E and F) is the maximum traffic flow at which the road is still free of jams. It is characterised by very low average travel speed (spatial speed), which is especially on roads with higher traffic function as a rule lower than that prescribed for roads of higher categories.

## 1.3.3 Decision making: planning and designing road facilities

### 1.3.3.1 Measures of effectiveness (MOEs)

The levels of service according to the HCM methodology (HCM computer program) are for every road type set based on one or more parameters, which represent the realistic conditions as regards the dimensions and structure of road elements as well as traffic conditions. When not all required parameters can be provided, the standard values specified in the HCM methodology may be used.

Individual selected parameters determining the level of service of a certain road type are considered as measures of effectiveness. They are collected in Table 5.

**Table 5: Measures of effectiveness as the basis for determining the level of service**

| Road or traffic type | Basic measures of effectiveness |
|---|---|
| motorway, basic section | density [pc/km/lane] |
| motorway, weaving distance | average travel speed [km/h] |
| motorway, points of access | flow [pc/h] |
| multi-lane road | density [pc/km/lane] |
| two-lane road | delay percentage [%] <br> average travel speed [km/h] |

| | flow [pc/h] |
|---|---|
| traffic light-controlled crossroads | average delay due to stopping [s/vehicle] |
| crossroads not controlled by traffic lights | saturation level of individual directions X [%] |
| | the number of vehicles in a queue in an individual direction [veh.] and the queue length [m] |
| city roads | average travel speed [km/h] |
| toll station | flow [pc/h] |
| | delay percentage [%] |
| urban passenger transport | occupancy rate [persons/seat] |
| pedestrians | available space [m$^2$/pedestrian] |

## 1.3.3.2 Defined road levels of service

A new road, crossroads or the reconstruction of an existing road or crossroads is designed based on the elements, which ensure that at the end of the planning period the defined level of service will be achieved for a particular road or crossroads.

The level of service is a socially defined and specified value that reflects the traffic function and the economic aspect of road transport. It is determined for an individual road category in the administrative act of a state or federal unit. Until such act is adopted, the values recommended in these Guidelines are applied.

The indicator of the level of service on roads with separate carriageways, at points of access and crossroads are degrees (A-E and F), and on single two-lane carriageways the average travel speed.

**Table 6: Minimum degrees of the LOS on different roads depending on the function**

| Road function | recommended Level of service | minimal Level of service |
|---|---|---|
| Long distance road | B | D |
| Connecting road | C | E |
| Collector road | D | E |
| Estate road | D | E |

## 1.3.3.3 Capacity and service volume of crossroads at grade

The following parameters and/or calculations are relevant for the capacity analysis and/or dimensioning of crossroads:

- phase sequence at light-controlled crossroads,
- planned traffic loads for the calculation, pc/h,
- level of service (LOS) depending on delays and saturation level,
- the number of vehicles in queue and the occupied length in an individual direction,
- average delay per vehicle (seconds/vehicle) in an individual direction.

The performance of crossroads operation depends on two criteria:

- traffic load criterion (capacity), which is expressed through the saturation level X = V/C and
- queuing time criterion, which is expressed through delays.

The performance criterion entails the level of service in individual directions of traffic flows through the crossroads.

At crossroads that are not controlled by traffic lights the saturation level of X = 0.85 is still satisfactory at the end of the planning period, while the queuing times and the peak LOS can be "E".

If for an individual traffic flow at crossroads at the end of the planning period LOS=F, the crossroads design has to be changed or supplemented.

If traffic flow in an individual direction increases by more than planned when the crossroads has been constructed, suitable measures have to be implemented increasing the performance and/or the capacity of an individual direction and the crossroads in general (expansion, installation of traffic lights, etc.) already before the end of the planning period.

In the case of light-controlled crossroads the traffic performance depends mainly on the saturation level of an individual direction (X = V/C), which represents the relationship between actual relevant traffic load (V) in relation to capacity (C), and is defined also by the ratio $X = Y/\lambda$. The saturation level of an individual direction of traffic light-controlled crossroads that is still acceptable equals X = 0.90 to 0.95.

The capacity depends on the geometric elements of the crossroads, the characteristics of the traffic flow and control parameters. It is defined by the relationship between the level of relevant load and the level of saturated traffic flow in an individual direction ($Y = Q_{mer}/S$) and the relationship between green lights in relation to the length of the cycle ($\lambda = g/C$).

The level of service (LOS) of the crossroads and individual directions is related to the delays and queuing time of vehicles. These depend on actual traffic load according to the green time distribution (queuing times at the red signal). The LOS E points to the fact that the queuing time criterion has been met, while the LOS F reflects that the queuing time criterion has been exceeded.

At roundabouts, the capacity depends on the capacity of points of access. Besides the geometric elements of the roundabout, this is influenced also by the geometric elements of the entry. Saturation level of points of access should not exceed X = 0.85, while the LOS still acceptable is E.

## 1.3.4 Planning period

The geometric design of new roads is based on the assessed traffic load for 20 years following the completion of the road. This is the result of the traffic study and the projected traffic load increase (traffic forecast). In justified cases, especially when a tunnel is planned on the layout, it is recommended that a period exceeding 20 years is taken into account. Extended planning period has to be approved by the road manager and specified in the project task.

As regards the reconstruction, rehabilitation or restoration of a road or major crossroads, the planning period for determining traffic load is as a rule 10 years following the completion of the construction of the planned measure, if the road manager does not set a longer period.

For other road measures (restoration, adaptation) the planning period can be shorter, but not less than 5 years following the implementation of the measure.

If a road is constructed by phase, the project has to provide measures for the road, which will ensure that during a particular phase the functioning of drainage devices will not be hindered and no measures will be implemented as regards the road cross section that would decrease traffic safety.

The expected planning period of an individual phase is set based on the calculation of the throughput of a particular phase in view of the increase in traffic load by year.

## 1.3.5 Traffic design of road elements

The throughput calculation is a simple condensed expression of basic factors affecting the design of a particular road to ensure unimpeded traffic flow.

Based on the calculation of the level of service (LOS A-E or F and average travel speed) at the end of the planning period it is tested whether the planned or selected structure and size of the elements of the normal cross section (NCS) and road axis geometric elements are sufficient.

The level of service is calculated for:

- open layout (general route at a selected section),
- individual ascents (steepness of ascent and the relevant length),
- points of access (at bifurcation, point of access, exchange lane) and
- crossroads.

When the throughput calculation results in a value that is significantly lower than defined for each road category, the NCS has to be designed so as to include additional lanes.

If the throughput calculation results in a value that is slightly lower than defined for each road category, the size of the geometric elements of the road axis has to be increased or the NCS supplemented.

The need for additional lane on ascent is justified based on the calculation of the level of service, which has to be the same as for open layout.

The test of the level of service at the road section where an additional lane is planned to be constructed for slow-moving vehicles is calculated based on traffic data (for an individual direction in the case of a double-carriageway road) without taking into account the percentage of heavy vehicles (as these are travelling on the additional lane).

The calculation of the level of service is an obligatory component of a technical report for the road project.

The calculation of the level of service need not be made for open road:

- in the case of double-carriageway multi-lane roads with the traffic volume AADT < 10,000 vehicles/day and
- in the case of single-carriageway double-lane roads with the traffic volume AADT < 2,500 vehicles/day.

The level of service has to be calculated for single-carriageway three-lane roads. Since such roads are usually physically separated by the direction of the drive, the relevant traffic load has to be first determined for every direction separately (distribution by direction: 70:30, 60:40, etc.) and the greater of the two values taken into account for both directions of the drive.

# 2  BASES FOR SELECTION OF ROAD ELEMENTS

## 2.1  BASIC ROAD ELEMENTS

### 2.1.1  Road body

A road body is composed of elements put together by the road design taking account of the traffic requirements and spatial conditions. Basic road design elements are the following:

- geometric elements of the road axis in both plan and longitudinal section,
- traffic lanes, and non-traffic lanes along the roadway, and
- technical elements (slopes, changing of slopes).

During designing, road elements are combined and dimensioned in accordance with the Law of Public Roads, theses Guidelines, and common professional methods. Other solutions can also be introduced, when this is required by the spatial conditions, or a special use of a road not provided by these Guidelines is foreseen. However, such alternative solutions shall be professionally justified for each individual case by the terms of reference or/and in the design plan.

The composing of road elements, their dimensions, and interrelations depend on the following:

- road category,
- traffic volume and its structure,
- spatial conditions and land-use,
- drivers' acquaintance with conditions on roads, and
- operation modes.

A road category is a road type, which is defined, in view of its traffic function and other conditions, by the relevant legal act, and which shall be so planned, constructed, and maintained as to be able, upon expiry of the design period, to operate at the level corresponding to the performed traffic function.

Traffic volume is the traffic flow volume on an individual road. For the road design, traffic flow volume at the end of the design period is relevant, unless justifiably specified otherwise by the terms of reference. The composition and the dimensions of road elements shall be defined in such a way that, at upon expiry of the design period, the particular road will be able to operate at the level specified with regard to the road category, and under conditions provided by the these Guidelines.

Spatial conditions arise from the land-use and series of events characteristic of the space, which the particular road will run through. In certain cases, both extent and importance of an individual use or events in the space can exceed the traffic importance of the planned road. In such cases, the level of services (LOS) on the road may be diminished on a section of particularly sensitive environment, however by one level maximum. The transition areas in both sides of the section where lower standard elements have been applied shall be treated with special attention to the traffic safety and a clear identification capability of the modification in the road accomplishment.

Acquaintance of drivers with driving conditions on a certain road depends on the frequency of the use of the same road. The frequency of use is typical of an individual road category. Drivers can use a particular road very rarely, periodically, or permanently.

On a certain road, either conditions for a drive with a constant speed, or only conditions for transportability are ensured.

### 2.1.2  Technical classification of roads

Road planning must be economical. Acquaintance of typical users (drivers) with conditions on a road enables to introduce differentiated dimensions of road geometric elements to ensure the same level of services on that road. The differentiation is made feasible by the following:

- utilization rate of the admissible value of the coefficient of side-friction ($f_{Rmax\ adm}$), and
- driver's reaction time.

With regard to the road operation mode, road element dimensions are designed either

- in view of driving dynamics (conditions of a constant speed and an undisturbed driving capability), or
- in view of a typical vehicle (ensuring transportability irrespective of the driving dynamics conditions).

On the above mentioned bases technical classification of roads into 4 groups (Table 7) has been carried through. Differentiated technical solutions are characteristic of these groups. Ranging of the road categories in individual groups in Table 7 can be modified, if the official road classification has changed.

**Table 7: Technical groups of roads**

| Technical group | Characteristic type of use | Design method | In principle it applies to category: * |
|---|---|---|---|
| A | rare (single) use | driving dynamics | M1, M2 |
| B – outside of settlement | periodical use | driving dynamics | M3, R1, R2, L1 |
| B – inside of settlement | frequent use | driving dynamics | M3, R1, L1, L2 |
| C | predominantly permanent use | driving dynamics | other road types |
| D | permanent use only | ensuring driving capability | low traffic volume roads |

\* Label of road category in this column is informative only. Changes in road ranging are expected to be done by

the authorities on the ground of the Act of road categorization and with regard to the traffic

function of each single category of the roads.

Limiting values of elements differentiated by technical groups enable the best possible adaptation to the road traffic function, as well as to the use and to other conditions in the space.  However, the basic assumptions must not be altered when individual geometric and/or technical elements of both road axis and carriageway are selected.

When, for special conditions such as spatial restrictions, limited funds, extended road function, etc., more moderate basic assumptions than those defined in the present document shall be introduced, this shall be supported by the planning documents, and/or by the terms of reference. For roads of the maximum possible complexity with regard to the traffic (technical group A, technical group B outside of settlements), provisions dealing with conformity of geometric elements shall in no way be ignored. Such more modest basic assumptions may only be applied without any special argumentation, when roads (streets) in a dense urban environment, and particularly in ancient urban centres are designed. In such cases the road (street) alignment and its elements shall be subordinated to spatial feasibilities to the greatest possible extent.

Conditions for a certain road shall only be selected within the scope of an individual technical group. Eventual exceptions being consequence of an unimaginable land-use shall be foreseen in the terms of reference, and shall be professionally presented by the design.

For the tourist road category it shall be determined by a planning document or by the terms of reference, with regard to specific circumstances, which conditions have to be considered (conditions of groups B or C – adapting of satisfying the traffic needs to spatial possibilities). In special cases it can be specified by the terms of reference that only transportability shall be ensured (group D).

## 2.1.3 Types of speeds

The following types of speeds apply to the road element design in view of the driving dynamics:

- *driving speed* ($V_{dri}$) is the actual speed of a vehicle on the carriageway;
- *design speed* ($V_{des}$) is any speed assumed to assess or calculate road technical elements;
- *admissible driving speed* ($V_{adm}$) is the speed directed on a road or a road section by a law or administrative restriction;
- *travelling speed* ($V_{tra}$) is the mean driving speed of vehicles on particular road;
- *conceptual speed* ($V_{con}$) is the design speed specified for an individual road category with regard to its traffic function and spatial conditions; dimensions of road geometric and technical elements are assessed on the basis of this speed;
- *free flow speed* ($V_{free}$) is the driving speed in a free traffic flow on a clean and wet carriageway; it is also called $V_{85\%}$ and is enabled by individual geometric and technical elements of either designed or existing road; it is used as design speed for traffic safety analyses, and for corrections of individual road technical elements (refer to Table 7);
- *transverse speed* ($V_{rad}$) is the radial speed of vehicle by moving to neighbour traffic lane.

*Free flow speed* ($V_{free}$) *assessment*:

The free flow speed is assessed analysing individual road elements. In the design it is presented as a design speed profile. The established speed cannot be higher than the maximum admissible speed on the road considered. Within the design, the mentioned analysis is performed for roads belonging to the group A, and for those roads of the group B outside settlement, where the assumed conceptual speed exceeds 70 km/h.

Unless established otherwise by a special analysis, the following shall apply:

- for two-way roads with separated carriageways, and where $V_{con} < V_{adm}$:

    $V_{free} = V_{con} + 10$ km/h          (for markedly curved roads)

    or

    $V_{free} = V_{con} + 20$ km/h          (for stretched road alignments),

- for two-way roads with single carriageways, and where $V_{con} < V_{adm}$:

    max $V_{free} = V_{adm}$          (for individual road type or category)

    min $V_{des} = V_{con}$

*Transverse speed* ($V_{rad}$):

The speed in the side direction is a quantity assumed to calculate the length of the transition area at changing the driving lanes. It depends on the width between the original and neighbour or one of neighbouring traffic lanes, on the driving speed, and on the directional course of the road alignment (in straight line, in curvature).

Unless directed otherwise in special cases, the following values shall apply:

- temperate       0.7 m/s       (for speeds > 70 km/h, for heavy vehicles, road in curvature)
- acceptable      1.0 m/s       (for speeds ≤ 70 km/h, for motorcars, road in straight line).

Note: warning against designing of the additional lane with S-form lane-changing drive!

## 2.1.4 Driving-dynamical conditions

Driving-dynamical values to be considered for ensuring the traffic safety, and which allow movement of a vehicle at the selected driving speed on roads designed according to the driving-dynamical requirements, are indicated in Table 8.

The most important difference between the technical groups relates to the utilization rate of the coefficient of side-friction, which is introduced to assess the radius of the horizontal circular arc at both maximum and minimum cross-fall of the carriageway.

Admissible values of the coefficient of friction ($f_{Rmax\ adm}$) to define the relation between the road element dimensions and the driving speed are indicated in Table 9.

**Table 8: Driving-dynamical conditions**

| Technical group | | Utilization rate of $f_{Rmax\ adm}$ at | | Maximum cross-fall* | Transition curve | Sequence of circular arcs | Reaction time | Overtaking sight distance |
|---|---|---|---|---|---|---|---|---|
| | | $q_{max}$ | $q_{min}$ | $q_{max}$ | | | | |
| A | | 50% | 10% | 7(8)% | mandatory | mandatory | 2.0 s | required |
| B | out of settle-ment | 60% | 30% | 7(8)% | mandatory | mandatory | 1.5 s | recommended |
| | within settle-ment | 60% | 30% | 5(7)% | mandatory | recommended | 1.5 s | not required |
| C | | 70% | 50% | 5(7)% | recommended | not mandatory | 1.5 s | not required |
| D | | $V_{des}$ is not specified. Arrangement conditions for C to be considered. | | 5(7)% | recommended | - | - | - |

*Note: The maximum cross-fall indicated in parentheses shall apply to renewal or reconstruction of existing roads.

**Table 9: Admissible (maximum) values of coefficients of friction to calculate road elements**

| Coefficient of friction | | Speed $V_i$ [km/h] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 |
| $f_{T\ max}$ | [-] | 0.42 | 0.37 | 0.33 | 0.30 | 0.26 | 0.23 | 0.21 | 0.19 | 0.17 | 0.16 | 0.15 |
| $f_{R\ max}$ | [-] | 0.381 | 0.345 | 0.310 | 0.279 | 0.250 | 0.225 | 0.203 | 0.187 | 0.169 | 0.161 | 0.151 |
| $f_{T\ 50\%}$ | [-] | 0.510 | 0.480 | 0.460 | 0.430 | 0.410 | 0.390 | 0.370 | 0.353 | 0.338 | 0.325 | 0.313 |

In Table 9, the values $f_{T\ max}$ and $f_{R\ max}$ are indicated for a wet and clean carriageway, with a asphalt wearing course made of calcite mineral aggregate, whereas the values $f_{T\ 50\%}$ for layers made of eruptive (silicate) aggregates. For pavements executed of different materials, the coefficient of friction shall be assessed extra for each individual case.

To calculate braking and stopping lengths, the total (maximum) admissible value of the coefficient of friction shall generally be assumed. To calculate the minimum radius of the horizontal circular arc ($R_{min}$), portions indicated in Table 8 for individual technical road group shall be applied.

Traffic surfaces, and limiting values of driving-dynamical parameters, which allow performing the traffic functions within defined limits are indicated in Table 10.

The execution of the traffic surfaces indicated in Table 10 can also be more modest, if this is sufficient in view of the traffic loading (traffic volume), or in case of construction in stages (first a two-lane road, which is subsequently widened to a four-lane road), provided that the traffic safety requirements are fully met.

In case that a road is constructed in stages, such an arrangement shall be considered and presented by a separate plan designed on the basis of the complete final plan. Traffic-safety requirements shall be fully met in each single stage.

## Table 10: Basic traffic and driving-dynamical characteristics of roads belonging to different technical groups

| Technical group | Traffic type | $V_{adm}$ [km/h] | $V_{tra}$ [1] [km/h] | Carriageway | Crossroads[2] | Feasible conceptual speed [3,4] [km/h] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **out of settlements** | | | | | | | | | | | | | | | |
| **A** | motor | 130 | 80-100 | separated directions | split level | 130 | 120 | 110 | 100 | | | | | | |
| **A** | motor | 90 | 60-80 | two-way | split level | | | | | 90 | 80 | | | | |
| **A** | motor | 100 | 70-90 | separated directions | split level | | | 110 | 100 | 90 | 80 | | | | |
| **A** | mixed | 90 | 50-70 | two-way | at grade wid. | | | | | 90 | 80 | 70 | 60 | | |
| **B** | mixed | 100 | 60-80 | separated directions | at grade wid. | | | | 90 | 80 | 70 | 60 | | | |
| **B** | mixed | 90 | 50-70 | two-way | at grade wid. | | | | 90 | 80 | 70 | 60 | 50 | 40 | |
| **B, C** | tourist | 70 | specif. | two-way | at grade equ. | | | | | | | 70 | 60 | 50 | 40 |
| **B** | mixed | 70 | 40-60 | two-way | at grade equ. | | | | | | | 70 | 60 | 50 | 40 |
| **C** | local | 70 | - | two-way | at grade min. | | | | | | | | 60 | 50 | 40 |
| **D** | access | 50 | - | two-way | at grade without | not specified | | | | | | | | | |
| **within settlements** | | | | | | | | | | | | | | | |
| **A** | motor | 100 | 60-90 | separated directions | split level | | | | 100 | 90 | 80 | | | | |
| **A** | motor | 90 | 50-70 | two-way | split level | | | | | 90 | 80 | 70 | 60 | 50 | |
| **B** | motor | 80 | 50-60 | separated directions | at grade wid. | | | | | | 80 | 70 | 60 | | |
| **B** | mixed | 70 | 40-50 | two-way | at grade wid. | | | | | | | 70 | 60 | 50 | 40 |
| **C** | mixed | 50 | - | two-way | at grade equ. | | | | | | | | | 50 | 40 |
| **D** | mixed | 50 | - | two-way | at grade min. | not specified | | | | | | | | | |
| **D** | access | 30 | - | two-way | at grade without | not specified | | | | | | | | | |
| **D** | access | at a walking pace | - | - | - | not specified | | | | | | | | | |

Legend:

[1] to be selected in view of the distances between centres of traffic potential (the greater the distance, the higher the $v_{tra}$)

[2] crossroads type to be selected with regard to traffic volume:

  wid. = crossroads widening,

  equ. = complete traffic equipment,

  min. = minimum traffic equipment

  without = without any traffic equipment – traffic sign only

[3] to be selected in view of spatial conditions and continuity

[4] lower $V_{con}$ to be only selected where the environment impressions clearly affect the driver, and the speed limitation shall be obligatorily marked with a supplemental board "at rain"

## 2.1.5 Typical traffic lane widths

A carriageway is composed of traffic lanes, overtaking lanes, additional lanes, and border strips. Typical traffic lane widths depend on the standard vehicle width (traffic gauge of 2.50 x 4.00 m), and on the driving speed, whilst in roads with elements of lower standards they depend on the design vehicle permanently driving on an individual road (Table 11).

When there is no central reserve between two driving directions, a separating strip measuring 0.50 m in width shall be designed between the inner traffic lanes. This width shall be added to the carriageway width having an indirect influence on the assessment of dimensions of individual geometric and technical road elements.

The carriageway width that affects indirectly the assessment of dimensions of individual geometric and technical road elements (transition curve length, camber, etc.), does not include the following items:

- additional lanes,
- border strips,
- emergency lanes, and
- protective strip ahead of raised kerb, if the kerb is foreseen locally only.

**Table 11: Typical traffic lane widths**

| Lane width [m] | Conceptual speed $V_{con}$ [km/h] | | | | | |
|---|---|---|---|---|---|---|
| | **40** | **50** | **60** | **80** | **100** | **≥120** |
| Commonly | 2.50 | 2.75 | 3.00 | 3.25 | 3.50 | 3.75 |
| Exceptionally | 2.25 | 2.50 | 2.75 | - | - | - |

### 2.1.6 Influence of traffic volume on road element dimensions

If on a two-lane road, upon expiry of the planned period, the design traffic loading caused a drop of the average travelling speed below the specified one, the traffic capacity should be increased by:

- increasing the portion of the road length suitable to overtaking,
- arranging additional lanes on major ascents, and
- increasing the traffic lane number.

In civil engineering investments subjected to economical studies (e.g. motorways) the decision on the selected measure shall be verified by adequate feasibility study. For other roads, a simple cost analysis is sufficient.

## 2.2 ASSESSMENT OF DIMENSIONS OF ROAD GEOMETRIC ELEMENTS

### 2.2.1 On roads belonging to technical groups A, B, and C

Dimensions of technical elements of a road axis line shall be assessed on the basis of the following:

- road category,
- conceptual speed ($V_{con}$), and
- defined level of services (traffic flow density on one-way carriageways, and specified travelling speed [$V_{tra}$] on two-way carriageways) to be ensured to a road of certain category at the end of the planned period.

As the conceptual speed $V_{con}$ the highest value among those indicated in Table 10 shall be selected. When selecting road alignment elements, the maximum possible conformity with spatial elements, as well as economical solutions shall be achieved. For this purpose Table 10 also provides lower feasible conceptual speeds, which shall be assumed in case of

- rigorous spatial conditions (already defined land-use, natural features, cultural heritage, urban areas, avoiding excessive interventions in space, reduction of disturbing impacts by the road),
- complex relief (significant differences in height, explicit heterogeneity),

- difficult geological – soil mechanical conditions, or
- other reasons,

which would make construction of a road, allowing the highest feasible conceptual speed, unacceptable in view of space, and/or too expensive comparing with the foreseen road traffic function, and with the traffic on the road. Any deviation shall be extra explained and justified in the road design.

For the technical group A, and for roads of the traffic group B of higher traffic volume (when $V_{con}$ = $V_{adm}$), the carriageway elements shall be corrected with regard to the free flow speed ($V_{free}$) – refer to Table 7.

When some shorter section of an individual road is arranged (the major part of the road has already been arranged previously), such dimensions of road elements shall be assumed for that section, that have already been introduced to the adjacent, already completed section (arrangement continuity), unless provided otherwise by the road planning documents, or such a traffic loading is expected, which is considerably higher or lower than that on the adjoining, already executed section. Such ascertainment shall be defined by the terms of reference.

To ensure a higher level of the traffic safety on all the roads it is recommended to assume the design speed for the assessment of the vertical alignment curvature radii, unless this is made impossible by spatial and economical reasons.

The width and the composition of elements of a normal cross-section (NCS) shall be assessed on the basis of the chosen conceptual speed, and of the road users (vehicles, pedestrians, cyclists), as well as of the traffic conditions (traffic volume, structure of vehicles, design volume per hour). The dimensions of the normal cross-section elements and the traffic equipment shall be at least the same as those specified for individual technical groups of roads, and for the traffic volume on the road. The widths of normal cross-section elements are standardized and comply with the dimensions indicated in these Guidelines. Deviations are only possible in special cases determined by the spatial planning acts, and extra indicated in the terms of reference.

## 2.2.2 On roads belonging to technical group D (roads of low traffic volume)

On roads belonging to the technical group D, assessment of dimensions of geometric elements in dependence on the conceptual speed can be omitted. To ensure the traffic safety on such roads the following shall be taken into consideration on determining technical elements:

- the normal cross-section is specified taking account of typical users, where the traffic lane widths can be smaller from those standardized for public roads;
- the highest driving speed on this roads amounts to 50 km/h, and the maximum cross-fall shall not exceed 5% as a rule;
- same provisions for assessing dimensions of carriageway elements as those applying to the technical group C are recommended;
- both cross-fall and sight distance at an individual circular arc shall be assessed with regard to the estimated driving speed on that arc;
- where the feasible driving speed on a circular arc significantly differs from that on the adjoining arc, the cross-fall of the larger arc shall be determined on the basis of such a speed, which is possible on the circular arc of smaller diameter;
- when stretched sections (straight lines or arcs of R > 400 m) longer than 200 m occur between individual groups of three or more circular arcs, the elements of an individual group of arcs shall be assessed taking account of the speed applicable to the smallest circular arc within this particular group at the maximum cross-fall;
- on certain road alignments, groups of arcs of different speeds but of the same normal cross-section can be situated; in case of major speed deviation between adjoining groups of arcs ($\Delta V \geq 20$ km/h) this shall be extra marked by means of suitable vertical traffic signs.

When foreseen by the terms of reference, and, afterwards, professionally explained in the design, the method indicated above may be introduced to roads of the technical groups C and B (out of settlements), when the traffic loading does not exceed 400 vehicles per day. The stretched portion of the road alignment between two successive groups of curves must not be shorter than 1.5 times the stopping length.

## 2.2.3 Influence of resulting carriageway slope

The resulting carriageway slope is a vector sum of the longitudinal fall and the cross-fall. On road sections where the resulting carriageway slope might exceed the maximum value (potential hazard of slips due to frost glaze on the carriageway), horizontal circular arcs of such a cross-fall shall be introduced that the cross-fall, which is read from the diagram in Figure 3 with regard to the value of the longitudinal fall for either of the maximum values of $q_{maxres}$, is not exceeded.

The following maximum admissible value of $q_{maxres}$ shall be considered:

- $q_{maxres}$ = 8 % on roads of the group A with traffic volume above 12,000 vehicles/day,
- $q_{maxres}$ = 10 % on other roads of the group A, on roads of the group B (out of settlements), as well as on other roads where the traffic volume exceeds 5,000 vehicles/day.

**Figure 3: Maximum cross fall $q_{max}$ as a function of longitudinal fall $s_i$ at resulting carriageway slopes $q_{res}$=8% and $q_{res}$=10%**
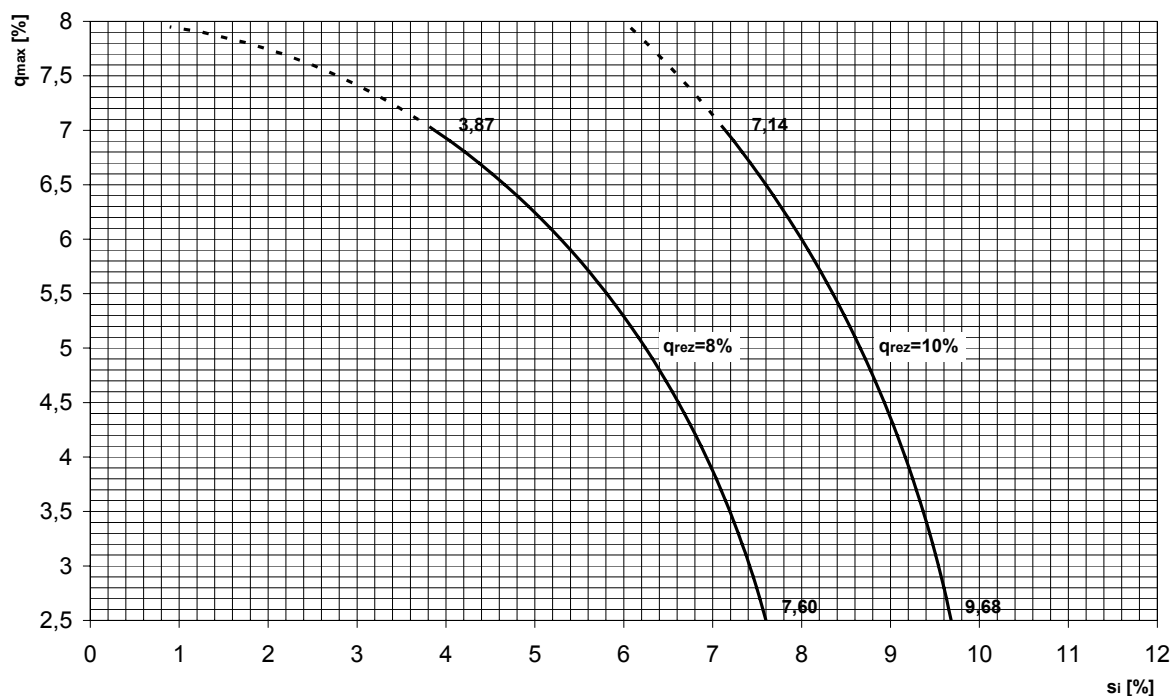


In special cases suitable protective measures against slip shall be foreseen (obligation of rigorous control and of thawing, protective barriers, etc.). On long-distance roads, emergency exits shall be designed as well.

In areas where it is statistically proven that no slippery ice can occur, the abovementioned condition needs not be fulfilled.

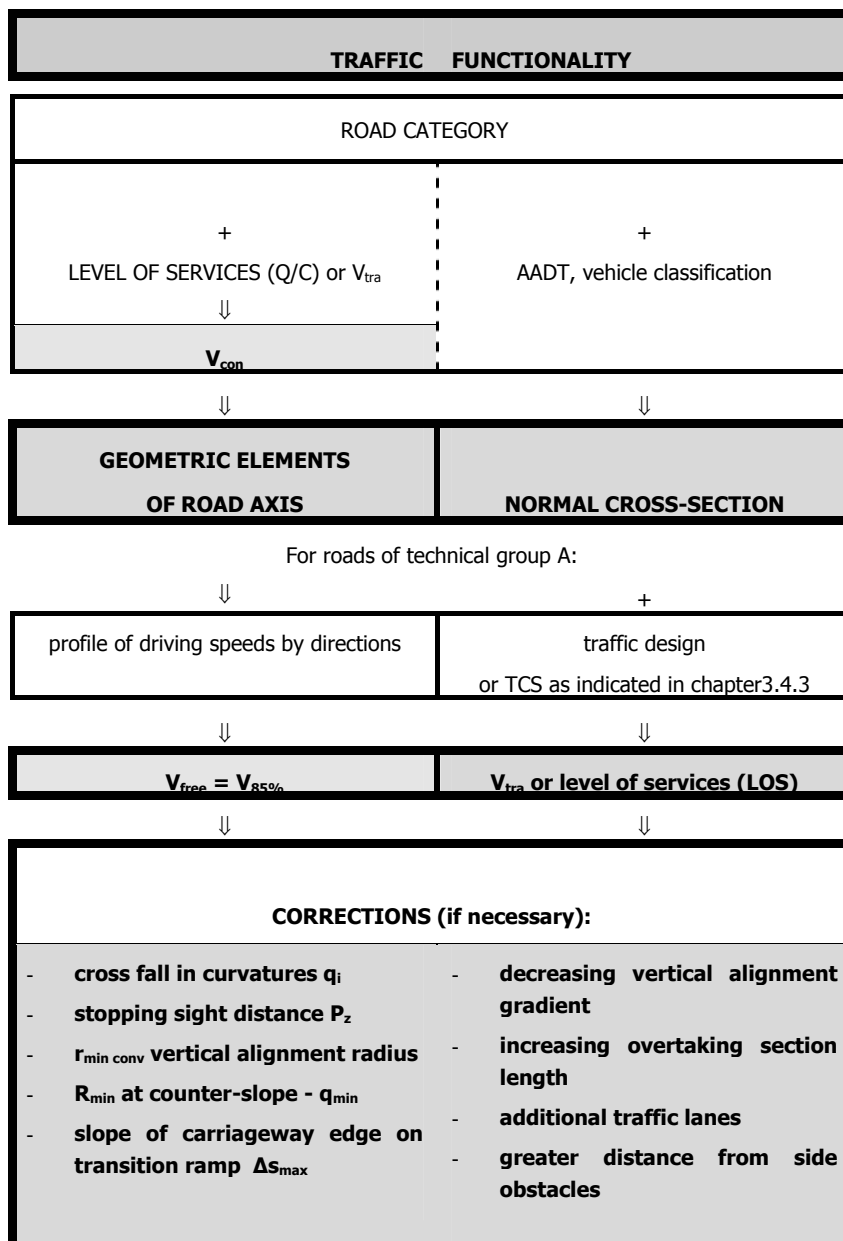### 2.2.3.1 Effect of minimum slopes required for surface drainage

When assessing dimensions of the technical elements (carriageway slopes) the following minimum slopes required to evacuate the surface water via drainage devices shall be considered:

- on cement concrete surfaces          0.2%,
- on asphalt surfaces                        0.3%,
- on grassy surfaces                         0.5%.

## 2.2.4 Method of assessing road element dimensions

When working out a road design, road element dimensions shall be assessed in sequence indicated in Table 12. These steps can be omitted in case of roads for which it is specified otherwise in this document and/or in other technical regulation.

**Table 12: Sequence of assessment of road element dimensions**

| TRAFFIC    FUNCTIONALITY | |
|---|---|
| ROAD CATEGORY | |
| +<br>LEVEL OF SERVICES (Q/C) or $V_{tra}$<br>$\Downarrow$<br>**$V_{con}$** | +<br>AADT, vehicle classification |

| $\Downarrow$ | $\Downarrow$ |
|---|---|
| **GEOMETRIC ELEMENTS**<br>**OF ROAD AXIS** | **NORMAL CROSS-SECTION** |

For roads of technical group A:

| $\Downarrow$ | + |
|---|---|
| profile of driving speeds by directions | traffic design<br>or TCS as indicated in chapter 3.4.3 |

| $\Downarrow$ | $\Downarrow$ |
|---|---|
| **$V_{free} = V_{85\%}$** | **$V_{tra}$ or level of services (LOS)** |

| $\Downarrow$ | $\Downarrow$ |
|---|---|

**CORRECTIONS (if necessary):**

| | |
|---|---|
| - **cross fall in curvatures $q_i$** | - **decreasing vertical alignment gradient** |
| - **stopping sight distance $P_z$** | |
| - **$r_{min\ conv}$ vertical alignment radius** | - **increasing overtaking section length** |
| - **$R_{min}$ at counter-slope - $q_{min}$** | - **additional traffic lanes** |
| - **slope of carriageway edge on transition ramp $\Delta s_{max}$** | - **greater distance from side obstacles** |

# 3  CROSS SECTION OF THE ROAD

## 3.1  GENERAL

Cross section of the road shall be designed rationally and selected in a way enabling normal driving conditions in projected traffic volumes and free traffic flow.

The following shall be taken into account in selection of elements of cross section: speed, structure, density and time distribution of projected traffic, dimensions of the selected relevant

vehicle, the number of expected meetings of vehicles, traffic significance and function of the road, economics, topography of the terrain, protection of the environment and requirements of the winter service.

The NCS (normal cross section) shall be the basic definition of contents, structure and dimensions of traffic and non-traffic areas in the cross section of an individual (type of) road. It shall, as regards traffic and driving dynamics depend on parameters and conditions discussed in the section 1 Traffic, and as regards construction technical aspect on parameters and conditions as discussed and specified hereunder.

Cross section of a public road in the broadest sense is the road body presented in cross section with all accompanying facilities.

The road body may be:

- In the height of the existing terrain;
- In a cut, embankment or a combination of both (mixed cross section);
- On bridges, viaducts, underpasses, overpasses;
- In tunnels and galleries;
- With stay and support structures;
- Along existing roads;
- Near watercourses;
- Along the railway;
- In unpopulated, rural or urban environment;
- In villages, towns, industrial areas;
- With noise protection measures;
- On water protection areas; etc.

Each of these possibilities has its own specifics regarding design and general rules for aligning individual facilities with the roadway and carriageway.

In the sense of designing the carriageway itself and accompanying elements of the cross section, such as: cyclist ways, pedestrian walkways, separating lanes, lanes for joining, braking, accelerating, border lanes, hard shoulders, slow traffic lanes, kerbs, berms, areas for draining, areas for traffic signs and areas for utility infrastructure, areas for noise protection measures; they are subject to rules, which will be specified in the analysis of elements of the cross section.

Design of the road body in cuts and embankments is conditioned foremost by the shape of the existing relief and by taking into account the geological – geomechanical parameters, which are in many cases the determining element for the final design of the cross section.

Supplementing of geological – geomechanical forms of the cross section shall be made in the landscape plan, which shall take into account the design of cuts and embankments in joints with the existing relief, or by designing of parts or whole areas of cuts and embankments by alleviating slopes depending on relief conditions of the existing terrain through which the road passes.

Particular attention should be given to longitudinal, line facilities passing along outer edges of roads, such as anti-noise fences and embankments, protection of underground water, traffic equipment (safety and protective fences), etc.

These facilities shall preserve the symmetry of linear layout by taking into account the external relief and specifics regarding urban or partially urbanised areas.

# 3.2 TRAFFIC PROFILE AND PROFILE CLEARANCES

## 3.2.1 Traffic Profile

Traffic profile is the area above the carriageway, consisting of:

- dimensions of the relevant vehicle;

- the area required for performance of the vehicle in straights and curves; and
- the safety width between vehicles.

Certain specified elements also apply to the traffic profile of a cyclist way and for the combination of a cyclist way and a pavement (cyclists and pedestrians).

The traffic profile consists of traffic and border lanes, safety widths and traffic lanes and safety widths for cyclists and pedestrians (mostly in urban areas). No physical hindrance shall extend to or be in the traffic section.

## 3.2.2 Profile Clearances

Clearance of the road cross-section consists of the area of traffic profile increased by safety width and height. Permanent physical hindrances shall not extend to clearance, in order not to endanger driving of vehicles with the projected speed $V_{cal}$ as well as movements of other road users.

Elements of traffic signs and equipment may be present in this area outside the traffic section, excluding those which may by their dimensions and placement limit visibility on the road (various boards). Anyway, the signs must be removed from the carriageway edge 0,50m in rural and 0,30m in urban areas.

Safety width in clearance shall depend on $V_{cal}$ (Table 13).

**Table 13: Safety width in clearance**

| $V_{cal}$ [km/h] | to 50 | 70 | > 70 |
|---|---|---|---|
| $W_s$  [m] | 0.50 | 1.00 | 1.25 |

Safety widths in traffic lanes for different users shall overlap, if they travel in the same direction.

If traffic on those lanes is in opposite directions, then a safety lane shall be provided between traffic sections of two adjacent lanes:

- For lanes used by motor vehicles 0.50 m;
- For other lanes 0.25 m.

Safety height above the road's traffic section shall equal h = 0.50 m. On roads in technical groups A and B (outside populated areas) the safety height shall generally be increased to 0.70 m to ensure subsequent interventions on the roadway (overlay) or in case of special circumstances (snow plank).

Safety height above the pavement's and cyclist way's traffic section shall equal h = 0.25 m.

Exceptionally a lower section (< 4.5 m) may be used for particular relevant vehicles, however not on roads in technical groups A and B (outside populated areas). Lower clearance shall be indicated by the appropriate traffic signs and signals. Equal conditions apply for the width of clearance.

On roads in the technical group D, the section shall be determined for the (largest) typical vehicle, driving on the road in question.

In case the adequate width of the side safety lane cannot be provided for substantiated reasons, the hindrance shall be protected by a safety fence. Safety fence shall be in such a case as well as in any other case minimally 0.50 m away from the edge of the roadway.

Forms of traffic and clearance sections are given in the following figures giving dimensions of clearance and traffic sections for roads:

- Outside urban areas (Figure 4);
- Within urban areas (Figure 5);
- On bridging facilities (Figure 6);
- In tunnels and galleries (Figure 7);
- Near and above railroads (Figure 8);
- For cyclists (Figure 9);

- For pedestrians (Figure 10);
- Example of a combined clearance (Figure 11).

**Figure 4: Traffic profile and profile clearances outside urban areas**

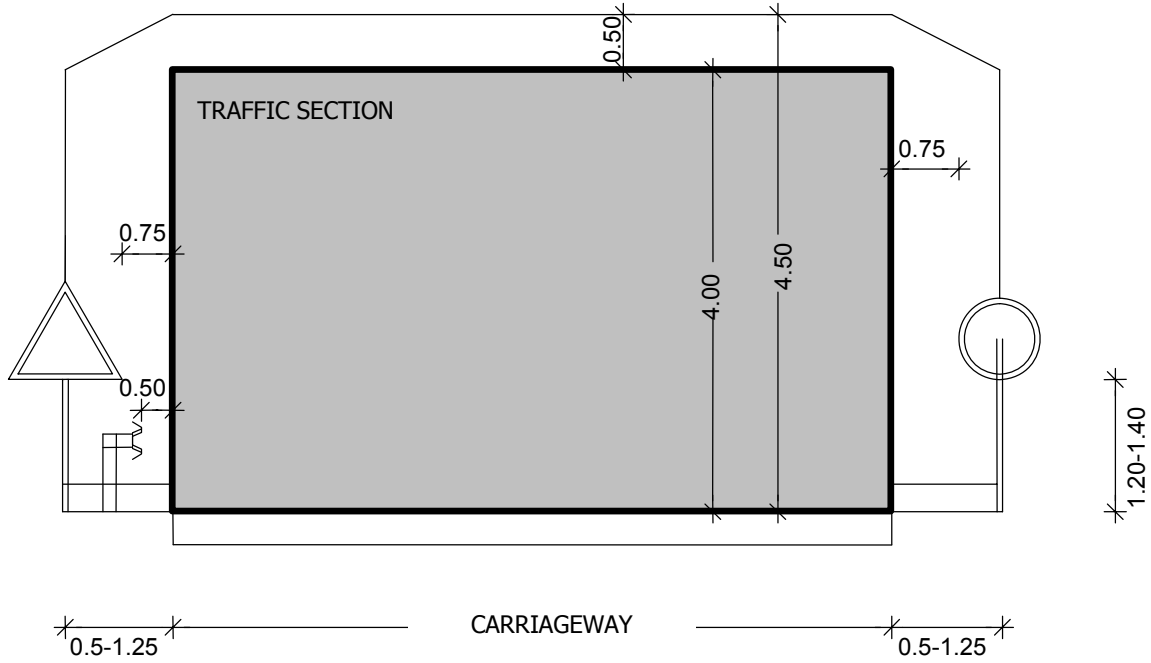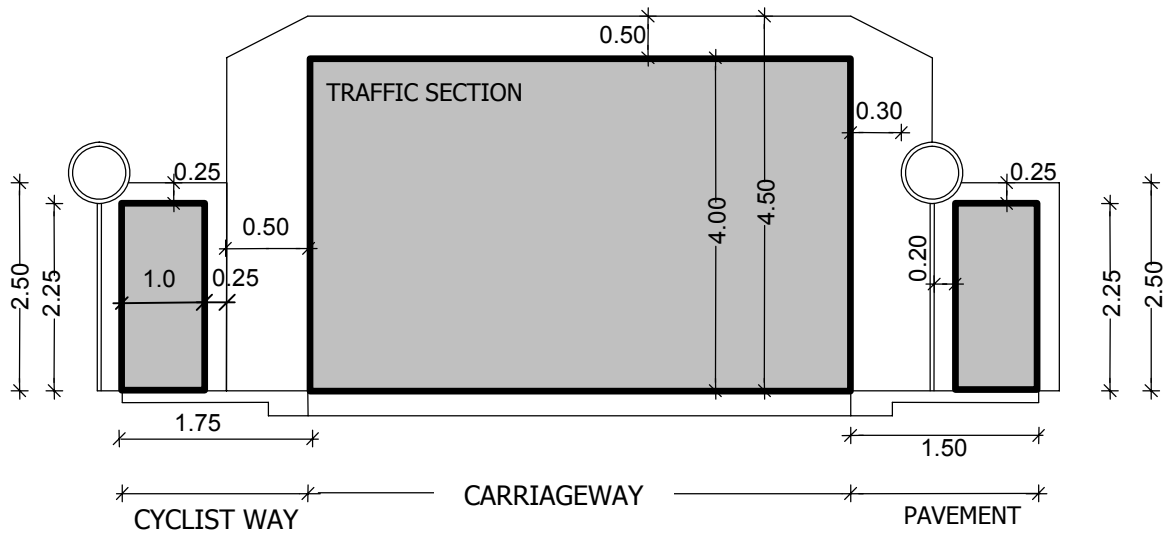## Figure 5: Traffic profile and profile clearances within urban areas



## Figure 6: Traffic profile and profile clearances on bridges with a pedestrian walkway
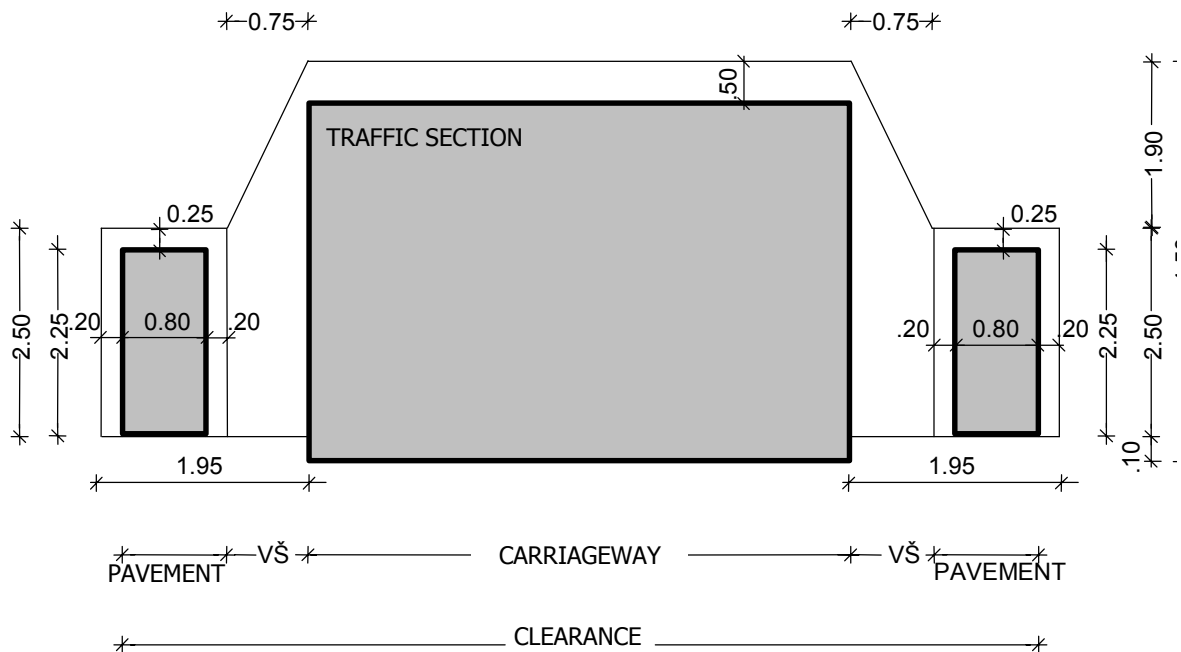
## Figure 7: Traffic profile and profile clearances in tunnels and galleries
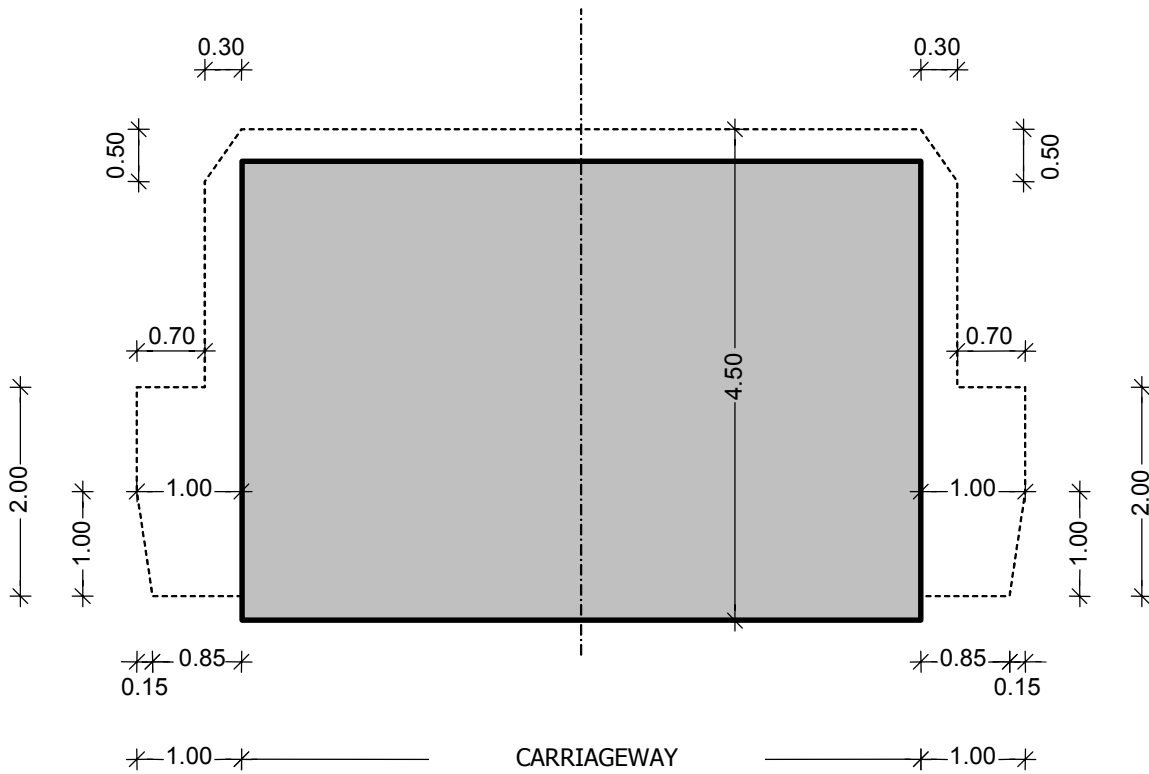


## Figure 8: Traffic profile and profile clearances by railway

FOR THE OPEN RAILROAD                *MEASURES IN MILLIMETRES*      FOR OTHER TRACKS ON STATIONS
AND MAIN TRANSPORT TRACKS
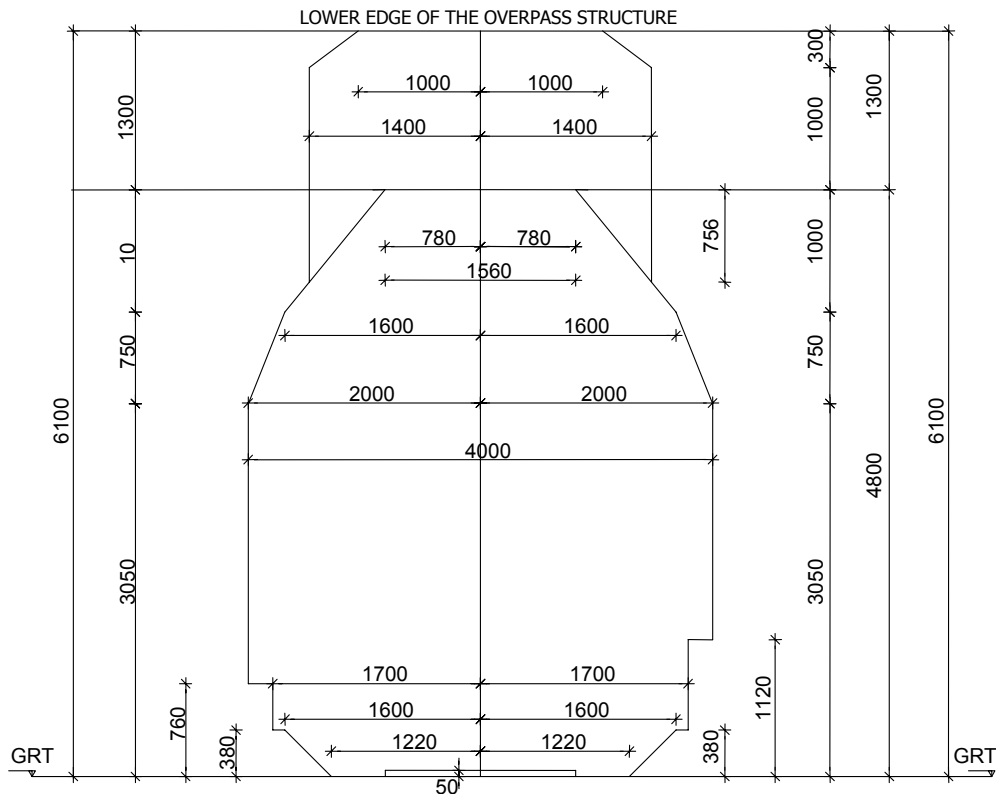
## Figure 9: Cyclist way: (a) one-way (b) two-way



**(a)**                                                                        **(b)**

## Figure 10: Pedestrian area: (a) one-way (b) two-way



**(a)**                                                                        **(b)**
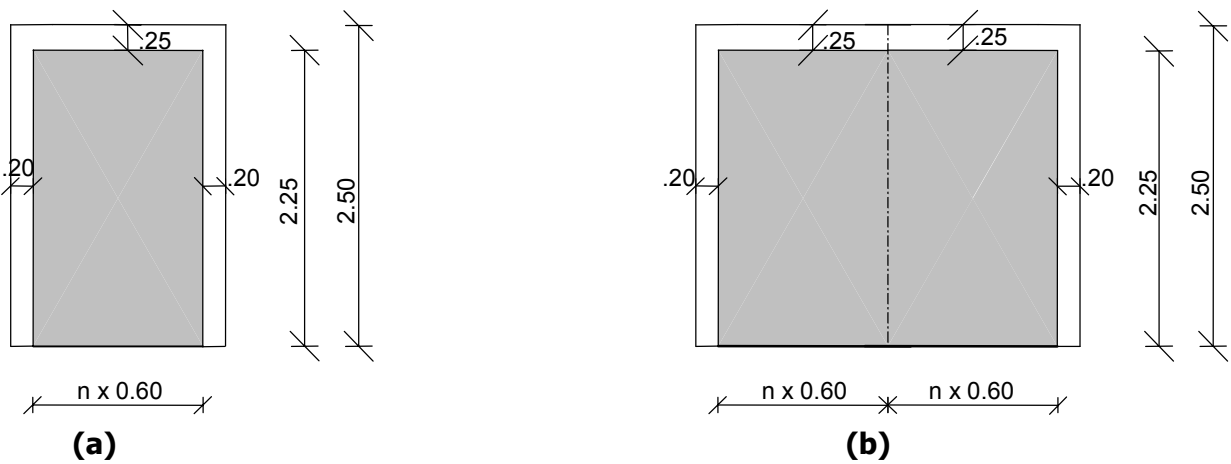
## Figure 11: Example of a combined clearances
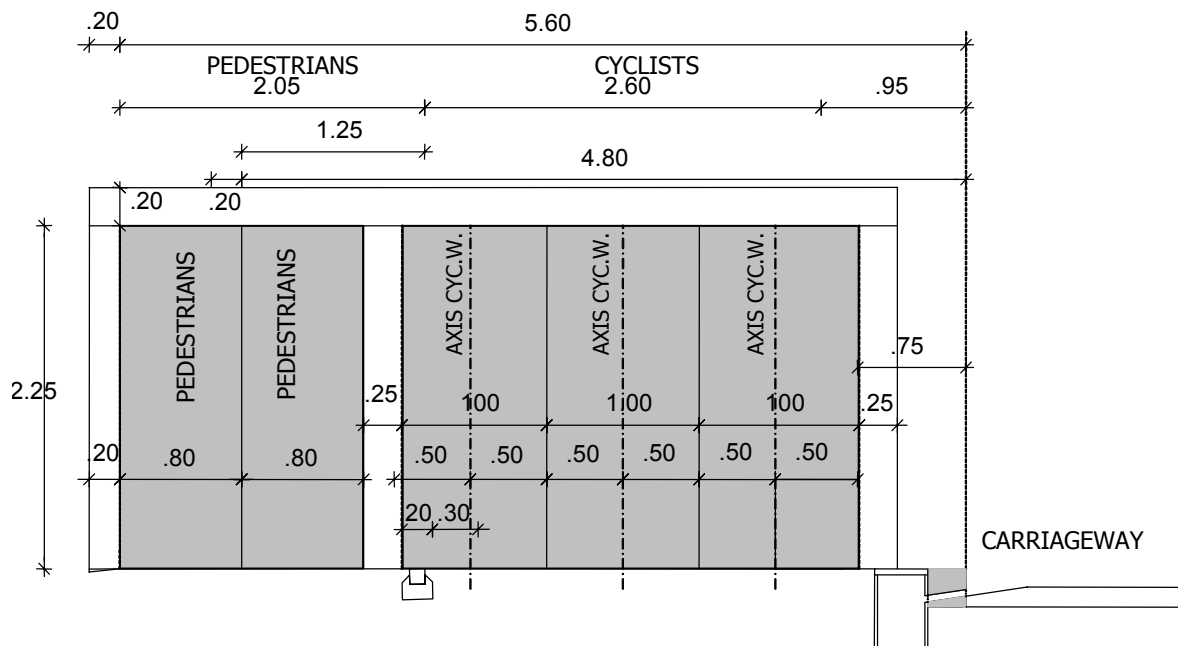


The minimum combined width for pedestrians and cyclists shall be:

$$\check{S} = 0,20 + \underbrace{0,80}_{\text{pedestrian}} + 0,25 + \underbrace{1,00}_{\text{cyclist}} + 0,25 = 2,50m$$

## 3.3  CROSS SECTION ELEMENTS

The carriageway is a part of the road cross-section between inner edges of slopes of the cut or embankment and consists of the following:

- Carriageway (traffic lanes for motor vehicles, additional lanes, border lanes or hard shoulders);
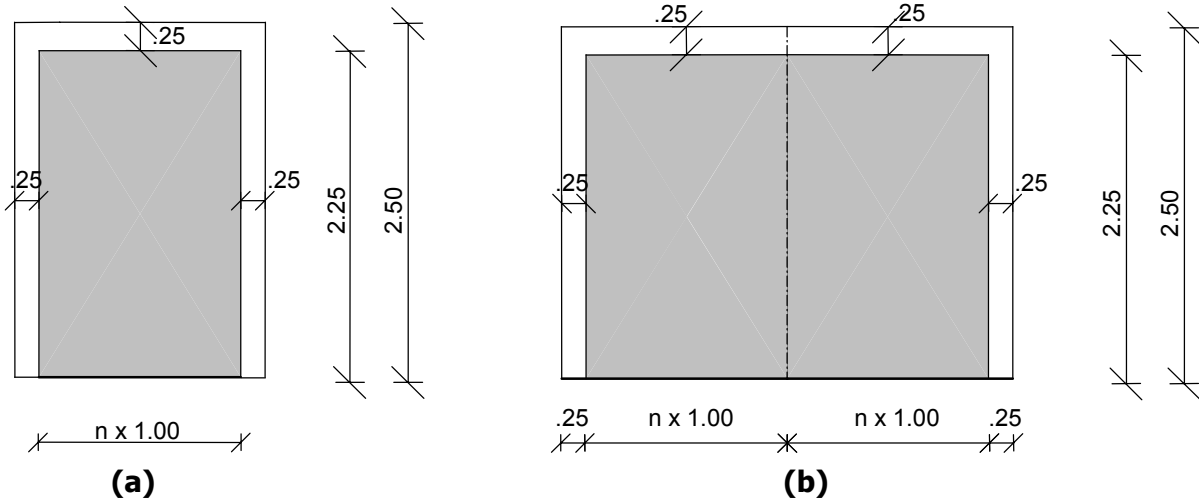- Side lanes or areas:
  - o Traffic lanes for non-motorised participants (cyclists, pedestrians, other);
  - o Non-traffic lanes (separation lanes between directional carriageways or between the carriageway and other traffic lanes, and parking lanes);
  - o Longitudinal strips for protection of the carriageway (verges);
  - o Longitudinal strips for protection and providing functionality to the roadway (berms); and
  - o Facilities for longitudinal drainage of the road (kerbs, pointed channels, curved channels).

Examples or basic elements of the cross section are presented in Figures 12 and 13.

### Figure 12: Example of a multilane road outside urban areas



### Figure 13: Example of a two-lane road within populated areas

### 3.3.1 Carriageway

Carriageway consists of carriage lanes for vehicles and border lanes with sufficient space for providing movement of vehicles (traffic section) and traffic safety (profile clearances).

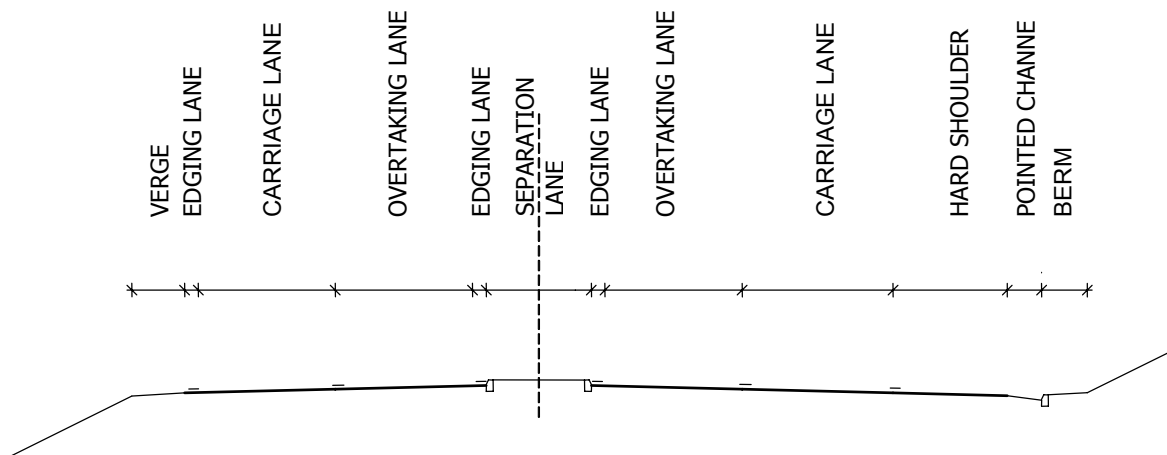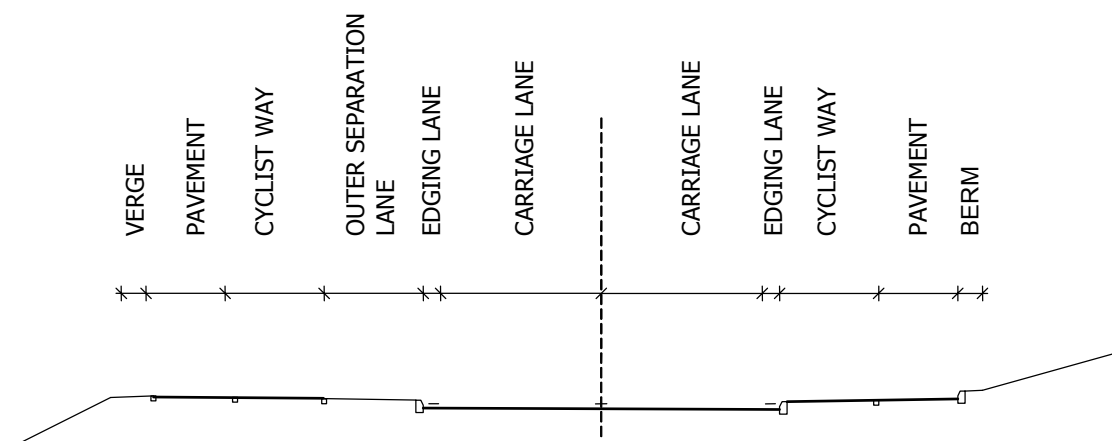#### 3.3.1.1 Carriage Lanes for Motor Vehicles

Carriage lanes for motor vehicles shall be:

- Carriage lanes (one, two or more for one direction);
- Overtaking lanes (one for one direction);
- Additional slow traffic lanes and special purpose lanes (buses, taxis); and
- Additional lanes for exit or access and change of traffic flows (in points of access and intersections).

**Table 14: Standardised widths of traffic lanes for free flowing motor traffic**

| Driving speed [km/h] | Width of a typical vehicle [m] | Lateral movement area [m] | Width of the carriage lane [m] |
|---|---|---|---|
| **30, 40 or 50** | 2.50 | 0.25 | 2.75 |
| **60 or 70** | 2.50 | 0.50 | 3.00 |
| **80 or 90** | 2.50 | 0.75 | 3.25 |
| **100 or 110** | 2.50 | 1.00 | 3.50 |
| **120 or 130** | 2.50 | 1.25 | 3.75 |

**Figure 14: Dimensions of traffic sections for structures of typical vehicles in very low driving speed (40 km/h)**
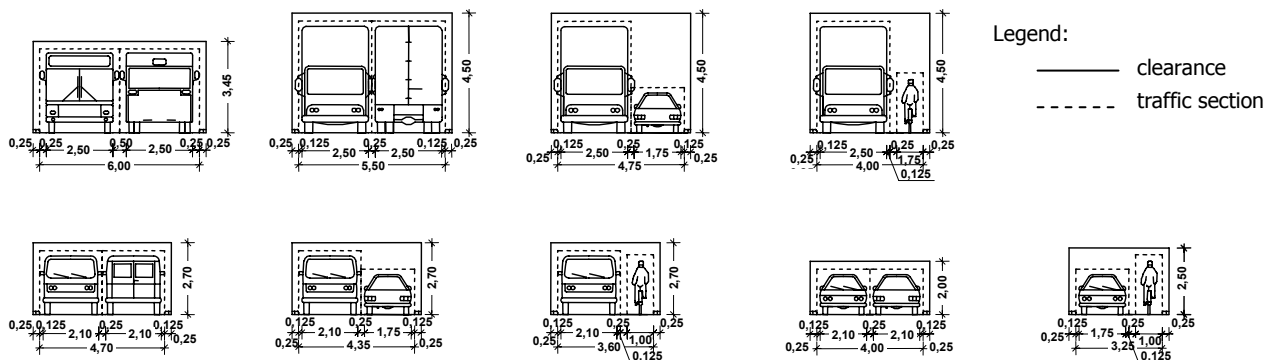


Widths of individual carriage lanes on the carriageway are based on driving speed and traffic volumes of individual traffic participants on the road. The width of a traffic (carriage, overtaking, additional) lane for motor traffic is influenced by the selected typical freight vehicle and driving speed reflected in the width of the lateral movement area (Table 14).

On roads built for lower traffic requirements (low traffic roads) used widths shall depend on typical road users. Combinations are presented in Figure 14.

#### 3.3.1.2 Widening of the Carriageway

Carriageway shall be widened:

- For the purpose of providing normal passability in arcs; and

- Due to changes in width or changes in the number of traffic lanes (intersections, bifurcations).

Dimensions of widening (widths and lengths) shall depend on the type of typical vehicles regularly using the particular road (in curves) and on driving speed (changes in lane widths).

### 3.3.1.2.1 Determining Dimensions of the Widening

Curves require widening of individual traffic lanes of $\Delta b_{pp}$ and thus of the carriageway in order to provide normal passability. Widening shall be determined by using the following formula:

$$\Delta b_{pp} = R_{ZU} - \sqrt{\left(R_{ZU}^2 - L_{OP}^2\right)}$$

The length of inter-axis distance with overhanging part of the vehicle in front ($L_{OP}$) for the most typical vehicles is presented in table 15.

**Table 15: Inter-axis distances with overhanging part of the vehicle**

| Type of vehicle | Inter-axis distance + overhanging part in front ($L_{OP}$) [m] |
|---|---|
| **Personal vehicles** | 4.00 |
| **Lorries** | 8.00 |
| **Trailer tractors** | 10.00 |
| **Line buses** | 8.50 |
| **Bending buses** | 9.00 |

**Figure 15: Widening for individual carriage lane by vehicle type**
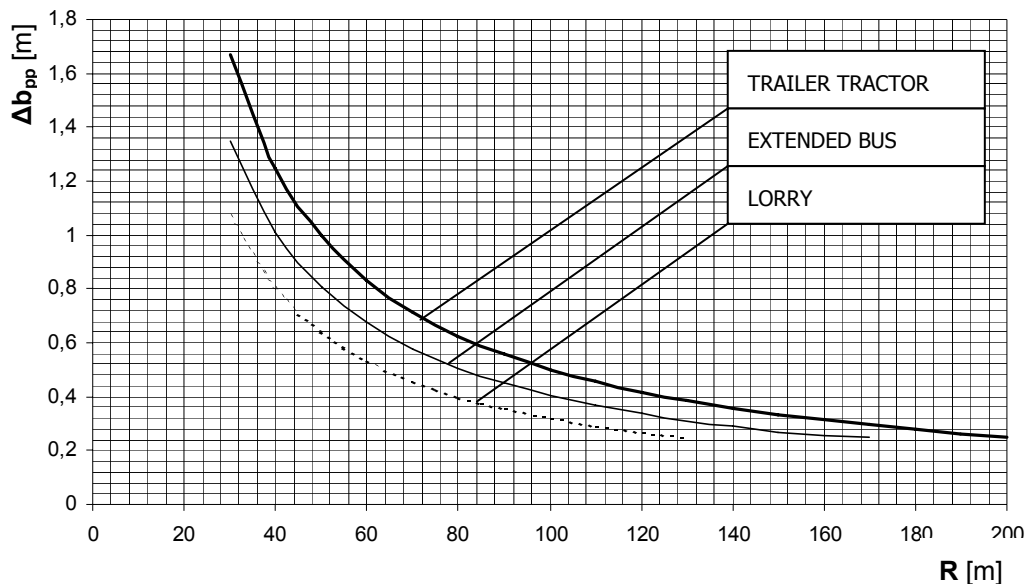


For arcs with R > 30 m the formula above can be simplified:

$$\Delta b_{pp} = \frac{L_{OP}^2}{2 \cdot R}$$

Dimension of widening of $\Delta b_{pp}$ for individual traffic lane may be read from the chart in Figure 15.

The overall widening of the carriageway shall be determined by summary of all traffic lanes on unseparated carriageway.

Widening in arcs with R < 30 m shall be calculated by using the exact formula or

- Selected from special tables of widths of turning planes;
- Graphically tested by turning plane; or
- By using software for determining vehicle traces.

### 3.3.1.2.2  Omitting or Reducing the Widening

Widening of traffic lanes on roads with carriageways separated by direction are virtually impossible due to generally large radii of arcs. In special cases, notably for urban multilane roads, widening should be determined separately just in case. We should thereby take into account the smaller mutual influence of two or more vehicles driving in the same direction, traffic structure and manner of driving as well as any administrative provisions (prohibitions, obligations) separately for each case.

For economic reasons, widening may be omitted on two-lane roads with carriageway width $b_{ev} \geq$ 6.00 m in the following two cases:

- If the number of heavy vehicles is less than 15 vehicles/day;
- If the overall widening does not exceed 0.50 m.

In case the width of the carriageway $b_{ev} > 6.00$ m, widening shall be reduced by the difference in width of the carriageway above 6.00 m. The zone of influence of radii of arc is for such a case 30 m < R ≤ 200 m.

Due to economic reasons widening is not required on two-lane roads with carriageway width 5.00 m < $b_{ev}$ < 6.00 m, if the overall widening does not exceed 0.25 m. The zone of influence of radii of arc is for such a case 30 m < R ≤ 400 m.

Widening of carriageway in curves on a two-lane road outside populated areas with carriageway width $b_{ev} \geq$ 4.75 m is not required if it is only used by personal vehicles.

Generally, widening in curves shall also be required on such roads, if the visibility in curves is not provided by construction technical means or traffic equipment (mirrors).

### 3.3.1.2.3  Implementation of Widening in Curves

#### Placement of Widening

Widening of carriageway shall be implemented along the entire length of the arc. Carriageway may be widened:

- Only on the inner side of the arc (permitted);
- On both sides of the arc (normal); or
- Only on the outer side of the arc (conditionally permitted).

In case the widening is implemented on both sides of the carriageway, the larger of both widening of individual traffic lane shall be made on the inner side, if different typical vehicles were taken into account in calculations. This procedure shall preserve the line of the road's axis. Notwithstanding this provision, the widening on the outer side of the curve shall be limited and shall not exceed size $L_{PR}^2/24$ or $A^4/24R^2$ (for clothoid). In case this size is exceeded, the excess part shall be implemented on the inner side of the curve.

Widening of carriageway only on the outer side is generally not allowed. It shall only be allowed if the project envisages the appropriate driving dynamics and esthetical layout of line of the outer widened edge of the carriageway to the inner widened or non-widened edge of carriageway of the adjacent arc (calculation of axis of the edge of carriageway on roads in the technical group A and edged roads in the technical group B).

Unless the road plan specifies otherwise, the middle separation line shall be drawn in the middle of the widened carriageway.
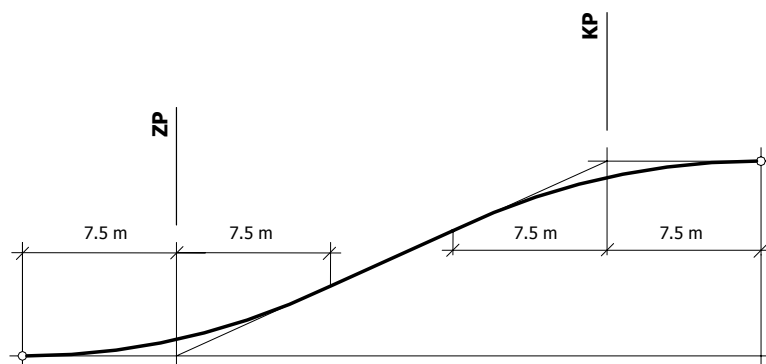
#### Implementation of the Transition in the Area of Transition Curve

The transition from non-widened to the widened carriageway shall be implemented gradually in the length of the transition curve, except in cases of partial or total widening on the outer side of

the curve in which case the transition shall be implemented in accordance with the section Placement of Widening.

The transition shall be linear. On roads in the technical group A, the initial and final parts shall be obligatory implemented by rounding, which by 1 of length exceeds the main points of the transition curves (IP and FP), with tangents 7.50 m long (Figure 16). As regards roads in the technical group B such implementation shall be recommended particularly in cases when the carriageway is edged.

**Figure 16: Widening with rounding**



The transition between two arcs with widened carriageways lying in the same direction shall be implemented in the area of intermediate transition curve. Due to esthetical reasons, either an arc or a clothoid, which shall as much as possible follow the linear method for changing the widening, shall be included between both arcs of edges of widened carriageways.

In case the road axis is implemented without any transitional curves (the possibility in technical groups C and D), the transition shall be implemented as straight line in the area and length of changing of cross fall of the carriageway.

Due to esthetical reasons (lines of kerbs), and notwithstanding any other provisions regarding widening of edged carriageway, implementation by procedure, previously specified for widening only on the outer side, shall be recommended. In such a case, the calculation of axis shall be made for both edges.

As regards widening in arcs with R < 30 m (serpentines) the widening shall be made for each lane separately (on the inner and outer side). In such a case, a continued line for each edge of the widened carriageway to the adjacent curve shall be provided separately.

In case the arc with R < 30 m lies between two straights (allowed only for subordinated urban roads, low traffic roads and in intersections), widening shall be made entirely on the inner side of the curve. The transition shall be made on the length of the transition curve, and should there be none, on length which approximately corresponds to the size of radius of the arc used. The line of transition shall be determined in the manual for tractrix (the line of traces of the rear tyre) or any other technical instructions, if specified for particular special cases (intersections). In old town centres, lines of carriageway edges shall be fully adjusted to spatial conditions (urban roads in technical roads C and D).

**Figure 17: Transition from straight to arc**
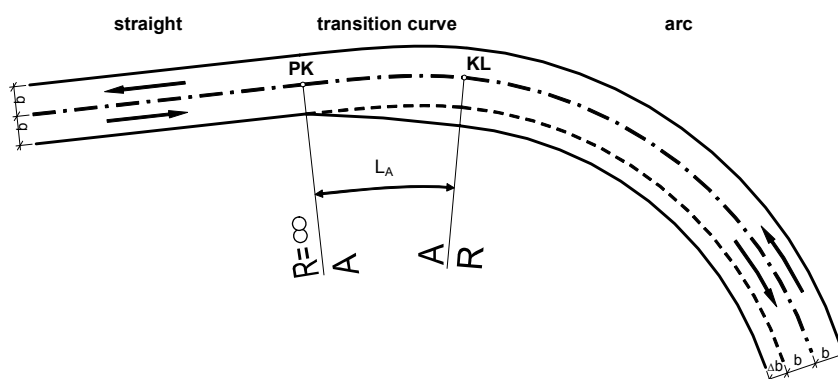


where:

| | | |
|---|---|---|
| $L_A$ | [m] | Length of the transitional curve |
| b | [m] | Width of carriage lane |
| $\Delta b$ | [m] | Widening in curve |
| PK | | Transition from straight to arc (clothoid) |
| KL | | Transition from transition curve to arc |

*Implementation of Transition from Straight to Arc*

In implementation of such widening (Figure 17) the provision on minimum length of widening ($L_{RZ}$), applying for implementation of change in width of the carriageway (wider traffic lane, additional lanes) shall be taken into account. In such a case, the required length of widening shall be:

$$L_{RZ} = 2 \cdot L_{OP} + \tfrac{1}{2} L_{PR}$$

or

$$L_{RZ} = \frac{A^4}{24 \cdot R^2},$$

which shall be implemented on the length of the transition curve. When $L_{RZ} > L_A$ the widening extends to the arc.

In case the length of the arc is small and $L_{RZ}$ exceeds the middle of the arc, the determined widening of carriageway $\Delta b_{ev}$ shall be reduced by using the following formula:

$$\text{reduc. } \Delta b_{ev} = \Delta b_{ev} \cdot \sqrt[3]{\frac{A^2 + 2 \cdot R \cdot L_{OP}}{4 \cdot R \cdot L_{OP}}}$$

and implemented entirely on the inner side of the curve.

*3.3.1.2.4  Widening and Narrowing of the Carriageway in Changes of Lane Width*

Widening or narrowing of the carriageway shall be required in:

- Changing of composition of elements in the cross section;
- Changing of width of individual traffic lanes;
- Adding or subtracting traffic lanes;
- Including exit and entry lanes (intersections); and
- Changing of width of the middle separation lane.

In changed conditions in the cross section, the layout of basic traffic lanes shall be adjusted to such changes and ensured that their layout in the area of widening or narrowing shall not be different from that on the other parts of the road.


*Widening of the Carriageway*

In order to provide an appropriate solution with regard to driving dynamics and aesthetics, the widening in the area of smaller radii of arcs shall be implemented on the inner side of the arc. Only in limited conditions for placement of the road axis, the widening may be implemented on both sides.

The length of the widening area shall be at least:

$$L_{RZ} = V \cdot \sqrt{\frac{\Delta b_i}{3}} \, ,$$

whereby the following shall be taken into account:
- $V = 0.75. \, V_{free}$ for all roads in the technical group A, except in cases of widening in intersections at grade (lanes for left and/or right turning);
- $V = V_{con}$ for all roads in the technical group A for cases of widening in intersections at grade (lanes for left and/or right turning) and for all roads in the technical group B and more complex roads, as regards traffic, in the technical group C ($V_{con} \geq 60$ km/h); and
- For $\Delta b_i$ deviation of the line of the left edge of the individual traffic lane or carriageway in individual direction of driving from the original line, where the larger of both deviations shall be selected in two-lane roads, should they be different.


The normal length of the widening area shall be

$$L_{RZ} = \Delta b_i \cdot \frac{V_{con}}{3{,}6 \cdot V_b}$$

where

| | | |
|---|---|---|
| $L_{RZ}$ | ... | length of widening [m] |
| $\Delta b_i$ | ... | width of deviation of the line [m] |
| $V_{con}$ | ... | conceptual design speed [km/h] |
| $V_{tran}$ | ... | transverse speed (side-moving speed) [km/h] |


In straights and in large radii of arcs, widening may be implemented by forming a transition with two double square parabolas.


In order to ensure esthetical appearance of the area of road widening, it is recommended that the line of lateral movement be brought in line with the basic line of road axis before and after the widened part of the road (implementation of the parallel axis by taking into account symmetry of geometric elements of this axis).


Change of the number of traffic lanes in changed normal cross section (NCS) shall be deemed a classic widening of the carriageway. In such a case:
- The traffic lane from the narrower NCS shall be directly continued in the traffic lane in the same direction in the wider NCS (carriage lane into carriage lane) where any corrections of the line of layout of this direct continuation shall be implemented as specified above.
- Additional lanes shall be added one by one, so that each additional lane shall begin from the basic or previously added lane at least in the transition distance, determined by the

linear widening of the carriageway 1:40 and implementation of rounding of tangents with $R = 3*R_{min}$.

*Passing Bay*

A special case of carriageway widening is the passing bay. It is intended for adequate and safe meeting of two vehicles, namely in the combination freight vehicle – freight vehicle, in case the NCS was selected for the case of meeting of the combination personal vehicle – personal vehicle or in case of a single-lane, two-way carriageway with the width less than 5.00 m. Dimensions of the passing bay are presented in the table below.

**Table 16: Dimensions of the passing bay for meeting of two freight vehicles**

| Width | | Length | | |
|---|---|---|---|---|
| Carriage lane b$^*$ [m] | Passing bay b$_{iz}$ [m] | Entry/exit L$_p$ [m] | Passing bay L$_{iz}$ [m] | Total L$_s$ [m] |
| 3.00 | 2.50 | 10 | 10 | 30 |
| 3.50 | 2.00 | 10 | 7 | 24 |
| 4.00 | 1.50 | 10 | 5 | 20 |
| 4.75 | 0.75 | 10 | 3 | 16 |

Note: * ... single-lane, two-way carriageway

*Narrowing of the Carriageway*

Narrowing of the carriageway due to changing of width of traffic lanes shall be implemented by using the procedure specified for widening (section Widening of the Carriageway), where the transition length shall be such that it enables deceleration of speed from $V_{free}$ on the wider lane to $V_{con}$ on the narrower lane. In case the traffic lane narrows by more than 0.25 m, the difference of the part of narrowing shall be implemented on the part of the wider lane (by using appropriate traffic signals – traffic signs, road markings) and the remaining 0.25 in the area of physical transition, calculated as specified in the section Widening of the Carriageway.

Narrowing of carriageway due to subtraction of traffic lanes shall be implemented in case of:

- Conclusion of an additional lane; and
- Reduction of the number of traffic lanes in the road's cross section.

*Conclusion of an Additional Traffic Lane*

Additional lanes on the carriageway, which are concluding on that carriageway, shall be lanes built for requirements of traffic flows entering the road or for increasing the road's Capacity and Service Volume .

Additional lanes for entering the road (intersections) shall as a rule be located on the right side of the carriageway and shall be concluded on it as specified in the section Multi-Level Points of Access and Knot-Points. The additional lane for increasing the road's Capacity and Service Volume may be on the right or left side of carriage lanes, intended for driving in a particular direction. Conclusion of additional lanes shall be gradual (one by one) regardless on which side of the driving direction they are located. The minimum conclusion transition length for each length is specified by (Figure 18):

- Narrowing of the edge of the lane in the proportion of decreasing 1:40; and
- Implementation of rounding with

    $R = 2.5*R_{min} \geq 1000m$.

**Figure 18: Drawing of conclusion of the left lane in widened carriageway**
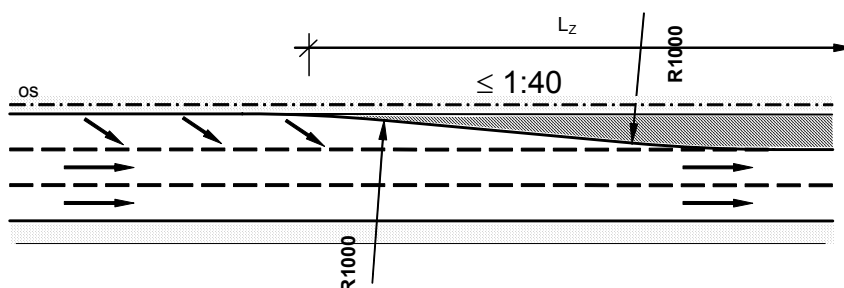


Whereby the concluded lane shall have at the end of transition length width of at least 2.0 m, non-carriage (safety) area shall be marked by a road marking.

Generally, lanes shall be concluded on the left side of individual driving directions and they are thus intended for higher driving speeds. Regardless of the provision regarding the minimum transition length, a warning on speed reduction and conclusion of the lane (traffic equipment) shall be given on the concluded lane at the appropriate distance from the transition length.

The total length of the transition for entering the adjacent traffic lane shall be tested by traffic dimensioning by using the HCM (Highway Capacity Manual) method.

*Reduction of the Number of Traffic Lanes*

Change in the number of traffic lanes in changed normal cross section (NCS) shall be implemented exclusively in the area of the wider NCS as specified in the section Conclusion of an Additional Traffic Lane. In case of a larger number of additional lanes, lanes shall be concluded gradually (Figure 19). Simultaneous conclusion of additional lanes on the right and left side of an individual driving direction shall not be allowed.

Reduction of number of traffic lanes shall be implemented entirely in the area of wider NCS. In the area of transition from the wider to the narrower NCS, only the number of traffic lanes equalling the number envisaged for an individual driving direction in the narrower NCS thereafter may be laid out.

The line of connection of the narrowed part of the wider NCS with the narrower NCS shall be implemented by continuous layout of the road axis from the narrower NCS to the area of the wider NCS. The position of the road axis shall retain its relative position with regard to the continuous layout of the traffic lane in narrower NCS. The line connecting both NCSs shall provide

- Gradual reduction of driving speed (symmetry of geometric elements of connecting axis of the transition part of the road); and

- Entry of the connecting line to the area of the narrower NCS in the area of arc to the left (in the direction of driving) or (exceptionally) straight.

Entry of the connecting line to the area of the narrower NCS in the area of arc to the right (in the direction of driving) shall only be allowed if driving directions are physically separated. In case driving directions are not physically separated, they shall be physically separated in the area of conclusion of the left carriage lane. Physical separation of driving directions through the curve to the right shall be laid out at least to the turning point of the clothoid leading to the left arc.

Continuous layout of the traffic lane shall be due to potential differences in size of geometric elements of the road axis in the narrower NCS, also in the area of the wider NCS redirected to the position as held in the cross section in the narrower NCS.

Physical separation of driving directions in the area of transition from the wider to the narrower NCS shall be implemented by non-giving safety fences. Width of the carriage lane along non-giving safety fences shall be 4.50 m (Figure 19).

**Figure 19: Drawing of transition of four-lane road to two-lane road**



**A**
redirection to the right carriage lane
**B**
redirection of the right carriage lane to the left one (closer to the opposite carriage lane and smaller horizontal radius)
**C**
transition area (up to the turning point protection with a safety fence)

preventing passage to the opposite lane (fence)

conclusion to the left curve
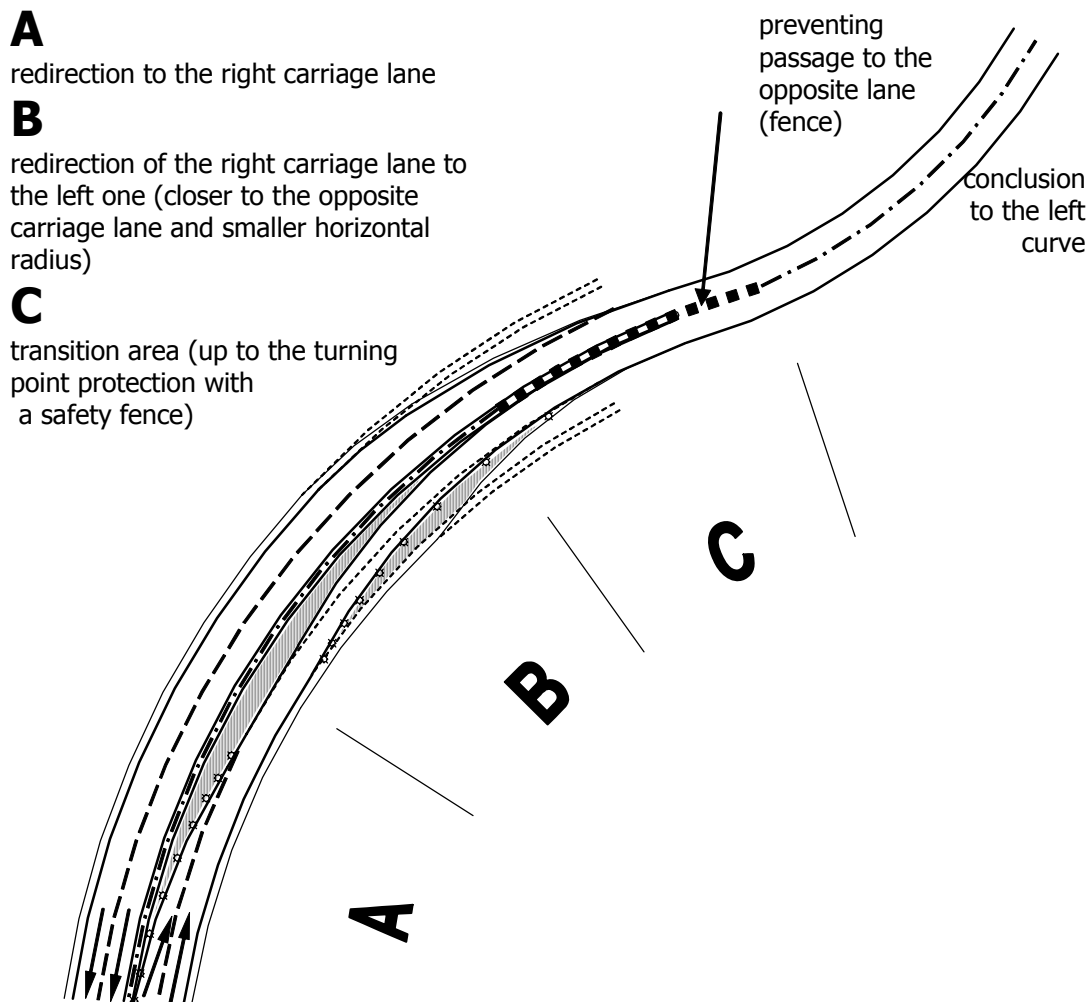
*3.3.1.2.5  Border Lanes Areas or Hard Shoulders*

*Border lanes*

Border lanes on the carriageway are an element of (directional) carriageway improving traffic safety (emergency passability), maintaining stability of roadway construction and enabling implementing road signs (edges of carriageway marking). Edges of carriageway marking shall be made on the inner (driving) side of the border lane. The cross-fall of the border lanes is the same as that of the carriageway.

The width of border lanes depends on speed of vehicles and on width of carriage lanes on the road. Table 17 presents relationship with the width of carriage lanes.

**Table 17: Width of border lanes**

| Width of carriage lane $w_{vp}$ [m] | Width of border lane $w_{rp}$ [m] |
|---|---|
| 3.75 | 0.50 |
| 3.00 – 3.25 | 0.30 |
| ≤ 2.75 | 0.20 |

A border lane shall also be implemented along kerbs on urban roads and roads in populated areas. Drainage of urban roads shall be generally implemented by intakes under kerbs. In such a case the width of border lanes along kerbs in populated areas equals the width of border lanes on roads outside populated areas. In case of urban roads drainage along kerbs with rain gratings, the border lane shall be widened to 0.50 m.

If raised kerbs are used in short sections of roads outside populated areas (bridges, bus stops…), a protective lane shall be implemented in addition to the border lane, the width of the protective lane shall equal that of the border lane.

Bearing capacity of roadway construction of border lanes shall equal that of the carriageway. Implementation may vary: asphalt ↔ cement concrete or vice versa (see also section Kerb and Pointed Channel.

*Hard Shoulders Areas*

Hard shoulders areas are:

- Hard shoulders for emergency stop;
- Lay-by areas.

Hard shoulders areas, when used, replace border lanes and supplement them by increasing the function of traffic safety and capacity and service volume of the road. They are intended for emergency stops of vehicles. Longitudinal edges of carriageway marking are implemented by using the same rules as in border lanes.

Selection of hard shoulders areas of a road is checked with regard to utilisation of road capacity and service volume in accordance with the HCM methodology. Generally, they are placed on roads in the technical group A (hard shoulders for emergency stop). Hard shoulders areas may be implemented along any road, regardless of utilisation of capacity and service volume, if the consequent increase of investment costs is substantiated.

Width of hard shoulders for emergency stop depends on frequency of stopping of the typical vehicle. Generally, widths of hard shoulders for emergency stop equals as follows:

- 2.50 m  for freight vehicles and $V_{pot} \geq 90$ km/h;
- 1.75 m  for personal vehicles and $V_{pot} \geq 90$ km/h; and
- 1.50 m  for personal vehicles and $V_{pot} < 90$ km/h.

Introduction of hard shoulders for emergency stop is not a rule but is assessed on a case-by-case basis with regard to traffic and traffic safety analysis.

Hard shoulders may also be interrupted (lay-by areas). Placement of lay-by areas is determined on the basis of traffic volume and driving speed on the relevant road.

In the area of additional lanes on the road, hard shoulders for emergency stop may be omitted, if road utilisation at the end of planned period does not exceed 70% of its capacity.  Should in such a case the length of hard shoulders for emergency stop exceed 400 m, lay-by areas shall be placed along them.

When placement of additional lanes is at the distance of < 200 m, two consecutive additional lanes shall be joined together (joined lane).

### 3.3.1.2.6  Additional Lanes

Additional lanes shall be included in the carriageway section when the need for introduction of separate lanes for a particular traffic function or traffic type exists. These shall include:

- Crawler lane;
- Lanes in intersection area; Exit and entry lanes and lane for joining (changing lane);
- Lane reserved for public passenger transport (buses, taxis, rail transport/tram);
- Lane for still traffic i.e. longitudinal parking.

The requirement for additional lanes shall be substantiated by testing traffic capacity and service volume. Adding and subtracting of additional traffic lanes shall be technically implemented by taking into account traffic safety and as regards length, by providing appropriate traffic capacity and service volume in areas of separation and joining of traffic flows.

### Crawler Lane

For roads with very large traffic volumes and a large proportion of freight vehicles, a crawler lane shall be implemented for driving in climb or descend and in accordance with the section Additional Lane.

Additional lanes on climbs/descends shall be generally implemented by adding a lane on the right side of the main carriage lane and concluding the far left overtaking lane or carriage lane of the part of carriageway intended for one direction of driving. Close section of the left lane shall not begin until vehicles on the additional lane (crawler lane) achieve driving speed, which is by less than 20 km/h below the travelling speed on the carriage lane of the relevant road.

The width of crawler lanes shall be 3.25 m.

### Additional Carriage Lanes at Intersections

Additional carriage lanes at intersections shall be implemented so that the trail of the vehicle does not extend to the area of the carriage lane to which the additional lane is being added.

Exit and entry lanes are additional lanes built to the right of the outer traffic lane on the road, intended for traffic and driving dynamics adjustment of driving in the area of combining and bifurcating of legs of multi-level points of access or bifurcations and in intersections at grade where such an arrangement is required by traffic conditions (number of vehicles in bifurcation or point of access).

Exit, entry and changing lanes shall be implemented in widths and lengths discussed in detail in the guideline Multi-Level Points of Access and Knot-Points.

The length of these lanes shall be determined by traffic dimensioning (HCM, HCS) and by taking into account driving speed on the main and exit or entry direction. Lanes have in principle the following elements:

- Exit lane: transition lane and lane for speed reduction;
- Entry lane: acceleration lane, lane for entering and transition lane;
- Changing lane: transition lane, lane for changing traffic flows, entering lane and transition lane.

### Lane Reserved for Public Passenger Transport

A lane for public transport (buses, taxis, rail transport/tram) intended for faster passability of public transport vehicles may be added on grouping roads in larger towns and cities along the carriage lane (outer side).

The width of lanes for public transport shall be 3.25 m.

*Lane for Still Traffic i.e. Longitudinal Parking*

Longitudinal lanes for still traffic are intended for stopping and parking of vehicles. Their width depends on the type of parking of vehicles. Dimensions and system of parking (longitudinal, angle or right-angled) shall be determined in the Rules on Road Design. Cross fall of these lanes shall equal that of the carriageway. If the fall is made in the opposite direction, the lane for still traffic shall be widened in order to place facilities for longitudinal drainage (cut drains). Their width shall equal 0.5 m, while depth shall not exceed 10% of width.

It is generally not allowed to place longitudinal lanes for still traffic on roads in technical groups A and B. In exceptional cases such placement shall be substantiated by an assessment of their impact on traffic safety on the road.

Planning of placement of lanes for still traffic shall provide appropriate stopping visibility on the road. In case such visibility is not provided, driving speed on the road shall be reduced.

As regards low traffic roads and public roads in populated areas with elements $V_{con} \leq 40$ km/h, it is allowed to implement lanes for longitudinal parking of vehicles, which shall be 2.50 m wide, of which 0.50 m shall be the protective lane.

### 3.3.1.3 Cross Falls of Carriageway

#### 3.3.1.3.1 Types of Cross Falls of Carriageway

Cross fall of the carriageway (q) shall be generally to one side and inclined to the inner side of the curve in order to provide maximum traffic safety (Figure 20).

Two-sided (roof) cross fall shall be permitted on multilane roads when enabled by horizontal elements of the road defined by the minimum radius of the horizontal arc with the cross fall $q_{min}$ ($R_k \rightarrow$ Table 32). In such a case, all carriage lanes in one direction shall have the same cross fall.

**Figure 20: Types of cross falls**
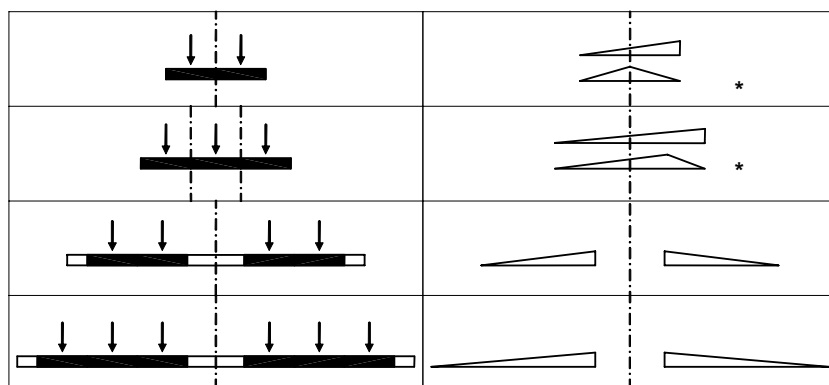


* allowed in road reconstructions

As regards roads in technical groups A and B, negative cross fall should in principle be avoided or not used if cross section of the level exceeds 3%.

As regards two-lane roads of single carriage roads, two-sided (roof) cross fall shall be exceptionally allowed in complex reconstruction of roads with roof cross fall. In such a case, the top of the turn of falls (roof) shall be rounded so that appropriate vertical rounding is achieved for driving from one lane to the other (overtaking). Unless the project specifies otherwise, rounding shall be made in the width of 3.0 m (1.5 m on each side) with bisectrix in the apex point of 0.03 m.

Any additional lanes on the carriageway (additional carriage lanes and stabilised side lanes) shall have the same cross fall as the main carriage lane. The exceptions are exit (deceleration) and entrance (acceleration) lanes, which shall have cross fall in line with their horizontal element. Whereby the difference between falls of the carriageway and the additional lane at the point of separation or connection (at the end of stabilised area) shall not exceed 5% on roads in technical groups A and B and 8% on other roads, respectively.  As regards a surface winding of the additional lane, quality longitudinal drainage shall be taken into account.

### 3.3.1.3.2  Border Values of Cross Falls

In order to provide quality outflow of surface water, the carriageway shall have minimum cross fall ($q_{min}$). Deviation from this minimal value shall be allowed only in the area of changing of cross fall between arcs in the opposite direction (winding) and in the area of intersections at grade.

With regard to the quality and type of material used for surfacing of the carriageway these values shall equal:

- For asphalt carriageways $\qquad$ $q_{min}$ = 2.5%
- For cement concrete carriageways $\quad$ $q_{min}$ = 2.0%
- For macadam carriageways $\qquad$ $q_{min}$ = 4.0%.

In order to prevent sliding in transversal direction in case of reduced coefficient of sliding friction (glazed frost ice, etc.) or slowing of driving, the maximum cross fall $q_{max}$ in arcs shall be determined.

- On roads in group A $\qquad$ 7% (8%)
- On roads in group B $\qquad$ 7% (8%)
- On roads in group C $\qquad$ 5% (7%)
- As regards larger longitudinal fall of level (see Table 8 and section Influence of resulting carriageway slope) the following shall apply:

$$\max q = \sqrt{q_{rez}^2 - s_i^2}$$

Values in brackets may be used on roads in technical groups A and B in order to improve driving dynamics conditions, when no other measures can be used in reconstruction of roads to increase the minimum radius of the arc. As regards new constructions, the use of fall $q_{max}$ = 8% shall not be allowed. On roads in the technical group C, the use of fall $q_{max}$ = 7% shall be allowed when it is conditioned by buildings and when points of access to the road are implemented in a special way or are non-existent.

Deviations (up to $q_{max}$ = 9%) shall only be allowed in special cases (serpentines).

### 3.3.1.3.3  Cross fall in Arcs

As regards arcs, the carriageway shall be for driving dynamics purposes inclined to the middle of the arc. The exception is $R_i > R_k$ (q = - 2.5%) in which case the implementation of cross fall also in the opposite direction shall be allowed. Values of border and other characteristic radii of horizontal arcs are given in the table 32.

The use of roof cross fall in arcs shall generally not be allowed. It shall be exceptionally allowed for radii $R_i > R_k$.

Intermediate values of cross falls for $R_{min} > R_i > R_g$ shall depend on calculative speed (design or project speed, depending on the road group) and on proportion of utilisation of SFC in transversal direction, as determined for each technical group of roads.

Figures from 21 to 23 present values of $V_i - R_i - q_i$ for various $V_{des}$ (for graphic reading). Read values shall be rounded to 0.5% upwards. In computer processing (accurate calculation) logarithmic interdependence $R_i \Leftrightarrow q_i$ shall be taken into account.

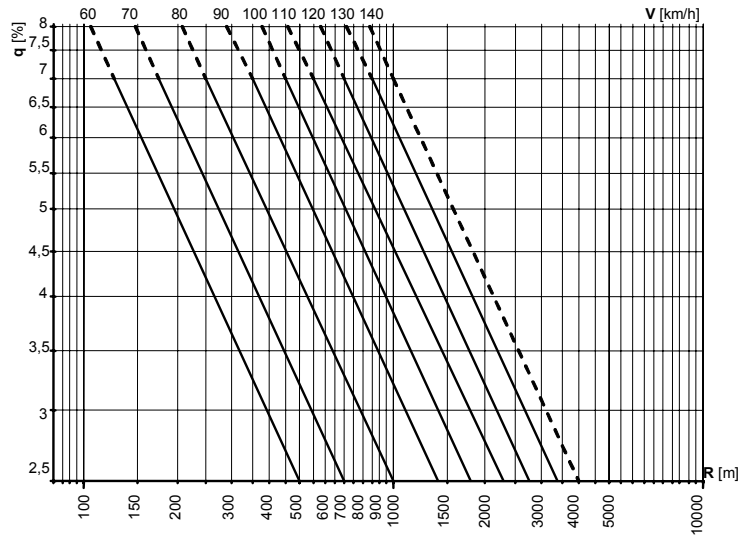## Figure 21: Interdependence of $V_i$ - $R_i$ -$q_i$ for roads in the technical group A



## Figure 22: Interdependence of $V_i$ - $R_i$ -$q_i$ for roads in the technical group B
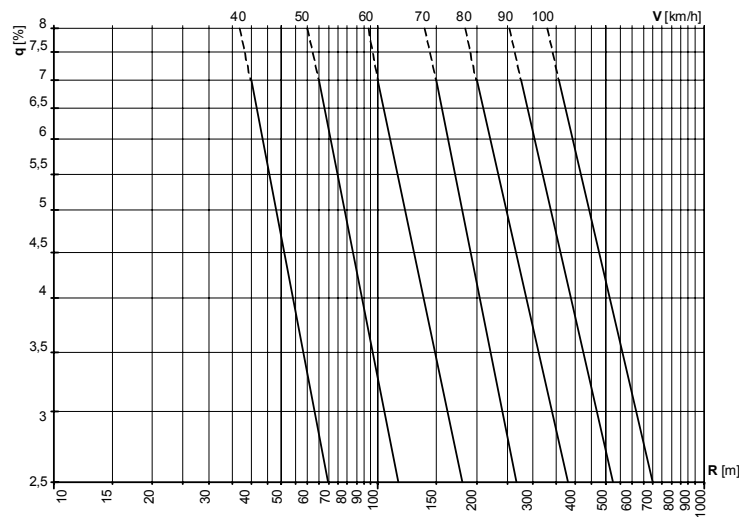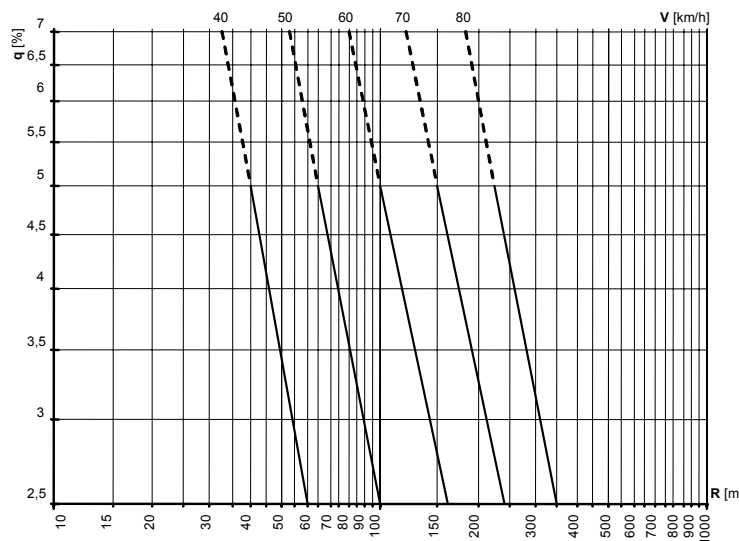


## Figure 23: Interdependence of $V_i$ - $R_i$ -$q_i$ for roads in the technical group C

### 3.3.1.3.4  Cross Fall Changing

**General Rules**

Cross fall changing shall be in principle implemented in the entire length of the transition curve (Figure 24). Whereby we distinguish the following:

- Cross fall changing between two cross falls lying in the same direction; and
- Cross fall changing between two cross falls lying in the opposite direction.

Changing of cross fall shall be linear, and transition parts between adjacent different longitudinal falls shall be implemented by vertical rounding with double square parabola. Cross fall changing between cross falls lying in the opposite direction in the area delimited by values of the cross falls $\pm q_{min}$ is known as the winding of the carriageway.

Unless, due to expertly substantiated reasons, (e.g. in non-proportional sizes of adjacent arcs connected by the transition curve, where the larger of the two is $R_i > R_g$) the project envisaged differently, the carriageway cross fall $q = 0\%$ shall be located on the inflection point of clothoid or close upon it.

The value $\Delta s$ with regard to the level of relative longitudinal fall of the carriageway edge (hereinafter: RLF), which appears in the carriageway's cross fall changing section, shall be:

- between cross falls lying in the same direction within $0\% \leq \Delta s \leq \Delta s_{max}$; and
- between cross falls lying in the opposite direction within $\Delta s_{min} \leq \Delta s \leq \Delta s_{max}$.

The value of RLF $\Delta s_{min}$ (providing for longitudinal drainage) and $\Delta s_{max}$ (torsion of the vehicle) are specified in detail below. The use of RLF $\Delta s_{min}$ is recommended for aesthetical reasons.

In case the projected RLF exceeds the limit $\Delta s_{max}$ the length of the transition curve shall be increased. As regards roads in the technical group C, the area of changing of cross fall may be exceptionally increased to the entry arc. Equally applies to roads in the technical group B in populated areas, when the changing of cross fall is implemented between consecutive arcs lying in the same direction.

When the projected RLF is less than $\Delta s_{min}$ winding shall be made in the narrower area of winding (between $\pm q_{min}$) with RLF = $\Delta s_{min}$ and the other part by using rules for changing cross fall between the carriageway's cross falls lying in the same direction.

In case the carriageway has hard shoulders for emergency stop, the width of the border lane replaced by hard shoulders for emergency stop shall be used for defining the carriageway's edge instead of hard shoulders for emergency stop.

The standard method for changing cross fall of the carriageway is presented in Figure 25. The carriageway cross fall changing shall be implemented so that water does not stay on any part of the carriageway (hydroplaning) and so that the sign of longitudinal fall (the "saw" principle) of any longitudinal line in the carriageway's cross section does not change.

The longitudinal fall of edges of the carriageway shall be sufficient to provide for implementation of appropriate facilities for longitudinal drainage of the carriageway.

Cross fall changing from two-sided (roof) to one-sided cross fall shall be implemented so that first levelling of cross fall is performed followed by adjustment to the required final cross fall.

Changing of fall in winding shall be implemented around longitudinal axis, which is for two-lane roads generally identical to the road axis. As regards roads with separated carriageways, the change of cross fall shall be implemented for each carriageway separately, where the left edge of each carriageway shall be used as axis of winding.

When and if winding cannot be performed by using the aforementioned procedure due to too small longitudinal grade of the road's nivelete or any other technical, economic or spatial reason, any longitudinal line in the road's cross section, including an imaginary one, being outside the carriageway, may be used for winding axis. In such a case the co-called jump of level shall be implemented, which shall be begun and concluded in the area of layout with constant cross fall.

# Figure 24: Methods for implementation of cross fall changing (winding) for various consecutive elements
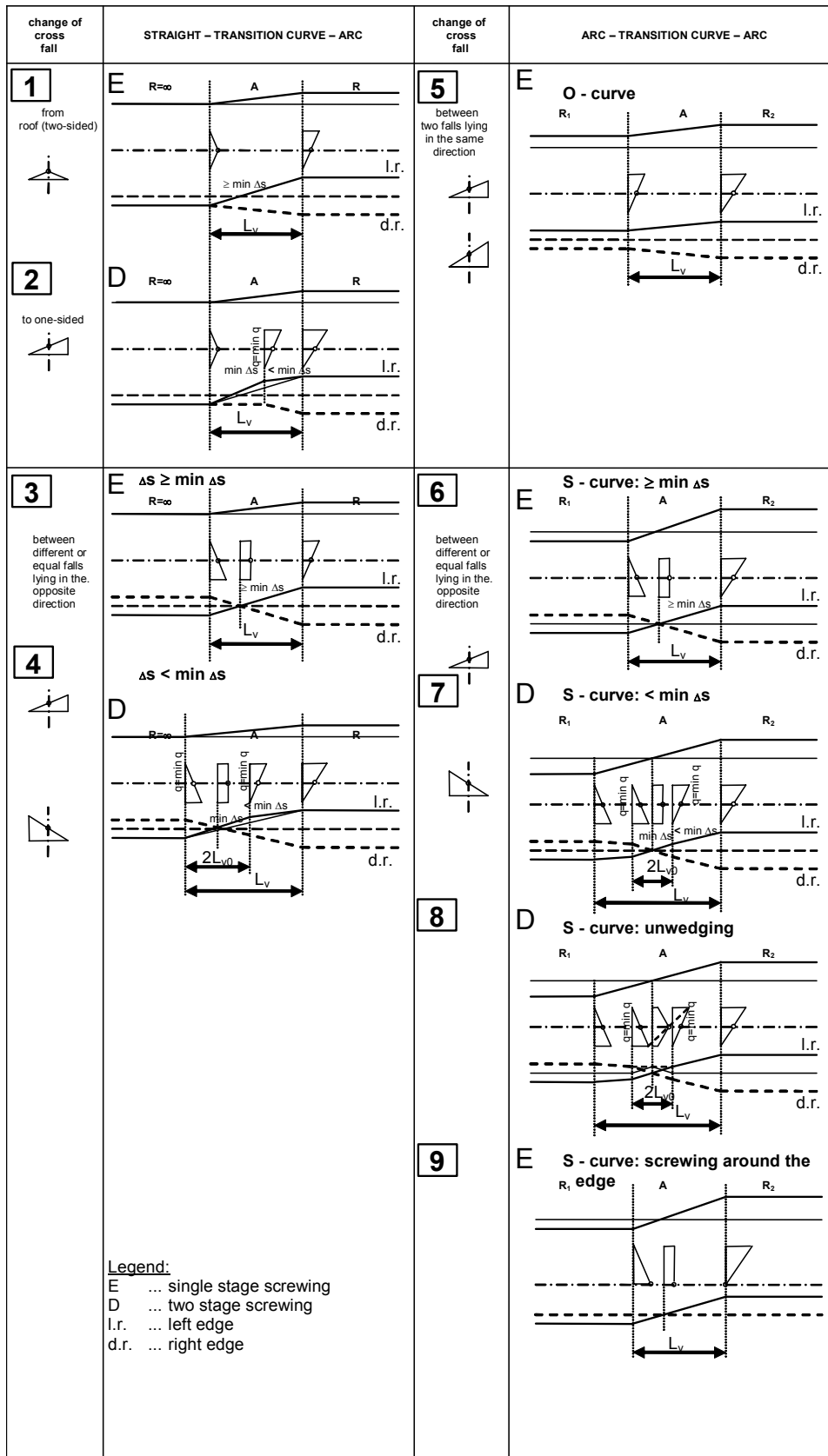


## Figure 25: Outline of implementation of wedge-like cross-fall changing
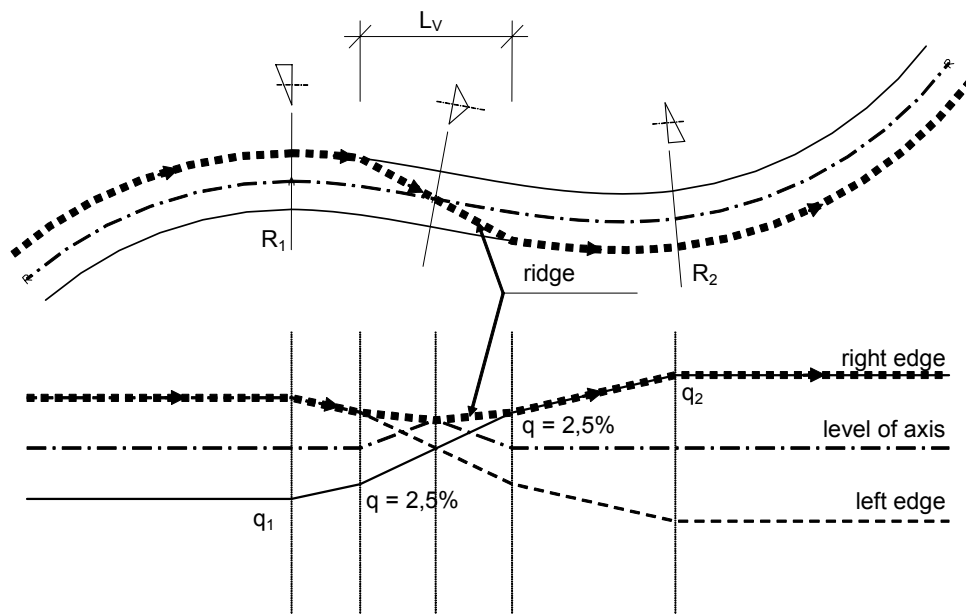
In long geometric elements and mild longitudinal falls of level, winding is implemented in accordance with special technical instructions.

The general principle for selection of the winding method in case of very modest longitudinal falls of level ($s_i$ < min $s_i$) is that it should be implemented so that falls of all longitudinal lines in cross section of the road will always and only increase (either as ascension or decline). The fall of none of these lines, lying on the carriageway, shall be less than $s_{min}$.

As regards roads where the use of transition curve in the form of clothoid is not obligatory (sufficient $R_I$, technical groups C and D), half of length of change of the cross fall shall be implemented on one and the other half on the other of both adjacent geometric elements.

With the exception of roads in the technical group A, change of fall between cross falls lying in the opposite direction may be implemented by using the system of wedge-like cross-fall changing as presented in Figure 26.

### Limit Values of Relative Longitudinal Fall

#### Maximum Relative Longitudinal Fall of Edge of the Carriageway

Maximum relative longitudinal fall RLF is based on conditions of torsion speed of the vehicle and is specified in the section Constructive condition (C-condition). Values, specified in the table 34, are specified for each traffic lane separately. When several lanes are located on the same axis of winding, values from the table shall be multiplied by the number of traffic lanes.

In case the calculated maximum RLF is smaller than the minimum RLF, the latter shall be taken into account as the maximum.

#### Minimum Relative Longitudinal Fall of Edge of the Carriageway

Minimum RLF stems from providing of conditions for drainage of the carriageway's surface in the narrower area of winding. It is determined by the following formula:

$$\Delta s_{min} = k_v \cdot b_v$$

where:

| | | |
|---|---|---|
| $\Delta s_{min}$ | [%] | Relative fall of the more distant edge of the carriageway with regard to level |
| $k_v$ | [%m$^{-1}$] | Coefficient of winding intensity |
| $b_v$ | [m] | Distance of the more distant edge of the carriageway from axis of winding |

Standardised value of "$k_v$" for two lane carriageways is 0.10 %m$^{-1}$.

On roads with large dimensions of geometric elements and width of the carriageway (in principle these are roads with separated carriageways by direction) the use of this value causes "flapping" of the carriageway (very poor visual appearance of the outer edge of the carriageway). Therefore a lower value "k" may be used for such roads (recommended: normally 0.06, in very mild level even 0.03 %m$^{-1}$). In such a case, the area potentially dangerous for aquaplaning, shall be extended proportionally with the reduction in value of "k". Special design measures shall be provided in this area (displacement of axis of winding, drainage asphalt and similar).

## Implementation of Winding by very small Grades of Nivelete

The minimum longitudinal gradient of nivelete is specified in the section Area of carriageway cross fall winding. Deviations from therein specified conditions appear in following cases:

- when sufficient longitudinal grade of nivelete cannot be provided because of terrain configuration; and
- in the area of vertical curvature on the part delimited by fictitious tangents with longitudinal fall $s<s_{min}$ joined to the rounding arc.

In both cases the sign of one of both edges of the carriageway changes (the "saw" principle) in the narrower area of winding, which is not permitted. At the same time, a field of staying water in the form of an almost perfect circle appears on the carriageway. On asphalt surfaces, the radius of this circle equals 3 m and surface 28 m$^2$. The proportion of the circle being on the carriageway depends on the value of longitudinal fall of level. In such conditions, winding shall be implemented by using a special expert procedure or the grade of nivelete shall be increased.

When, due to substantive reasons, the narrower area of winding cannot be displaced to the area having sufficient longitudinal fall of level, the axis of winding in the cross section of the road shall be moved. Jump of level shall be implemented as described above.

Displacement shall be implemented on that side in the road's section having the edge of the carriageway for which the longitudinal fall is reduced in winding in comparison with the fall of level. Displacement of axis in cross section of the road by 1 (one) meter shall increase longitudinal fall of each longitudinal line in section by 0.1%.

When longitudinal falls of both edges of the carriageway are smaller than the required longitudinal fall of facilities for longitudinal drainage along the carriageway, the axis of winding shall be placed outside the carriageway (virtual axis).

Altitude difference in level (double jump of level with the same sign!) between adjacent arcs where winding is carried out, shall be equalised outside the narrower area of winding.

For the purpose of providing maximum uniformity of altitude layout of both directional carriageways on roads with physically separated directional carriageways (preserving the shape of the separation lane), it is recommended that equalising of altitude difference appearing due to displacement of axis of winding be implemented by half on each of the directional carriageways.

## Wedge-like cross-fall changing

In case of forced horizontal layout of level a cross fall change shall be exceptionally allowed using wedge-like procedure. This procedure may be used on roads in the technical group C and other roads not dimensioned with regard to driving dynamics and, by special substantiation, also on roads in the technical group B, where driving speed does not exceed 80 km/h. In principle, wedge-like cross-fall changing can also be used on roads, where taking into account $V_{free}$ is not prescribed. Wedge-like cross-fall changing shall be implemented in the area delimited by cross falls $\pm q_{min}$. Layout und vertical run of wedge-like cross-fall changing are presented in Figure 25. Wedged two-sided fall has the shape of roof with changing length of both sides with the cross fall $q_{min}$. The length of this area $L_v$ depends on speed and width of the carriageway and is defined by the following formula:

$$L_v = 0,1 \cdot B \cdot V_{con} \quad , \qquad \text{where:}$$

| | | |
|---|---|---|
| $L_v$ | [m] | Length of the area |
| B | [m] | Width of the carriageway |
| $V_{con}$ | [km/h] | Conceptual design speed |

**Figure 26: Ridge (a) and mitigation of the ridge (b)**



|                    (a)                    |                    (b)                    |
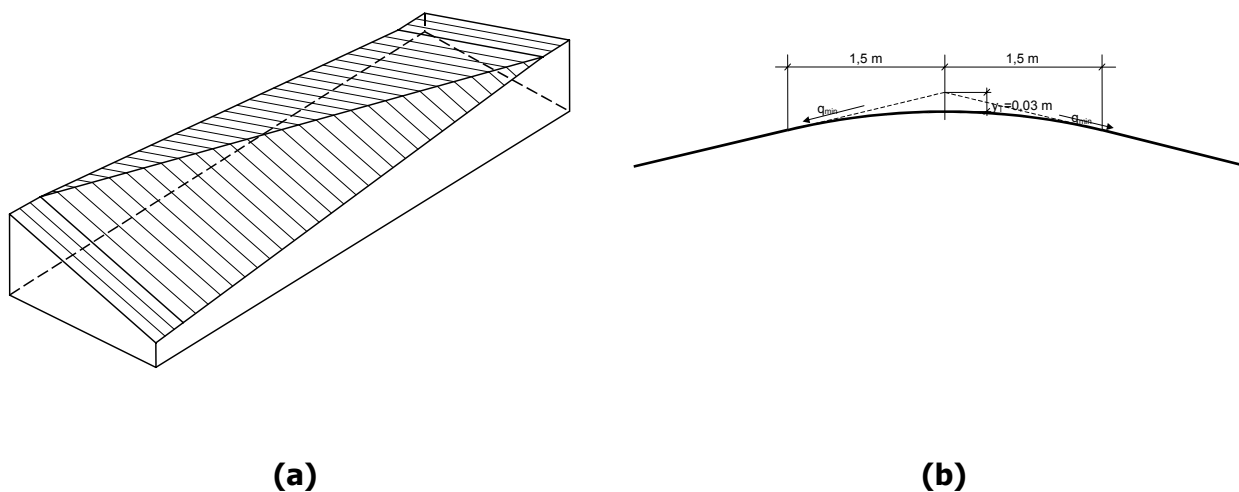
In wedge-like cross-fall changing section, a ridge appears in the angled direction (Figure 26a). The ridge should be mitigated by a vertical rounding in transversal direction in the width of 1.5 m on each side and with bisectrix (altitude difference between the top of the roof and the rounding) $y_T$ = 0.03 m. Mitigation of the ridge is presented in Figure 26b.

### Vertical Rounding of Elevation of the Carriageway

In changing of cross fall of the carriageway, both edges of the carriageway (or one of them – in case of winding around one of the edges of the carriageway) have, with regard to the road level, different vertical layout, defined by the inserted tangent.

Rounding of the additional tangent (at the beginning and the end of the inserted tangent) shall be carried out by using the procedure, which also applies to rounding in vertical alignment.

In case rounding of the carriageway edge coincides the area of vertical curve, then for esthetical reasons rounding of the inserted tangent shall be implemented with radius being at least 2x larger than the radius of rounding of level.

In case rounding is carried out in two stages, the number of inserted tangents may increase. Because of minimal differences in grades between inserted tangents, it is no need to place vertical rounding between them.

## 3.3.2 Border lanes / areas

### 3.3.2.1 Traffic Lanes for Non-Motorised Participants (Cyclists, Pedestrians, etc.)

They are as a rule physically, by height or a separation lane separated from traffic lanes for motor vehicles. The required distance depends on driving speed of motor vehicles (protective width). They are discussed in detail in the section Road surfaces for cyclists, pedestrians and handicapped persons.

### 3.3.2.2 Non-Traffic Lanes (Separation Lanes)

Non-traffic lanes on the carriageway are separation lanes between directional carriageways or between the carriageway and other traffic lanes and lanes for still traffic. They are also known as division lanes. External appearance and stabilisation of separation lanes visually differ from lanes in the traffic area. Depending on the implementation method, they may be paved or implemented by placement of appropriate road markings on them or they could be implemented as green areas. Facilities for longitudinal drainage of the carriageway may be built on and in separation lanes.

Minimum width of separation lanes shall equal the protective width (the distance between traffic and clearance section of the road) and depend on driving speed.

The width of separation lanes shall be in principle equal along the road except in areas of intersections or other point arrangements and in case of widening and/or narrowing for additional lanes. In case of complex level, spatial or economic conditions, a separation lane may be implemented in variable width, whereby each of both edges of the lane shall be parallel to "its" axis of the directional carriageway.

On roads with driving speed ≥ 70 km/h, the separation lane shall be physically separated from the carriageway either by a safety fence or by elevated kerb or a combination of the two.

In case the green area is edged, then for maintenance purposes its minimal width shall be 1.20 m, including kerbs on both sides. Narrower areas shall be implemented by paving (various paving slabs), and the project should include assessment of traffic safety with regard to narrow separation lane (driving speed).

Planting of trees may be envisaged in a separation lane implemented as green area. In such a case, the distance of trees from the edge of carriageway shall be determined so that trees are outside the road's clearance. The lane's width shall also depend on the selection of type of trees (different canopies and various roots).

On roads with speed ≥ 70 km/h, it is not recommended to plant a tree promenade due to safety reasons (sliding, crashes). In such a case, the level of traffic safety shall be assessed (placement of safety fences and prompt cleaning of fallen leaves or time limited speed limit).

The following separation lanes are distinguished with regard to position in the carriageway's cross section: medium separation lane and side separation lane.

### 3.3.2.2.1 Medium Separation Lane

As regards multilane roads, a medium separation lane is envisaged, enabling separated management of traffic flows, drainage of the carriageway and placement of traffic signs and public lighting.

The following minimum widths of separation lanes are envisaged on roads:

- On motorways:                                  3.20 – 4.00 m (grassing envisaged);
- On other roads outside populated areas:        1.25 – 2.50 (paving or asphalt envisaged);
- On multilane roads in populated areas:         1.60 – 4.50 m;
- On single carriageway multilane roads (V≤70 km/h): 0.50 m (stabilised as the carriageway).

### 3.3.2.2.2 Side Separation Lanes

Side separation lanes shall be envisaged foremost in towns and cities and populated areas, in case such lanes are used for distancing cyclists or pedestrians from the carriageway, arrangement of planting (bushes, tree promenades) along the road or for lanes enabling installation of longitudinal utility facilities along the carriageway.

Minimum width of a separation lane shall be 1.20 m. Width of a separation lane with planting shall be at least 2.0 m.

Separation lanes may be at the level of carriageway or raised from it by elevated kerbs, namely:

- $h_{min}$ = 7 cm    if the safety fence distance from the kerb ≥ 50 cm;
- $h_{min}$ = 10 cm   on roads outside urban areas, if the kerb is built in up to 10 cm before the fence; or
- $h$  = 12-13 cm       on roads in urban areas (combination with fence is prohibited).

## 3.3.2.3 Longitudinal Areas for Protection of the Carriageway and Installation of Traffic Equipment

### 3.3.2.3.1 Verge

Verges are longitudinal strips for protection of the carriageway and installation of traffic equipment. Stabilisation and external appearance of verges visually differ from those on traffic

areas (sand, grass, paved, coloured). In case it is implemented as the carriageway, it must be separated by a continuous white edge of carriageway marking.

Verges are intended for:

- ensuring better traffic safety (emergency use of additional width);
- placement of facilities for line management and protection of traffic (delineators and safety fences);
- placement of facilities for longitudinal drainage of the carriageway (pointed channels, shallow circular ditches, elevated kerbs with protective area); and
- for protection of pavements (see section Kerb and Pointed Channel).

The width of verges depend on the type (traffic function) of the road, driving speed and facilities (traffic equipment, drainage), installed thereon. Top soil part of the embanked or cut slope, extending into verge, shall not be included in the verge width.

Minimum width of verges shall be 1.00 m. Widths of verges are specified in Table 18, depending on the design speed.

**Table 18: Widths of verges**

| $V_{con}$ [km/h] | $\geq 100$ | 90 - 70 | 60 - 40 |
|---|---|---|---|
| $W_b$      [m] | 1.50 | 1.30 | 1.00 |

The minimum width of the verge along hard shoulder for emergency stop shall be 1.00 m.

Exceptionally, on roads in technical groups C and D, widths of verges may equal 0.50 m (roads without delineators) and 0.75 m (with delineators). Such exception may also be used on roads in the technical group B (outside populated areas), if the traffic volume on such road is below 1000 vehicles per day.

The verge width along cyclist ways or pavements shall be 0.50 m, if the edge of the cyclist way or the pavement is specially stabilised (granite cubes, concrete kerbs…) the respective width may be 0.25 m.

The area of the verge may be implemented as sand (crushed stone or gravel), top soil or may be paved or bound (concrete or processed stone paving slabs, asphalt, cement concrete). The external appearance of the stabilised verge shall visually differ from the carriageway (material, colour).

In case the verge surface is stabilised with the same structure as the carriageway and the possibility exists for occasional use for meeting of vehicles, a berm at least 0.5 m wide shall be implemented on the outer side of the verge.

The verge along hard shoulder for emergency stop may be implemented as a berm (rolled in and top soiled).

The connecting edge between the verge and the carriageway shall be implemented at the same level or up to 2 cm lower and the verge shall be appropriately stabilised against draught of tyres. In case the verge is not stabilised (usually a temporary arrangement), the roadway shall be equipped with appropriate and visible traffic signs.

Cross fall of the verge area shall be implemented towards the outer edge of the verge (away from the carriageway). Minimum size of the verge's cross fall shall depend on the material used for surfacing (sand verge 4%, grass verge 6%).

The size of verge's cross fall:

- on the higher (outer) side of the carriageway – always the minimum size

- on the lower (inner) side of the carriageway – equal to carriageway cross-fall but not lower as the minimum size (usually between 4 and 7%)

When the verge is used for placement of facilities for longitudinal drainage, a back side berm at least 0.5 m wide shall be implemented on the outer side of these facilities.

When the verge is used for placement of pavement, provisions regarding placement of kerbs and on safety widths (the distance between the traffic profile and profile clearance) and their overlapping shall be taken into account.

### 3.3.2.4 Longitudinal Areas for Protection and Providing Functionality to the Roadway

#### 3.3.2.4.1 Berm

Berms shall be areas for providing functionality of the roadway, built on the outer road side of drainage facilities and/or traffic areas for non-motorised traffic (cyclists, pedestrians. They are used for providing stabilisation protection of drainage facilities, the area for placement of traffic equipment and road visibility. They also serve as service areas for removal of snow. When drainage of the road area is due to spatial – protective reasons implemented separately (carriageway and road surroundings separately), the berm beyond the kerb may be used for implementation of longitudinal facilities for drainage of the road surroundings (curved channel with intake shafts).

The berm's width beyond drainage facilities and beyond stabilised verge shall be specified in the project whereby its width shall not be less than 0.50 m. The minimum berm width beyond cyclist and pedestrian areas shall be 0.25 m.

Berm area shall be generally implemented with top soil and grass, however other methods of stabilisation may also be used. Implementation of berms only with filling of bounding soil materials shall not be permitted.

In case the berm is implemented with grass, its inclination shall equal 6%.

The following shall also be taken into account in determining of the berm's width:

- Providing protection of roadways and facilities along them;
- Providing visibility field in curves;
- The possibility for storing removed snow;
- The possibility for placement of traffic equipment;
- The possibility for installation of various infrastructure;
- Driving on the berm.

#### 3.3.2.4.2 Providing Protection of Roadways and Facilities Along Them

Minimum width of the berm for compliance with this criterion shall be equal to the thickness of the structure it is protecting. In case the berm is in cut section of the road, it may be narrower.

As regards protection, possible erosion of material from the slope and implementation of top soil layer, when the slope and the berm are top soiled, shall be taken into account.

#### 3.3.2.4.3 Providing Visibility Field (Clear zone)

The width of berm shall provide sufficient visibility on stopping distance, calculated on the basis of defined driving speed. Visibility distance shall be determined by taking into account the following conditions:

- The driver in the vehicle is one half of width of the carriage lane away from the inner edge of the carriage lane with eyes in the height of 1.0 m;
- The driver must be able to see a hindrance being on half of the width of the carriage lane from the inner edge of the carriageway;

- Standardised height of a hindrance shall depend on the road type and driving speed (on high-speed roads and on other roads, this height equals up to 0.45 m and 0.05 m, respectively);

- Vertical layout of the road shall also be taken into account in determining of the visibility field;

- The height of the hindrance in vision field on the height of visibility distance shall not in any case exceed 40% of the difference between height of eyes and the hindrance;

- Placement of traffic equipment on the berm shall be selective (e.g. traffic sign – yes, signpost – no);

- Planting the berm with bushes or trees in curves shall not be allowed;

- In building of roads in stages, the visibility field shall be provided for dimensions after the final stage.

### 3.3.2.4.4  Deposit of Snow

With regard to statistical data on snowfalls and snow quantity, the road project shall envisage berm width, providing sufficient surface and volume for removing snow from the carriageway.

### 3.3.2.4.5  Placement of Traffic Equipment

The width of berm shall provide the space for placement of traffic equipment. Minimum width of berm shall suffice for placement of delineators.

Conditions for providing visibility (the visibility field) shall be taken into account in placement of traffic equipment.

### 3.3.2.4.6  Installation of Various Infrastructure

All types of utility and telecommunication lines and sewage can be installed in the berm. In case several lines and sewage are installed, their selection depends on mutual impact of particular lines. The berm width shall provide for appropriate technical distance between lines, the possibility for their installation, maintenance and reconstruction (replacement) as well as installation and maintenance of access points for these lines (shafts).

### 3.3.2.4.7  Driving on the Berm

Appropriately stabilised berm shall also be usable for occasional passage. In case the driving speed on the carriageway > 50 km/h, appropriate moveable longitudinal physical protection (fence) shall be implemented on the edge of the berm facing the carriageway. Minimum width of the berm for driving (traffic section) shall not be less than 0.70 m.

## 3.3.2.5  Facilities for Longitudinal Drainage of the Road

### 3.3.2.5.1  Kerb and Pointed Channel

Kerbs (elevated, lowered, angled) are elements for separation of longitudinal areas on the roadway by height. The kerb element consists of the kerb and the width of the protective layer along the kerb (Table 19).

Standard dimension of kerbs providing resistance against rolling over in impact shall be 15x25 cm (on motorways, 20x24 cm with chamfer of 7 cm) whereby the part in the height of 0.12 to 0.13 m shall be elevated above the carriageway. As regards the bridging structures, the standard height of kerbs above the carriageway shall be between 0.18 and 0.20 m.

Elevated kerbs shall also be used as a facility for longitudinal drainage.

In case the elevated kerb is installed in combination with ≥ 0.10 m distanced safety fence, its height above the carriageway shall not exceed 0.07 m and the area behind it shall be, at least to the safety fence, stabilised and inclined towards the carriageway.

Kerbs in entries to individual land plots shall be installed as lowered kerbs. The length of lowered kerbs shall depend on the width of drive entrance, however it shall not be less than 3 m. In case entries are consecutively in the distance < 5 m, kerbs in the intermediate distance shall also be implemented as lowered kerbs. For the purpose of providing longitudinal drainage of water from the carriageway, kerbs shall be lowered to the height of +2 cm above the carriageway edge. The height for drainage shall not be required if the carriageway's cross fall is to the other side.

Connection of the upper edge of elevated and lowered kerbs shall be implemented with angled kerbs as specified in Table 19.

Connection between elevated and raised kerbs by using classic elements for implementation of entries via the pavement (border kerbs with horizontal rounding of the upper edge) shall be permitted only in built areas on roads with driving speed ≤ 50 km/h.

Standard dimensions of kerbs for implementation of traffic lanes for cyclists and pedestrians (optical separation of areas and separation of the area from the back side berm) shall equal 6(7)x20 cm. As regards placement for the purpose of optical separation of traffic lanes, the kerb shall be implemented entirely as lowered kerb to the height of lanes, while in separation of the berm from traffic lanes, as 0.10 m elevated kerb, beyond which a berm of minimal width equalling 0.25 m is implemented. Granite cubes with dimensions of 6x6x6 cm or 8x8x8 cm may be used instead of classic kerbs for separation of areas.

Kerbs shall be – except for bridging structures, where they are included in the structure of facilities – built on concrete foundations at least 10 cm thick and coated with concrete on both sides (10 cm in the back and 5 cm in front). The height of concrete coating shall conclude 5 cm under the edge of the kerb or under the stabilised adjacent area. Cement concrete MB 15 shall be used for foundations and concrete coating. The outer upper edge of the elevated kerb shall be cut short.

A combination of the kerb and angled implementation of the part of stabilised verge is the pointed channel intended for longitudinal drainage of surface water from the carriageway and cuts. Standard dimensions of pointed channels are presented in Figure 27. The width of 0.50 and 0.75 m shall be used in two-lane roads and carriageways with more than two traffic lanes, respectively.

### Table 19: Characteristics of implementation of elevated kerbs

| Road type | Maximum driving speed | Inclination of chamfer of angled kerb | Width of protective layer along the kerb |
|---|---|---|---|
| Outside populated areas | ≥ 80 km/h | 4% | 0.50 m |
| Main roads in populated areas and roads outside populated areas | ≥ 60 km/h | 6,5% | 0.20 m |
| Other roads | ≤ 50 km/h | 12% | 0.00 m |

**Figure 27: Kerb and pointed channel (width and cross fall)**
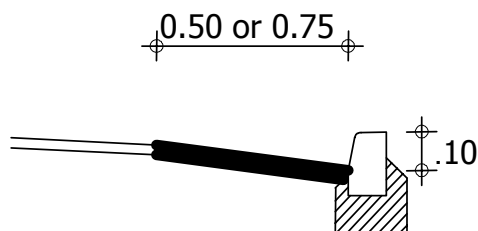


### 3.3.2.5.2 Curved Channel

A special form of channel for drainage of water from the carriageway and cuts shall be sidewalk curved channel placed on the edge an in the level of the carriageway. It fits much better in the cross section and provides better traffic safety against any driving of vehicles off the road. On roads in technical groups C and D it shall be in case of low traffic volumes and implementation of NCS with narrowed dimensions of the carriageway also envisaged as the area for avoiding of vehicles. In such a case, its stabilisation shall equal that of the carriageway.

Curved channel shall be implemented by:

- Asphalt stabilisation (width of 0.50 to 0.80 cm);
- Paved (width of 0.50 to 0.80 cm);
- Concrete cement stabilisation (width 0.50 cm); and
- Grass stabilisation (width from 1.00 to 1.50 and exceptionally up to 2.00 m).

Form and position and certain dimensions of the curved channel are presented in Figure 28.

**Figure 28: Curved Channel**
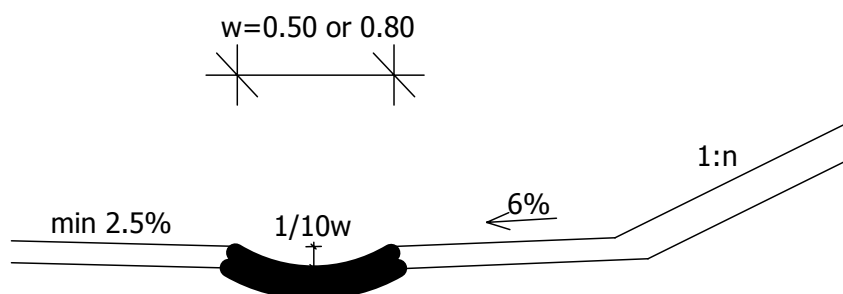


## 3.3.3 Design of slopes of embankments and cuts along the road

Falls of slopes of cuts and embankments along the road foremost depend on geomechanical properties of hills in cuts and the respective properties of the filling material.

The accounting for geomechanical parameters is followed by design of falls of cuts and embankments from the point of view of landscaping of relief along the carriageway to provide the best possible fitting in of the road to the relief along the road whereby the characteristic of the local relief and microrelief embankments shall be taken into account to the greatest possible extent.

Specifically:

- Reducing permitted geomechanical falls (cuts and embankments);
- Rounding of connections of cuts and embankments with the natural terrain;
- Use of partition berms as the design element and solution for drainage of slopes.

**Figure 29: Example of cross section in an embankment**
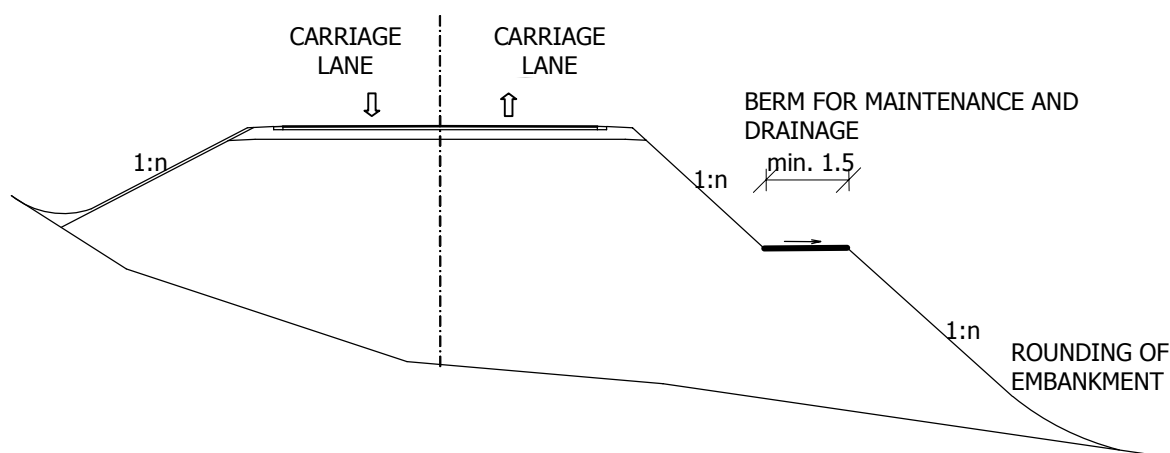


Design of cuts and embankments may have a significant impact on fitting of the road in the landscape. Below are certain characteristics of visualisation analyses:

- Lower embankments are better looking if they have milder inclination of slopes;
- In certain cases, it is more natural to implement equal length of embankments rather than a constant fall;
- Optical layout shall be improved if a mild inclination of slopes is implemented on the inner side of the cut;
- Mild cuts and embankments shall blend better with the landscape if the formation level of the road is extended to the natural inclination of the terrain.

The road designer has two solutions available:

- Use of equal inclinations of slopes of cuts and embankments (classic solution); or
- Equal lengths of slopes of cuts and embankments.

As regards the view from the road (view of the driver / user), solutions with equal lengths of slopes are more visually appropriate, however only up to height of 5 meters with length of slopes of up to 10 meters.

As regards the view on the road from surroundings, better solutions are those using equal inclinations, as this makes the intervention less conspicuous – except in case of very low cuts and embankments (up to 3 meters) where solutions with equal lengths of slopes are also very good.

### 3.3.4 Planting of Areas Lateral to Roads

In principle, it is possible to plant all top soiled areas on or along the road unless visibility on the road is in any way hindered.

#### 3.3.4.1.1 Road on an Embankment

The basic rule of planting is that branches of trees shall not extend to clearance of the road along with taking into account visibility in concave curves.

On the outer side of the curve, the distance of bushes shall be at least 3.00 m and trees shall be at least 5.00 m away from the roadway. Visibility is important on the inner side of the curve, hence the visibility criteria shall prevail here. In straight layout of the road, bushes and trees shall be planted in the same distance as on the outer side of curves. Bushes shall not be less than 1.00 m from the border of exclusive land use.

**Figure 30: Planting of slopes of embankment**

Outer side of the curve                    Embankment          Inner side of the curve

5.00
DISTANCE OF TREES
FROM THE ROADWAY EDGE

WIDTH OF TOP OF EMBANKMENT IN
ACCORDANCE WITH NORMS

BORDER OF
BODY OF THE
ROAD

3.00

DISTANCE OF BUSHES
FROM THE ROADWAY
EDGE

DISTANCE OF PLANTING
WITH REGARD TO
VISIBILITY ASSESSMEN

BORDER OF
BODY OF
THE ROAD

DISTANCE OF TREE GROUPS
FROM CURVED CHANNEL
FOR DRAINAGE OF AT LEAST
1 m

CURVED CHANNEL

VERGE

WIDTH OF THE
CARRIAGEWAY

1.00    WIDTH OF SLOPE

### 3.3.4.1.2 Road in a Cut

In such position of the road, visibility is the decisive factor. Bushes or trees shall not be less than 1.00 m from the curved channel for drainage of meteoric water.

**Figure 31: Planting of slopes of cut**

CUT

WIDTH OF TOP IN ACCORDANCE
WITH NORMS

BORDER OF BODY
OF THE ROAD

BORDER OF BODY
OF THE ROAD

VERGE

DISTANCE OF PLANTING
WITH REGARD TO VISIBILITY
ASSESSMENT

1.00    WIDTH OF SLOPE    1.00    WIDTH OF THE CARRIAGEWAY
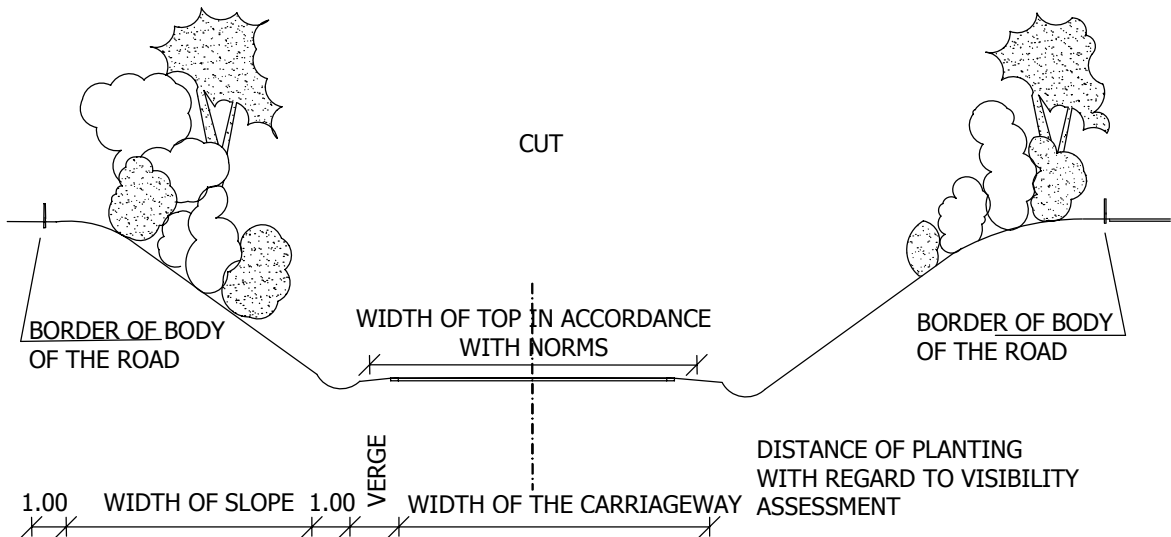
### 3.3.4.1.3 Road in Straight

**Figure 32: Planting of slopes in straight**
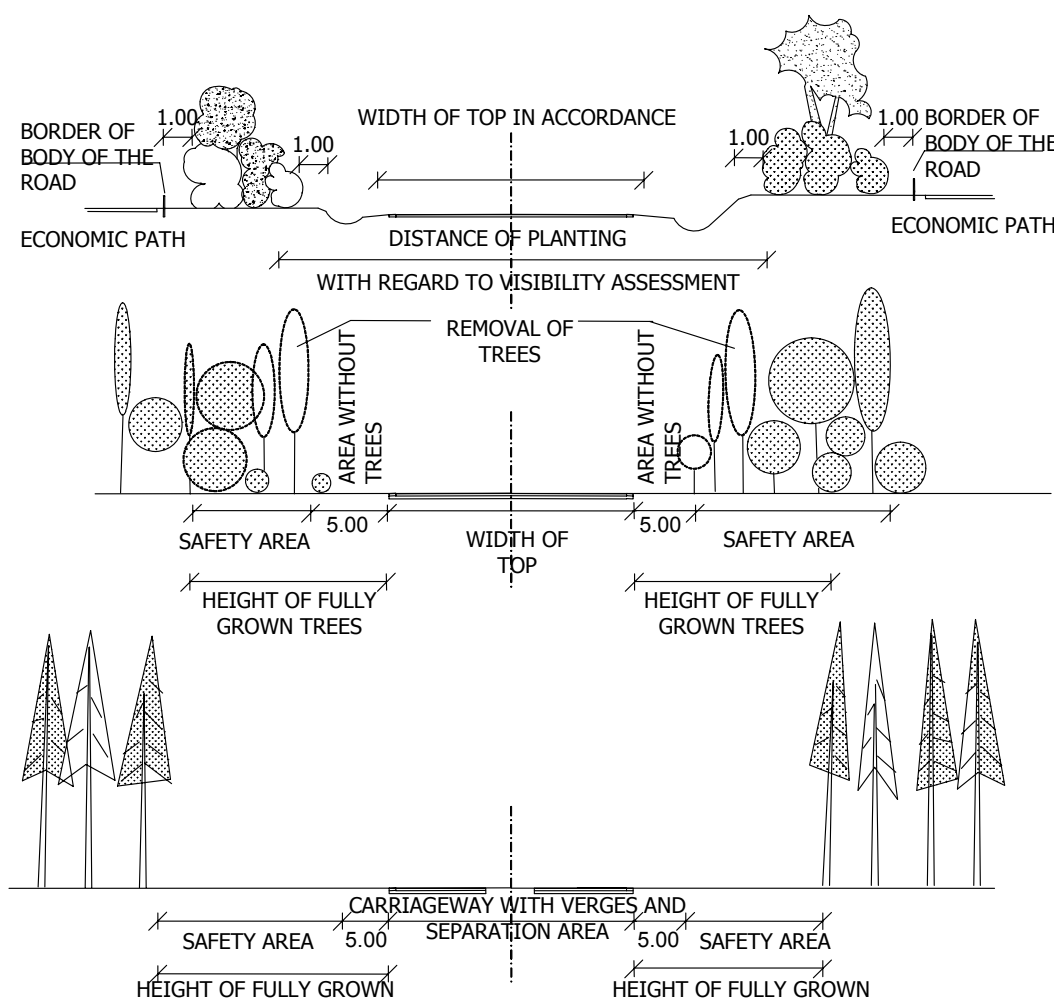


## 3.4 STANDARD CROSS PROFILES – SCP

### 3.4.1 Types of cross profiles on the road

The cross profile is the first projected image in road design works. It defines a sort of the road and the dimensions of the strips, applied on the road profile, limits the designed road ground, and enables the estimation of the exploitable and investment effects, resulting from the chosen elements and their composition in the profile.

For the purpose of the road planning, designing and constructing the following different types of cross profile are differentiated:

- geometrical cross profile (GCP),
- typical cross profile (TCP),
- normal cross profile (NCP),
- characteristic cross profile (CCP) and
- detailed cross profile (DCS).

### 3.4.2 Geometrical cross profile (GCP)

Geometrical cross profile (GCP) is a graphic presentation of traffic and non-traffic lanes and other longitudinal areas on the carriageway surface (driving lanes, delineation by curbs, separation lanes

and areas, shoulders or sewing devices, traffic lanes for non-motorized users etc), chosen and defined related to the type of the designed road and traffic-flow on it, to achieve an operability of the designed road inside the frame of traffic and driving-dynamic characteristics (average travel speed, level of service, congestion of traffic flow), officially ratifying in accordance with the traffic function of the designed road (road category).

**Figure 33: Geometrical cross profile (GCP) - examples**
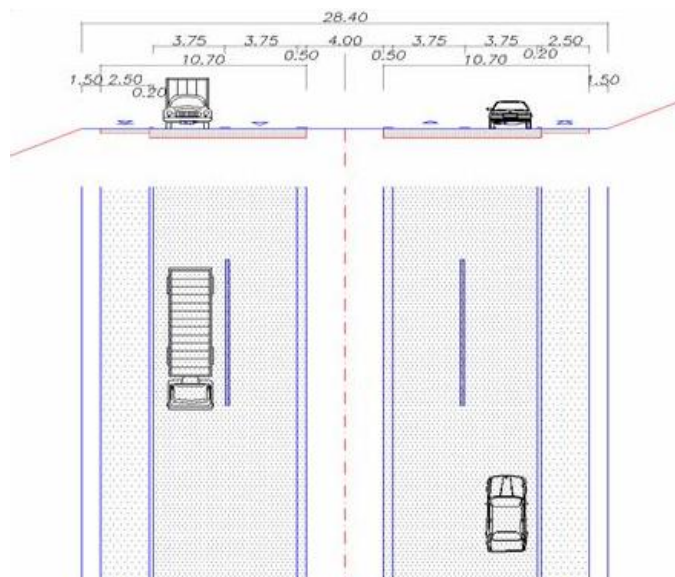


The GCP consists of:

- number, disposition and widths of traffic lanes,
- basic traffic operational regime (one or two separated carriageways),
- horizontal separation and vertical delineation of separate elements in profile,
- traffic and clearance profile and
- construction per phases (final design and from it derived phases)

Application of GCP:

- in the prognostic road-net planning,
- in general studies as entry definition,
- in spatial studies for the defining of road-compatibility with the environment,
- in outline and execution projects as basis to define normal cross-profiles and
- in expert studies (traffic regime on the road, application of intelligent traffic system etc).

### 3.4.3 Typical Cross Profiles

3.4.3.1 Properties of TCP

Typical cross profile (TCP) is a geometrical cross profile (GCP) defined as one of few possible solutions for each single type or category of the designed road to achieve an unique proceedings in road designing in the country.

Typical cross profile (TCP) is to be defined according to:

- traffic operational regime (one or two separated carriageways),
- traffic and driving-dynamic characteristics for each single type of road (number and disposition of traffic lanes, border and emergency lanes, separation stripes) and
- dimensions of each single element of carriageway (lane widths).

In this guideline each single TCP is presented with the relation between speed ($V_{des}$) and congestion of traffic flow ($Q_{rel}/C$) as a basic display of a traffic flow quality under the conditions of rolly terrain and traffic parameters, which are as standard ones taken into consideration in the methodology of the handbook HCM (Highway Capacity Manual) for the dimensioning of capacity and service volume of the road (personal vehicles + 5% of heavy vehicles + without overtaking restrictions). This methodology is acknowledged as officially accepted methodology with this guideline.

Where a road is led through the land under different characteristics (outside or inside urban zone, flat or mountain terrain, without or with bycicle lanes or pedestrian ways) more typical cross profiles are considered to be anticipate in the same project to enable normal functioning of a road in these different conditions.

The selection of TCP in the project is done on the base of the parameters, given in this guideline. These parameters provide driving-dynamic quality of traffic flow ($V_{des}$ and $V_{trav}$ as primary) and attributes (regarded to category) of the designed road.

If the indications of the traffic flow quality are as expected, there is no need to perform the traffic dimensioning of the profile.

In case of different traffic (more heavy vehicles) and relief (flat or hilly terrain) parameters the indicators of the traffic flow quality need to be specially checked and the results should be adequately adapted to confirm the correctness of the chosen TCP. In this case it is necessary to apply the measures for increasing of level of service or to choose a TCP with greater capacity.

In this guideline presented TCPs are marked with ciphers (A-1, C-2), which show the basic characteristics of a particular TCP. When using the TCPs from this guideline no additional traffic dimensioning is needed to be done in the project.

### 3.4.3.2 Classification of Typical Cross Sections

Typical cross sections – for certain design speeds and individual road categories shall be used the following typical cross sections (TCS):

A-1		Motorways (physically separated carriageways) four lanes or more, with hard shoulders for emergency stop;

A-2		Highways with narrower hard shoulders for emergency stop (mostly personal vehicles) or lay-by areas and narrowed middle separation lane;

A-3		Urban roads (lighting), number of lanes unlimited;

A-4		Grouping roads, 0.50 m of separation lane (only for marking);

B-1		Three-lane roads with physically separated directional carriageways;

B-2		Three-lane roads without physically separated directional carriageways;

B-3		Three-lane roads in urban areas, where the middle lane is intended exclusively for left turning or two lanes are intended for one direction of driving and the third for the other one;

C-1		Two-lane roads with hard shoulders for emergency stop;

C-2		Two-lane roads without hard shoulders for emergency stop;

C-3		Two-lane roads in urban areas;

C-4		Two-lane roads with cyclist lanes in urban areas;

D-1		Single-lane roads;

D-2		Single-lane roads in urban areas;

E-1		Arrangement of longitudinal areas along single-lane roads;

E-2      Arrangement of longitudinal areas along two-lane roads.


### 3.4.3.3 Capacity and Service Volume of TCSs

Traffic capacity and service volume (vehicles per hour) for selected driving speed is affected by the following:

1. Road type;
2. Number of lanes;
3. Width of carriage lanes and distance of side hindrances;
4. Ascends and descends;
5. Traffic related parameters (vehicle types, types of drivers, distribution of traffic by direction); and
6. Speed in free traffic flow.


Traffic capacities and service volumes in various speed of travel for individual TCSs are listed below. The following is taken into account:

- Elementary TCSs shall be those entered in the TCS classification;
- Physical separation of both directions of driving was taken into account;
- The proposed carriage lane widths and their number as well as distance of side hindrances were taken into account;
- Hilly terrain and 5% share of heavy vehicles were taken into account;
- Various speeds in free traffic flow, enabled by horizontal geometric elements of the road axis, were taken into account.


Values in tables and charts shall apply to:

- Each direction of driving in TCS of A category; and
- Both directions of driving in TCS of C category.


In determining of traffic capacity and service volume of TCS of B and D categories, other conditions and parameters shall be taken into account (system, length, etc.) in addition to the basic ones specified above.


Hence, these TCSs shall not be deemed elementary and the traffic capacity and service volume shall not be defined in advance for them.

### 3.4.3.4 Use of Quantities Specified in Tables and Charts

Quantities specified in tables and charts are approximate and were calculated by using the specified underlying parameters.

They are used foremost in planning measures on roads (management planning) and for rough preliminary estimates of traffic adequacy of an individual selected TCS with regard to projection data on traffic on an individual road or a section thereof.

### 3.4.3.5 Impact of Additional Lanes on Carriageway  Capacity and Service Volume

In case a traffic lane on an individual carriageway is intended only for selected vehicle types or selected types of users, such a lane shall not be included in the TCS to which it was added.

As regards calculation of traffic capacity and service volume the following shall apply due to (re)arranged carriageway on account of additional lane:

- Calculation of traffic capacity and service volume shall be implemented with regard to basic composition and dimensions of the TCS;
- Reduction of traffic load because of the additional lane shall be taken into account;
- Traffic on the additional lane shall be taken into account as a side hindrance.

## 3.4.3.6 Tables and Charts of Capacity and Service Volume of TCS

**Symbols:**

$V_{PT}$ [km/h]     Speed of free flow

$V_{pot}$ [km/h]     Travel speed

$Q_{h2}$ [veh/h]     Two-way hourly flow

b [m]          Width of the carriageway

$b_b$ [m]          Width of the verge, clearance

## 3.4.3.7 TCS A-1: Motorways (physically separated carriageways) four lanes or more, with hard shoulders for emergency stop

**Figure 34: Chart TCS A-1**
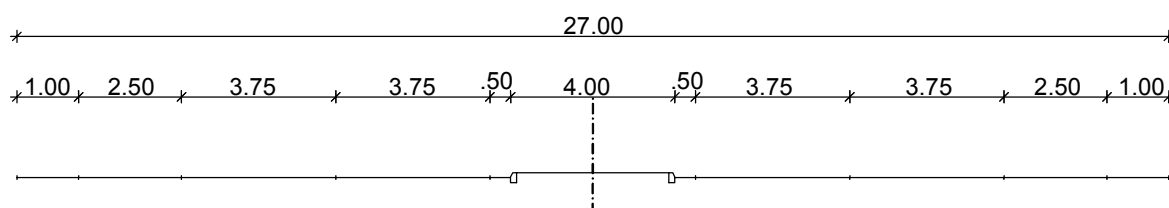


**Table 20: Capacity and Service Volume of TCS A-1, four lanes**

| | $V_{PT}$ = 120 km/h | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | b = 3.75 m (3.6 m) | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2050 | 2100 | 2400 | 2700 | 3000 | 3300 | 3550 |
| $V_{pot}$ [km/h] | 120.0 | 120.0 | 119.9 | 118.7 | 115.3 | 108.8 | 98.6 | 86.9 |
| | b = 3.50 m | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2050 | 2100 | 2400 | 2700 | 3000 | 3300 | 3550 |
| $V_{pot}$ [km/h] | 119 | 119 | 118.9 | 117.8 | 114.5 | 108.1 | 98 | 86.3 |
| | b = 3.25 m (3.2 m) | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2150 | 2200 | 2500 | 2800 | 3100 | 3400 | 3500 |
| $V_{pot}$ [km/h] | 114.4 | 114.4 | 114.3 | 113.1 | 109.4 | 102.3 | 91.1 | 86.3 |

| | $V_{PT}$ = 100 km/h | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | b = 3.75 m (3.6 m) | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2450 | 2500 | 2700 | 2900 | 3100 | 3300 | 3400 |
| $V_{pot}$ [km/h] | 100.0 | 100.0 | 99.9 | 99.2 | 97.1 | 93.2 | 87.1 | 83.2 |
| | b = 3.50 m | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2500 | 2550 | 2700 | 2900 | 3100 | 3300 | 3400 |
| $V_{pot}$ [km/h] | 99 | 99 | 98.9 | 98.3 | 96.3 | 92.6 | 86.6 | 82.7 |
| | b = 3.25 m (3.2 m) | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2600 | 2650 | 2800 | 3000 | 3200 | 3300 | 3350 |
| $V_{pot}$ [km/h] | 94.4 | 94.4 | 94.3 | 93.6 | 91.4 | 87.2 | 84.1 | 82.3 |

| | $V_{PT}$ = 90 km/h | | | | | | |
|---|---|---|---|---|---|---|---|
| | b = 3.75 m (3.6 m) | | | | | | |
| $Q_h$ [veh/h] | 0 | 2700 | 2750 | 2800 | 3000 | 3200 | 3300 |
| $V_{pot}$ [km/h] | 90.0 | 90.0 | 89.9 | 89.7 | 88.1 | 84.6 | 81.9 |

**Table 21: Capacity and Service Volume of TCS A-1, six lanes**

| | $V_{PT}$ = 120 km/h | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | b = 3.75 m (3.6 m) | | | | | | | | |
| $Q_h$ [veh/h] | 0 | 3300 | 3350 | 3700 | 4100 | 4500 | 4900 | 5300 | 5750 |
| $V_{pot}$ [km/h] | 120.0 | 120.0 | 119.9 | 119.3 | 117.4 | 113.7 | 107.7 | 99.2 | 86 |
| | b = 3.50 m | | | | | | | | |

| Q$_h$ [veh/h] | | 0 | 3350 | 3400 | 3700 | 4100 | 4500 | 4900 | 5300 | 5700 |
|---|---|---|---|---|---|---|---|---|---|---|
| V$_{pot}$ [km/h] | 119 | 119 | 118.9 | 118.4 | 116.6 | 112.9 | 107 | 98.6 | 87.1 |
| b = 3.25 m (3.2 m) | | | | | | | | | | |
| Q$_h$ [veh/h] | | 0 | 3500 | 3550 | 3900 | 4300 | 4700 | 5100 | 5500 | 5650 |
| V$_{pot}$ [km/h] | 114.4 | 114.4 | 114.3 | 113.6 | 111.4 | 107.2 | 100.3 | 90.6 | 86.1 |

| V$_{PT}$ = 100 km/h | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| b = 3.75 m (3.6 m) | | | | | | | | |
| Q$_h$ [veh/h] | | 0 | 4000 | 4050 | 4300 | 4600 | 4900 | 5200 | 5500 |
| V$_{pot}$ [km/h] | 100.0 | 100.0 | 99.9 | 99.4 | 97.7 | 94.6 | 89.7 | 82.7 |
| b = 3.50 m | | | | | | | | |
| Q$_h$ [veh/h] | | 0 | 4050 | 4100 | 4300 | 4600 | 4900 | 5200 | 5450 |
| V$_{pot}$ [km/h] | 99 | 99 | 98.9 | 98.5 | 96.9 | 93.9 | 89.1 | 83.5 |
| b = 3.25 m (3.2 m) | | | | | | | | |
| Q$_h$ [veh/h] | | 0 | 4200 | 4250 | 4400 | 4700 | 5000 | 5300 | 5450 |
| V$_{pot}$ [km/h] | 94.4 | 94.4 | 94.3 | 94 | 92.6 | 89.6 | 84.6 | 81.2 |

### 3.4.3.8 TCS A-2: Highways with narrower hard shoulders for emergency stop (mostly personal vehicles) or lay-by areas and narrowed middle separation lane

**Figure 35: Chart TCS A-2**
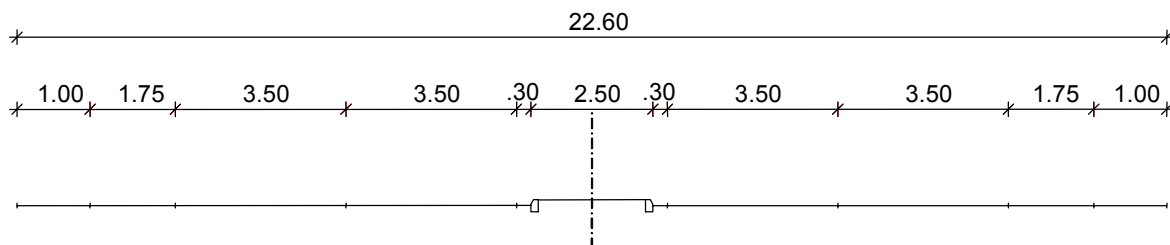


**Table 22: Capacity and Service Volume of TCS A-2**

| V$_{PT}$ = 100 km/h | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| b = 3.5 m; without hard shoulder for emergency stop | | | | | | | | | |
| Q$_h$ [veh/h] | | 0 | 2100 | 2150 | 2300 | 2500 | 2700 | 2900 | 3100 | 3200 |
| V$_{pot}$ [km/h] | 97.1 | 97.1 | 96.8 | 96.1 | 94.1 | 92.1 | 89.9 | 87.5 | 86.2 |
| b = 3.25 m (3.2 m); without hard shoulder for emergency stop | | | | | | | | | |
| Q$_h$ [veh/h] | | 0 | 1000 | 2100 | 2150 | 2300 | 2500 | 2700 | 2900 | 3100 |
| V$_{pot}$ [km/h] | 92.5 | 92.5 | 92.5 | 92.2 | 91.3 | 89.6 | 87.7 | 85.6 | 83.3 |

| V$_{PT}$ = 100 km/h | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| b = 3.5 m; hard shoulder for emergency stop | | | | | | | | | |
| Q$_h$ [veh/h] | | 0 | 2100 | 2150 | 2300 | 2500 | 2700 | 2900 | 3100 | 3200 |
| V$_{pot}$ [km/h] | 98.7 | 98.7 | 98.4 | 97.4 | 95.4 | 93.6 | 91.4 | 89 | 87.7 |
| b = 3.25 m (3.2 m); hard shoulder for emergency stop | | | | | | | | | |
| Q$_h$ [veh/h] | | 0 | 1000 | 2100 | 2150 | 2300 | 2500 | 2700 | 2900 | 3100 |

| $V_{pot}$ [km/h] | | 94.1 | 94.1 | 94.1 | 93.8 | 92.9 | 91.2 | 89.2 | 87.1 | 84.7 |
|---|---|---|---|---|---|---|---|---|---|---|

| $V_{PT}$ = 90 km/h | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| b = 3.5 m; without hard shoulder for emergency stop | | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2100 | 2150 | 2300 | 2500 | 2700 | 2900 | 3050 |
| $V_{pot}$ [km/h] | 87.1 | 87.1 | 86.9 | 86.0 | 84.5 | 82.8 | 80.8 | 79.3 |
| b = 3.25 m (3.2 m); without hard shoulder for emergency stop | | | | | | | | |
| $Q_h$ [veh/h] | 0 | 1000 | 2100 | 2150 | 2300 | 2500 | 2700 | 2900 |
| $V_{pot}$ [km/h] | 82.5 | 82.5 | 82.5 | 82.3 | 81.5 | 80.2 | 78.6 | 76.8 |

| $V_{PT}$ = 90 km/h | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| b = 3.5 m; hard shoulder for emergency stop | | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2100 | 2150 | 2300 | 2500 | 2700 | 2900 | 3100 |
| $V_{pot}$ [km/h] | 88.7 | 88.7 | 88.5 | 87.6 | 86.0 | 84.2 | 82.3 | 80.1 |
| b = 3.25 m (3.2 m); hard shoulder for emergency stop | | | | | | | | |
| $Q_h$ [veh/h] | 0 | 1000 | 2100 | 2150 | 2300 | 2500 | 2700 | 2950 |
| $V_{pot}$ [km/h] | 84.1 | 84.1 | 84.1 | 83.9 | 83.1 | 81.7 | 80 | 77.7 |

| $V_{PT}$ = 80 km/h | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| b = 3.5 m; without hard shoulder for emergency stop | | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2100 | 2150 | 2300 | 2500 | 2700 | 2900 | 2950 |
| $V_{pot}$ [km/h] | 77.1 | 77.1 | 77.0 | 76.7 | 76.2 | 75.6 | 74.9 | 74.7 |
| b = 3.25 m (3.2 m); without hard shoulder for emergency stop | | | | | | | | |
| $Q_h$ [veh/h] | 0 | 1000 | 2100 | 2150 | 2300 | 2500 | 2700 | 2800 |
| $V_{pot}$ [km/h] | 72.5 | 72.5 | 72.5 | 72.4 | 72.1 | 71.5 | 70.9 | 70.5 |

| $V_{PT}$ = 80 km/h | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| b = 3.5 m; hard shoulder for emergency stop | | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2100 | 2150 | 2300 | 2500 | 2700 | 2900 | 3050 |
| $V_{pot}$ [km/h] | 78.7 | 78.7 | 78.6 | 78.3 | 77.8 | 77.2 | 76.5 | 76 |
| b = 3.25 m (3.2 m); hard shoulder for emergency stop | | | | | | | | |
| $Q_h$ [veh/h] | 0 | 1000 | 2100 | 2150 | 2300 | 2500 | 2700 | 2850 |
| $V_{pot}$ [km/h] | 74.1 | 74.1 | 74.1 | 74 | 73.7 | 73.2 | 72.5 | 72 |

## 3.4.3.9 TCS A-3: Urban roads (lighting), number of lanes unlimited

**Figure 36: Chart TCS A-3**
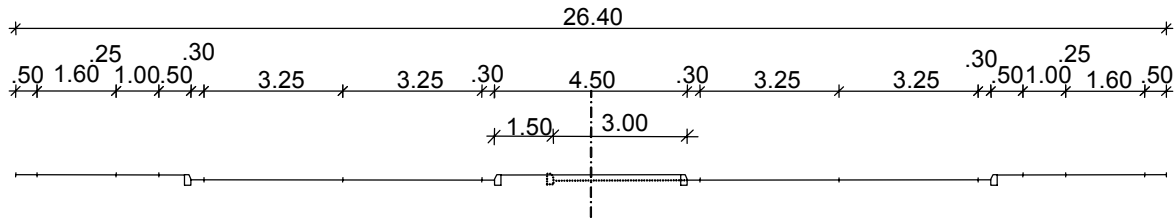


**Table 23: Capacity and Service Volume of TCS A-3**

| $V_{PT}$ = 90 km/h | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| b = 3,5 m; lighting | | | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2000 | 2300 | 2500 | 2700 | 2900 | 3100 | 3300 | 3500 | 3650 |
| $V_{pot}$ [km/h] | 88.4 | 88.4 | 88.4 | 88.3 | 87.5 | 86.2 | 84.8 | 83.2 | 81.5 | 80.2 |
| b = 3.25 m (3.2 m); lighting | | | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2000 | 2150 | 2300 | 2550 | 2700 | 2900 | 3100 | 3300 | 3540 |
| $V_{pot}$ [km/h] | 83.8 | 83.8 | 83.8 | 83.8 | 83.6 | 82.9 | 81.8 | 80.5 | 79 | 77.2 |

| $V_{PT}$ = 90 km/h | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| b = 3.5 m; no lighting | | | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2000 | 2300 | 2500 | 2700 | 2900 | 3100 | 3300 | 3500 | 3650 |
| $V_{pot}$ [km/h] | 88.7 | 88.7 | 88.7 | 88.6 | 87.8 | 86.5 | 85.1 | 83.5 | 81.8 | 80.4 |
| b = 3.25 m (3.2 m); no lighting | | | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2000 | 2500 | 2650 | 2700 | 2900 | 3100 | 3300 | 3500 | 3550 |
| $V_{pot}$ [km/h] | 84.1 | 84.1 | 84.1 | 83.5 | 83.2 | 82.1 | 80.8 | 79.3 | 77.7 | 77.3 |

| $V_{PT}$ = 80 km/h | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| b = 3.5 m; lighting | | | | | | | | |
| $Q_h$ [veh/h] | | 0 | 2500 | 2700 | 2900 | 3100 | 3300 | 3500 | 3600 |
| $V_{pot}$ [km/h] | | 78.4 | 78.4 | 78.1 | 77.7 | 77.2 | 76.6 | 76.1 | 75.8 |
| b = 3.25 m (3.2 m); lighting | | | | | | | | |
| $Q_h$ [veh/h] | | 0 | 2500 | 2700 | 2900 | 3100 | 3300 | 3350 | 3400 |
| $V_{pot}$ [km/h] | | 73.8 | 73.8 | 73.5 | 73 | 72.5 | 71.9 | 71.8 | 71.6 |

### 3.4.3.10      TCS A-4: Grouping roads, 0.50 m of separation lane (only for marking)

**Figure 37: Chart TCS A-4**
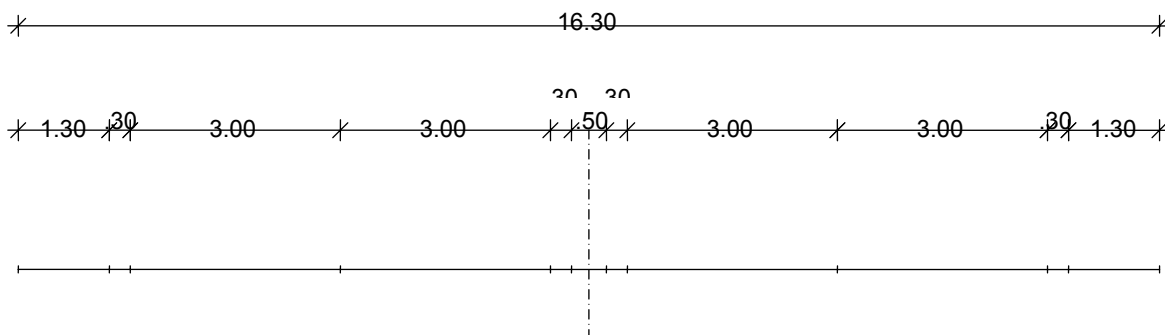


**Table 24: Capacity and Service Volume of TCS A-4**

| $V_{PT}$ = 90 km/h | | | | | | | |
|---|---|---|---|---|---|---|---|
| b = 3.5 m | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2500 | 2700 | 2900 | 3100 | 3300 | 3500 | 3600 |
| $V_{pot}$ [km/h] | 86.1 | 86.0 | 85.2 | 84.0 | 82.6 | 81.1 | 79.5 | 78.6 |
| b = 3.25 m (3.2 m) | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2500 | 2700 | 2900 | 3100 | 3300 | 3400 | 3450 |
| $V_{pot}$ [km/h] | 81.5 | 81.5 | 80.7 | 79.6 | 78.4 | 77 | 76.3 | 75.9 |

| $V_{PT}$ = 80 km/h | | | | | | | |
|---|---|---|---|---|---|---|---|
| b = 3.25 m (3.2 m) | | | | | | | |
| $Q_h$ [veh/h] | 0 | 2500 | 2700 | 2900 | 3100 | 3300 | 3315 |
| $V_{pot}$ [km/h] | 71.5 | 71.5 | 71.2 | 70.7 | 70.2 | 69.6 | 69.5 |

### 3.4.3.11      TCS B-1: Three-lane roads with physically separated directional carriageways

**Figure 38: Chart TCS B-1**
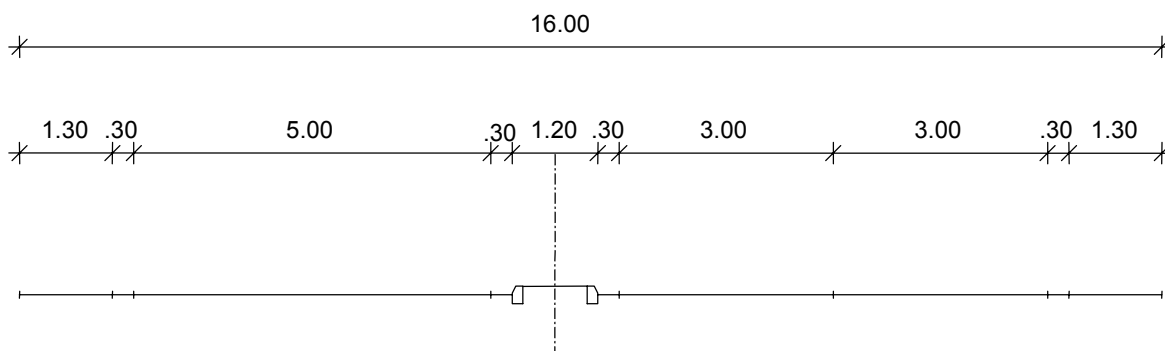
## 3.4.3.12    TCS B-2: Three-lane roads without physically separated directional carriageways

**Figure 39: Chart TCS B-2**
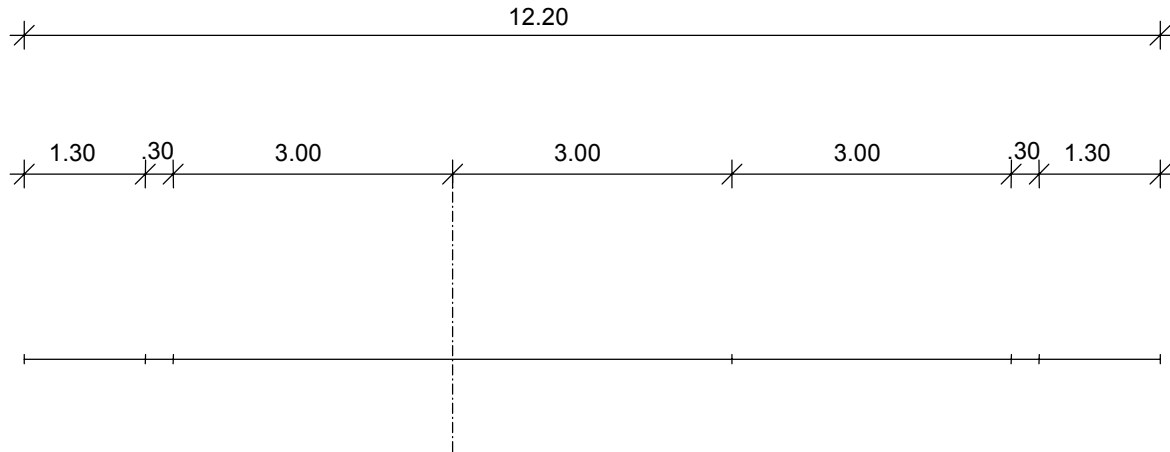


## 3.4.3.13    TCS B-3: Three-lane roads in urban areas. where the middle lane is intended exclusively for left turning or two lanes are intended for one direction of driving and the third for the other one

**Figure 40: Chart TCS B-3**
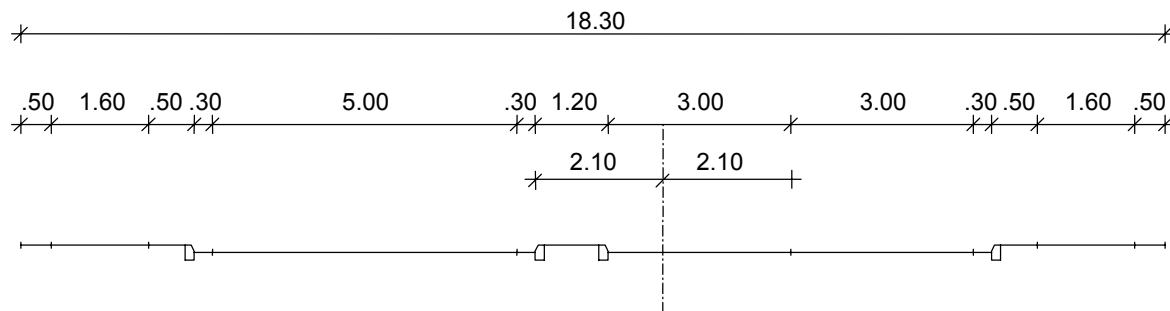
### 3.4.3.14    TCS C-1: Two-lane roads with hard shoulders for emergency stop

**Figure 41: Chart TCS C-1**
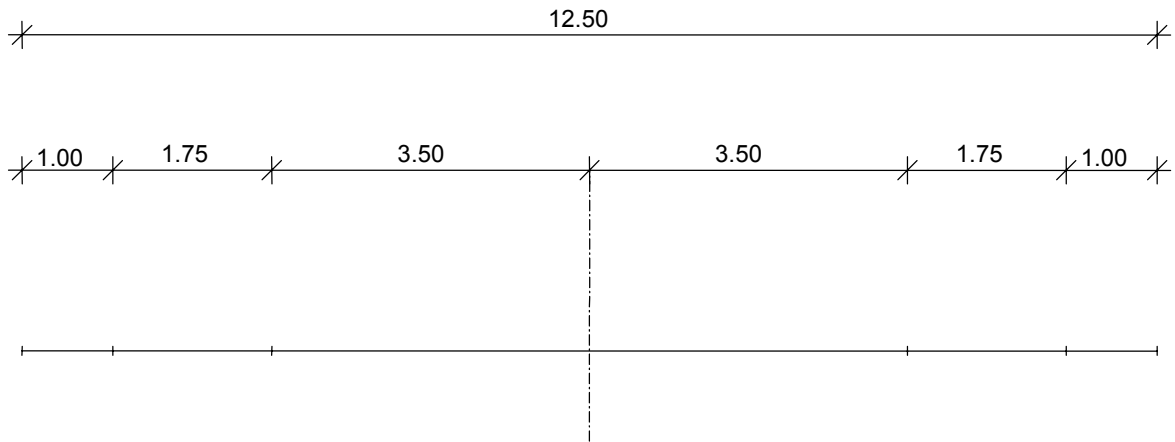


**Table 25: Capacity and Service Volume  of TCS A-4**

| $V_{PT}$ = 70 km/h | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| b = 3.5 m | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | 69.3 | 69.2 | 68.1 | 66.9 | 62.2 | 58.8 | 54.7 | 49.9 | 45 | 40.2 | 35.3 | 28.7 |
| b = 3.25 m (3.2 m) | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | 68.3 | 68.2 | 67.1 | 65.9 | 61.2 | 57.8 | 53.7 | 48.9 | 44 | 39.2 | 34.3 | 28.7 |

### 3.4.3.15    TCS C-2: Two-lane roads without hard shoulders for emergency stop

**Figure 42: Chart TCS C-2**

## Table 26: Capacity and Service Volume of TCS C-2

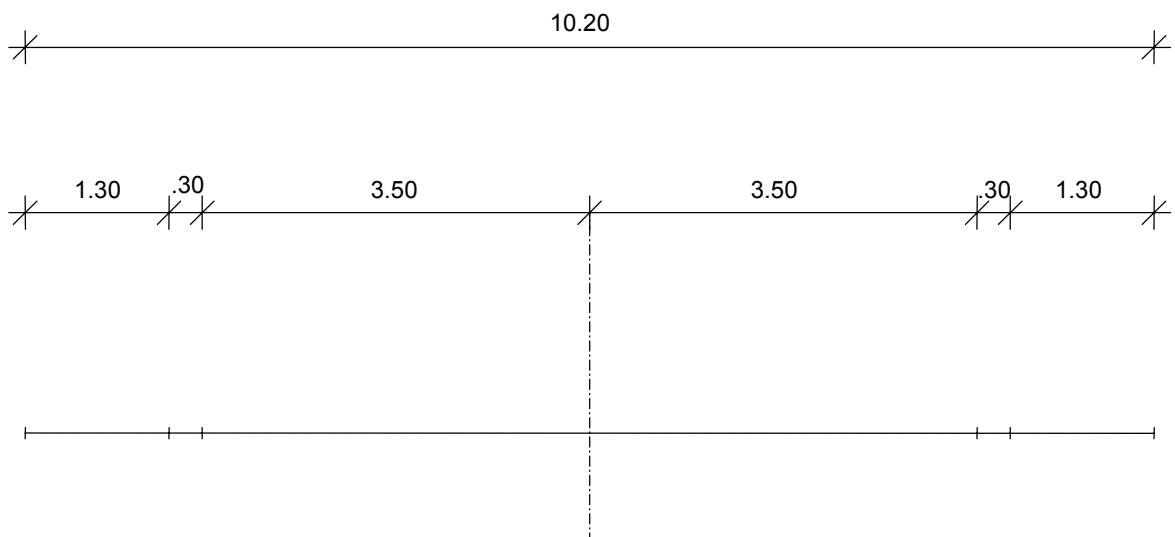| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$V_{PT}$ = 100 km/h** | | | | | | | | | | | | |
| b = 3.5 m; $b_b$ = 1.5 m | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | 99.3 | 99.2 | 98.1 | 96.9 | 92.2 | 88.8 | 84.7 | 79.9 | 75 | 70.2 | 65.3 | 59.7 |
| b = 3.5 m; $b_b$ = 1.3 m | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | 97.2 | 97.1 | 96 | 94.8 | 90.1 | 86.7 | 82.6 | 77.8 | 72.9 | 68.1 | 63.2 | 57.6 |
| b = 3.2 m (3.25 m); $b_b$ = 1.3 m | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | 96.2 | 96.1 | 95 | 93.8 | 89.1 | 85.7 | 81.6 | 76.8 | 71.9 | 67.1 | 62.2 | 56.6 |
| b = 3.0 m; $b_b$ = 1.0 m | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | 96.2 | 96.1 | 95 | 93.8 | 89.1 | 85.7 | 81.6 | 76.8 | 71.9 | 67.1 | 62.2 | 56.6 |
| **$V_{PT}$ = 90 km/h** | | | | | | | | | | | | |
| b = 3.5 m; $b_b$ = 1.5 m | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | 89.3 | 89.2 | 88.1 | 86.9 | 82.2 | 78.8 | 74.7 | 69.9 | 65 | 60.2 | 55.3 | 49.7 |
| b = 3.5 m; $b_b$ = 1.3 m | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | 87.2 | 87.1 | 86 | 84.8 | 80.1 | 76.7 | 72.6 | 67.8 | 62.9 | 58.1 | 53.2 | 47.6 |
| b = 3.2 m (3.25 m); $b_b$ = 1.3 m | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | 86.2 | 86.1 | 85 | 83.8 | 79.1 | 75.7 | 71.6 | 66.8 | 61.9 | 57.1 | 52.2 | 46.6 |
| b = 3.0 m; $b_b$ = 1.0 m | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | 86.2 | 86.1 | 85 | 83.8 | 79.1 | 75.7 | 71.6 | 66.8 | 61.9 | 57.1 | 52.2 | 46.6 |
| **$V_{PT}$ = 80 km/h** | | | | | | | | | | | | |
| b = 3.5 m; $b_b$ = 1.5 m | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | | 79.3 | 79.2 | 78.1 | 76.9 | 72.2 | 68.8 | 64.7 | 59.9 | 55 | 50.2 | 45.3 | 39.7 |
| b = 3.5 m; $b_b$ = 1.3 m | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | | 77.2 | 77.1 | 76 | 74.8 | 70.1 | 66.7 | 62.6 | 57.8 | 52.9 | 48.1 | 43.2 | 37.6 |
| b = 3.2 m (3.25 m); $b_b$ = 1.3 m | | | | | | | | | | | | |

| Q$_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| V$_{pot}$ [km/h] | 76.2 | 76.1 | 75 | 73.8 | 69.1 | 65.7 | 61.6 | 56.8 | 51.9 | 47.1 | 42.2 | 36.6 |
| b = 3.0 m; b$_b$ = 1.0 m | | | | | | | | | | | | |
| Q$_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| V$_{pot}$ [km/h] | 76.2 | 76.1 | 75 | 73.8 | 69.1 | 65.7 | 61.6 | 56.8 | 51.9 | 47.1 | 42.2 | 36.6 |

| V$_{PT}$ = 70 km/h | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| b = 3.5 m; b$_b$ = 1.5 m | | | | | | | | | | | | |
| Q$_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| V$_{pot}$ [km/h] | 69.3 | 69.32 | 68.1 | 66.9 | 62.2 | 58.8 | 54.7 | 49.9 | 45 | 40.2 | 35.3 | 29.7 |
| b = 3.5 m; b$_b$ = 1.3 m | | | | | | | | | | | | |
| Q$_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| V$_{pot}$ [km/h] | 67.2 | 67.1 | 66 | 64.8 | 60.1 | 56.7 | 52.6 | 47.8 | 42.9 | 38.1 | 33.2 | 27.6 |
| b = 3.2 m (3.25 m); b$_b$ = 1.3 m | | | | | | | | | | | | |
| Q$_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| V$_{pot}$ [km/h] | 66.2 | 66.1 | 65 | 63.8 | 59.1 | 55.7 | 51.6 | 46.8 | 41.9 | 37.1 | 32.2 | 26.6 |
| b = 3.0 m; b$_b$ = 1.0 m | | | | | | | | | | | | |
| Q$_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| V$_{pot}$ [km/h] | 66.2 | 66.1 | 65 | 63.8 | 59.1 | 55.7 | 51.6 | 46.8 | 41.9 | 37.1 | 32.2 | 26.6 |
| b = 2.75 m; b$_b$ = 1.0 m | | | | | | | | | | | | |
| Q$_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| V$_{pot}$ [km/h] | 64.4 | 64.3 | 63.2 | 62 | 57.3 | 53.9 | 49.8 | 45 | 40.1 | 35.3 | 30.4 | 24.8 |

### 3.4.3.16      TCS C-3: Two-lane roads in urban areas

**Figure 43: Chart TCS C-3**
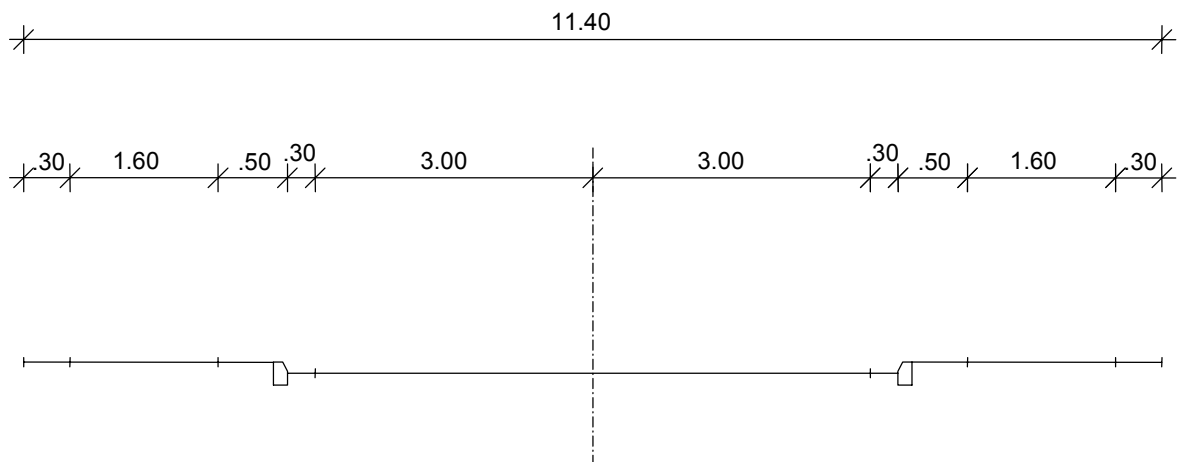


**Table 27: Capacity and Service Volume  of TCS C-3**

| V$_{PT}$ = 70 km/h |
|---|
| b = 3.2 m (3.25 m) |

| $Q_{h2}$ [veh/h] | | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{pot}$ [km/h] | | 61.5 | 61.4 | 60.3 | 59.1 | 54.4 | 51 | 46.9 | 42.1 | 37.2 | 32.4 | 27.5 | 21.9 |
| b = 3.0 m | | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | | 61.5 | 61.4 | 60.3 | 59.1 | 54.4 | 51 | 46.9 | 42.1 | 37.2 | 32.4 | 27.5 | 21.9 |
| b = 2.7 m (2.75 m) | | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | | 59.7 | 59.6 | 58.5 | 57.3 | 52.6 | 49.2 | 45.1 | 40.3 | 35.4 | 30.6 | 25.7 | 20.1 |

### 3.4.3.17    TCS C-4: Two-lane roads with cyclist lanes in urban areas
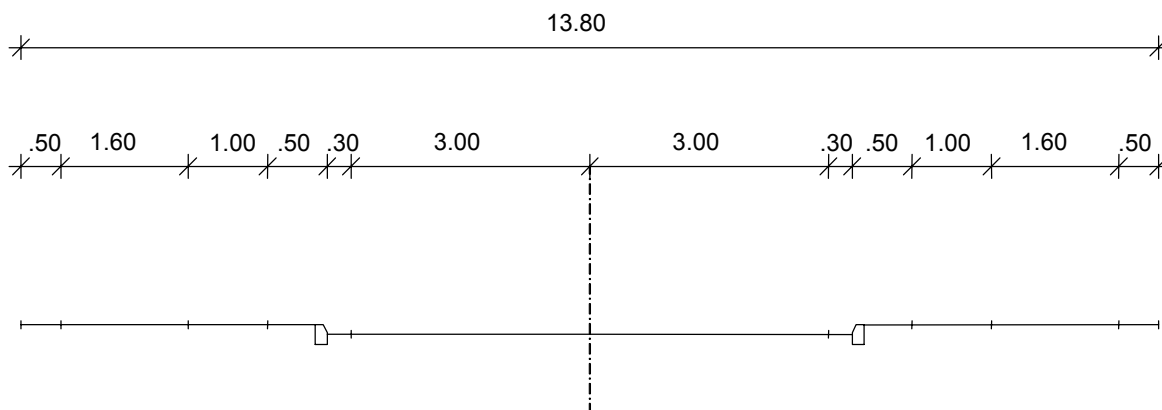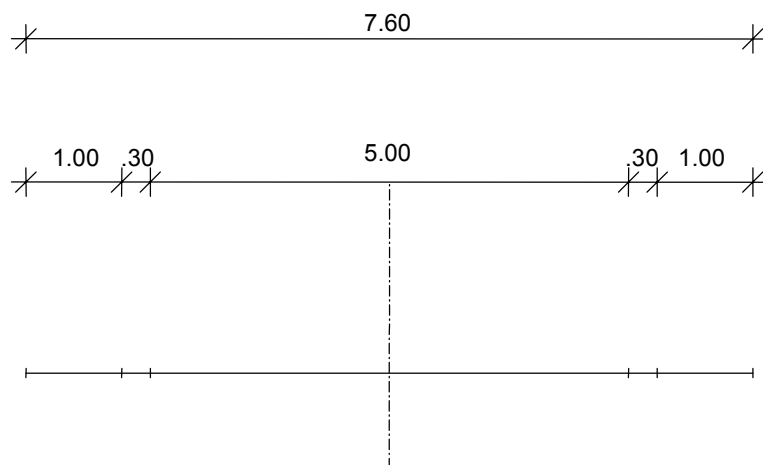
**Figure 44: Chart TCS C-4**



**Table 28: Capacity and Service Volume  of TCS C-4**

| $V_{PT}$ = 70 km/h | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| b = 3.2 m (3.25 m) | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | 64.1 | 64 | 62.9 | 61.7 | 57 | 53.6 | 49.5 | 44.7 | 39.8 | 35 | 30.1 | 24.5 |
| b = 3.0 m | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | 64.1 | 64 | 62.9 | 61.7 | 57 | 53.6 | 49.5 | 44.7 | 39.8 | 35 | 30.1 | 24.5 |
| b = 2.7 m (2.75 m) | | | | | | | | | | | | |
| $Q_{h2}$ [veh/h] | 1 | 5 | 50 | 100 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2450 |
| $V_{pot}$ [km/h] | 62.3 | 62.2 | 61.1 | 59.9 | 55.2 | 51.8 | 47.7 | 42.9 | 38 | 33.2 | 28.3 | 22.7 |

### 3.4.3.18    TCS D-1: Single-lane roads

**Figure 45: Chart TCS D-1**

7.60

1.00   .30          5.00          .30   1.00

### 3.4.3.19    TCS D-2: Single-lane roads in urban areas

**Figure 46: Chart TCS D-2**

10.80

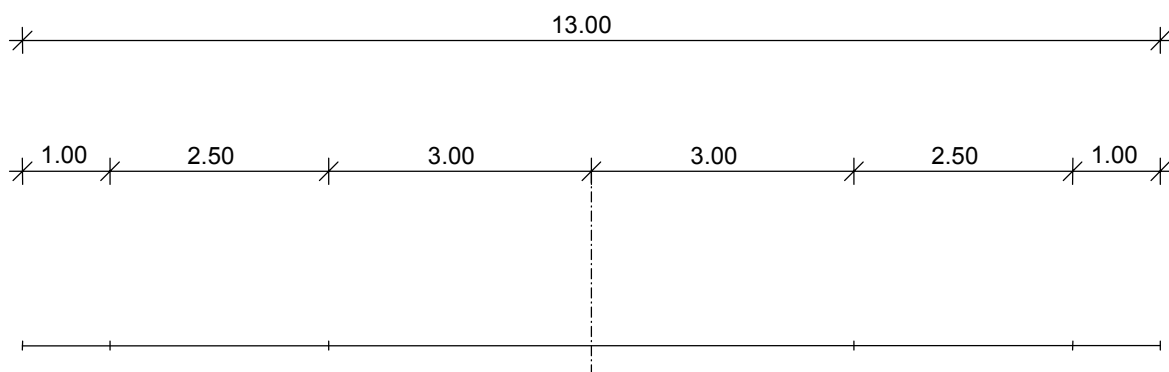.50    1.60    .50  .30        5.00        .30   .50    1.60      .50
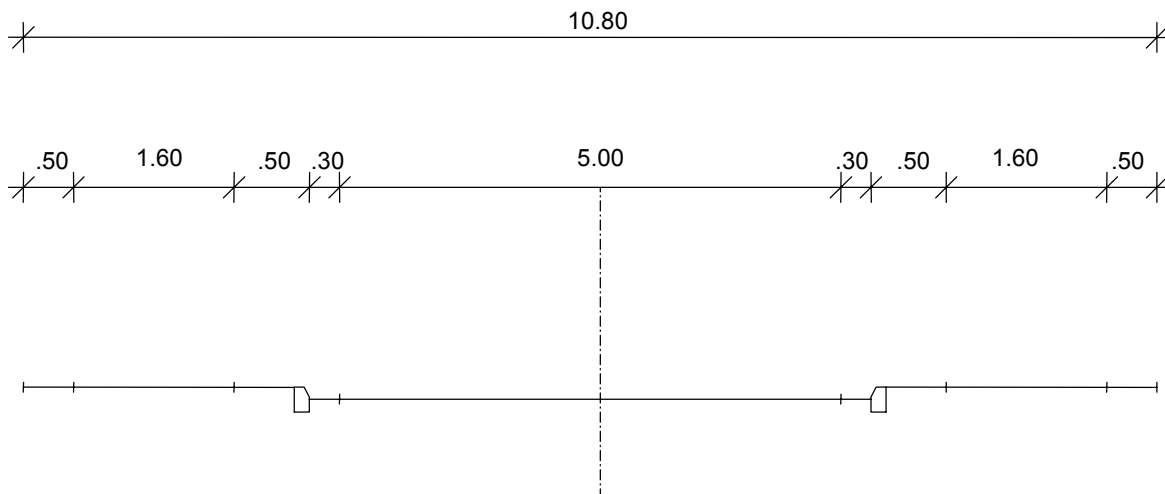
### 3.4.3.20      TCS E-1: Arrangement of longitudinal areas along single-lane roads

**Figure 47: Chart TCS E-1**
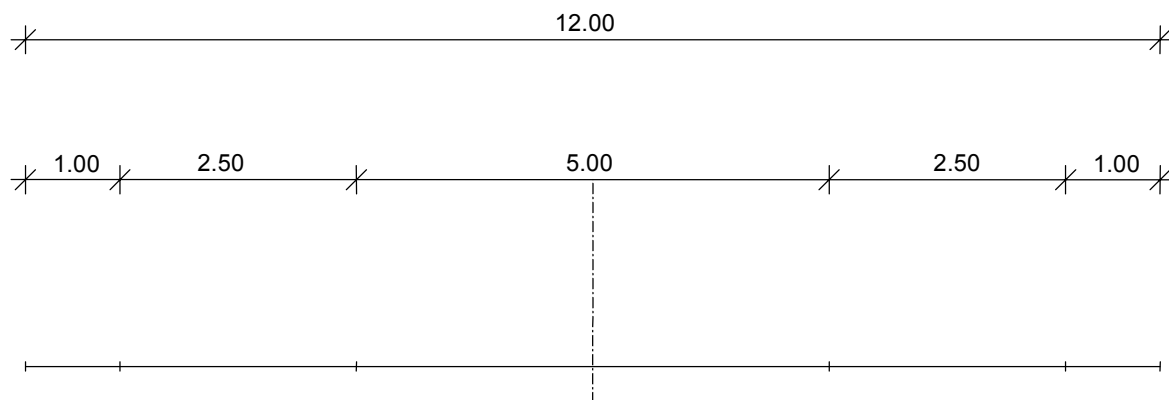


### 3.4.3.21      TCS E-2: Arrangement of longitudinal areas along two-lane roads

**Figure 48: Chart TCS E-2**



## 3.4.4 Normal Cross Profile

A Normal Cross Profile (NCP) is a graphic survey of the GCP under the standard natural and traffic conditions. Shortly: NCP is with the body of the road and with construction details supplemented GCP, put into real dimensions of the space.

The NCPs are used for define:

- the forms and dimensions of traffic lanes and accompanying elements on the roadway (road body protection lanes and drainage arrangements),
- internal relations among the strips (system of separation – green lanes, curbs or/and fences),
- kind and location of the elements for the road and environment protection (outer wire fence, noise protection barriers),
- the location of the basic elements of traffic control devices (edge-posts, traffic signs and markings, safety fences),
- kind and location of infrastructural and communal installations,
- the details for the construction-works and

- total width of the road-ground
- required to enable the road traffic function operations under the traffic and driving-dynamic conditions regulated by the technical rules.

Beside the above quoted parameters the NCP includes (as necessary):

- the terrain-line with the denotation of top soil thickness and terrain level point on the road-axis,
- the position of the nivelete-line with the height of the level point,
- the slopes of the road surface and substructure,
- the thickness of the pavement structure and the layers of it,
- accompanying elements of a road with construction solutions, dimensions and slopes of them (shoulder, berm [verge], drainage elements, separation strips),
- kind and size of road-body substructure (cut, fill, combined profile, slopes),
- constructional solutions for the execution of earth-works (building slopes by the use of different earth materials, part cut, wedge-cut, trench plough, deep drainage),
- position and constructional solutions of road protection elements (channels, pillars, retaining walls),
- position and the depth in the road-body built-in communal and infrastructure installations and spacing among them (sewage system, waterworks, gas, electricity, public lightning, TV cables, hot water installation, the owner's internal communication cables and suchlike).

Normally at least 3 basic NCPs have to be presented in the design. They are:

- NCP in fill,
- NCP in cut and
- NCP in combined profile.

In the design for the road with directional carriageways it is necessary to show also:

- NCP in straight-line,
- NCP in curve and
- NCP with horizontal and/or vertical separation of carriageways
- to define the levelling of each single carriageway and to include the additional areas and arrangements as well (as necessary) to assure a normal exploitation of the road.

Application of NCP:

- in spatial studies for the defining of road-compatibility with the environment and to survey the real situation after the opening of new road,
- in outline and execution projects as obligatory enclosure,
- in expert studies (geotechnical studies, defining of traffic regime on the road, application of intelligent traffic system and suchlike studies).

## Figure 49: Normal cross profile (NCP) - examples

NCS – TWO LANE ROAD
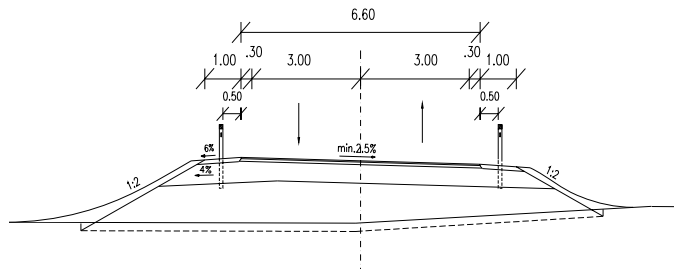
NCS – MIXED PROFILE TWO LANE ROAD
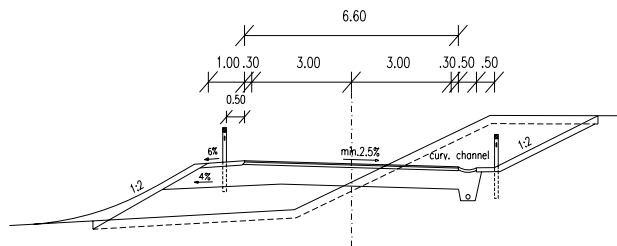
NCS – MOTORWAY

IN CUT

NCS – JUNCTION RAMP

ONE WAY

## 3.4.5 Characteristic Cross Profile (CCP)

A Characteristic Cross Profile (CCP) is a graphic survey of the NCP on the particular section of the road or on the particular location on the road axis, where the normally used NCP has to be changed in some details or where some additional areas of a special functionality are added to it.
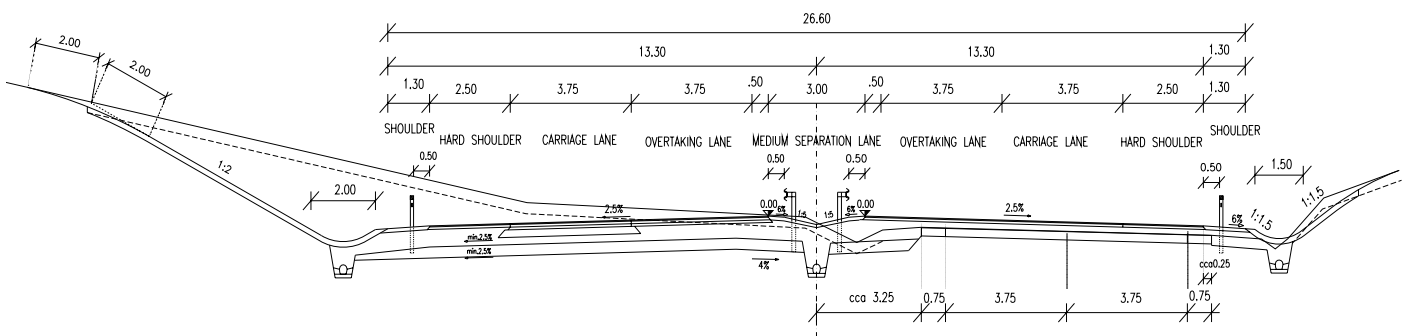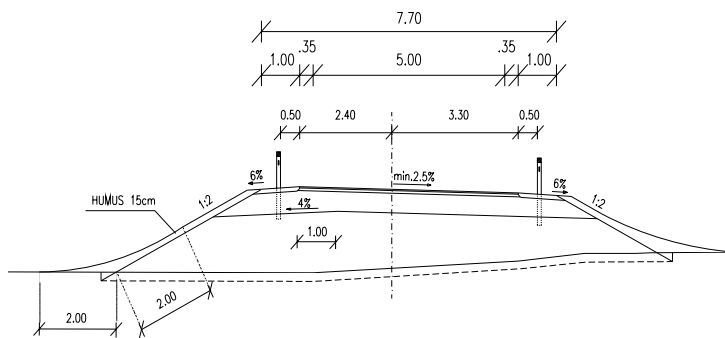
The influential diversities are:

- the structure and form of road-body (bridge, viaduct, tunnel, retaining walls),

- traffic demands (widening of traffic lanes, additional lanes for overtaking or for slow-motion vehicles or for parking, additional lanes inside junctions and crossroads, cancellation of lanes),

- levelling relations between two separated carriageways (carriageway-rotation by very poor grades of nivelete,  displacement of the nivelete-line in cross-profile, completely separate runs of carriageways),

- (re)positioning of roadway traffic elements on behalf of locally implemented measures in traffic regime and/or improved traffic safety (traffic islands for different purposes),

- contents and positioning of the areas alongside the road (cycle strips, cycle lanes, pavements and other arrangements),

- the elements of longitudinal drainage system (trench plough, deep drainage, channels, pointed channel, canalization),

- the elements of the environmental protection alongside the road (noise barriers, strong wind barriers)

- composition and/or thickness of pavement structure and its layers,

- different content and position of particular infrastructure installation.

Additional areas of a special functionality are:

- toll-stations or customs yards,

- BUS-stop

- service areas by the road (rest areas, petrol stations, motels, traffic control areas, various depot areas),

- areas for the placing of various arrangement by the road (emergency call places, emergency stop-bays, standing place for putting up the pillars for various purposes and suchlike areas).

Application of CCP:

- in outline and execution projects as obligatory enclosure,

- in expert studies (geotechnical studies, application of intelligent traffic system, environment protection studies and others).

**Figure 50: Characteristic cross profile (CCP) - examples**

NCS – TWO LANE ROAD WITH ONE SIDE WALKWAY

NCS – TWO LANE ROAD

noise barrier

retaining wall
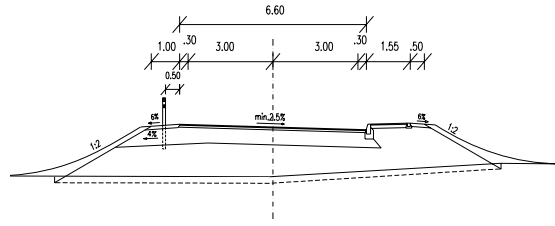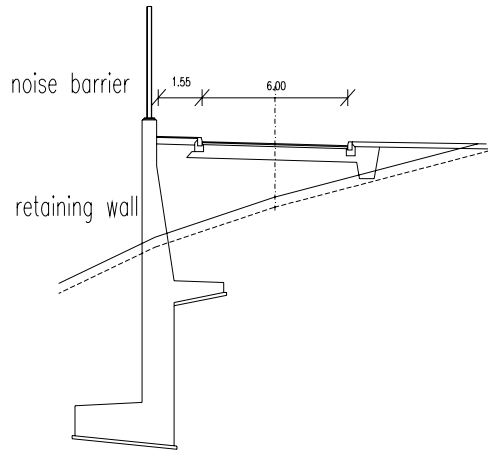
NCS – MOTORWAY

ENVIRONMENT PROTECTION (CONTROLLED OUTFLOW)

NCS – MOTORWAY

ADDITIONAL LANE

### 3.4.6 Detailed Cross Profile (DCP)

A Detailed Cross Profile (DCP) is a graphic survey of the road cross section on the exactly defined location on the road axis with the purpose:

- to define the level position of the road and its extremes (terrain and nivelete height of road axis, the height of both carriageway edges, the height of the curbs, slopes of embankment, the distances of side-placed elements),

- to show the inclination of the carriageway and all strips united to,

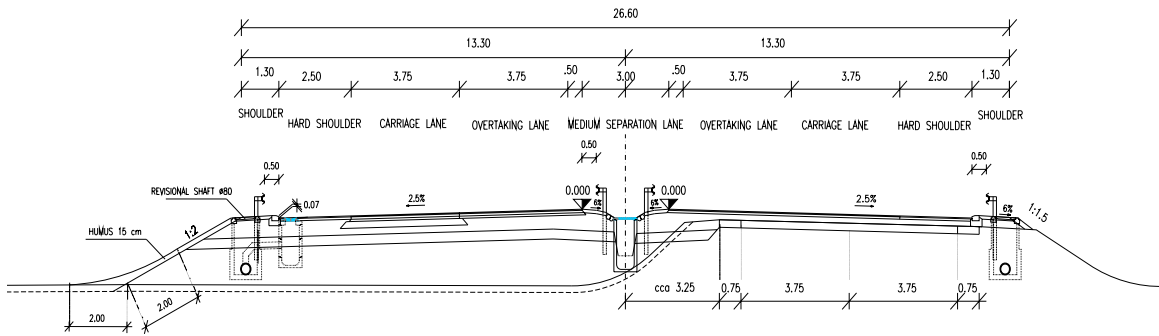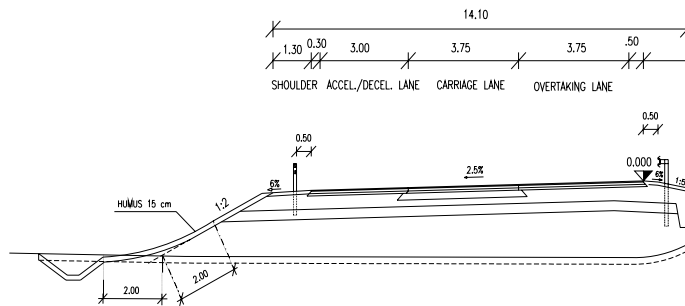- to measure or to calculate the planes of earthworks for the mass-profile and disposition plan of earthworks (top soil, cut, fill, embankments top-soil covering),

- to show the position of the installations and/or drainage elements in the road body,

- to define the details of the element for the leading of water flow through the road body (culverts) when it is placed in the profile and

- to show the kind and position of various arrangements alongside the road (foundation of the pillars etc) when they are placed in the profile.

Detailed cross profiles are prepared on the base of the NCP or CCP and located on the beforehand defined distances along the road axis. They are used for:

- the calculation of the quantities and costs of the designed road components,

- the execution of earthworks and

- for the controlling of the executed works.

The distances between two neighbour DCPs are different by different level of the design and depend upon the intensiveness of road-axis curvature as well.

In the design-maps and on the building site (marked wooden posts) the DCPs are marked with:

- current numbering,

- cipher (P-xx),

- length-position on the road-axis (stationing) or

- combination of before quoted marks,

to enable full recognition for following their disposition by the designers, by executers of construction works and by the members of controlling team as well.


Application of DCP:

- in general studies as single figure to show the relations between road and existing land-use, as anxious enclosure,

- in outline design with constant disposition (20, 25 or 50 m) or on the points of terrain and nivelete crossings, as obligatory enclosure,

- in execution projects with constant disposition (5, 10, 20 or 25 m) or with independent disposition ( not greater as 20 m), as obligatory enclosure,

- in the building site to mark the location of each designed DCP and to lay out the slopes of the embankment (building profiles).

# Figure 51: Detailed cross profile (DCP) – examples
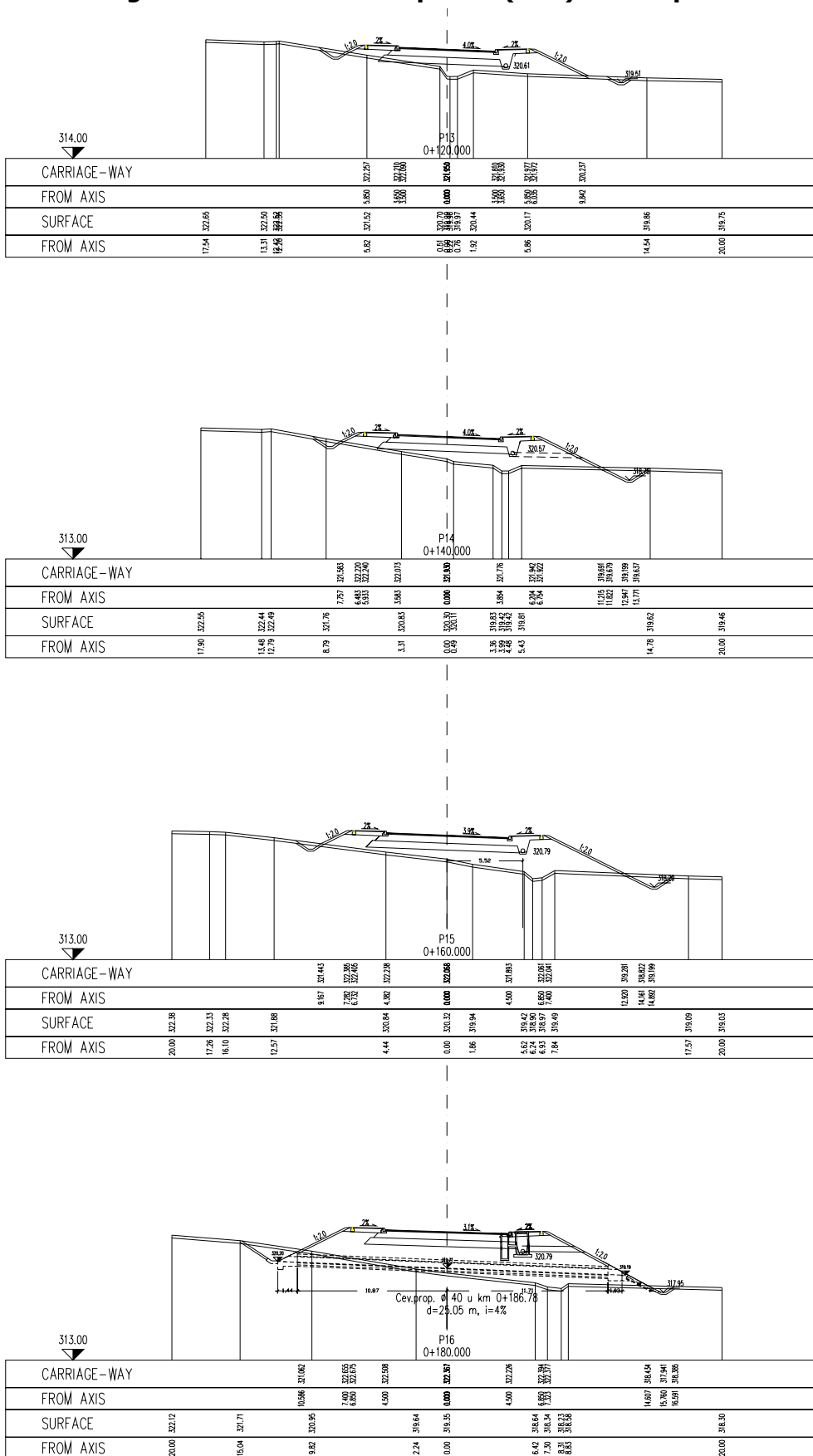
# 4  PROJECT ROAD ELEMENTS

## 4.1 GENERAL BASIS

A kind and dimensions of geometrical and technical elements of the roads using for the composition of the design-plan and the interacting harmony among them depend of:

- type of the road (category),
- public defined highest admissible speeds on the roads,
- public advantageous average speeds for each type of roads,
- land-use and other spatial qualities in the region where the road is incorporated (inside/outside urban zone, sensitivity of existing land-use elements and from them arisen restrictions),
- different psychophysical characteristics of the typical drivers,
- carriageway characteristics by clean and wet surface (coefficient of friction, kind of surface material, distance from carriageway edge to lateral obstructions),
- carriageway surface draining characteristics (slopes, outflow conditions),
- traffic volume and a portion of heavy vehicles,
- rationality and feasibility of the investment by constructing and maintaining the road,
- bounds of possibility for the spatial (3D) harmonization of road elements,
- bounds of possibility for the harmonization of road elements to the disposition and form of the road belonging surfaces or installations (crossroads, crossings, internal and public infrastructure) and
- correlated impacts on the use of single element

to achieve as good results as possible regarding to

- functionality of the road,
- realization of drive-dynamic effects
- pleasant feeling at driving
- traffic safety
- harmonized spatial incorporation of the road,
- as low as possible construction and maintenance costs and
- as low as possible operational (users) costs.

This guideline adduces the limit values of the dimensions of each single element, theoretical procedures, and practical calculations with tables and diagrams for the use of elements outside the limited values and terms and conditions for forming the composition of them.

The guideline consists of four main components:

- basic data and calculations,
- sight clearance,
- geometrical elements of road-axis in horizontal and vertical alignment and
- cross-section elements, the structure and composition of them, and typical cross-sections with added practical traffic capacities.

## 4.2 SIGHT DISTANCE

Both traffic safety and traffic flow quality require adequate sight distance on the road to allow due speed reduction, stopping the vehicle, or overtaking.

The stopping sight distance lengths are bases to calculate the following:

- width of the sight field along the road alignment (sight widening),

- sight distance triangle at crossroads (refer to crossroads at grade, item 2.1.5.8.1),
- minimum radius of the vertical curvature,
- overtaking distance, and
- sight distance on the left lane (roads with physically separated one-way carriageways).

For the mentioned calculations the conceptual speed $V_{con}$ shall be assumed.

To ensure a higher level of the traffic safety it is recommended to consider the speed $V_{des}$ or $V_i = (V_{con} + 20$ km/h$) \leq V_{adm}$ for the calculation of the minimum radius of the vertical curvature, and of the overtaking distance on two-lane two-way roads of groups A and B (out of settlements).

In extremely severe spatial conditions the stopping distance can be reduced by:

- introducing better mineral aggregate (silicate aggregate), or
- more frequent renewal of the wearing course (it is mandatory to measure the coefficient of friction more frequently), or
- reducing the driving speed (speed restriction).

## 4.2.1 Speed decreasing distance

The distance required for the speed reduction (crossroads, points of access) shall be calculated from the following expression:

$$L_z = (V_z^2 - V_k^2)/26(a_z + 0.1 \cdot s_i)$$

where:

$V_Z$ ... start speed [km/h]

$V_K$ ... end speed [km/h]

The deceleration value $a_z$ [ms$^{-2}$] shall not exceed the admissible value of the coefficient of friction indicated in Table 9.

## 4.2.2 Stopping distance and sight distance clearance

### 4.2.2.1 Stopping distance

Stopping distance $L_z$ is the minimum length on which a driver can stop the vehicle on a wet and clean carriageway in conditions of admissible value of the coefficient of friction (= $f_{T\ 90\%}$).

The values indicated in Table 9 have been specified for asphalt wearing courses made of carbonate aggregate.

For different types of wearing course materials the stopping distance shall be assessed on professionally established values of coefficient of friction.

### 4.2.2.2 Shortened stopping distance

Introducing silicate aggregate grains to the asphalt wearing course, higher values of coefficient of friction can be achieved ($f_{T\ 50\%}$ in Table 9), thus the stopping distance is shortened (to ~60%).

When a shortened stopping distance is applied to a carriageway which wearing course is made of carbonate grains, a programme of early control measurements of the coefficient of friction on that particular road shall be specified in the design.

### 4.2.2.3 Stopping sight distance

Stopping sight distance $P_z$ is the minimum length, at which a driver becomes aware of an obstacle, to completely stop the vehicle in conditions of the admissible value of the coefficient of friction:

$$P_z = L_z + 7m$$

The safety distance of 7 m can also be omitted, which is not the case for roads of the technical group A.

The stopping sight distances $L_z$ are plotted as follows:

- in Figure 52 for a shortened stopping length,

- in Figure 53 for the technical group A,
- in Figure 54 for the technical group B, and
- in Figure 55 for the technical group C.

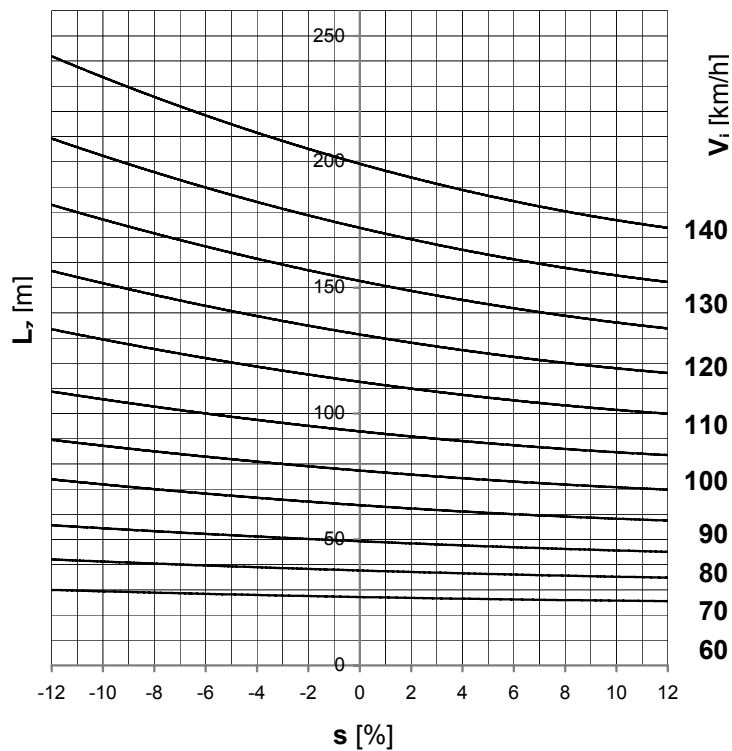**Figure 52: Shortened stopping sight distance ( $f_{T50\%}$ )**

**Figure 53: Stopping sight distance – road technical group A**
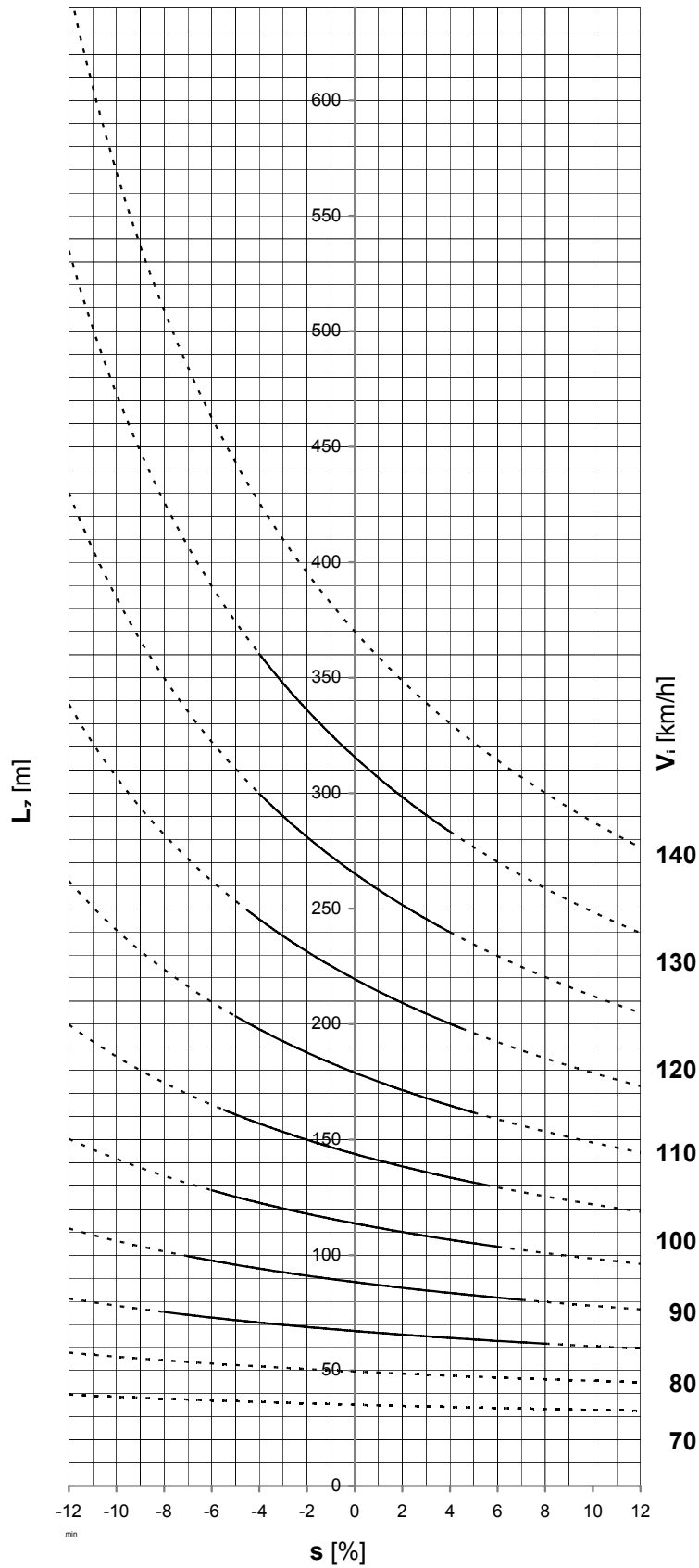
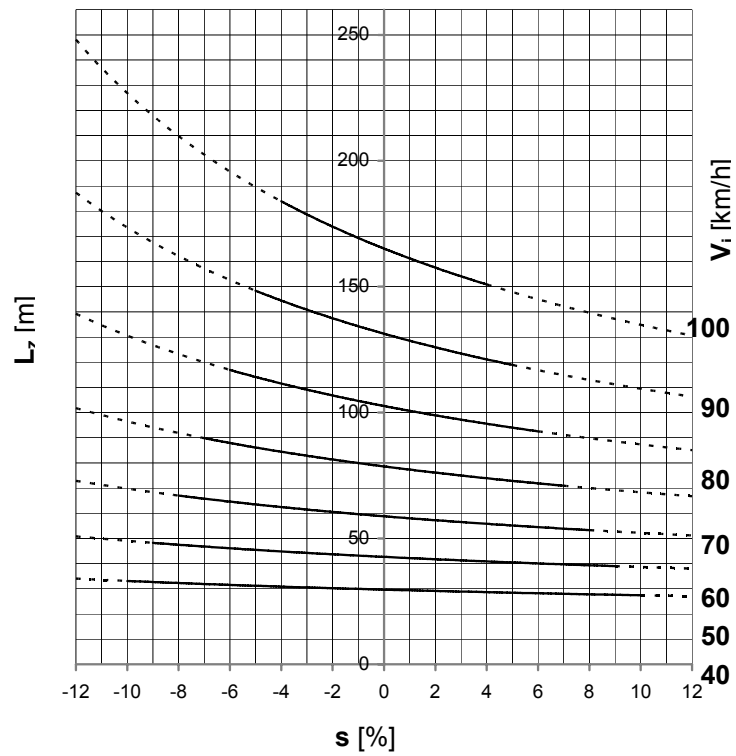## Figure 54: Stopping sight distance – road technical group B



## Figure 55: Stopping sight distance – road technical group C
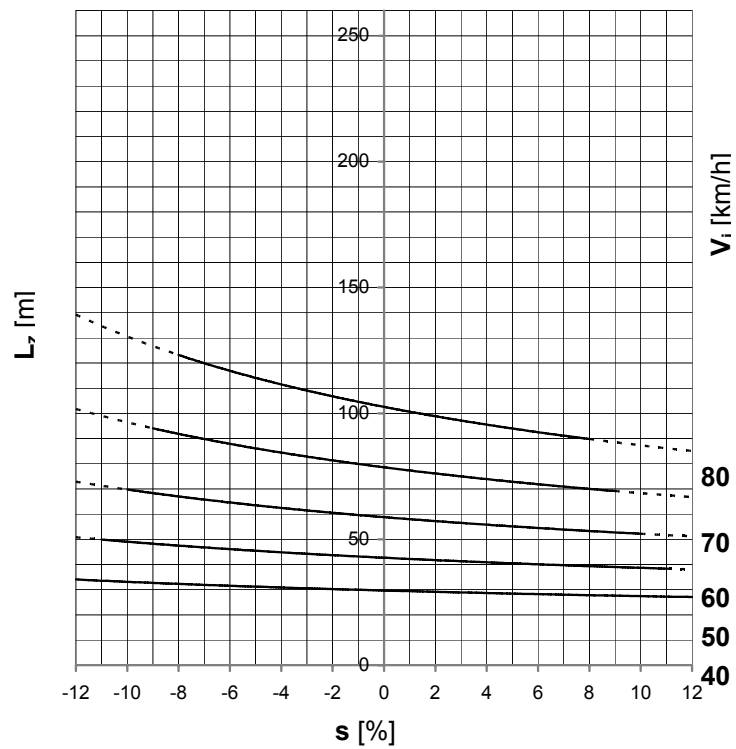
Sight distance shall be ensured extra for each individual traffic direction. From the design point of view, the sight distance is ensured in both plan (horizontal sight distance) and elevation (vertical sight distance).

## 4.2.3 Horizontal sight clearance

### 4.2.3.1 Horizontal sight distance

Horizontal sight distance ($P_z$) shall be ensured by excluding all the continuous obstacles on the inner side of the horizontal curvature (on both right and left side), including mobile obstacles (parked cars, deposit areas, etc.), at suitable distance from the carriageway edge. The area obtained in this way is called sight field or sight widening (berm).

Within this area only traffic equipment elements can be situated, except concrete safety barriers, way marks, boards to confirm the direction, and noise barriers.

Steel safety barriers represent an obstacle when horizontal circular arc is accompanied with vertical alignment runs in a convex curvature. Such location shall be extra verified in the road design. If required, additional distance to steel safety barriers shall be provided.

Where it is impossible to ensure sufficient sight distance, the radius of the horizontal curvature shall be increased (e.g. in tunnels or on viaducts), or the driving speed shall be limited by means of appropriate traffic signs. A shortened stopping distance is only admissible when a wearing course made of silicate aggregate is foreseen on that particular location ($f_{t50\%}$).

Sight widening (berm):

A scheme and parameters of a sight widening (berm) are indicated in Figure 56. The driver is situated in the middle of the inner traffic lane.

$$b_p = \frac{P_z^2}{8 \cdot R} \text{ and } b' = b_p - \frac{b}{2}$$

where:

b'      [m]     width of sight widening (berm)
$b_p$    [m]     width of sight field
$P_z$    [m]     stopping sight distance
R       [m]     radius of horizontal curvature

A transition to the sight field width shall be carried out proportionally along the entire transition curve length.

**Figure 56: Scheme of horizontal sight field**
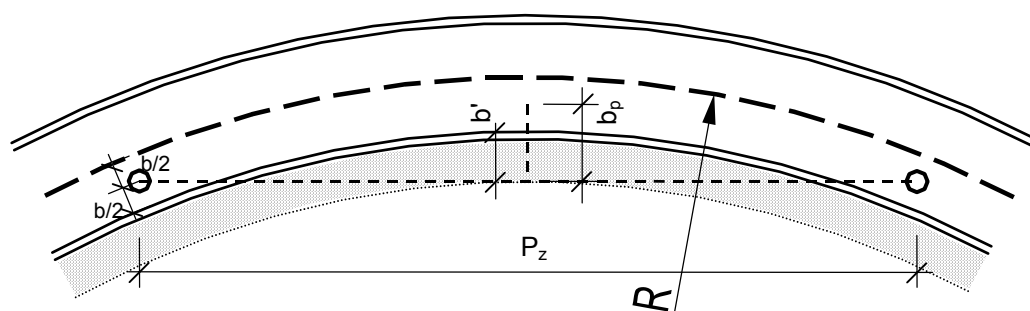


On roads consisting of two separated one-way carriageways the sight distance shall also be ensured on the extreme left traffic lane. This sight distance shall be verified in the design in the following cases:

* when steel safety barriers are foreseen on such a road section, which is situated in both horizontal and vertical curvature at the same time,
* through tunnels, and
* on viaducts.

The sight distance scheme is indicated in Figure 57, whilst the required radius of the horizontal circular arc can be determined using the nomogram in Figure 58.

## 4.2.4 Vertical sight distance

On certain road, the vertical sight distance is defined by the driver's eye height (1.00 m), and by the height of an obstacle on the road at stopping sight distance. On principle, the height of an obstacle is equal to zero. However, as some irrational solutions occur at a higher speed, the invisible portion of the obstacle is tolerated. The minimum visible heights of obstacles on roads are indicated in Table 29.

Minimum radius of convex vertical curvature:

$$P_z = \sqrt{\left(r_{minkonv} + h_1\right)^2 - r_{minkonv}^2} + \sqrt{\left(r_{minkonv} + h_2\right)^2 - r_{minkonv}^2}$$

where:

| | | |
|---|---|---|
| $P_z$ | [m] | stopping sight distance |
| $r_{minkonv}$ | [m] | minimum radius of convex curvature |
| $h_1$. | [m] | driver's eye height above carriageway - $h_1$ = 1.0 m |
| $h_2$ | [m] | height of obstacle on the road (Table 29 ) |

### Table 29: Minimum visible height of obstacles on roads

| $V_i$ | [km/h] | 40 | 50 | 50 | 60 | 70 | 80 | 90 | 100 | 100 | 110 | 120 | 130 | 140 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $h_2$ | [m] | 0.00 | 0.00 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.10 | 0.10 | 0.15 | 0.15 | 0.15 |

Note: Different values for speeds 50 or 100 km/h are considered for road technical groups of different complexity.

For the minimum radius of convex curvature $r_{minkonv}$ refer to section Vertical curvatures.

### Figure 57: Sight distance on the extreme left traffic lane
### (source: RAS-L, 1995)



Legend:
a ... distance between the edge of the
       inner traffic lane and the obstacle
b ... driver's position (b=1.80 m or
       ½ of the traffic lane width)
$\Delta R_h$ = a + b
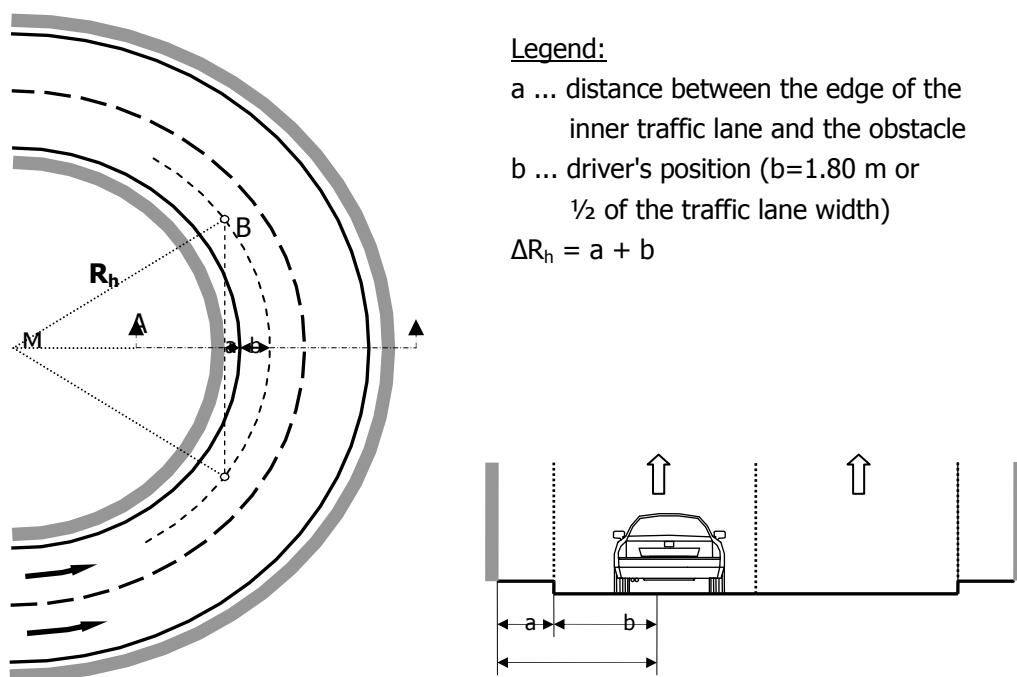
### Figure 58: Radius $R_h$ as a function of the distance between an obstacle and the extreme traffic lane edge, and of the vertical alignment longitudinal fall

**(source: RAS-L, 1995)**

L_z [m]

$R_h=1200m$

$R_h=1000m$

$R_h=800m$

$R_h=600\ m$

clean and wet
roadway

s=-4%
s=-2%
s=0%
s=2%
s=4%

dry
roadway
s=0%

300

250

200

150

8,0   7,0   6,0   5,0   4,0   3,0   2,0   1,0        40        60        80       100       120

a [m]                                        $V_i \leq V_{dov}$ [km/h]
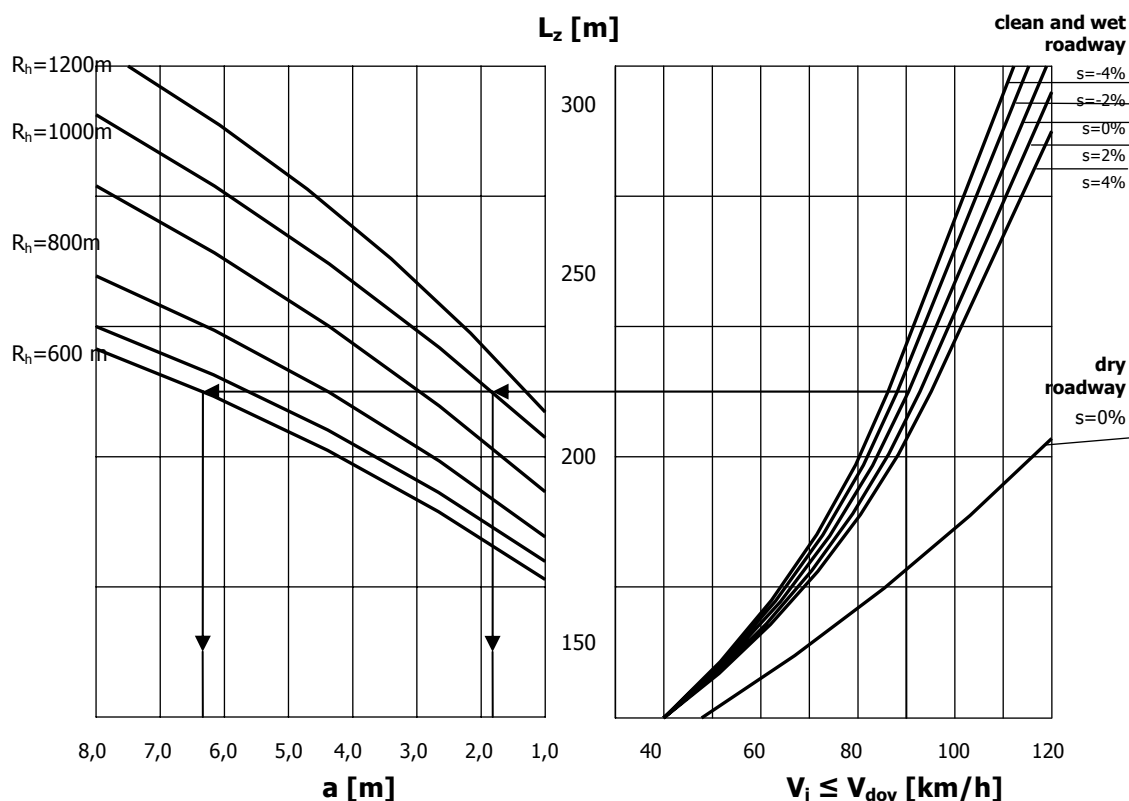
## 4.2.5 Overtaking sight distance

### 4.2.5.1 Overtaking sight distance – horizontally

The quality of traffic flow and the traffic safety decisively depend on the portion of the road provided for the overtaking manoeuvre.

Overtaking sight distance ($P_P$) is the minimum sight distance that must be available to enable the driver of one vehicle to overtake another vehicle safely and comfortably, without interfering with the speed of an oncoming vehicle travelling at the design speed should it come into view after the overtaking manoeuvre is started.

The minimum overtaking sight distances in Table 30 are calculated on the base of a commonly acceptable acceleration ($a = 1,5\ ms^{-2}$) considering the highest admissible speeds of both, the overtaking as well as the oncoming vehicle.

**Table 30: Minimum overtaking sight distance**

| $V_i$ | [km/h] | **40** | **50** | **60** | **70** | **80** | **90** | **100** |
|---|---|---|---|---|---|---|---|---|
| **min $P_P$** | [m] | - | 330 | 380 | 450 | 520 | 600 | 680 |

### 4.2.5.2 Overtaking sight distance – vertically

On two-way carriageways overtaking is not admitted in the areas of vertical convex curvatures (traffic sign + continuous separating line) which radius is smaller than the minimum required radius which enable the overtaking.

When assessing the radius of the vertical convex curvature on which overtaking is permitted, the curvature radius calculation shall take account of the sum of stopping distances of vehicles driving in opposite directions, of the speed $V_{des} \leq V_{adm}$, and of the obstacle height $h_2 = 1.0$ m.

For practical methods of assessing the areas where overtaking is not admitted it is sufficiently accurate to carry out such interdiction on all the vertical convex curvatures of the following radius:

$$r < 1{,}75 \cdot r_{min\ konv}$$

### 4.2.5.3 Ensuring overtaking sight distance

On two-way roads of a single carriageway and of the technical group A, the overtaking sight distance shall be ensured at such a length as to achieve the foreseen sufficient capacity of the road at selected travelling speed. As the road length the whole section between adjacent centres defining the road category shall be considered.

Where the traffic design does not define the required length of sections to ensure the overtaking sight distance, the following shall be considered as the minimum section length of sufficient overtaking sight distance on two-way roads (between two centres):

> 25% of the road length for roads belonging to the technical group A, and

> 15% of the road length for roads belonging to the technical groups B, and C.

In extremely severe conditions in view of the relief, or in case of other spatial restrictions, the above mentioned minimum section length where overtaking is feasible can be omitted. Such an approach shall be specified by the terms of reference separately for each individual road.

On longer ascents where an additional lane (slow traffic lane) is arranged overtaking is not allowed when driving downhill as this is very dangerous.

## 4.2.6 Sight distance in crossroads areas

### 4.2.6.1 Sight distance upon entering crossroads

Sight distance upon entering a crossroads is a length enabling a driver on a priority road to stop his vehicle before the crossroads, if a vehicle arriving from a side road is already entering his traffic lane, or is crossing the crossroads. The sight distance is equal to the stopping distance.

The sight distance upon entering a crossroads is presented in detail in the chapter Crossroads and points of access at grade.

### 4.2.6.2 Sight distance upon approaching crossroads

Sight distance on approaching a crossroads is a distance allowing a vehicle arriving on a side road to enter the crossroads without any speed reduction, or to stop in time in case that the crossroads is occupied.

This sight distance is discussed in detail in the chapter Crossroads and points of access at grade.

# 4.3 ROAD AXIS IN SPACE

Road axis line is a 3D-curve, which is, in the practical part, presented in plan (layout), whilst in elevation as a longitudinal section along the axis in its line, or, in special cases, in the line parallel to it in the road cross section. An adequate 3D-course of the road axis line is achieved by taking account of the conformity of geometric elements in both projections.

Road axis line is a curve composed of geometric elements, which, jointly with the carriageway technical elements (particularly cross-fall) ensure driving-dynamic conditions for both safe traffic and aesthetic appearance of the road.

When a route of particularly important roads is located, it is recommended to verify additionally the suitability of the spatial (3D) course of the road axis. This can be carried out by a computer visualisation, which basic intention is to ensure aesthetic appearance of the planned road

## 4.3.1 Normal position of road axis in cross-section

As a rule, a road axis line is always located to the left of the traffic lanes for the individual driving direction: in roads consisting of a single carriageway, of two or more lanes, the road axis lade is situated at the boundary between both traffic directions (in the carriageway middle as a rule), whereas in roads consisting of two separated carriageways, one for each directions, it is located in the middle of the central reserve (Figure 59).

**Figure 59: Road axis position: normal, favourable, and exceptional**
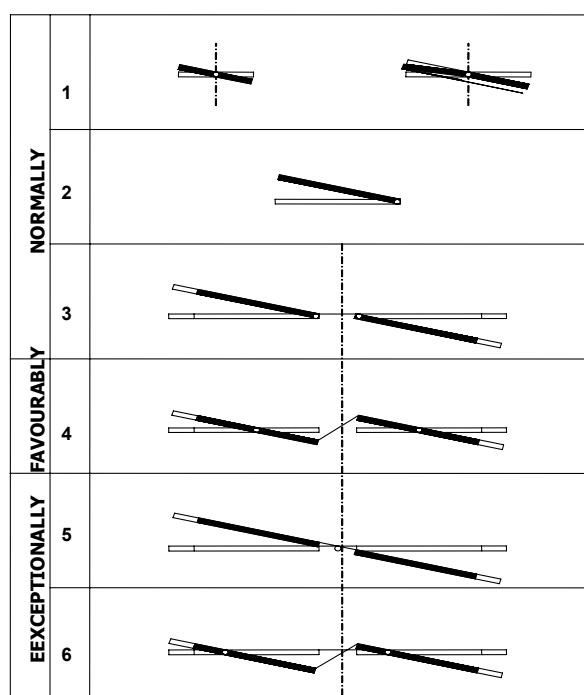


The rule of conducting the road axis along the left edge also applies to cases where special traffic lanes supplementing the carriageway are conducted otherwise than the road basic line, and particularly to the following:

- to entering and exit lanes at split level crossroads,
- to entering and exit lanes at crossroads at grade, where the traffic flow is conducted independently of the main traffic flow,
- where traffic lanes are shifted due to arranging an additional lane for turning left at crossroads, if such shifting is not carried through according to special method (refer to chapter Crossroads and points of access at grade), and
- where the central reserve on two-carriageway roads is modified.

Where a central reserve located between two carriageways running in opposite directions is widened for constructive needs (e.g. a tunnel, each individual direction conducted separately), the road axis line is conducted extra for each direction taking account of the rules, which apply to one-carriageway roads.

A road axis line can also be situated on any other longitudinal line in the road cross-section, or individual one-way carriageway, if justified reasons exist (Figure 59). Such a position of the road axis line is acceptable without any special argumentation, when reconstruction of a one-carriageway road under traffic is designed. As a rule, in such cases the road axis line is foreseen at either of the carriageway edges.

## 4.3.2 Position of vertical alignment in cross-section

As a rule, the road axis line is also the vertical alignment line at the same time. In two-carriageway roads with central reserve where the road axis line is located in the middle of the central reserve, the vertical alignment line generally runs, parallel with the road axis line, along the left edge of each of both one-way carriageways.

Vertical alignment line can also be selected in any other position in the road cross-section, within or outside the carriageway, provided that justified reasons exist (very gentle slopes of the vertical alignment, twisting, etc.).

The vertical alignment position in cross-section is shown in Figure 59.

The vertical alignment jump in the cross-section shall be obligatorily performed on the horizontal element of constant curvature (i.e. on an arc or a straight line).

On roads consisting of two separated carriageways, where at least two traffic lanes run in each direction, the vertical alignment shall be defined at either right or left edge of the traffic lane (not at the edge of the emergency lane). The position shall be selected in view of the feasibility of central reserve execution (i.e. width and arrangement). By conducting the vertical alignment along the left edge of the inner lane a uniform arrangement of the central reserve is achieved, which is favourable to execute drainage equipment within the central reserve (longitudinal ditch and inflow shafts). In addition, steel safety barriers interconnected by diagonal bracing can be installed (in the central reserve there is a shallow through-shaped, and not a deep ditch). Conducting the vertical alignment along the right edge of the inner traffic lane, favourable effects of the protection against dazzle resulting from the vehicles driving in opposite direction, smaller twisting length, and better accommodation to the ground where a road runs on a slope are achieved. Other effects, however, are less favourable. The position of the vertical alignment shall be specified by the design.

The position of the vertical alignment in cross-profile has decisive ascendancy over the dimensions of elements enabling execution of the cross-fall variation (twisting length).

In view of vertical alignment, two-way roads consisting of separated carriageways can be conducted by different height course, where this is directed by spatial requirements or construction economy. In such a case vertical alignment elements are different for each one-way carriageway, yet both alignments shall be harmonized. As a rule, the vertical alignment position is shifted to the middle of each one-way carriageway.

## 4.3.3 Sectional jump of road axis and vertical alignment

Where technical, spatial, or constructional reasons exist, due to which, on an individual road section part, the road axis line, or the vertical alignment line have to shifted in the cross-section, this shifting shall be carried through by the method called "jump" of the road axis or vertical alignment in cross-section. As a rule, two jumps always exist: forwards and backwards. Each of both jumps shall be executed in the area of a uniform axis curvature (i.e. in an area of an arc or a straight line) to ensure parallelism of the line course (Figures 60 and 61).

Road axis jump out of the area of uniform curvature (in the transition curve area) is admitted, yet is shall be so executed as to avoid discontinuity of road axis curvature and the vertical alignment course on both separated axes, when the vertical alignment is conducted in the road axis line.

**Figure 60: Axis jump before tunnel or any other structure**

Tunnel (or any other structure)

Axis jump
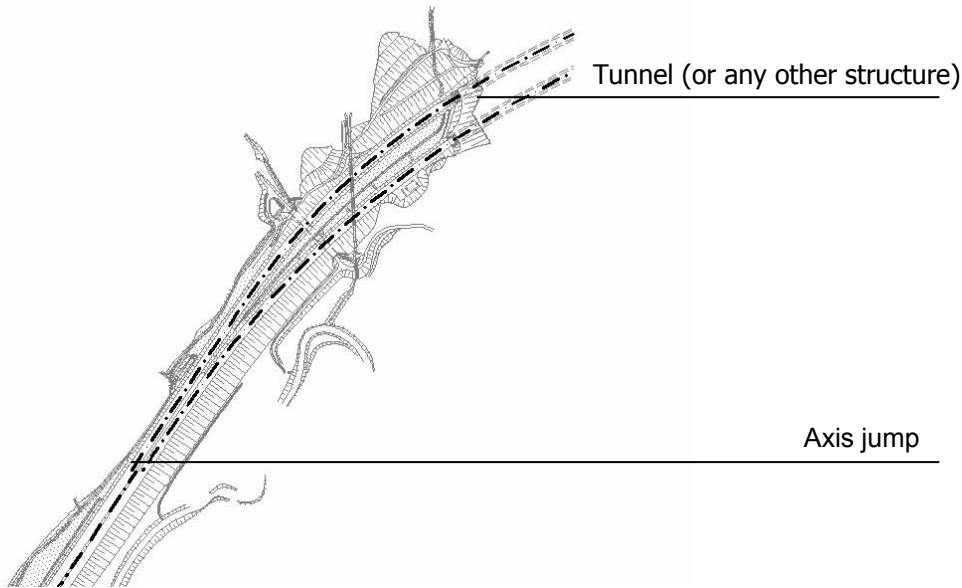
Where, on a planned road, existing, entering, and/or changing lanes are arranged, which are a part of the system of a split level or a major at grade crossroads (separated lanes for individual directions), the axis line, and the vertical alignment of these additional lanes shall be obligatorily conducted along the left edge to allow an undisturbed accomplishment of the cross-fall on the additional lane.  The beginning and/or terminal part of the additional lane axis shall be executed by a jump of both axis and vertical alignment (Figure 62).

**Figure 61: Axis and vertical alignment jump**

**(a)**

in the area of the cross-fall
in the same direction

road axis

R

R

road vertical alignment

**(b)**

in the area of the cross-fall
in the opposite direction

road axis

A

A

R
A

R
A

road vertical alignment
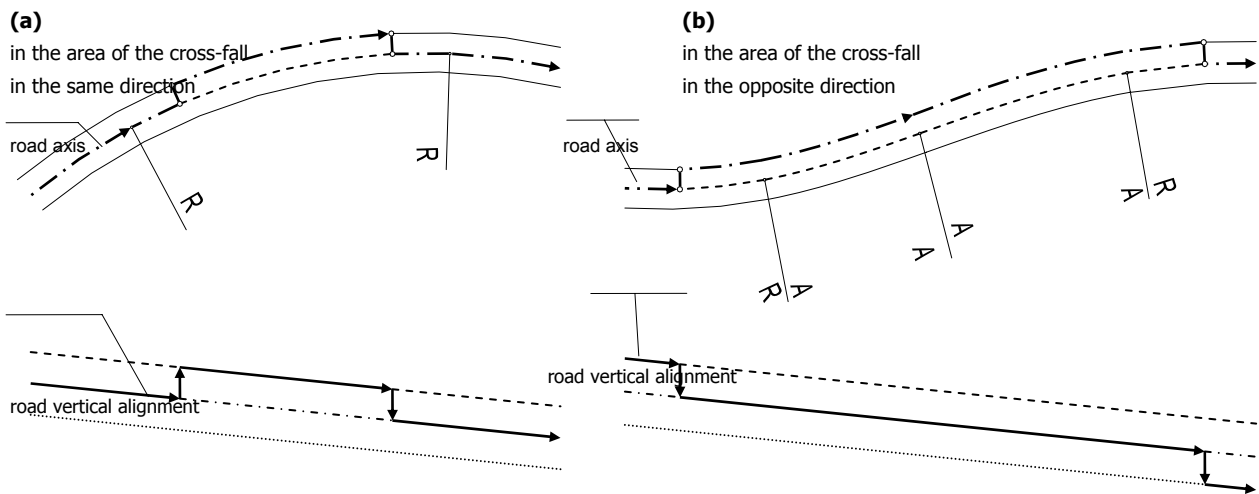
**Figure 62: Axes of crossroads entering/exit ramps**



Position of road axis and vertical alignment (primary axis)

Position and vertical alignments of ramps and other lanes (secondary axis)
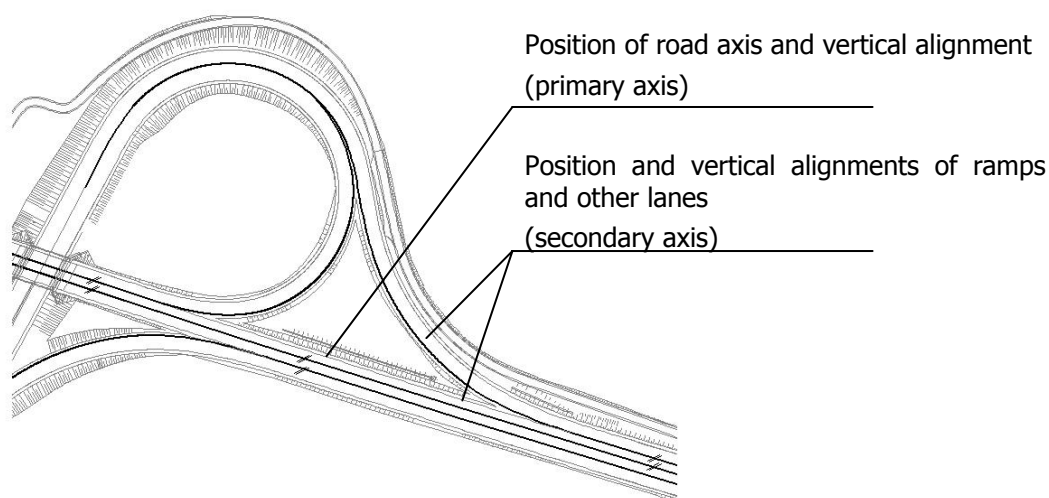
# 4.4 ROAD AXIS GEOMETRIC ELEMENTS IN PLAN (HORIZONTAL ALIGNMENT)

Road axis horizontal geometric elements are the following:
- Straight line,
- Arc, and
- Clothoid (transition curve).

For an individual road technical group the limiting values are assessed under different conditions. In case that, for different reasons, a need of introducing elements, which are more complex than those foreseen for certain technical group, occurs on an individual road, such elements shall be designed, which apply to a higher technical group of roads. In such a case, all the elements shall be adjusted accordingly, not only the horizontal ones.

## 4.4.1 Straight line

### 4.4.1.1 Application and selection of dimension

On roads of the technical group A, a straight line is designed in special topographic conditions only (roads in valleys, roads running along infrastructure, etc.), in special spatial conditions (in settlements), or on sections where its use is reasonable for traffic-technical reasons (crossroads and points of access, ensuring overtaking sections, significant structures, etc.).

A straight line is most frequently an unnatural form in the space.

When designing a straight line its following deficiencies shall be considered:
- Aggravated estimation of the speed of a vehicle driving in the opposite direction,
- Tiresome driving,
- Dazzle due to headlights of a vehicle driving in the opposite direction (at night),
- Insufficient sight distance from behind the preceding vehicle,
- Unstable position of the steering wheel during driving (Figure 63).

When introducing long straight lines special attention shall be paid to the following:
- Dimension of the arc connected to the straight line, and
- Sufficient dimension of vertical alignment curvatures (Figure 64).

The use of straight line is not limited on roads of technical groups B (within settlements), C, and D.

**Figure 63: Road with separated carriageways (a), and two-lane road (b) in a straight line  on a flat land**



**(a)**                                                        **(b)**
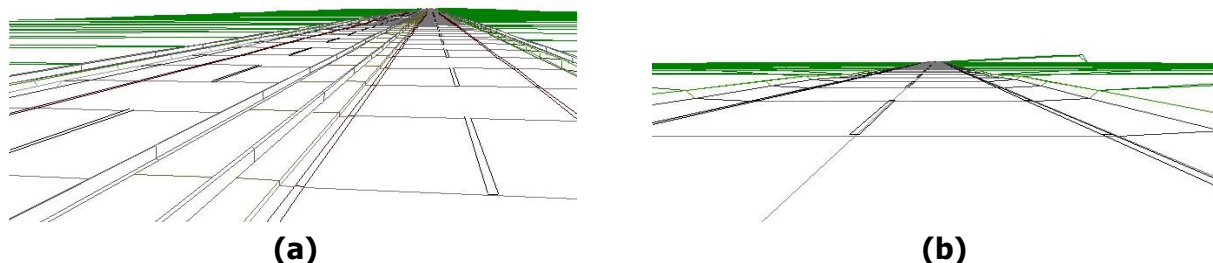
**Figure 64: Road with separated carriageway of insufficient concave (a), and insufficient convex (b) vertical curvature**



**(a)**                                                        **(b)**
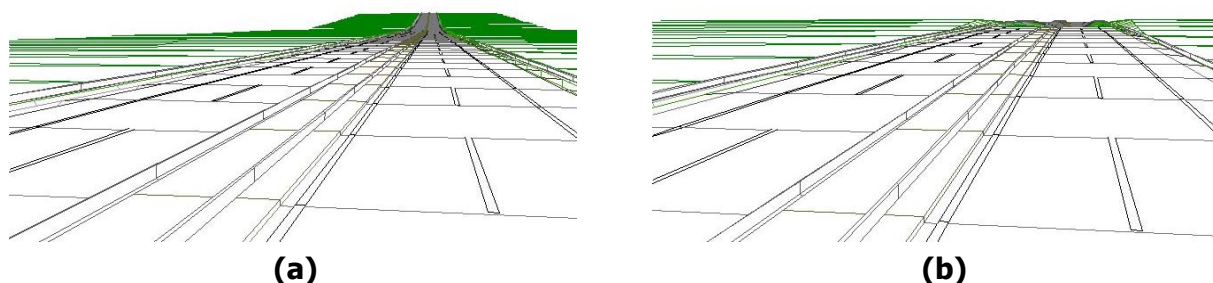
### 4.4.1.2 Limiting values

For possible continuous dazzling and tiresome driving the length of the straight line ($L_{sl}$) is limited to the maximum visibility depth of $L_{sl} < 20\ V_{con}$ on roads of the technical group A. When selecting the length of the straight line, harmonization with the vertical course of the route shall be considered as well.

Straight lines shorter than $L_{sl} = 4xV_{con}$ between two arcs of the same direction, and shorter than $L_{sl} = 2xV_{con}$ between two arcs of the opposite direction (called "short straight line") shall be avoided on roads of the technical group A, whilst on roads of the technical group B they should only be designed under certain conditions. In such a case the length of the straight line shall be such as to allow at least 5 seconds of driving on it.

On roads of other technical groups there are no restrictions concerning the use of the straight line.

## 4.4.2 Arc

### 4.4.2.1 Application and selection of dimension

Dimensions of arcs shall be selected to allow such a driving speed, which is as close as possible to the foreseen travelling speed on an individual road (ensuring functionality and economy). In case of a very steep vertical alignment such a dimension of the arc may be selected, that its cross-fall, in combination with the longitudinal fall (resulting carriageway slope $q_{res}$) does not exceed the admissible value of 10% for roads of the technical groups A ($q_{rez}=8\%$ is recommended), and B. On roads of the technical group C such limitation is not mandatory, however it is recommended.

The arc length depends on the duration of driving on it:

- 7 seconds to ensure a comfortable drive, and an aesthetic appearance of the route, and
- minimum requirement with regard to the conditions indicated in Table 8 (2 or 1.5 seconds).

In case of large radii the arcs become so stretched that they can be visually perceived as straight lines. This is especially evident on relatively short sections of arcs, and in such curvatures where the change of direction is insignificant. The upper limit at which the part of a curvature still differs from the straight line is the following:

$$\hat{\alpha} = 0{,}02 = \frac{L_{KL}}{R} = \frac{1}{50}$$ , which corresponds to an angle of $\alpha = 1°$.

Experiencing a curvature depends on the ratio of the curvature radius to the curvature length. For larger curvatures (R > 5,000) it applies that the curvature is perceived at the ratio of R:$L_{KL}$ = 20:1 ($\alpha = 3°$). The length of smaller curvatures shall be such as to allow driving on it at least 2 seconds. (driver's sight).

In areas of crossroads and points of access sight distances and correct execution with regard to the height of the connecting road shall be ensured. To fulfil these conditions, the radius of the horizontal arc of the primary direction shall be generally such that the cross-fall (q) does not exceed 4%.

In areas of crossroads, major structures, or in case of permanent obstacles in the central reserve on roads consisting of two one-way carriageways such arc radii shall be selected as to ensure the stopping sight distance $V_{des}$ on the extreme left (overtaking) traffic lane as well.

Where the vertical alignment of the road route allows significant exceeding of speed of vehicles in a free traffic flow ($V_{des}$ is substantially higher than $V_{con}$), larger arcs shall be designed for the road axis than the minimum recommended ones, whilst the harmonization of successive arcs shall be ensured in compliance with the most rigorous requirement (Figure 68).

Circular arcs shall be so selected as to ensure their incorporation to the natural environment to the greatest possible extent, and to enable a harmonized creation of the road vertical alignment, as well as a mutual conformity of adjoining arcs (Figure 65).

**Figure 65: Concave (a) and convex (b) vertical curvature**



(a)                                                                                   (b)
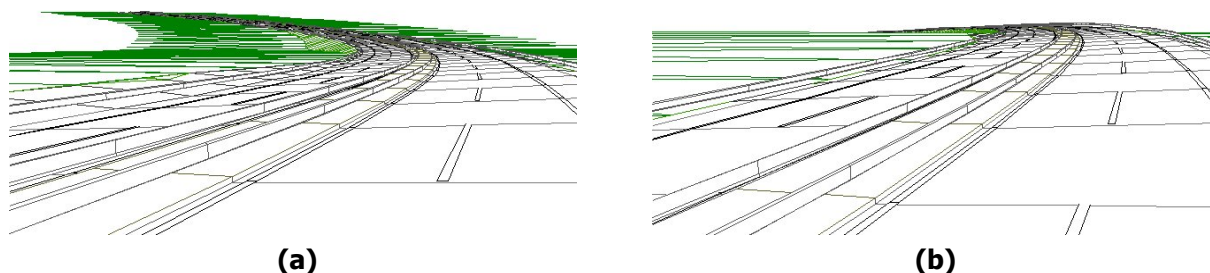
*4.4.2.1.1  Arc length*

A normal arc length depends on the following:

- duration of driving on the arc (psychophysical effect),
- lengths of adjoining circular arcs and transition curves (aesthetical effect of uniformity), and
- adapting to condition of application in space.

The smallest length of an arc for roads of the technical groups A and B (out of settlements) is defined by the duration of driving on the arc (normally 5 to 7 seconds, minimum 2 or 1.5 seconds). There are no limitations for other roads. Theoretically, for other roads, a value of $L_{KL}$ = 0 (apex clothoid) may be used as well, yet this is not recommended.

The greatest length of an arc is not extra limited, and depends exclusively on the conformity with the dimension of the adjoining arc.

For traffic-safety reasons the following can be distinguished in view of the arc middle angle:

- a short curvature, and
- a long curvature.

The limit between abovementioned curvatures is defined by the condition of visibility upon leaving the arc (the sight distance on the road and the driver's field of visibility are ensured in dependence on the driving speed), namely, that a driver can estimate the feasible speed of driving on the road arc. Long curvatures (drivers cannot see the end of the curvature) shall be equipped with suitable traffic signs (a sign for a hairpin bend or a serpentine + recommended speed).

No special measures are necessary for curvatures of arcs of R ≥ 400 m.

## 4.4.2.2 Limiting values (technical, and in view of applicability)

The minimum radius of an arc connected to a long straight line of length $L_{sl}$ is indicated in Table 31.

### Table 31: Minimum radius of an arc connected to a long straight line

| $L_{sl}$ [m] | min R [m] |
|:---:|:---:|
| ≥ 300 | > 400 |
| < 300 | > $L_{sl}$ |

Limiting values of circular arcs $R_x$ ($R_{min}$, $R_g$, $R_k$) depend from:

- chosen conceptual speed $V_i$ ($V_{con}$, $V_{free}$) ,
- gravitational acceleration (9.81 ms$^{-2}$),
- cross-fall of the carriageway $q_x$ ($q_{max}$ or $q_{min}$ or $q_k$ = - $q_{min}$) and
- utilization rate of admissible value of the coefficient of friction  (x% . $f_{Rmax\ adm}$) (Table 9).

Limiting values of circular arcs:

$$R_x = \frac{V_i^2}{127\left(x\% \cdot f_{R\max adm} + q_x\right)}$$

where:

| | |
|---|---|
| $R_x$ | Limiting values of circular arcs, |
| $f_{Rmax\ adm}$ | admissible value of the coefficient of friction, |
| x% | utilization rate of admissible value of the coefficient of friction, |
| $q_x$ | limiting  cross-fall of the carriageway. |

Characteristic values of circular arcs $R_{min}$, $R_g$, $R_k$ and $D_{kl}$ are indicated in Table 32. All the values indicated are defined for a pavement asphalt wearing course made of carbonate aggregate and bituminous binder, and in compliance with the conditions indicated in Table 9).

$R_{min}$ is defined by the maximum cross-fall of the carriageway $q_{max}$ in accordance with conditions indicated in Tables 8, and 9; $R_g$ is defined by the minimum cross-fall $q_{min}$, whereas $R_k$ by the cross-fall outwards (q= -$q_{min}$).

Values of $R_{min}$ and $R_g$ are different for different road technical groups, and spatial conditions – outside and within settlements.

The arc length ($L_a$) in Table 32 is indicated for a condition of the minimum duration of driving on the arc. The upper limiting value of the arc radius is defined by the parameter of the lower limit speed of turning the steering wheel. The recommended limit amounts to R = 5,000 m, whilst the still acceptable one is R = 10,000 m.

When roads of the technical groups B (outside settlements), and C are designed in particularly restricted spatial conditions, and when dangerous ("black") points on existing roads of these technical groups are mended, radii of $R_i < R_{min}$ are exceptionally admissible. However, their cross-fall $q_i$ must not exceed 8%.

When road routes are located in areas of major structures such as tunnels or viaducts, of significant vertical alignment slopes, as well as in case of specific execution of the central reserve on two-carriageway roads, $R_{min}$ shall be extra verified. As a rule, $R_i > R_{min}$ may be applied to such road sections to ensure the sight distance, and to achieve the condition of the resulting carriageway cross-fall. Regulation dealing with designing structures on roads shall also be considered.

**Table 32: Limiting values of arcs for road technical groups**

| Technical group | | Conceptual speed $V_{con}$ [km/h] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **40** | **50** | **60** | **70** | **80** | **90** | **100** | **110** | **120** | **130** | **140** |
| **A** | $R_{min}$ | | | 125 | 175 | 250 | 350 | 450 | 550 | 700 | 850 | 1,000 |
| | $R_g$ | | | 500 | 700 | 1000 | 1400 | 1800 | 2300 | 2750 | 3400 | 4000 |
| | $R_k$ | | | 2000 | 2000 | 2000 | 2000 | 2500 | 3500 | 5000 | 7000 | 9000 |
| | $L_a$ | | | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 80 |
| **B** | $R_{min}$ (q=7%) | 40 | 65 | 100 | 150 | 200 | 275 | 360 | | | | |
| | $R_{min}$ (q=5%) | 50 | 80 | 125 | 180 | 250 | 350 | 475 | | | | |
| | $R_g$ | 70 | 115 | 180 | 265 | 380 | 525 | 700 | | | | |
| | $R_k$ | 200 | 300 | 500 | 800 | 1250 | 1500 | 2500 | | | | |
| | $L_a$ | 15 | 20 | 25 | 30 | 35 | 40 | 45 | | | | |
| **C** | $R_{min}$ | 40 | 65 | 100 | 150 | 225 | | | | | | |
| | $R_g$ | 60 | 100 | 160 | 240 | 350 | | | | | | |
| | $R_k$ | 120 | 200 | 325 | 500 | 750 | | | | | | |
| | $L_a$ | 15 | 20 | 25 | 30 | 35 | | | | | | |

## 4.4.3 Transition curve

4.4.3.1 Application and selection of parameter value

Transition curve is a road route element ensuring a continuous interconnecting of arcs, or connecting of arcs with a straight line, as well as an optical and aesthetical performance of the route locating. To accomplish the transition, a mathematical curve called clothoid is introduced, which ensures the following:

- Complete matching of tangents at the points of contact with the arc or the straight line;
- Gradual linearly proportional changing of road curvature between adjoining arcs;
- Gradual linearly proportional changing of side acceleration;
- Length to accomplish the cross-fall change between adjoining arcs (twisting);
- Aesthetic appearance of carriageway edge lines.

The following equations for the clothoid and the angle between it initial and final tangent (clothoid middle angle) apply:

$$A_i^2 = R_i \cdot L_i \quad \text{in} \quad \widehat{\tau} = \frac{L_i}{2 \cdot R_i} = \frac{A_i^2}{2 \cdot R_i^2}$$

Where:

| | | |
|---|---|---|
| $A_i$ | [m] | Clothoid parameter |
| $R_i$ | [m] | Arc radius at length $L_I$ |
| $L_i$ | [m] | Length along clothoid arc up to $R_i$ |
| $\widehat{\tau}$ | [rad] | Middle angle |

A clothoid is a +/- symmetrical curve enabling connecting of the same kind of each pair of arcs irrespective of their radius or orientation.

The obligation of clothoid application is defined in Table 8.

The applicable value of the clothoid parameter is within the limits of $\frac{R_i}{3} \leq A_i < R_i$, where $R_i$ is the arc radius to which the clothoid is connected.

The minimum value of the clothoid parameter ($A_{min}$) applies to the arc of radius $R_{min}$ only. For arcs of $R_i > R_{min}$ adequately higher values of $A_i$ shall be used.

A complete omission of the transition part between adjacent arcs is only allowed in case of a sequence of significant arcs indicated in Table 33. Here it is also recommendable to insert an intermediate straight line to ensure adequate arc spacing.

Table 33: Minimum arc radius when a clothoid is omitted

| $V_{con}$ [km/h] | min R [m] |
|:---:|:---:|
| $\leq 80$ | 1,500 (1,000) |
| > 80 | 3,000 (2,000) |

Note: Values in parentheses exceptionally apply to settlements

In addition to driving-dynamical properties a clothoid (transition curve) has a great aesthetical effect (Figure 66), which directly influences the psychophysical condition of drivers, and their decisions (traffic safety).

**Figure 66: Aesthetic appearance of transition from a straight line to a curvature without (a) and with (b) transition curve**



**(a)**                                                                    **(b)**
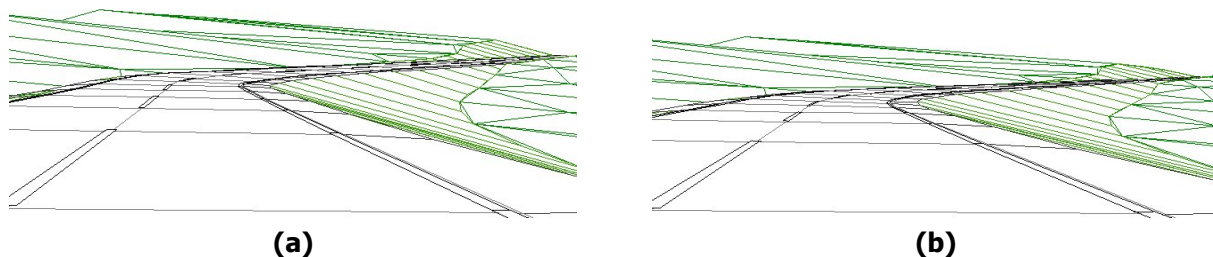
_Special cases where transition curves are introduced:_

Parameters $A \geq R$ are only used in designing urban streets (architectonic needs of road technical groups B and C), and for ramps of split level interchanges.

The minimum value of the clothoid parameter ($A_{min}$) is also assumed where (too) high driving speeds shall be prevented by suitable dimensions of road axis geometric elements.

On roads of the technical groups C and D, if a clothoid is omitted, suitable distance between adjoining arcs shall be ensured to allow the required length for driving from one arc to the other (turning the steering wheel), and the necessary length to execute the cross-fall change. The type (form) of connection between those arcs is not prescribed (it can also be a straight line).

When traffic lanes narrower than the standard ones are foreseen (roads of insignificant traffic volume), a transition curve, in view of the driving speed, is recommended on principle only. However, from the point of view of driveability it is indispensable to ensure a traffic surface which a vehicle needs when driving into an arc (prevention of driving on shoulders).

Application of other transition curve forms:

In exceptional cases (streets in old urban centres, road of technical groups C and D, special architectonic requirements, etc.) other curve than the clothoid to carry out a transition curve can be used. However, in such cases the maximum speed amounts to 70 km/h.

## 4.4.3.2 Limiting values

The transition curve (clothoid) length shall meet driving-dynamical, constructive, and aesthetic requirements (Figure 67), where the criterion is decisive, which provides a greater value of the clothoid parameter A.

In the text and the tables quantities for the speed of 140 km/h are indicated as well. Notwithstanding that this speed is higher than the $V_{adm}$, it is assumed in driving-dynamical analyses. To speeds of $V_i < 40$ km/h, either other methods (tractrix, three multicenter curve), or values valid for the speed of 40 km/h shall be introduced.

### 4.4.3.2.1 Minimum value of clothoid parameter ($A_{min}$)

The minimum value of the clothoid parameter $A_{min}$ is determined by the driving-dynamical circumstances in the conditions of the carriageway maximum cross-fall, which still ensure a comfortable drive in the clothoid area.

The following basic equation (the driving-dynamical condition) shall apply:

$$A_i^2 = \left(\frac{V_i}{3,6}\right)^3 \frac{1}{X_{adm}},$$

supplemented by the cross-fall $q_{max}$ :

$$A_{min}^2 = \frac{V_{con}^3}{46,656 \cdot X_{adm}} - \frac{q_{max} \cdot V_{con} \cdot R_{min}}{0,367 \cdot X_{adm}}$$

where:

$A_{min}$   [m]        Minimum value of clothoid parameter

$V_{con}$   [km/h]   Conceptual speed

$R_{min}$   [m]        Arc radius at assumed $V_{con \, (con)}$

$q_{max}$   [%]        Maximum cross-fall

$X_{adm}$   [m/s$^3$]   Admissible rate of change of radial acceleration at assumed $V_{(con)}$

The limiting value of $A_{min}$ may only be used at the minimum arc $R_{min}$ for an individual conceptual speed $V_{con}$.

For practical use, values of input parameters, as well as rounded-off values of $A_{min}$ and $L_{min}$, which belong to an individual conceptual speed $V_{con}$, are indicated in Table 35.

Values of $A_{min}$ are also plotted in the diagram in Figure 67 (curve $A_{min\ VD}$).

### 4.4.3.2.2    Minimum value of clothoid parameter ($A_{min}$) at $R_i > R_{min}$

The minimum value of the clothoid parameter $A_{i\ min}$ for $R_i > R_{min}$ shall be assessed with regard to the following:

- driving-dynamical conditions,
- aesthetical requirements, and
- constructive conditions,

which ensure the drive comfort enabled by:

- admissible value of side acceleration (nosing force ?),
- aesthetic course of the road line, and
- acceptable speed of cross-fall changing (torsional speed).

#### 4.4.3.2.2.1 Driving-dynamical condition (VD-condition)

To ensure the traffic safety, for radii of $R_i > R_{min}$ (higher driving speeds are feasible) the parameters $A_{i\ min\ DD}$ may be assumed preserving the transition curve length $L_i$, which results from the criterion of the minimum value of the clothoid parameter $A_{min}$ at individual conceptual speed $V_{con}$ ($L_i = A_{min}^2/R_{min}$). The following equation applies:

$$A_{i\ min\ VD}^2 = A_{min}^2\ \frac{R_i}{R_{min}}$$

#### 4.4.3.2.2.2 Aesthetical condition (E-condition)

The minimum value of the clothoid parameter $A_{i\ min\ E}$ to ensure favourable aesthetic appearance of the road course only depends on the size of the arc connected to the subject clothoid, and shall be assessed on the basis of the

- minimum distance between the arc and the tangent through the clothoid turning point, amounting to $\Delta R = 0.30$ m, or
- minimum middle angle of the clothoid ($\tau = 3^0 11'$ for $A = R/3$ ).

The intersection of functions of both conditions is at the radius of $R_M = 583.2$ m, where the following equations apply:

- $A_{i\ min\ E1}^2 = \sqrt{7,2 \cdot R_i^3}$      for $R_i < R_M = 583.2$ m,  and

- $A_{i\ min\ E2}^2 = \dfrac{R_i^2}{9}$          for $R_i \geq R_M = 583.2$ m.

Where:

| | | |
|---|---|---|
| $A_{i\ min\ Ei}$ | [m] | Minimum clothoid parameter acc. to aesthetical condition at $R_i$ |
| $R_i$ | [m] | Arc radius |
| $R_M$ | [m] | Limiting arc radius at the point where both E-conditions change |

#### 4.4.3.2.2.3 Limiting radius $R_{AE}$ between VD-condition and E-condition

To assess $A_{i\ min}$ for individual $R_i$ in the area of $R_i > R_{min}$ the condition requiring the greater value of the parameter $A_{i\ min}$ shall apply.

The limiting radius $R_i = R_E$, at which the clothoid parameter $A_{i\ min\ E}$ according to the E-condition ($\Delta R = 0.30$ m or $A = R/3$) exceeds the parameter according to the VD-condition, is achieved in the

- area of $R_E < R_M = 583.2$ m for $\qquad R_E = \dfrac{A_{min}^4}{7{,}2 \cdot R_{min}^2}$

- area of $R_E \geq R_M = 583.2$ m for $\qquad R_E = \dfrac{9 \cdot A_{min}^2}{R_{min}}$

Where:

$A_{i\ min\ VD}$     [m]     Minimum clothoid parameter acc. to VD-condition

$R_{min}$     [m]     Minimum arc radius for selected $V_{con}$

$R_{E(E)}$     [m]     Limiting arc radius for selected $V_{con}$

For practical use the values $A_{i\ min}$ for an individual conceptual speed $V_{con}$ are plotted in the diagram in Figure 67 (line $A_{i\ min\ DD} - A_{i\ min\ E1} - A_{i\ min\ E2}$), whilst the values $R_E$ and $A_{min\ E}$ are indicated in Table 35.

### 4.4.3.2.2.4 Constructive condition (K-condition)

The minimum value of the clothoid parameter $A_{i\ min\ C}$ shall ensure sufficient transition curve length to execute twisting or altering the carriageway cross-fall. The following conditions to assess the parameter $A_{i\ min\ C}$ shall apply:

- position of twisting axis in the road cross-section,
- wing of twisting (greater of both possible distances between carriageway edges and twisting axis) – $b_v$ ,
- carriageway cross-fall – $q_i$, and
- relative longitudinal fall of the carriageway (in further text: RLF) with regard to the vertical alignment slope – $\Delta s_{max}$ .

The RLF value depends on both driving and torsional speed (speed of cross-fall change), amounting to 4%s$^{-1}$ for comfortable drive, as well as on the traffic lane width.

For practical use the maximum admissible values of $\Delta s_{max}$ are indicated in Table 34 for standard traffic lane widths (Table 11).

The value $\Delta s_{favourable}$ indicated in the table shall be assumed in case where, on a planned road, such $V_{des}$ is expected, which is substantially higher than the $V_{con}$ (traffic safety!).

As the RLF values (in %) apply to each individual traffic lane separately, $A_{i\ min\ C}$ shall be verified in view of one single traffic lane width only.

**Table 34: RLF$_{max}$ of carriageway edge with regard to vertical alignment (for individual traffic lane)**

| Relative fall | Conceptual speed V$_{con}$ [km/h] | | | |
|---|---|---|---|---|
| [%] | < 50 | 50 - 70 | 80 - 100 | ≥ 100 |
| $\Delta s_{favourable}$ | 1.05 | 0.75 | 0.50 | 0.40 |
| $\Delta s_{max}$ | 1.5 | 1.0 | 0.75 | 0.5 |

The minimum value of the clothoid parameter according to the K-condition is as follows:

$$A_{i\ min\ K}^2 = \frac{R_{min} \cdot b_p \cdot (q_k - q_z)}{100 \cdot \Delta s_{max}}$$

Where:

| | | |
|---|---|---|
| $A_{i\ min\ K}$ | [m] | Minimum clothoid parameter |
| $R_{min}$ | [m] | Minimum arc radius at selected $V_{con}$ |
| $b_p$ | [m] | Traffic lane width |
| $q_k$ | [%] | Cross-fall of the connecting arc |
| $q_z$ | [%] | Cross-fall at beginning of twisting (in transition arc or at clothoid turning point ($q_z = 0\%$) |
| $\Delta s_{max}$ | [%] | Maximum value of RLF of carriageway edge with regard to vertical alignment |

The constructive condition is independent on the speed, and shall be calculated for each individual case separately. As a rule, this condition shall be verified when designing the twisting. In case that the value $\Delta s_{max}$ is exceeded, the parameter A shall be increased.

**Table 35: Clothoid – characteristic quantities**

| Characteristic quantities | | Conceptual speed [km/h] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **40** | **50** | **60** | **70** | **80** | **90** | **100** | **110** | **120** | **130** | **140** |
| $X_{adm}$ | [m/s$^3$] | 0.95 | 0.80 | 0.68 | 0.59 | 0.52 | 0.45 | 0.40 | 0.36 | 0.33 | 0.31 | 0.30 |
| $R_{min}$ | [m] | 45 | 75 | 125 | 175 | 250 | 350 | 450 | 550 | 700 | 850 | 1000 |
| $A_{min}$ q=7% | [m] | 30 | 50 | 70 | 90 | 115 | 150 | 180 | 210 | 250 | 290 | 340 |
| $L_{min}$ | [m] | 20 | 35 | 40 | 45 | 50 | 65 | 70 | 80 | 90 | 100 | 115 |
| $A_{rec}$ | [m] | 35 | 60 | 85 | 115 | 150 | 190 | 225 | 260 | 295 | 325 | 350 |
| $R_{AE}$ | [m] | 55 | 155 | 215 | 300 | 390 | 575 | 650 | 720 | 805 | 890 | 1040 |
| $A_{AE}$ | [m] | 35 | 70 | 90 | 115 | 145 | 185 | 215 | 240 | 270 | 300 | 350 |

Where:

| | | |
|---|---|---|
| $V_{con}$ | [km/h] | Conceptual speed |
| $X_{adm}$ | [m/s$^3$] | Admissible rate of change of side acceleration (nosing force) at assumed $V_{con}$ |
| $R_{min}$ | [m] | Minimum arc radius at assumed $V_{con}$ |
| $A_{min}$ | [m] | Minimum clothoid parameter according to the DD-condition at assumed $V_{con}$ and maximum cross-fall $q_{max}=7\%$ |
| $A_{rec}$ | [m] | Recommended clothoid parameter at assumed $V_{con}$, which ensures traffic safety and comfortable drive |
| $R_E$ | [m] | Radius of limiting arc between lines defined according to DD-conditions and AE-conditions at assumed $V_{con}$ |
| $A_E$ | [m] | Clothoid parameter at limiting arc radius $R_{AE}$ |

### 4.4.3.2.3    Maximum value of clothoid parameter ($A_{max}$)

On principle, the clothoid parameter is unlimited. However, the following shall be considered:
- physiological effect of intensity of increasing the rate of changing of side acceleration acting on a driver (driving speed control), and
- physical limitation of possibility to turn the steering wheel (limitation applying to both driver and vehicle),

as in such a case the transition curve loses its function.

The maximum value of the clothoid parameter is defined by the relation $A_{max} = R$ or $\tau = 28^0 39'$.

Irrespective of this provision, parameters A > R may also be used, yet in special cases only (e.g. for very small R, on ramps at points of access, on roads in settlements). It is recommended to keep the parameter A below the value defined by $\tau = 90^0$, i.e. A < 1,77 R.

**Figure 67: Minimum transition curve (clothoid) parameter**
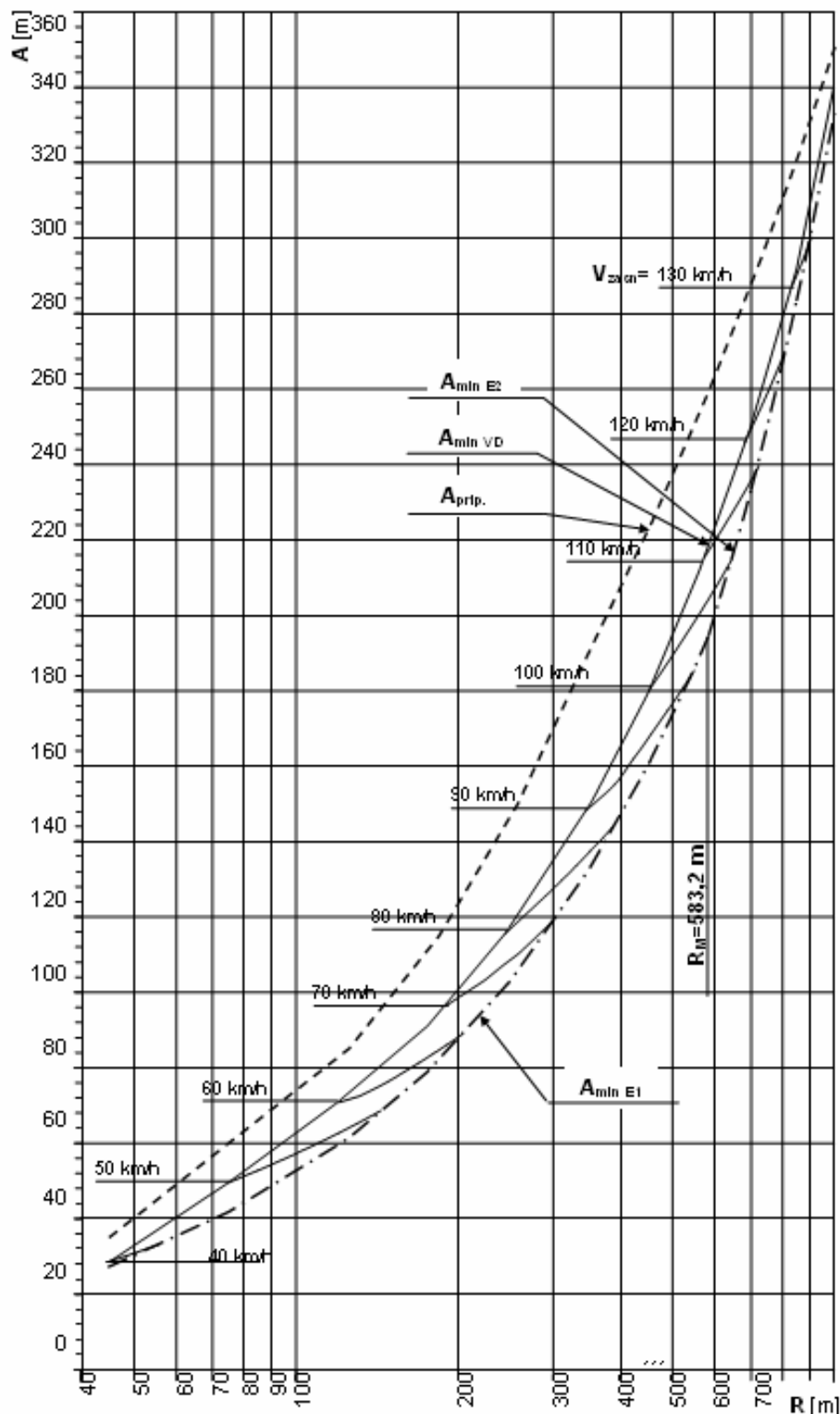


### 4.4.3.3  Parameter $A_{i\ min}$ and traffic safety

#### 4.4.3.3.1    Recommended value of clothoid parameter ($A_{prip}$)

Each value of $R_i$ assumed in the road axis can theoretically be defined as $R_{min}$ for any speed $V_i$ as well. The relation $A_{min} \leftrightarrow R_{min}$ for the complete series of speeds of 40 km/h < $V_i$ < 140 km/h is indicated by the curve $A_{minVD}$ in Figure 67.

The use of the values $A_i$ according to the abovementioned curve is recommended as the minimum one on roads of the technical group A, as well as on those roads of the technical group B, where major deviations from the specified sequence of arc dimensions occur (chapter Combining and conformity of horizontal elements).

The use of the curve $A_{minVD}$ indicated in Figure 67 ensures sufficient traffic safety on routes of distinctive changing of possible driving speeds.

Very (too) long transition curves are not welcome from the point of view of traffic safety, as the intensity of rate of changing of the side acceleration (nosing force, side acceleration) is reduced to such an extent that the driver does not perceive the road curvature.

The values of the parameter A, which approximately correspond to this upper limit, and, at the same time, ensure a very comfortable drive, are defined by the curve $A_{prip} \leftrightarrow R_i$ indicated in Figure 67.

### 4.4.3.3.2 Practical values of clothoid parameter ($A_i$) with regard to $R_i$ value

For the practical use the following relations can be used on roads of the technical group C (and D), as well as on roads f the group B ($V_{con}$ < 70 km/h):

- for  40 m < $R_i \leq$ 100 m:     $\frac{3}{4}R_i \leq A_i < R_i$
- for 100 m < $R_i \leq$ 200 m:     $\frac{2}{3}R_i \leq A_i < \frac{3}{4}R_i$
- for 200 m < $R_i \leq$ 500 m:     $\frac{1}{2}R_i \leq A_i < \frac{2}{3}R_i$
- for 500 m < $R_i \leq$ 1000 m:     $\frac{1}{3}R_i \leq A_i < \frac{1}{2}R_i$

These relations are sufficient for the needs of determining the route elements at the preliminary stage of the road design.

## 4.4.4 Combining and conformity of horizontal elements

### 4.4.4.1 Shapes of combining curvatures, conditions

**Regular shapes** of combining successive arcs are the following:

- "S-curvature", where the curvatures of two successive arcs are orientated in opposite directions, and
- "O-curvature", where the curvatures of two successive arcs are orientated in the same direction.

Both normal shapes of combining successive arcs are applicable in all cases. The transition curve length at the O-curvature shall ensure minimum driving duration of 1 second.

**Special shapes** of combining successive arcs are "basket-shaped" curvatures:

- "C-curvature", which is composed of three arcs of the same orientation, i.e. of two outer and smaller arcs, and of the middle and larger connecting arc, and
- "K-curvature", which is composed of three arcs of the same orientation, i.e. of two outer and larger arcs, and of the middle and smaller connecting arc.

Both aforementioned special shapes of combining successive arcs are only conditionally admissible on roads of the technical group A. This is only allowed on condition that the transition curve lengths between both pairs of incorporated arcs are such as to allow, without any speed reduction by means of brakes (with passive deceleration only) enable a change of realistic driving speeds from the larger into the smaller arc (passive deceleration $a_m$ = 0.85 ms$^{-2}$).

A mandatory intermediate element between arcs is a transition curve in a shape of a clothoid. Where a transition curve is not obligatory (in the technical group D, and conditionally in the technical group C), both circular arcs shall be connected by means of a different type of a curve, yet, in any case, such distance shall be foreseen between the arcs that the manoeuvre of turning

the steering wheel from one arc to another can be carried through. Within the course of a basket-shaped curvature it is not allowed to alter the carriageway cross-fall direction. However, there are some exceptional cases where, from the point of view of the traffic safety, a change of the carriageway cross-fall direction is deliberately designed in the middle arc. In this way, a physical effect on the driver to reduce the speed is achieved. Such an arrangement shall be explained in detail in the road design.

**Table 36: Additional condition for an »O« curvature or a »basket-shaped« curvature**

| $R_{greater}$ (outer radius) [m] | $R_{greater} : R_{smaller}$ (ratio of radii) [-] | min $L_A$ (intermediate clothoid length) [m] |
|---|---|---|
| < 125 | 1,5 | $V_{con}$ / 3.6 |
| 125 - 450 | 2,0 | $V_{con}$ / 3.6 |
| > 450 | unlimited | $V_{con}$ / 3.6 |

For roads of the technical groups A and B (outside settlements, and for $V_{con}$ > 70 km/h, omission of incorporating a transition curve between arcs of O-, C-, and K-curvature is only admitted, if the criteria indicated in Table 36 are fulfilled. A transition curve between arcs on roads of the technical groups B (within settlements, and for $V_{con}$ < 70 km/h), C, and D can also be omitted under conditions, which do not meet the requirements of Table 36, provided that general conditions to ensure turning the steering wheel.

### 4.4.4.2 Conditions to assess sequence of dimensions of adjoining arcs

When designing the route of a public road, the elements of the horizontal route course shall be mutually harmonized in view of the radii of adjoining circular arcs, and, if feasible, of the length of the element itself. In case that the suitability of the selected arc sequence cannot be verified by a special argumentation, it is admitted to introduce the graph shown in Figure 68.

A very favourable range "A" in Figure 68 shall be applied to the road technical group A. For roads of the technical group B at least a favourable range "B", whereas for roads of the group C, at least a still applicable range "C" shall be used. When on roads of the technical groups B and C such geometric elements are introduced, which allow very high driving speeds (more than 80 km/h for B, and over 60 km/h for C), provisions higher by one degree shall be considered.

For roads of the technical groups B and C within settlements such conformity is not required, as the route conducting is adapted to town planning.

In case of execution of an "O"-curvature, and when the vertical alignment slope is substantial ($s_i$ > 4 %), the arc of smaller radius shall be located at a lower level in view of the vertical alignment (the vertical alignment fall from the smaller to the larger arc, and not inversely). When such condition cannot be fulfilled, the speed shall already be limited in the area of the upper, i.e. larger circular arc.

In individual special cases where, for indeed justified reasons (spatial and/or economical), it is impossible to introduce the foreseen $R_{min}$ or an adequate sequence of arcs at some location on the route, such places shall be marked extremely accurately (increased sight distance, directional boards, shrubbery / tree zone protected with safety barrier on the outer side, traffic signs, etc.). In addition, an increased cross-fall (Table 8, values in parentheses) shall be taken into account, and, if feasible, the dimensions of adjoining arcs shall be diminished to enable uniform speed reduction (a motor deceleration of $a_z$ = 0.85 ms$^{-2}$).

**Figure 68: Relations of sequence of arc radii**
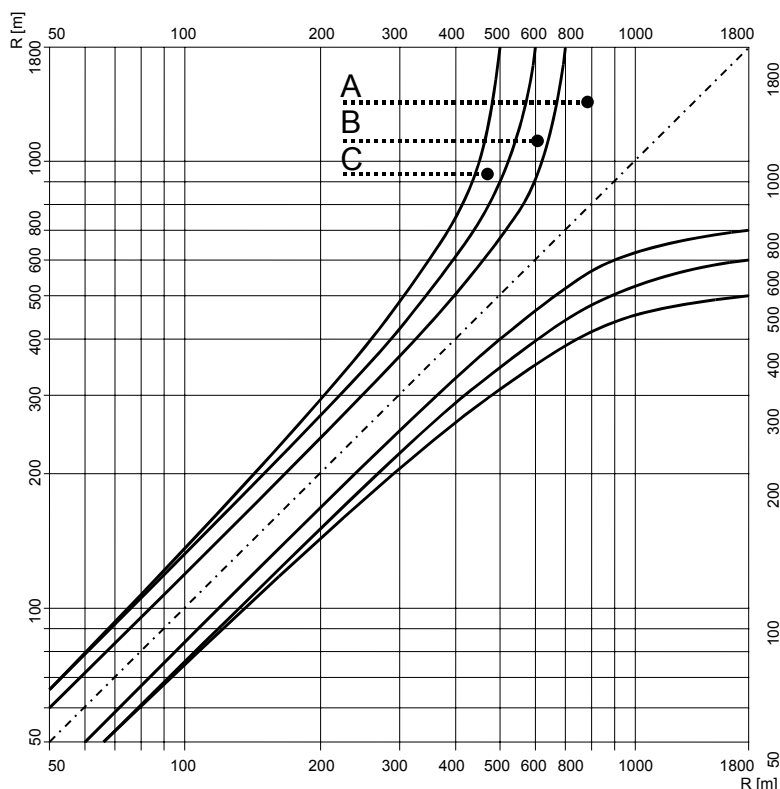


### 4.4.4.3 Combining transition curves, conditions

Any transition curve shall be accomplished by a geometric curve called clothoid. For aesthetical reasons, among others, a sequence of the same lengths of both transition curve and circular arc is recommended (1:1).

When restricted by spatial reasons, the transition between two arcs, or between an arc and a straight line, with the exception of roads of the technical group A, may also be executed by a combined clothoid composed of two different parameters. The ratio of parameters ($A_1 : A_2$) must not exceed the value 1.5 ($A_1 > A_2$). The clothoids shall be joined at such a location on the clothoid where the radius of the connecting circular arc reaches a value of at least R = 600 m.

The use of an "apex" clothoid (the length of the arc between clothoids equal to zero), and connecting of an arc with a straight line without any transition curve is not admitted for roads of the technical group A. On other roads this is allowed, but the conditions already mentioned afore shall be fulfilled (sufficient arc dimension, ensuring the length required for turning the steering wheel, ensuring traffic surface in case of very narrow traffic lanes, etc.).

# 4.5 ROAD AXIS ELEMENTS IN LONGITUDINAL SECTION (VERTICAL ALIGNMENT)

Vertical alignment is a spatial (3D) curve defining height relations of a road. It consists of the carriageway plane section, and of the vertical plane along the road axis or parallel with it.  In the design, the vertical alignment height course shall be presented as a vertical projection by means of tangents (straight lines), and vertical curvatures between them (circular arcs). To execute a vertical curvature, other geometric functions are acceptable as well (parabolas, clothoids, etc.). However, they shall ensure reaching the minimum curvature radius at the location of their maximum curvature.

For an individual road technical group, limiting values of elements are assessed under different conditions. In case that on an individual road, for whatever reason, a need of introducing more complex elements than those foreseen for the particular road group occurs, such values shall be assumed, which apply to the higher road technical group. In such a case all other elements, not only vertical alignment ones, shall be introduced analogically.

When the planned travelling speed on a road cannot be achieved by the vertical alignment elements, either the cross-section (introducing additional traffic lanes), or the road axis horizontal course (dimensions of elements), or both of them shall be modified.

### 4.5.1 Longitudinal gradient of vertical alignment

Vertical alignment longitudinal gradient have an essential influence on the investment costs and users' costs. Depending on the purpose the following alternatives can be carried out:

- Gentle gradients: better traffic safety, energy saving, lower operation costs, lower emissions of exhaust gases and noise, higher traffic capacity, favourable psychological effects on drivers;
- Steeper gradients: lower construction costs, general economy of the investment, minor interventions in natural environment.

Vertical alignment elements shall be designed for the design speed ($V_{des}$) allowed by horizontal geometric elements, unless the investment economy is negatively affected.

In case of significant gradients of vertical alignment tangents (above 5%), which cannot be reduced for whatever reason, it is recommended to increase the horizontal geometric elements at the end of the downgrade, and to adapt them to driving speeds expected due to a steep vertical alignment (free flow speed $V_{free}$). On roads of the technical group A such harmonization is required, whilst on other roads it is advised.

When on roads of the technical group A it is impossible to harmonize the speed and the dimensions of horizontal geometric elements, emergency exits shall be foreseen.

### 4.5.2 Maximum gradient of vertical alignment

#### 4.5.2.1 Maximum feasible gradient of vertical alignment

The maximum feasible vertical alignment gradient depends on the motor traction force:
- For an average motorcar the threshold value is 30%, and
- For a heavy lorry the threshold value amounts to 15% (1st gear drive).

The maximum vertical alignment gradient may only be designed in special cases (ramps).

#### 4.5.2.2 Maximum admissible gradient of vertical tangent ($s_{max}$)

The maximum admissible vertical tangent gradient, denoted by the slope in any point, depends on both conceptual speed ($V_{con}$) and road type. Admissible values are indicated in Table 37.

Values stated in Table 37 shall be considered in road designs in connection with the required travelling speed or traffic capacity of an individual road (traffic design), and with the feasibility study, indicating when and where an additional traffic lane should be introduced, or the ascent diminished. The number of heavy vehicles is decisive. For motorcars inclinations of up to 8% practically have no influence on the driving speed.

Gradients of $s_i$ >4 % shall be avoided in areas of

- crossroads at grade for constructive reasons (unfavourable vertical execution of secondary road connection), and for traffic-safety reasons (substantial counter-slope upon "turning" in crossroads, long braking distances);
- long bridges and viaducts for constructive reasons (tearing both wearing course and waterproofing upon driving-off), and for traffic-safety reasons (undercooling of the structure resulting in frost glaze),

- tunnels (reducing the speed of heavy vehicles, high concentration of exhaust gases, increased hazard of traffic accidents, quick expansion of ignition of inflammable materials, etc.).

For the abovementioned reasons it is recommendable, particularly in long tunnels, to reduce the maximum vertical alignment fall to 2.5%. Irrespective of that, in individual cases the vertical alignment slope shall be assessed according to criteria specially prescribed for tunnels (ventilation during construction and service, drainage, etc.).

**Table 37: Admissible values of the vertical tangent maximum gradient**

| Technical group | Conceptual speed $V_{con}$ [km/h] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **40** | **50** | **60** | **70** | **80** | **90** | **100** | **110** | **120** | **130** |
| **A** | - | - | 8 | 7 | 6 | 5.5 | 5 | 4.5 | 4 | 4 |
| **B** | (10) | 9 | 8 | 7 | 6 | 5 | 4 | - | - | - |
| **C** | 12 | 11 | 10 | 9 | 8 | - | - | - | - | - |

## 4.5.3 Minimum gradient of vertical alignment

The minimum longitudinal gradient of vertical alignment shall allow a free water outflow from the pavement, and, at the same time, it shall ensure an aesthetic conducting of pavement edges at twisting.

Notwithstanding other restriction the following applies:

- $s_{min} = 0.5 \%$  on open route sections, and
- $s_{min} = 0.7 \%$  on long bridges and viaducts.

On road sections where the slope $s_{min}$ cannot be achieved (vertical curvatures, cross-fall winding) carriageway drainage shall be ensured by additional design measures (shifting the winding axis, drainage asphalt, etc.).

In view of the road mileage (km) no coincidence of the vertical curvature area of a slope of $s_i <$ $s_{min}$ with a narrower area of carriageway cross-fall winding from $-q_{min}$ to $+q_{min}$ is admissible (aquaplaning phenomenon).

Conditions to select $s_{min}$ are different for areas of the cross-fall of the same direction, than for areas where the cross-fall direction changes (winding).

### 4.5.3.1 Road section of constant cross-fall direction

As the area of constant cross-fall direction, the road section is defined where the carriageway cross-fall does not change its direction, and where it is not smaller than $q_i = 2.5\%$. Two cases can be distinguished:

- The minimum longitudinal fall of vertical alignment is limited by the required value of the minimum longitudinal fall of drainage devices along the carriageway (gutters, through-shaped channel, or raised kerb), thus $s_{min} = min\ s_{drain}$.

  Min $s_{drain}$ amounts to:
  - for cement concrete surfaces        0.2%,
  - for asphalt and paved surfaces       0.3%,
  - for grassed surfaces               0.5%.

On route sections where the slope $s_{min} <$ min $s_{drain}$ cannot be avoided the longitudinal drainage devices shall be adequately rearranged.

The road section length in the vertical curvature area where $s_i < s_{min}$ is defined by the equation $L = 0,01 \cdot s_{min} \cdot r_i$, where $r_i$ is the vertical curvature radius.

- Unless restrained by dewatering devices (on a fill, open deep ditch, etc.), a vertical alignment of $s_{min} = 0$ can be designed; in addition, no limitations apply to the vertical concave curvature.

## 4.5.3.2 Area of carriageway cross fall winding

The cross-fall change between adjacent circular arcs shall be generally carried through in the entire transition curve (clothoid) area. Both pavement edges (or one of them, depending on the position of the twisting axis in cross-section) shall be so conducted by level, that the relative differences of the longitudinal gradient with regard to the vertical alignment winding axis amounts to at least $\Delta s_{min}$ (refer to equation in the chapter Minimum relative longitudinal gradient of carriageway edge).

Where the longitudinal fall of vertical alignment is less than or equal to the minimum relative slope of the vertical alignment edge ($s_i \leq \Delta s_{min}$), either carriageway edge has locally the longitudinal fall of different sign than the vertical alignment. This will result in not aesthetical appearance of the pavement edge course, and represents a special problem in view of drainage arrangement.

In this case the minimum longitudinal fall of vertical alignment depends on the pavement longitudinal drainage devices, i.e.:

- in case of a raised kerb or a gutter:              $s_{min} = \Delta s_{min} +$ min $s_{drain}$
- in case of a free water outflow from pavement:     $s_{min} = \Delta s_{min}$

In view of realistic possibility of how accurately pavement surface can be accomplished it is recommended to foresee by at least 0.2% greater values than the abovementioned minimum ones.

## 4.5.4 Curvatures between tangents (vertical curvatures)

A vertical alignment transition between adjoining tangents shall be executed by introducing a curvature. The following can be distinguished:

- a convex curvature (the difference of slopes of adjoining tangents is positive), and
- a concave curvature (the difference of slopes of adjoining tangents is negative)

To perform a curvature, the geometric element circular arc shall be introduced. It is also allowed to use a quadratic or cubic parabola if this is required by spatial conditions (forced conducting of vertical alignment). In such a case the curvature shall nowhere be smaller than that specified as the minimum for the arc.

The transition from the tangent to the arc shall be carried out without or with an intermediate transition curve.

Radii of vertical curvatures shall be so selected as to achieve the following:

- traffic safety by a suitable length of the stopping sight distance ($P_z$),
- balanced spatial conducting of road route line (harmonization of vertical elements with the horizontal ones, and of tangent lengths with curvature lengths),
- adapting to the ground, and reducing construction costs (for roads, which are not well exploited in the economical point of view), and
- preserving and protecting the environment (a cut instead of additional noise barriers, etc.).

For the assessment of dimensions of vertical curvature radii it is recommended to consider sight distances for the design speed - $P_z = f(V_{des})$.

In restorations, modernizations, and reconstructions of existing roads the required dimensions of vertical curvature radii cannot be achieved at certain places (a walled-in road, arrangement of entries, etc.):

- for roads of the technical groups A and B (outside settlements) no deviation is admitted;
- for roads of the technical groups B (within settlements) and C such a deviation is allowed provided that the speed is limited by means of adequate traffic signs (either generally, or for conditions of a wet carriageway only),
- for roads of the technical group D no special requirements apply, except that driveability is ensured. For this purpose a radius of at least r = 50 m for a convex, and at least r = 30 m for a concave curvature shall be assumed. Any deviation from these values is only admissible in case that the road use is limited to motorcars only, which shall be extra mentioned in the design.

When assessing the radius of a convex curvature which still makes overtaking feasible, braking distances of two vehicles driving in opposite directions shall be considered by an additional safety distance of 20% $V_{des}$.

## 4.5.4.1 Limiting values

The dimension of minimum radii of a convex vertical curvature (the difference of slopes of adjacent tangents is positive) depends on the stopping sight distance, which is calculated between the height of driver's eye ($h_1 = 1.0$ m) and the height of an obstacle on the road ($h_2$), and which is different for $V_{con}$ and $V_{des}$ respectively (Table):

$$P_z = \sqrt{2 \times r_{min} \times h_1} + \sqrt{2 \times r_{min} \times h_2}$$

In Table 29 values for a "hidden" height of an obstacle on the road are indicated, whereas in Table 38 the minimum radii of the convex curvature for the stopping sight distance at vertical alignment slope of 0% are given (refer to chapter Vertical sight distance). In addition, exceptional minimum values resulting from the equation below are indicated as well:

$$r_{minkonv} = 0.25 \cdot P_z^2$$

The minimum values indicated in Table 38 take account, for limiting speeds of 50 or 100 km/h, of different obstacle heights $h_2$ for different road technical groups (C and B, or B and A).

The dimension of the minimum radii of a concave vertical curvature results form the driving conditions at night (the length of carriageway lighting in the drive direction).

For the calculation the following equation applies (the results are indicated in Table 38):

$$P_z = \sqrt{2 \cdot r_{minkonk} \cdot \left( h + P_z \cdot sin\varphi \right)}$$

Where:

| | | |
|---|---|---|
| $P_z$ | [m] | Stopping sight distance |
| $r_{minkonk}$ | [m] | Minimum radius of concave curvature |
| h | [m] | Height of headlights on a vehicle – regularly h = 0.70 m |
| $\varphi$ | [°] | Lighting angle with regard to the tangential plane – regularly $\varphi = 1°$ |

For traffic safety and aesthetical reasons the dimension of the radius of a concave vertical curvature depends on the dimension of the adjoining convex vertical curvature in the following way:

$$r_{minkonk} \geq \tfrac{2}{3} \text{ adjoin } r_{konv}$$

**Table 38: Minimum radii of vertical curvatures of vertical alignment at tangent grade of s = 0° (at top point)**

| [m] | Conceptual speed V$_{con}$ [km/h] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 40 | 50 | 50 | 60 | 70 | 80 | 90 | 100 | 100 | 110 | 120 | 130 | 140 |
| **h$_2$** | 0.00 | 0.00 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.10 | 0.10 | 0.15 | 0.15 | 0.15 |
| **r$_{minkonv}$** | 600 | 1250 | 850 | 1500 | 2600 | 4250 | 6750 | 10250 | 9000 | 13000 | 17000 | 23500 | 32000 |
| **r$_{minkonv}$** (exceptionally) | 300 | 650 | 650 | 1200 | 2000 | 3500 | 5000 | 8000 | - | - | - | - | - |
| **r$_{minkonk}$** | 500 | 800 | 800 | 1200 | 1700 | 2400 | 3100 | 4000 | 4000 | 5100 | 6000 | 7600 | 9000 |

The values indicated in Table 38 apply uniformly to all the roads. On roads particularly complex in view of the traffic, design speed (V$_{des}$) shall be assumed instead of conceptual speed.

In case of reconstructions, or special spatial restrictions, or for economical reasons, dimensions of radii shall be calculated for each individual case separately.

## 4.5.4.2 Particularities in selecting curvature radii

In a limited area of the vertical curvature the carriageway longitudinal fall is reduced under the dimension specified as the minimum one for carriageway surface drainage.

The length of the area of too small longitudinal fall D$_s$ is as follows:

- for s$_{min}$ = 0.5% (normal conditions on the road):     $D_s = \dfrac{r}{100}$

- for s$_{min}$ = 0.7% (in the area of large structures):     $D_s = 1,4 \cdot \dfrac{r}{100}$

The centre of this area is located at the mileage (km) of the highest or the lowest point of the vertical alignment. This area of the reduced longitudinal fall must not coincide with the narrower area of twisting (q$_i$<q$_{min}$) to prevent the phenomenon of aquaplaning on the road.

In case of a convex curvature the water can be at a deadlock on the pavement, whilst in case of a concave curvature the amount of water on the pavement is even increased (water at deadlock and recurrent water).

Below flyovers (overpasses) or other physical obstacles running over the particular road (ensuring clearance gauge), the arc radius shall be, in case of a concave curvature, increased to such a value that the sight plane of the stopping sight distance extends below the obstacle.

On roads of the technical groups A and B (outside settlements), it is recommended, below flyovers or any other physical obstacles, to carry out an increase and evaluation of the radius dimension of a concave curvature from the point of view of effects occurring during driving as well (a flyover must not produce an effect of a barrier).

## 4.5.4.3 Selection of vertical curvature

The stopping sight distance and, consequently, the dimension of the convex vertical curvature radius as well, depend on the vertical alignment longitudinal fall. To calculate the curvature dimension, the mean value of slopes of adjoining tangents, and the corresponding sight distance shall be considered (Figure 69).
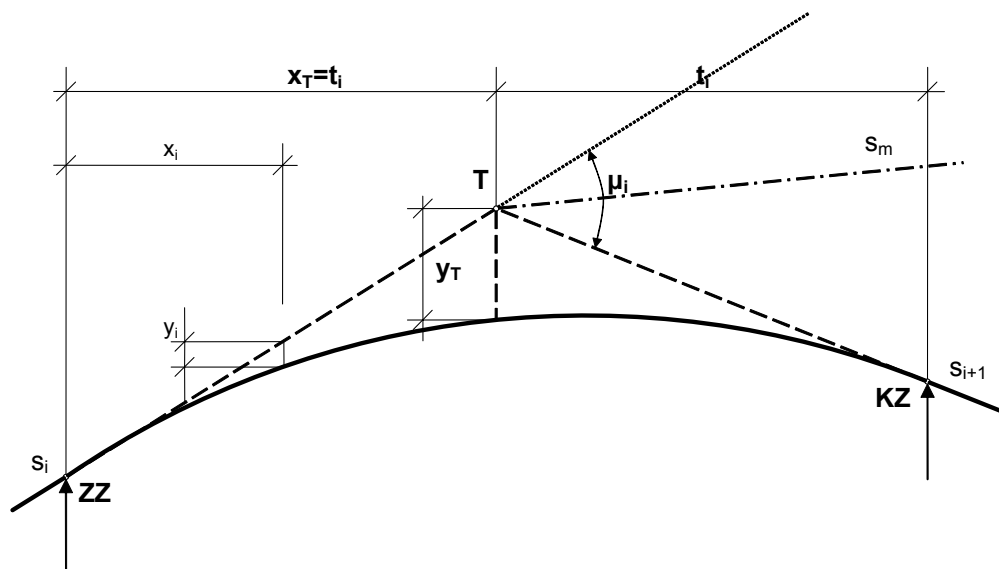
Elements of the vertical alignment curvature are as follows:

- Difference of grades of adjoining tangents          $\mu_i = s_i - s_{i+1}$ [%]
- Designed grade of tangent to assess P$_z$          $s_m = 0,5 \cdot (s_i - s_{i+1})$ [%]
- Curvature radius r$_i$ [m]

- Curvature arc tangent

$$t_i = \frac{r_i}{2} \cdot \frac{\mu_i}{100} \ [m]$$

- Distance between apex and arc

$$y_T = \frac{x_T^2}{2r_i} \ [m] \text{ , and}$$

- Distance between vertical curvature and tangent in cross-section $\quad y_i = \frac{x_i^2}{2r_i} \ [m].$

The calculated values of individual curvature elements shall be fully considered in horizontal or vertical projection (there are no reductions due to slopes).

### Figure 69: Scheme of convex vertical alignment curvature



Where:

| | | |
|---|---|---|
| $r_i$ | [m] | Curvature radius: $r_i = f(P_z(s_m))$ |
| $s_i$ | [%] | Vertical alignment gradient |
| $s_m$ | [%] | Designed tangent grade: $s_m = \frac{1}{2}(s_i - s_{i+1})$ |
| T | | Apex point – refraction of tangents |
| $t_i$ | [m] | Tangent of curvature arc |
| $y_i$ | [m] | Distance between vertical curvature and tangent |
| $\mu_i$ | [%] | Difference of grades of adjoining tangents |
| ZZ | | Beginning of curvature |
| KZ | | End of curvature |

## 4.5.5 Combining and conformity of adjoining elements of vertical alignment

As a rule, such curvature radii shall be foreseen, which dimensions are greater than the minimum values.

When a convex and a concave curvature are combined, the dimension of the concave arc radius shall amount to at least 2/3 of the adjacent larger convex curvature radius. Any deviation from this rule shall be explained in detail in the road design. No exceptions are admitted for roads of the technical groups A and B (out of settlements).

Taking account of aesthetical requirements it is recommendable that the concave curvature radius amounts to at least 1/2 of the radius of the adjoining convex curvature, when the tangent between these curvatures is substantially shorter than the length of an individual curvature.

In addition to the dimension of the smallest radius of the vertical curvature, sufficient length of the vertical curvature in terms of driving duration on an individual geometric element shall be ensured as well (5-7 seconds of drive).

Both aesthetically and psychophysically it is very favourable to keep the element lengths within the succession curvature – tangent – curvature approximately the same.

To ensure visual conformity with the horizontal geometric elements of the road axis, such a curvature length shall be selected, which will not commence and terminate in the area of the same road axis horizontal element.

To ensure traffic safety it is not allowed to design a vertical curvature between two adjoining vertical alignment tangents of different signs, when a portion of the arc of that curvature of inclination $s_i < s_{min}$ (0.5% or 0.7%) entirely or partly coincides with the narrower area of cross-fall twisting within the limits $q = +/- q_{min}$.

In addition to the abovementioned provisions, the following shall be considered for aesthetical and traffic safety reasons for roads of the technical groups A and B:

- longitudinal falls under 0.8 % act as a plane, and are practically imperceptible,
- longitudinal falls between 1% and 3% are sufficiently recognizable and divisible,
- longitudinal falls between 4% and 8% are visually very steep,
- short vertical curvatures shall be avoided,
- in minor changes of vertical alignment fall ($\mu \leq 3\%$), minimum vertical curvatures cause very short tangents and, consequently, unfavourable visual effects,
- visually good solutions can be achieved introducing such vertical curvatures, which are at least three times greater than the minimum values,
- where on a flat land, or in an extremely stretched road axis course in plan, a concave and a convex vertical curvature follow a very long tangent, the radius of the concave curvature shall be greater than the radius of the convex curvature (prevention of the "wall" effect),
- where the tangent between two curvatures of opposite direction is disproportionately short in comparison with the length of curvatures, it shall be minimized, which contributes to a harmonic conducting of the longitudinal profile at transition of one curvature to another.

# 4.6 COMBINING ROAD AXIS GEOMETRIC ELEMENTS

On roads of the technical group A, as well as on important roads of the group B, geometric elements of road axis and technical elements of road vertical alignment shall be introduced in such a way that they run in certain sequence, and that they are mutually conform.

The following element conformities can be distinguished:
- by direction and dimension of radii,
- by their lengths, and
- in view of the spatial (3D) course of the road axis line.

## 4.6.1 Spatial conformity of axis horizontal elements and vertical alignment

Road axis is a spatial (3D) curve where the horizontal elements of both axis and vertical alignment shall be harmonized, should the road axis have aesthetically and traffic-technically suitable course in the space.

In addition to provisions on ensuring sufficient falls to drain the pavement surface (prevention of aquaplaning), the following shall be considered:
- the vertical curvature length should be greater than the length of an individual road axis horizontal element, to which it is adjusted (both beginning and termination of the vertical curvature must not be located in the area of the same road axis horizontal element);
- the ratio of the horizontal (R) to the vertical radius (r) shall be as small as possible (1:10 to 1:20);

- when it is impossible to achieve a favourable ratio of radii, which dimension affect the perception of the road course in perspective, a computer visualisation of the road course is recommended;
- incorporating two successive vertical curvatures of the same sense in the sight distance area is only admissible on roads of the technical groups C and D, as well as on roads in urban milieu;
- turning points of both horizontal and vertical road axis course should be situated at approximately the same mileages (km);
- in case of an outstanding relief (substantial longitudinal falls of vertical alignment) it is wished-for that a section of a constant longitudinal fall is foreseen between two vertical curvatures; in this way, a driver gets an impression of a horizontal course of the road ahead of him; the horizontal turning point should be located as close as possible to the beginning of the concave curvature;
- on roads of the groups A and B (outside settlements), bridge/viaduct axes shall match the road axis line;
- when significant viaducts on roads of the technical groups A and B (outside settlements) are incorporated in the area of vertical curvatures, it shall be ensured by conducting the vertical alignment, and by sufficient width of the sight widening (berm), that their end is visible (recognizable) as well;
- the same provision also applies to incorporating crossroads at grade on roads of the technical groups A and B (outside settlements).

Fundamental rules for ensuring conformity of the spatial (3D) course of the road axis are shown in Figures 70 to 74.

## Figure 70: Modes of harmonizing the succession of geometric elements

$R_{min}$

$R_{min}$

**conformity/nonconformity of horizontal elements**

$r_{kk}$   $r_{kk}$   $r_{kk}$

$r_{kv}$   $r_{kv}$        $r_{kv}>r_{kk}$

*hilly/mountainous topography*

$r_{kk}$   $r_{kk}$   $r_{kk}$   $r_{kk}$   $r_{kk}$   $r_{kk}$

$r_{kv}<r_{kk}$

*flat land topography*

**conformity of vertical curvatures - $r_{kk}$ : $r_{kv}$**

vertical course

s%   s%

s=0%        $r_{kk}$        s=0%

$r_{kv}$                    $r_{kv}$

vertical course

s%   s%

s=0%        $r_{kk}$        s=0%

$r_{kv}$   ZKV        KKV   $r_{kv}$

horizontal course

q%              q%

q=0%                    q=0%

q%

**spatial (3D) conformity of axis elements**
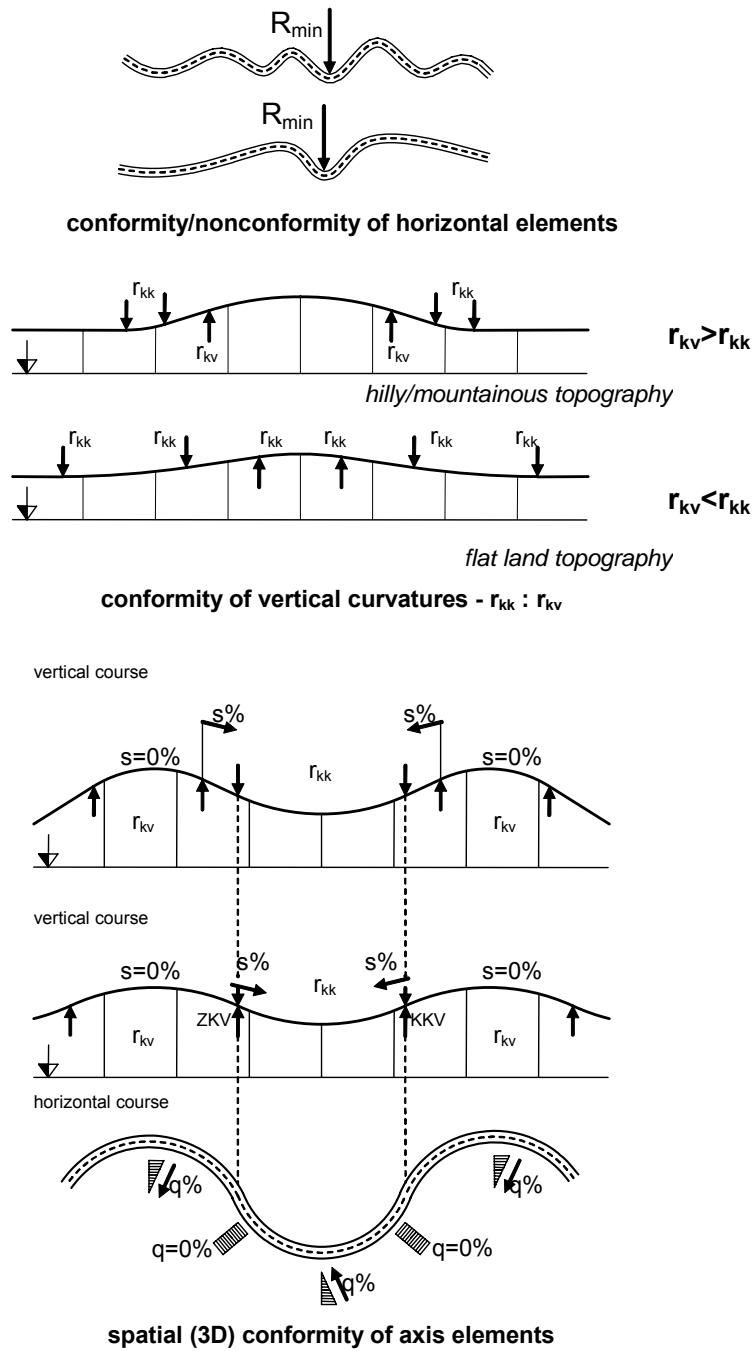
## Figure 71: Characteristics of conducting road axis in 3D view



HC                                VC

Short intermediate straight line (unsuitably)



HC                VC                HC                VC

Insufficient horizontal radius                Suitable solution

**Horizontal route conducting**



HC                VC                                              VC

With short intermediate tangent (unsuitably)        Single vertical curvature (suitably)

**Adjoining concave curvatures**

Legend: HC ... horizontal route course; VC ... vertical route course
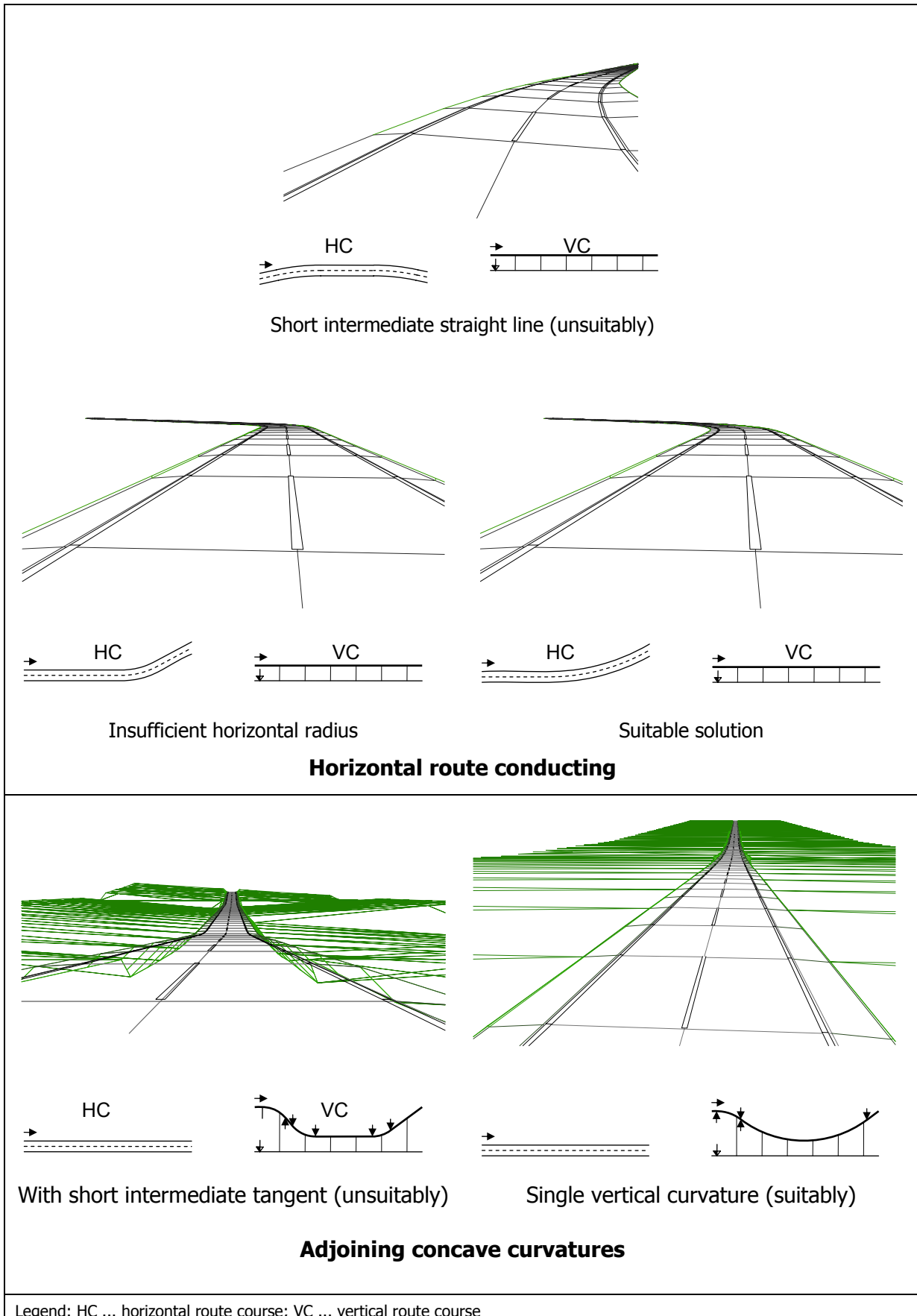
**Figure 72: Characteristics of conducting road axis in 3D view**

HC    VC        HC    VC

With a short intermediate tangent (unsuitably)   Single vertical curvature (suitably)

**Adjoining convex curvatures**

HC    VC            VC

In a straight line       In a curvature of substantial horizontal radius

**Visually broken vertical alignment – insufficient concave curvature (unsuitably)**

HC    VC

**Vertical break as a consequence of a short convex curvature in a straight line**

Legend: HC ... horizontal route course; VC ... vertical route course

**Figure 73: Characteristics of conducting road axis in 3D view**



HC          VC

In a straight line                    In a horizontal curvature
**Loss of vertical alignment**

HC          VC

**Jumps of vertical alignment**

HC          VC

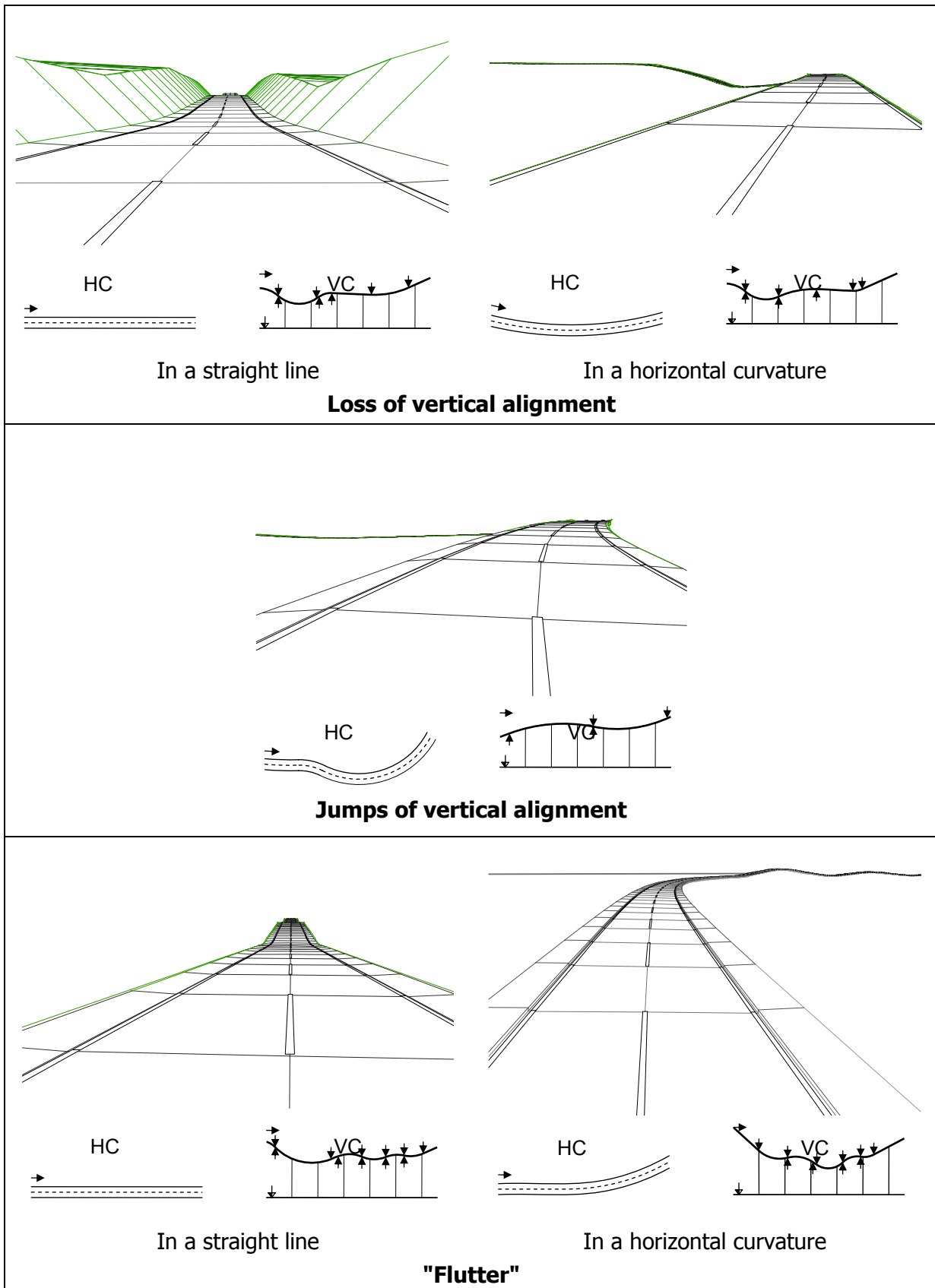In a straight line                    In a horizontal curvature
**"Flutter"**

**Figure 74: Characteristics of conducting road axis in 3D view**



| "Board" effect and unsuitable design of the left slope of beginning curvature | Better solution – vertical alignment on bridge is a constituent part of the entire road vertical alignment |

**Vertical alignment on a bridge located on the route**