2022.

Guidance for Local Roads Design (GLRD)

3. DRAINAGE

[COMPANY NAME] | [Company address]

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1 INTRODUCTION

Road structure is exposed to atmospheric impact that can significantly affect the traffic flow and safety, as well as road structure itself. As a result of atmospheric impact, such as rainfall and snowfall, a layer of water is formed on the road surface that need to be collected and removed from the road in a controlled manner. If water on the road is not being adequately conveyed to the area outside of the road structure, traffic could be endangered (traffic slowing down, reducing vehicle skid resistance, potentials for motorist hydroplaning, reduced visibility, etc.) and stability of the road structure could be jeopardized.

Road operation and its' impact on environment largely depends on properly designed, well-built and well-maintained drainage system. Depending on a range of road, allowable vehicle speed, traffic load and economic criteria, adequate criteria for selection of road cross section, road longitudinal profile, design rainfall (i.e. rainfall return period, rainfall intensity), type of drainage system and drainage system facilities, are applied in order to achieve satisfactory level of road protection.

Road drainage system includes facilities for collection of surface water, from the road surface and adjacent terrain, collection of penetrated water, from the road structure, and water from underground. It also includes facilities for river training works and culverts on sections where road interferes with natural watercourses.

When planning drainage systems, the local condition of construction site and adjacent areas affected by the construction, must be considered. Terrain configuration, characteristics of soil, visual impression of type of plants, inclination of trees, landslides, water retention areas and direction of water flow, for an example, can indicate potential best solutions for drainage of road construction and adjacent areas and, thus, for design and construction of stable and sustainable road structure.

Design of road drainage system is based on correct assessment of design rainfall and respectable runoff quantities that have an impact on road structure and adjacent areas. Disposition and size of facilities in the drainage system is determined on a basis of the design/assessed water quantities, road structure design and terrain elevations.

2 REGULATIONS AND TECHNICAL DOCUMENTATION

2.1 The role of state and local governments in drainage permitting for rural and local roads

Development of road design and associated drainage systems is based on legal documents issued by relevant authorities. These documents include *Local Conditions* that contain all urban, technical and other conditions and data necessary for the development of the Conceptual Design, Preliminary Design, General Project, Design for Construction Permit and Design for Construction, in accordance with the *Law on Planning and Construction* ("Official Gazette of RS ", No. 72/2009, 81/2009 - Rev., 64/2010 – Decision US, 24/2011, 121/2012, 42/2013 - Decision US, 50/2013 - Decision US, 98/2013 - Decision US, 132/2014, 145/2014, 83/2018, 31/2019, 37/2019 – other Law, 9/2020 and 52/2021*).*

Ministry of Construction, Transport and Infrastructure is responsible for issuance of *Local Conditions* for state roads of I and II ranks, road facilities and traffic connections to these roads and border crossings. If listed facilities are completely located on a territory of the autonomous province than relevant authority of the autonomous province is responsible authority. Local Conditions for other traffic facilities are issued by relevant authority of municipality.

Water Acts are being issued for the purpose of insurance of unified water regime and achievement of water management in accordance with the *Water Law* ("Official Gazette of RS ", No. 30/2010, 93/2012, 101/2016, 95/2018 i 95/2018 - other Law). Water Acts are issued by the Ministry of Agriculture, Forestry and Water Management and public water company, for roads located in the autonomous province by relevant authority of the autonomous province, for roads located on the City of Belgrade by relevant authority of the City and for roads located on territory of municipality by relevant authority of the municipality. Water Acts relevant for construction/reconstruction of roads include Water Conditions and Water Consent.

Water Conditions are part of the Local Conditions and are issued for the construction and reconstruction of structures/facilities which may permanently, occasionally or temporarily affect changes in the water regime, i.e. endanger the environment. The Water Conditions are issued for highways and regional roads and bridges on them. The Water Conditions cease to be valid after two years from the date of issue if the request for issuance of Water Consent was not submitted to relevant authority in that period.

Water Consent confirms that the technical documentation is prepared in accordance with the issued Water Conditions and is being issued prior to commencement of construction / reconstruction of facilities. Exceptionally, Water Consent can be issued without Water Conditions if the authority responsible for issuing Water Consent decides that construction of facilities or works that are subject of the technical documentation does not affect the water regime. The Water Consent is being issued by the authority that issued Water Conditions. The Water Consent ceased to be valid after two years from the date of issue if the construction, reconstruction or extension of the facility, execution of works, i.e. preparation of planning documents is not started.

General Project and *Preliminary Design* are subject to expert control by Review Commission formed by the Ministry of Construction, Transport and Infrastructure. The Republic Review Commission is a body that does expert control of projects and prepare Report on Executed Expert Control. The Report contains obligatory measures that must be applied during preparation of the Design for Construction Permit. Design for Construction Permit is subject to technical review.

Building Permit is issued prior to commencement of construction/reconstruction and is issued on a basis of the Design for the Construction Permit. Relevant authorities for issuing of Building Permit for State roads, classes I and II, and for facilities that are being built on the territory of two or more municipalities is Ministry of Construction, Transport and Infrastructure, while Local government unit (municipality) is responsible for municipal roads (local roads).

Article 23 of the *Law on Environmental Protection* ("Official Gazette of RS ", No. 135/2004, 36/2009, 36/2009 - other Law, 72/2009 - other Law, 43/2011 - Decision US, 14/2016, 76/2018 and 95/2018) defines that water can be used and loaded, and wastewater can be discharged into recipients with the application of appropriate treatment, in a way and to a level that does not pose a danger to natural processes or the restoration of water quality and quantity and that does not reduce the possibility of their multipurpose use.

Environmental impact assessment is being prepared for transport projects and for projects planned in protected natural assets and in protected environment of immovable cultural property. If EIA is obligatory for particular project, realization of the project is possible only if relevant authority issues approval for the EIA. The EIA should contain description of factors exposed to impacts, description of possible significant negative impacts of project and description of measures envisages in order to prevent, reduce and eliminate significant harmful effects. Authorities responsible for conducting environmental impact procedure and issuance of approval of Environmental Impact Assessment for projects for which the construction permit is issued by the Ministry of Construction, Transport and Infrastructure is Ministry of Environmental Protection, for projects for which the construction permit is issued by autonomous province (Provincial Secretariat for Energy, Civil Engineering and Transport) is relevant authority of autonomous province (Provincial Secretariat for Urbanism and Environmental Protection), and for projects for which the construction permit is issued by local authority is local municipality.

2.2 Relevant technical documentation

Serbian Road Design Manual (Transport Rehabilitation Project, JP Putevi Srbije, 2012) [1] is guiding document for design of drainage systems in highways. It covers all aspect of design, from hydrology and consideration of rainfall intensity and rainfall runoff, to hydraulics aspect related to runoff flow and design of drainage system elements. The Manual also gives the guidance on facilities that comprises the drainage system with an overview on their design, dimensions and materials they made of.

Technical Conditions for Construction of Roads in the Republic of Serbia (Transport Rehabilitation Project, JP Putevi Srbije, 2018), Part 2. Special Technical Conditions, Section 2.3. Drainage systems describes materials used for construction of drainage system facilities and requirements related to construction of the facilities. The materials used for works on drainage systems mostly include mixtures of stone grains for underlying layers, mixtures of cement concrete for underlying layers and for drainage elements and cement mortars, pipe materials, prefabricated elements, and others. For materials used for drainage works, quality of materials is prescribed (composition, mechanical/chemical characteristics). The document defines criteria for method of construction, from sources of material, method of depositing materials prior to commencement of construction, production of material/elements for construction, as well as criteria for quality of construction, measurement of as built works, acceptance of works by supervision and preparation of bill of quantities of executed works.

Rulebook on Works on Regular Maintenance of Public Roads [5] regulates the types of works, technical conditions and the manner of performing works on regular maintenance of public roads. Conditions of public roads are determined by inspections performed regularly, seasonally, systematically and extraordinary. Drainage facilities are maintained to enable their functionality and works include maintenance of surface water drainage facilities (open ditches, gutters, channels, with concrete or stone linings, and culverts), maintenance of underground water drainage facilities (sewerage, manholes, infiltration basins, water inception chambers, springs, etc.), maintenance of bridges (cleaning and/or repair of gullies and drainage pipes) and maintenance of tunnels and galleries (cleaning of drainage channels in the tunnel).

STANDARDS

1. ISC number: 93.030 External Wastewater Drainage Systems;
2. 93.080.01 (SRPS U.C.4.016) Design and Construction of Roads – Climatic and hydrological conditions;
3. SRPS EN 598:2012: Ductile iron pipes, fittings, accessories and their joints for sewerage applications - Requirements and test methods;
4. SRPS EN 588-2:2008: Fibre cement pipes for drains and sewers - Part 2: Manholes and inspection chambers;
5. SRPS EN 1916:2007, SRPS EN 1916:2007/AC:2011: Concrete pipes and fittings, unreinforced, steel fiber and reinforced;
6. SRPS EN 1917:2007, SRPS EN 1917:2007/AC:2011: Concrete manholes and inspection chambers, unreinforced, steel fiber and reinforced;
7. SRPS EN 1825-1:2011: Grease separators - Part 1: Principles of design, performance and testing, marking and quality control;
8. SRPS EN 858-1:2008: Separator systems for light liquids (e.g. oil and petrol) – Part 1: Principles of product design, performance and testing, marking and quality contro;l
9. SRPS EN 13476-1,2,3:2018: Plastics piping systems for non-pressure underground drainage and sewerage - Structured-wall piping systems of unplasticized polyvinyl chloride) (PVC-U), polypropylene (PP) and polyethylene (PE) - Part 2: Specifications for pipes and fittings with smooth internal and external surface and the system, Type A.

DECREES

1. Regulation on emission limit values of pollutants in water and deadlines for their achievement ("Official Gazette of RS ", No. 67/2011 and 48/2012) ;
2. Regulation on limit values of pollutants in surface and ground waters and sediments, and deadlines for achieving them ("Official Gazette of RS ", No. 50/2012).

Climate Change Adaptation documents related to road drainage

The problem of climate change and the adaptation of infrastructure to its consequences are the subject of current studies and technical instructions, the application of which depends on their implementation in the regulations related to the design of road drainage systems.

3 PLANNING

Planning of drainage systems is affected by local conditions and selected type of road structure. Under local conditions we can consider terrain configuration, soil characteristics, presence of surface and underground waters, rainfall intensity and duration, temperatures, frost depths, level of area ecological sensitivity and others.

Official topographic maps could give a general overview of the terrain and surface watersheds but cannot indicate underground watersheds. Preliminary indication of underground water presence and location could be obtained from the data taken from the existing technical documentation, if any, but correct information could be obtained only as a result of the measurement of groundwater levels.

As a general preliminary assessment, forms of the natural terrain and properties of soil could indicate existing or potential landslides through a humped-undulating surface of the slopes or inclined and bent trees.

The occurrence of certain plant species is a criterion for assessing the hydrological conditions of the terrain since that type of vegetation varies in arid and humid areas. Information on origin, type and quantity of water, as well as water quality, could be obtained from the state water management administration. For planning of the drainage facilities values from long-term observations should be used.

Terrain configuration is also a key factor in selection of road structure type, thus the road drainage concept (Chapter 4) should be planned together with the designer of road structure who defines elements of road structure, including road cross sections in embankments and cuts, bridge and tunnel sections, road crossing structures, and others.

Aims of the drainage systems is to control runoff water within the roadway, including water from the road surface and infiltrated water from the road structure, and to control runoff on the roadside area beyond the roadway, including runoff coming from neighbouring terrain, that will ensure safe traffic conditions and durability of the road structure.

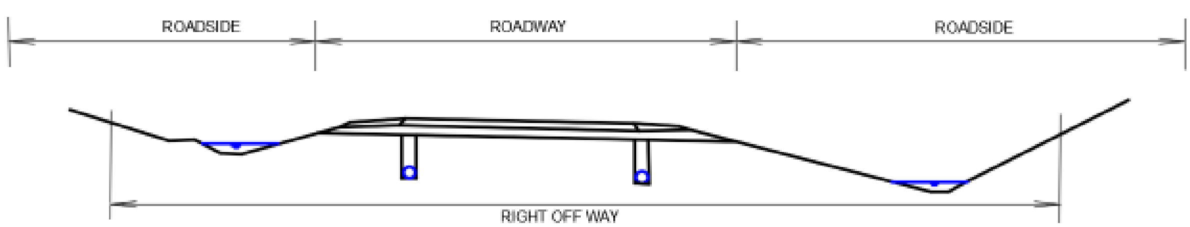


Figure 1 Roadway and roadside drainage

Collection of surface water is done either in surface or underground facilities and discharge of collected water could be planned at a suitable location in natural watercourses or could be infiltrated in underground. Any discharge in the environment must not endanger retention and recharge capacities of natural environment nor impair quality of surface or underground water. With this approach the designed drainage system will be environmentally friendly.

Selection of adequate drainage measures depends on ecological sensitivity of road location. Ecologically sensitive areas could include areas used for water abstraction, areas with high groundwater levels, areas with surface waters of particular ecological importance, areas with valuable animal and plan populations, areas used for recreation, and others.

Flowchart of the procedure for selecting drainage measures is presented in the following figure [2].

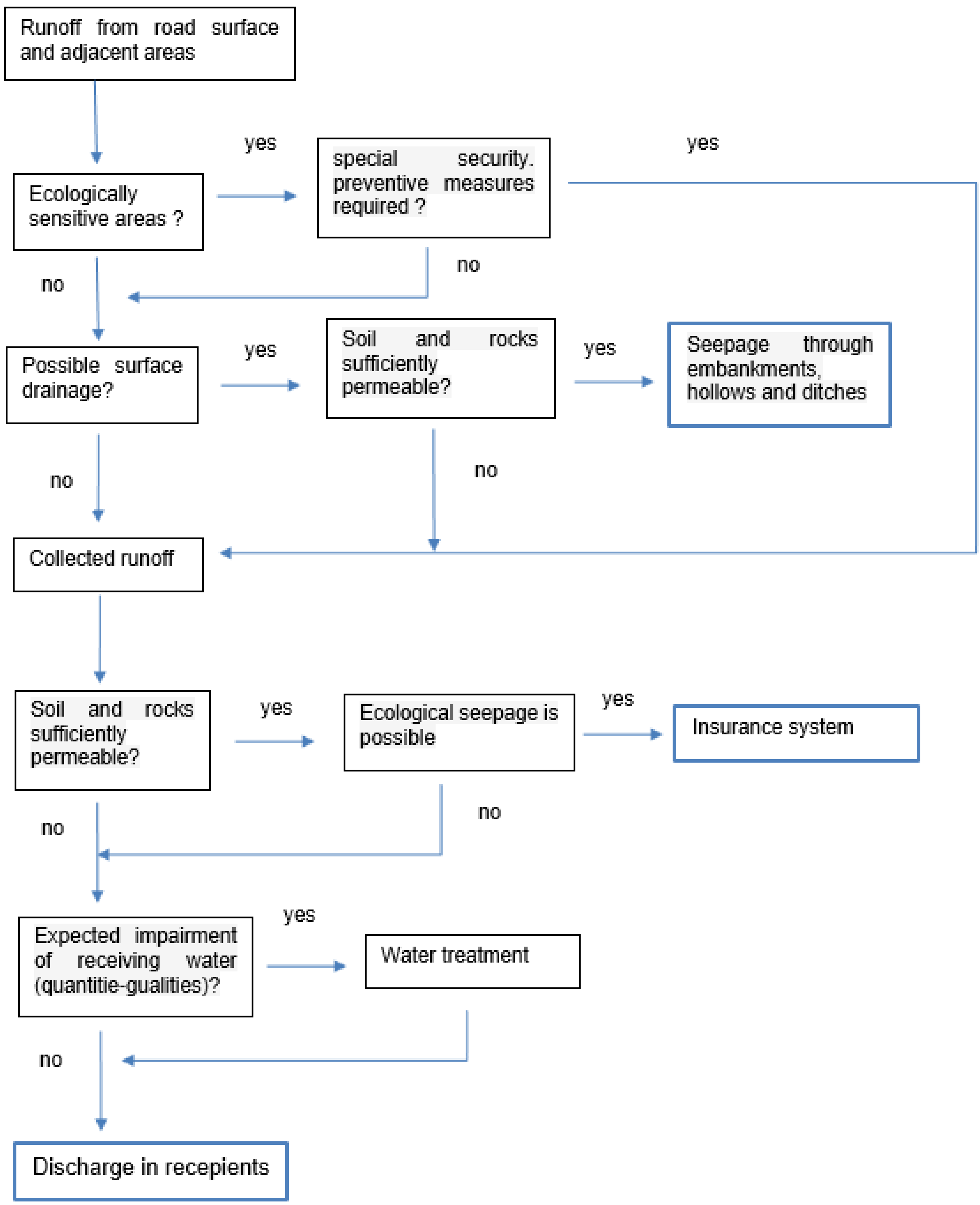


Figure 2 Flowchart for selection of drainage measures

Relevant regulations must be obeyed to ensure good status of receiving water bodies (Chapter 2). Discharge of particular runoff into surface water, runoff infiltration and groundwater recharge is subject to procedures defined in the Water Law.

Drainage of roads could be designed as surface or underground systems. Surface drainage include facilities located above ground and are positioned either in longitudinal direction, such as gutters, gullies, open channels, etc., or in lateral direction, i.e. culverts. Surface drainage also includes facilities for water retention and control of runoff quantity and quality. Underground systems include facilities located below surface, such as sewer systems, drainage pipes, etc.

All drainage facilities should be installed/built to allow their functioning in a simple manner and that activities related to maintenance and repair can be easily performed, without significantly affecting the traffic. Design of facilities planned to be built outside of the road body, such as channels, retention basins, infiltration ponds, and others, must take into account local natural conditions and natural building materials should be used wherever possible, in order to maximally integrate facility into the landscape and to provide habitat for flora and fauna.

Sizing of drainage facilities depends on assessed runoff quantities, type of road surface (paved, unpaved), selected geometric elements of the alignment (road surface longitudinal and lateral slopes), flow paths, flow times and arrangement of drainage facilities. Hydrology and hydraulic aspects of road drainage design is presented in Chapter 6.

4 ROAD DRAINAGE CONCEPT

Since that collected water could contain polluted substances resulting from pollution that is washed away from the road surface or nearby land, or is a consequence of accidental situation, such as traffic accident or vehicle failure, its discharge into environment could cause contamination of surface and ground waters. The most polluted runoff usually comes from the first flash, at a runoff commencement, when the most contaminated substances accumulated on impermeable surface is being washed out. The initial runoff contains suspended substances and substances bonded to them, such as oil and grease, and other pollutants. Decision on selection of drainage system types depends on location of road in regard to water recipients and required level of their protection, and relevant regulations related to environmental protection. Serbian legislation still does not clearly define requirements related to measures for protection of water and land from pollution.

Depending on a type of collected runoff discharge in terms of water quality, the drainage concept could be open or close [3].

Open drainage systems collect runoff water from the road surface into open channels that also receive unpolluted water from surrounding land that gravitates toward the road structure. Collected runoff is being discharged into environment without any treatment.

Closed drainage system implies complete separation of polluted runoff from the road surface and unpolluted runoff from the surrounding land that gravitates toward the road structure. This is only reasonable concept when treatment of rainfall runoff is planned. Closed drainage system could contain various combination of drainage facilities, such as curb + gutter + gully + sewer + outlet, or curb + gutter + drain flume along embankment slope + open channel + outlet, or combination of these.

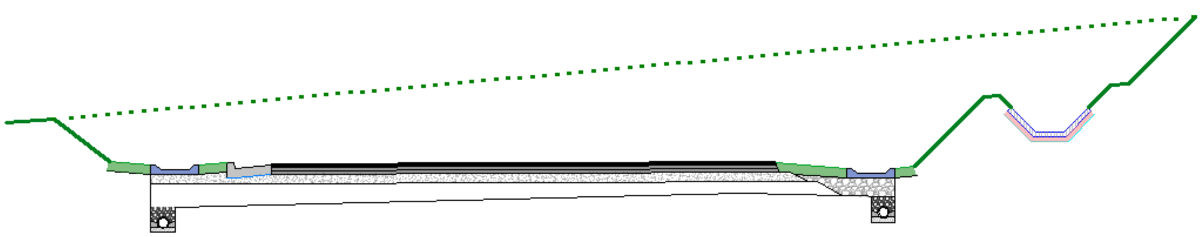


Figure 3 Conceptual road drainage system

During the design procedure and selection of the road route, it is necessary to do research on natural water courses that will interfere with the road, i.e. locations where road crosses the water course, and on required level of protection of water resources and soil from pollution from road.

Required measures for protection of water and soil, depending on local conditions, will be presenter hereinafter.

5 REPRESENTATION OF ROAD DRAINAGE IN PROJECTS

Design of road structure must contain detail information on road drainage. The drainage design includes results of hydrological and hydraulic calculation and design drainage measures presented graphically. Content of design documentation depends on the level of design and required information that are defined by the regulations. Generally, the design consists of the following:

- Background information
- Hydrological calculation
- Hydraulic calculation
- Bill of Quantities
- Graphical presentation
- Pipe placing and pipe material
- Technical conditions for work execution

Background information provides data on subject of the design, previously completed technical documentation, geodetic and topographic data, geotechnical conditions, etc.

Hydrological calculation contains analysis of rainfall data for project site in a sense of rainfall duration, rainfall intensity and rainfall frequency. Results of the calculation are design rainfall and design runoff that will be used in designing of drainage system facilities.

The result of hydraulic calculation is sizing of road drainage system facilities. Technical documentation should contain criteria for calculation, calculation results presented numerically, and data on dimensions of drainage facilities.

Bill of quantities gives breakdown of unit prices, quantities and total prices of items ranked by categories (preparation works, earth works, carpentry, installation works, concrete and reinforced concrete works, other works, etc.)

Graphical presentation contains location map, layout (scale usually 1: 500 and 1:1000), longitudinal section (scale usually 1: 100/1000), details (manholes, gullies and gratings, reinforced elements, channels, cascades, outlet structures, water treatment facilities, retention basins, excavation trench, trench strutting, manhole cover, manhole climbers, oil water separators, formwork plans and reinforcement, etc.)

Chapter Pipe placing and pipe material gives description of procedure for excavation of trench that will be used for placing of sewers, protection of trench and laying of pipes, installation, testing and filling of trench.

Technical conditions for execution of works defines general conditions that contractor must fulfill during execution of works, technical conditions that refer to the works (excavation, earth works, concrete works, reinforcing works, installation works, etc.), material for construction, security of works, and others.

6 DESIGN

6.1 Hydrology

Sizing of drainage system facilities is based on assessment of rainfall quantities that the drainage system is to collect and transfer. Design rainfall is selected for particular location and desired level of protection. Absolute protection of road facilities is not feasible because occurrence of extreme rains and high rainfall intensities that exceed the observed values could not be excluded with certainty.

Key role in selecting the design rainfall is type of facility since that drainage facilities located on the road structure have relatively small drainage areas comparing to significantly greater catchment areas of watercourses that crosses the road through culverts.

Methodology for calculation of runoff depends on available discharge records at a specific section. If the data on discharge exist, the drainage areas are named „gauged catchment“, if the discharge data do not exist, the drainage areas are named „ungauged catchment“, and if short term discharge records exist the drainage areas are named „insufficiently gauged catchment“.

Calculation of the design discharges on “gauged catchment“ is based on recorded discharges that are usually available for hydrological stations operated by the Republic Hydrometeorological Service of Serbia. The design discharge is determined by statistical analysis of recorded discharge. This methodology could be applied at location of road crossing and larger watercourses that have records on hydrological observations.

In a case of “insufficiently gauged catchments“, for which short term discharge record exist, sometimes it is possible to establish regression relation with the measured discharge at surrounding stations and extend the discharge series that will be used for statistical analysis.

The most frequent catchments are “ungauged“ where no data on discharge measurement exist. The design discharge is calculated based on the design rainfall. The transformation of design rainfalls into the design discharge is done using various methods called precipitation-runoff models. Application of design rainfall for calculation of design runoff implies attribution of rainfall return period to calculated design runoff.

Detailed consideration of application of hydrological analysis to design of road drainage could be found in literature [3,9].

The relevant amounts of precipitation should be harmonized with the recommendations from legal regulations and technical standards related to adaptation to climate change.

6.1.1 Rainfall quantities

Rainfall characteristics important for calculation of quantities are duration of rainfall, total rainfall depth, time distribution/unevenness of rain intensity and spatial unevenness of rainfall.

Duration of rainfall is fixed time interval in which certain (maximum) amount of rain falls. Thus, to define the design rainfall with duration of e.g. 20 minutes, in a real rain episode, the part with the highest rainfall depth during any 20 minutes is selected.

The time unevenness of rain is a change in rainfall intensity during its duration, i.e. change in rain depth per unit time (most often expressed in mm/min or mm/h, and in $L/(s \cdot ha)$ (1 mm/min = 167 L/ $s \cdot ha$)).

Since that the rainfall is not evenly distributed in space, rainfall data from close and representative rain-gauge stations should be selected. When choosing a representative station, care must be taken in a sense that the meteorological conditions are similar to the site conditions. Data from several rain-gauge stations should be used for larger catchments and average rainfall should be calculated using some method for interpolation.

Rainfall depth and intensity is taken from the statistical analysis of observed rainfall of fixed duration, that is depth-duration-frequency relationship (DDF) or intensity – duration – frequency (IDF). DDF and IDF relations for rain-gauge stations that are recorded are available from the Republic Hydrometeorological Service of Serbia.

Example of DDF relations for rain-gauge station Vračar (Belgrade), for recorded period 1925-1989, is presented in Table 1 [7]. Data on rainfall depth (in mm) for selected rainfall duration (5 to 360 minutes) and return period (2 to 500 years) are given in this table.

Table 1 Rainfall depth (mm) for rain-gauge station Vračar (Belgrade) [7]

Rainfall duration (min)	Return Period (year)							
	2	**5**	**10**	**20**	**50**	**100**	**200**	**500**
5	8.5	11.2	12.9	14.5	16.4	17.9	19.3	21.2
10	12.1	17	20.3	23.5	27.6	30.8	33.9	38.1
15	14.7	20.8	25.2	29.5	35.3	39.6	44.1	50
20	16.6	23.6	28.3	32.9	38.9	43.4	47.9	53.9
30	18.8	26.7	32.1	37.4	44.3	49.5	54.8	61.7
45	20.4	29.7	36.4	43.1	52.1	59	66.1	75.6
60	21.8	31.4	38.4	45.4	54.9	62.2	69.7	79.7
90	23.9	35.3	43.3	51.3	61.9	70	78.2	89.2
120	25.5	37.2	45.3	53.4	64.1	72.3	80.6	91.6
180	28	39.9	48.4	57	68.4	77.2	86.1	98.1
360	31.3	45.5	56.6	68.1	84	96.4	109.3	127

Detailed calculation of design rainfalls of uneven intensity is given in literature [3,9].

Recommended values for *design frequences* for drainage facilities in local roads are as follows:

- Road drainage facilities, including bridges: 5 years
- Culverts: 5-10 years (low traffic), 10-25 years (intermediate to height traffic)
- Infiltration basins: 2-10 years

Time of concentration is the longest travel time of water from a point in the catchment to the catchment discharge point. Time of concentration (t_c) consists of time of overland flow (pavements, land surface) (t_0), and time of flow in gutters, channels and pipes (t_t):

$$t_c = t_0 + t_t$$

Time of concentration could be calculated from formulas given in Table 2.

Table 2 Equations for time concentration, modified from [3]

Method/ author	Formula for t_c (min)	Note
Kinematic wave	$t_c = 1.36 \frac{L^{0.6} n^{0.6}}{i^{0.4} S^{0.3}}$ L = length of overland flow (m) n = Manning roughness coefficient i = net rainfall intensity (mm/min) S = average overland slope (m/m)	for overland flow on developed surfaces; the formula is calculated in iterations since it includes net rainfall intensity that depends on time of concentration (with the use of intensity-duration-frequency relationship)
FAA	$t_c = 0.7(1.1 - c)L^{0.5} S^{-0.333}$ c = runoff coefficient in the rational method L = length of overland flow (m) S = surface slope (m/m)	a formula developed for airport drainage, but also suitable for urban catchments
Yen and Chow	$t_c = 1.2 \frac{L^{0.6} n^{0.6}}{S^{0.5}}$ L = length of overland flow (m) n = Manning roughness coefficient S = average surface slope (m/m)	for overland flow on urban surfaces; developed as a simplification of the kinematic wave formula
SCS velocity method	$t_c = \frac{1}{60} \sum \frac{L_i}{v_i}$ L = length of flow path (m) v_i = average flow velocity (m/s)	includes estimation of surface runoff velocities
SCS lag method	$t_c = 0.0136 \frac{L^{0.8}}{S^{0.5}} (1000/\mathrm{CN} - 9)^{0.7}$ L = length of the hydraulically longest flow path on the catchment (m) CN = SCS curve number S = average catchment slope (m/m)	for small rural catchments; it is considered good for completely paved areas, while for mixed areas it tends to overestimate t_c; developed on the assumption that t_c = 1.67 t_p where t_p is the catchment lag time
Kirpich	$t_c = 0.0195 L^{0.77} S^{-0.385}$ L = stream length from headwater to outlet (m) S = average catchment slope (m/m)	for rural catchments with well defined channel and steep slopes; it is recommended to multiply t_c with 0.4 for asphalt and concrete surfaces, and with 0.2 for concrete channels

Kinematic wave (Table 2) is applicable for flow over surface at length up to 130 m. For longer surfaces flow tends to concentrate in small watercourses and time of concentration is calculated on a basis of velocity:

$$v = k \cdot \sqrt{S}$$

Where $v\left[\frac{l}{s}\right]$ is velocity of water, k is coefficient (equal to 0.619 for impermeable pavement-asphalt, concrete) and $S[\%]$ is slope in flow direction, and is calculated from longitudinal (S_p) and lateral (S_x) slopes:

$$S = \sqrt{S_x^2 + S_p^2}$$

In design practice, it is usually to assume 5 min as a travel time of runoff from the road to the gulley.

Time of concentration for runoff from natural catchments (surrounding area of road) to intersection of watercourse and road structure is equal to the sum of travel times for specific sections. Travel times is determined as a ratio of length and velocity. First estimation of velocity in watercourses could be done using the Manning's equation.

Manning's equation is used for calculation of water velocities, $v\left[\frac{l}{s}\right]$, in free surface flow in natural watercourses, channels and pipes:

$$v = \frac{1}{n} \cdot A \cdot R^{2/3}\sqrt{S}$$

Where $n\left[m^{-1/3}s\right]$ is Manning's roughness coefficient (Table 3), $A\left[m^2\right]$ is cross section area, $R = \frac{A}{O}\ [m]$ is hydraulic radius, and S is a friction slope that is assumed to be equal to bottom slope.

Rainfall duration recommended for local roads depends on a method for calculation of rainfall runoff:

- Rational method - duration is equal to time of concentration of the drainage area;
- Other runoff estimation methods - calculation of several rainfall duration, ranging from 0.5 to 3 times of concentration, and selection of the rainfall with the greatest calculated runoff;
- SCS curve number (CN) - application of the SCS method for estimation of runoff on small rural catchments could underestimate the runoff for short rainfall durations that are close to the time of concentration. Therefore, the daily rainfall with time distribution determined from IDF relationship should be used (the alternating block method described in reference [3,9]).

For initial calculation, recommended values for rainfall duration, applicable for small catchments, are [2]: for flat catchment area 15 minutes, for steeper slopes 10 minute, and for road low points 5 minute.

Local practice recommends 5 minutes rainfall duration for road drainage design, particulary applicable for flows in gutters and calculation of distance between gullies.

Table 3 Manning's roughness coefficient, modified from [3]

Surface type	Recommended value	Range
Asphalt	0.011	0.010-0.013
Concrete, smooth	0.012	0.010-0.013
Concrete lining	0.013	
Brick with cement mortar	0.014	
Closed conduits:		
Cast-iron pipes, coated	0.013	0.010-0.014
Concrete pipes	0.013	0.011-0.015
Concrete sewers with manholes and inlets	0.015	0.013-0.017
Corrugated metal pipes	0.027	0.025-0.030
Culverts:		
Concrete culvert, straight and free of debris	0.011	0.010-0.013
Concrete culverts, with bends, connections and some debris	0.013	0.011-0.014
Open channels (artificial watercourses):		
Channels with lining:		
Concrete bottom and slopes		0.011-0.014
Concrete bottom, slopes of arranged grouted stone		0.015-0.020
Concrete bottom, slopes of rock fill		0.020-0.035
Gravel bottom, concrete slopes		0.017-0.025
Gravel bottom, grouted stone slopes		0.020-0.026
Gravel bottom, slopes of rock fill		0.023-0.036
Brick lining in mortar		0.012-0.018
Asphalt lining		0.013-0.016
Channels with no lining:		
Soil bed, straight, dug		0.016-0.020
Soil bed, straight, old, bare		0.018-0.025
Soil bed, straight, covered with low grass		0.022-0.033
Soil bed, winding, bare		0.023-0.030
Soil bed, winding, covered with thick grass		0.030-0.040
Gravel bottom and slopes		0.030-0.050
Stone bottom, slopes covered with weed		0.025-0.040
Bed formed in rock		0.025-0.050
Unmaintained bed, vegetation height lower than water depth		0.040-0.080
Unmaintained bed, vegetation height equal to water depth		0.050-0.120
Natural watercourses (small watercourses with major bed width < 30 m)		
Mountain (torrential) watercourses:		
Gravel bottom, no vegetation, steep banks		0.030-0.050
Bed covered with gravel and large stones		0.040-0.070
Lowland (alluvial) watercourses:		
Clean straight section without calm areas		0.025-0.033
Clean straight section without calm areas, with more grass and stone in the bed		0.030-0.040
Clean meandering section with shallow and calm water		0.033-0.045
Clean meandering section with shallow and calm water, with more grass and stone in the bed		0.035-0.050
Section covered with vegetation, with deep calm water		0.050-0.080
Section heavily covered with vegetation, with tree root		0.075-0.150

remains		

6.1.2 Rainfall runoff

Rainfall runoff is quantity of water that reaches discharge point of the catchment and, in a case of local roads, enters natural environment, i.e. watercourses or surrounding land. It consists of surface, subsurface and groundwater runoff. Surface water flows on road surface and adjacent land surfaces and happen relatively quickly after commencement of precipitation which causes increase of discharge in recipients in short period of time. Subsurface and groundwater flows depends of soil saturation and previous precipitation events and generally happens more slowly than surface flows.

Direct runoff is a part of the hydrograph that is a direct consequence of runoff resulted from rainfall and is of main concern for design of road drainage systems. Subsurface and groundwater flows generate baseflow that should be included in an assessment of runoff quantities, if it makes considerable part of total runoff.

Various methods are used for calculation of rainfall runoff, depending on catchment area size:

- Rational method – applicable for small catchment areas, up to 80 ha, and for design of storm sewer networks, including road drainage systems (for catchments with short time of concentration);
- SCS method – applicable for calculation of runoff from natural catchment areas (road surrounding terrain) and is particularly used for design of channels located along the road and culverts at the intersection of watercourse/channel and road.

Implementation of particular methods for calculation of rainfall runoff is given in detail in literature [3,9]. A summary of the methods is given hereinafter.

Rational method

The most used method for calculation of rainfall runoff from roads is the rational method. The rational method is applicable for catchments up to 80 ha and, hence, the rational method is convenient for calculation of runoff from road surfaces (pavement, impervious surfaces). Usage of the Rational method implies fulfilment of the following assumptions: the rainfall has constant intensity, rainfall is evenly distributed over entire catchment, maximum discharge occurs after time of concentration is up and maximum runoff and design rainfall have identical return period. Calculation of maximum runoff is done for rainfall with duration equal to the time of concentration in the catchment.

The peak runoff discharge, $Q_m\left[\frac{l}{s}\right]$, is equal to:

$$Q_m = C \cdot i \cdot A$$

Where C is runoff coefficient, $i\left[\frac{L}{s\cdot ha}\right]$ is design rainfall intensity, and $A\ [ha]$ is catchment area.

The *runoff coefficient* C represents proportion of rainfall that transforms into the runoff, and has values between 0 and 1. The runoff coefficient mainly depends on type of surface, i.e. land cover, but also on retention capacity, rainfall intensity, evaporation, and others. If surface consists of different land types (covers), the runoff coefficient should be calculated as a weighted average of runoff coefficients on specific sections.

$$C_{av} = \frac{\sum C_j \cdot A_j}{A}$$

Where C_j and A_j are respectively runoff coefficient and catchment area in section j, and A is total area of catchment.

Runoff coefficient values for various types of surfaces are given in the following table [3]:

Table 4 Koeficijenti Runoff coefficient in the rational method, modified from [3]

Cover type	Runoff coefficient*
Commercial and business use:	
Central urban areas	0.70 - 0.95
Non-central developed areas	0.50 - 0.70
Residential use:	
Individual houses	0.30 - 0.50
Multiunit, detached	0.40 - 0.60
Multiunit, attached	0.60 - 0.75
Suburban residential areas	0.25 - 0.40
Apartment type	0.50 - 0.70
Industrial use:	
Smaller share of impervious surfaces	0.50 - 0.80
Greater share of impervious surfaces	0.60 - 0.90
Parks, cemeteries	0.10 - 0.25
Railroad yards	0.20 - 0.35
Undeveloped areas	0.10 - 0.30
Pavement:	
Asphalt or concrete	0.70 - 0.95
Stone or brick	0.70 - 0.85
Roofs	0.70 - 0.95
Lawns:	
Sandy soil, flat (2%)	0.05 - 0.10
Sandy soil, medium slopes (2-7%)	0.10 - 0.15
Sandy soil, steep slope (7%)	0.15 - 0.20
Clay soil, flat (2%)	0.13 - 0.17
Clay soil, medium slopes (2-7%)	0.18 - 0.22
Clay soil, steep slopes (7%)	0.25 - 0.35

* For return periods longer than 25 to 100 years, runoff coefficient values greater by 10-25% may be appropriate (but not greater than 1).

Application of the rational method for multiple catchment areas in a raw – refers to road sections between discharge points (gullies, slope drains or channels) and design discharge for facilities:

1. Discharge from the first catchment area (the most upstream one) A_1 , that reaches gulley or other discharge point (pipe inlet, channel inlet, etc.), is calculated using the Kinematic wave method for calculation of time of concentration (minimum value is 5 minutes) which is used ($t_k = t_c$) for selection of rainfall intensity from DDF curve/table and calculation of discharge.
2. Facility located downstream of the second catchment area A_2 is sized to the discharge that is equal to sum of the discharge from area A_2 and discharge from the first catchment area (the most upstream one) A_1. The rational method is used for area $A_1 + A_2$, and time of concentration is equal to sum of travel time of surface flow and travel time of flow in the upstream (first) collector. If previous gulley or other discharge point (pipe inlet, channel inlet, etc.) does not collect entire discharge from the corresponding catchment, then the next facility, located downstream, should collect remaining part of flow.
3. The same procedure is being repeated for other downstream road sections

SCS method

The SCS method, developed by Soil Conservation Service of the United State Department of Agriculture, is applicable for calculation of runoff from larger catchment areas, i.e. for sizing of channels and facilities at intersections with roads.

Effective rainfall, P_e $[mm]$ is calculated as

$$P_e = \frac{(P - 0.2 \cdot d)^2}{P + 0.8 \cdot d}$$

where $P[mm]$ is total rainfall depth, and d is maximum soil retention capacity.

Maximum soil retention capacity $d[mm]$ is calculated as:

$$d = 25.4 \cdot \left(\frac{1000}{CN} - 10\right)$$

where CN is curve number defined for soil type and land cover and could range from 0 and 100 (CN=100 for impervious surfaces). Values for CN for selected soil group (Table 7) and specific hydraulic runoff conditions (Table 8) for rural and urban areas are given in Table 5 and Table 6 [3].

Table 5 Runoff curve numbers for urban areas, modified from [3]

Land use	Hydrological soil group			
	A	B	C	D
Open spaces, lawns, grassed sport courts, cemeteries, etc.				
poor condition: grass cover on 75% or less of the area	68	79	86	89
fair condition: grass cover on 50-75% of the area	49	69	79	84
good condition: grass on 75% or more of the area	39	61	74	80
Paved parking lots, roofs, driveways	98	98	98	98
Streets and roads:				
paved with curbs and inlets	98	98	98	98
paved with open ditches	83	89	92	93
gravel	76	85	89	91
dirt	72	82	87	89
City centres, business and commercial areas (85% impervious area)	89	92	94	95
Industrial zones (72% impervious areas)	81	88	91	93
Residential areas:				
5-are lots with 65% impervious areas	77	85	90	92
10-are lots with 38% impervious areas	61	75	83	87
13.5-are lots with 30% impervious areas	57	72	81	86
20-are lots with 25% impervious areas	54	70	80	85
40-are lots with 20% impervious areas	51	68	79	84
80-are lots with 12% impervious areas	46	65	77	82
Developing urban areas (only pervious newly graded area, no vegetation)	77	86	91	94

Table 6 Runoff curve numbers for rural areas, modified from [3]

Land use	Treatment	Hydrologic conditions	Hydrological soil group			
			A	B	C	D
Fallow	SR		77	86	91	94
Row crops	SR	poor	72	81	88	91
	SR	good	67	78	85	89
	C	poor	70	79	84	88
	C	good	65	75	82	86
	C/T	poor	66	74	80	82
	C/T	good	62	71	78	81
Small grain	SR	poor	65	76	84	88
	SR	good	63	75	83	87
	C	poor	63	74	82	85
	C	good	61	73	81	84
	C/T	poor	61	72	79	82
	C/T	good	69	70	78	81
Close seeded legumes or rotation meadows	SR	poor	66	77	85	89
	SR	good	58	72	81	85
	C	poor	64	75	83	85
	C	good	55	69	78	83
	C/T	poor	63	73	80	83
	C/T	good	51	67	76	80
Pasture or range		poor	68	79	86	89
		fair	49	69	79	84
		good	39	61	74	80
	C	poor	47	67	81	80
	C	fair	25	59	75	83
	C	good	6	35	70	79
Meadow		good	30	58	71	78
Woods		poor	45	66	77	83
		fair	36	60	73	79
		good	25	55	70	77
Farmsteads			59	74	83	86
Dirt roads			72	82	87	87
compacted			74	84	90	92
Legend: SR straight row; C contoured; T terraced; C/T contoured and terraced						

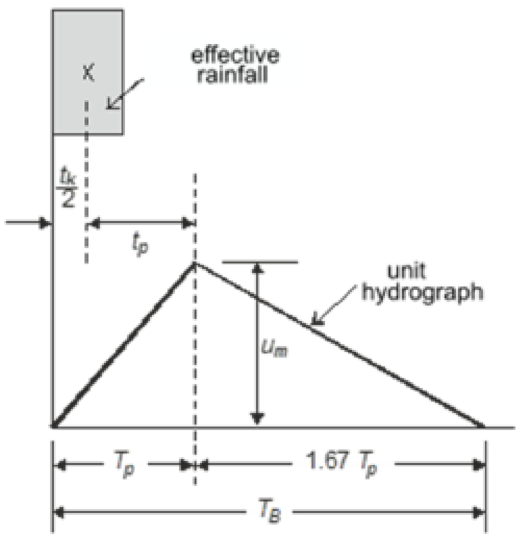
Table 7 Hydrological soil groups in the SCS method, modified from [3]

Group	Properties and types of soil
A	High permeability and low runoff potential: deep sand, deep loess, aggregated silts.
B	Medium permeability in completely wet condition: shallow loess, sandy loam.
C	Low permeability in completely wet condition: clay loams, shallow sandy loam, soils with low organic content, soils with high content of clay.
D	Very low permeability and high runoff potential: soils that swell considerably when wet, soils with constantly high groundwater table, shallow soils on impermeable layers, heavy plastic clays, some saline soils.

Table 8 Hydrological runoff conditions for the choice of the curve number,modified from [3]

Runoff condition	Description
Poor (high runoff)	Heavily grazed or regularly burned areas. Less than 50% of the ground surface is protected by vegetation, brush or treetops.
Fair	Moderate cover with 50-75% of the ground surface protected by vegetation.
Good (low runoff)	Dense cover with more than 75% of the ground surface protected by vegetation.

Discharge of runoff is calculated using the unit hydrograph representing the direct runoff caused by unit effective rainfall (rainfall depth of 1 mm) with constant intensity evenly distributed over the catchment area. Unit hydrograph used in SCS method is given below. Discharge $Q\ (t)\ [l/s]$ due to effective rainfall, $P_e\ [mm]$, is calculated as follows:



$$Q\ (t) = u(t) \cdot P_e$$

$$u_m = \frac{208.33\ \cdot A}{T_p}$$

$$T_p = t_p + \frac{t_k}{2}$$

Where:

$u\ (t)\ [m^3/(s \cdot mm)]$ is an ordinate of unit hydrograph

$T_p\ \ [hr]$ is rise duration

$t_k\ \ [hr]$ is rainfall duration

$t_p\ \approx 0.6 \cdot t_c\ [hr]$ is lag time

$t_c\ \ [hr]$ is time of concentration

Figure 4 SCS synthetic unit hydrograph, modified from [3]

6.1.3 Infiltration rates

Green areas located in/around road structures that are covered with plants (embankments, dividing lines, retention basins, infiltration basins, etc.) have significant infiltration potential that must be taken into account for calculation of runoff.

Infiltration capacity is affected by soil type, antecedent soil moisture, type and density of vegetation, land use, surface slope and rainfall intensity. It is recommended to assess the infiltration rate based on the site measurements.

Design rainfall for sizing of infiltration basin is generally not known and calculation must be done for various rainfall duration. In conditions in our country, the most used rainfall durations vary between 6 to 24 hours.

Quantity of water that can infiltrate into the soil depends on soil storage volume (soil porosity) and conveyance capacity (hydraulic gradient and conductivity). Calculation of steady laminar flow through saturated soil is done using Darcy’s Law:

$$q = K \cdot i \cdot A \left[\frac{m^3}{s}\right]$$

where $K \left[\frac{m}{s}\right]$ is hydraulic conductivity (Table 9), i is hydraulic gradient and $A\ [m^2]$ is catchment area.

Hydraulic gradient, i, is energy or head loss (Δh) per unit length (Δx) along the flow path and is calculated as follows:

$$i = \frac{\Delta h}{\Delta x}$$

Table 9 Hydraulic conductivity for various porous media

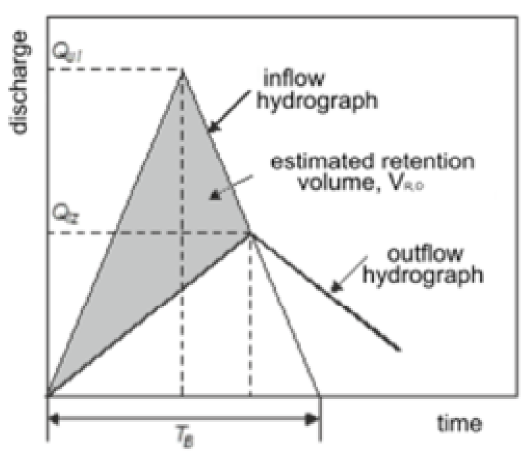
Material	Hydraulic conductivity, $K \left[\frac{cm}{s}\right]$
Gravel	10^{-1} to 1
Sand	10^{-3} to 10^{-1}
Silt/loam	10^{-5} to 10^{-3}
Clay	10^{-9} to 10^{-5}

6.1.4 Retention capacities

Control of excess runoff could be done in temporary retention facilities which relieves the drainage systems and enables non-overloading of the system downstream of the road drainage outlet. As a result of usage of the retention facilities, size of the downstream sewerage is reduced and, consequently, the cost is lower.

Design of retention basins is based on inflow hydrograph (i.e. runoff hydrograph from the road drainage system), stage-storage relationship of the facility and stage-discharge relationship for the outflow structure. Last two elements depend on the size of retention facility.

Initial estimation of retention volume, $V_{R,0}\ [m^3]$, is obtained from difference in volume of runoff inflow and estimated outflow volume.



$$V_{R,0} = \frac{Q_{inf} - Q_{out}}{2} \cdot T_B\ [m^3]$$

where

$Q_{inf} \left[\frac{m^3}{s}\right]$ - initial estimate of the required retention storage

$Q_{out} \left[\frac{m^3}{s}\right]$ - the peak of the outflow hydrograph

$T_B\ [s]$ – time base of the inflow hydrograph

Figure 5 Initial estimate of retention volume, modified from [3]

Stage-storage relationship specifies relation between water depth in the retention facility and its volume. Storage for stage z_i, $V_{z_i}\ [m^3]$ is calculated on a basis of storage for stage z_{i-1}, $V_{z_{i-1}}\ [m^3]$, and associated areas of the retention basin for stages z_i and z_{i-1}, $A_{z_i}\ [m^2]$and $A_{z_{i-1}}\ [m^2]$:

$$V(z_i) = V(z_{i-1}) + \frac{A(z_i) + A(z_{i-1})}{2} \cdot (z_i - z_{i-1})[m^3]$$

Initial volume, V_{z_0} $[m^3]$ for the lowest stage in the basin z_0, is equal to zero.

Stage-discharge relationship is corelation between water depth in the retention facility and outflow from the retention facility.

Outflow depends on type of outflow structure. Rating curve (relation between discharge and depth) for outlet structure is calculated for particular outlet. Equations for various types of outlet structures could be found in literature [8]. Retention facilities usually have main and emergency outlets.

Water balance calculation on for one year period is required for retention facilities. It includes all input and output components: rainfall, inflow, infiltration, evaporation and outflow.

Change of volume in the retention facility is based on the continuity equation and is calculated assuming quasi-stationary method where difference between inflow, $Q_{inf}\left[\frac{m^3}{s}\right]$, and outflow, $Q_{out}\left[\frac{m^3}{s}\right]$, in one calculation step is balanced with the change in volume in the retention facility.

$$Q_{inf} - Q_{out} = \frac{\Delta V}{\Delta t}$$

Sizing of the retention basin is done after trial-and-error procedure, based on routing of the inflow hydrograph and correction of input data.

Detail information on design principles for retention facilities are available from literature [1,3].

6.2 Dimensioning of drainage system

Selection of geometric elements of the road and type of pavement surface is of crucial importance for drainage, thus it is necessary to consider the road drainage problems during the process of designing road structure. Longitudinal (S_y) and lateral (S_x) slopes of road surface affect flow in a sense of flow direction and width of flooded area.

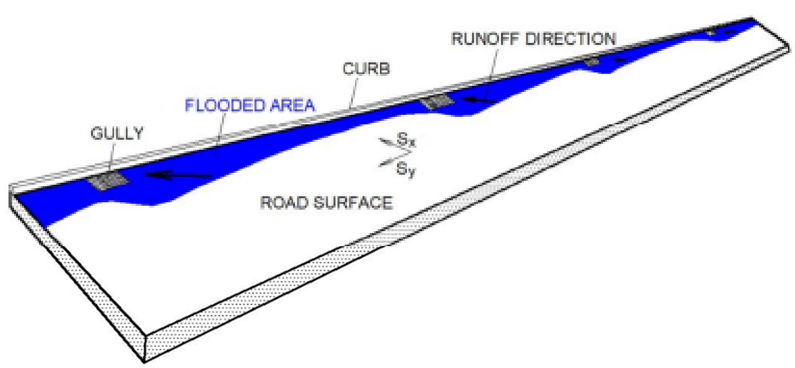


Figure 6 Runoff flow over the roadway surface

All drainage facilities should be designed and built to allow easy usage and simple monitoring and maintenance. Facilities should be easily accessible so maintenance and repair works will not significantly affect neither traffic nor other road facilities.

Surface facilities, such as open channels, retention ponds, infiltration areas, etc. should be designed to fit into the natural landscape. Design of facilities at intersection point with the road (culverts) should accommodate for needs of flora and fauna and requirements for habitat preservation.

6.2.1 Design Criteria

Rainfall return period for drainage systems on local roads and bridges is 5 years, for road crossing structures (culverts) is 5-10 years (low traffic) and 10-25 years (intermediate to heavy traffic), and for infiltration basins 2-10 years.

Recommendation for assessment of time concentration is given in Chapter 6.1.2.

Design runoff, $Q[l/s]$, is calculated to determine the hydraulic load of the system, or part of the system, in order to design basic geometric elements of facilities (longitudinal and lateral slopes, geometry of cross section, types of lining, size of channels, size of sewers, etc.). Methods for calculation of design runoff for road and road crossing structures are given in Chapter 6.1. Rational theory is the most often used in practice for calculation of design runoff from road surface.

Design of road drainage system must comply with the criteria that refer to acceptable width of traffic lane flooding during relevant participation. For local roads, allowable width of flooding is a half of traffic lane width, and allowable maximum water depth is 10 cm.

6.2.2 Surface Drainage

Flow over road surface

Road surface is drained in lateral and longitudinal directions and runoff is being transferred toward the road edge where it is being discharged over the embankments and infiltrated, if local conditions allow, or is being collected in closed or open drainage systems and being transferred to the receiving waters. Runoff from the road surface should be taken to the road edge in the shortest possible route.

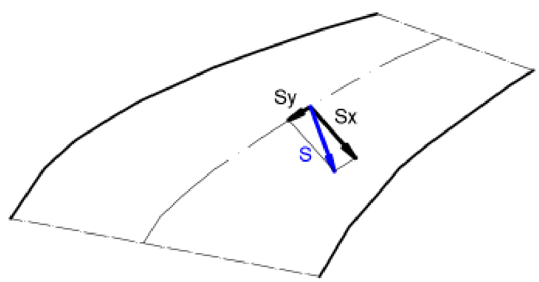


Figure 7 Direction of runoff flow on road surface

Longitudinal (S_y) and lateral (S_x) slopes of road surfaces enable collection of surface runoff and drainage of road surface. Direction of runoff (S) is calculated as follows:

$$S = \sqrt{S_x^2 + S_y^2}$$

According to the recommendations from the literature [3], the Kinematic wave method is used for calculation of flow on road surface to maximum length of 130 m (Table 2). For longer flow lengths, the runoff forms small streams and runoff velocity is calculated by the following equation:

$$v = k\sqrt{S}\,[m/s]$$

Where k is coefficient that is equal to $k = 0.619$ for paved surfaces (asphalt, concrete).

Open Channels

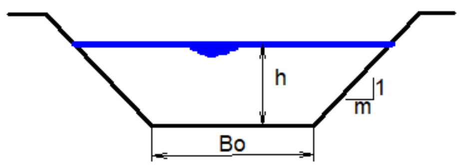
Part of the runoff from road surface reaches side channels, as well as the runoff from surface of surrounding area. Chezy-Manning's equation is used for sizing of open channels for the design discharge:

$$Q = \frac{1}{n} \cdot A \cdot R^{\frac{2}{3}} \cdot \sqrt{S_y}$$

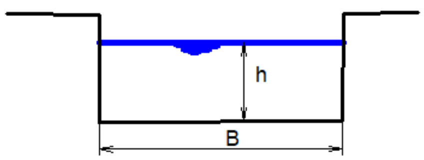
where $n\,[m^{-1/3}s]$ is Manning's coefficient (Table 3), $A\,[m^2]$ is cross section area, $R = \frac{A}{O}\,[m]$ is hydraulic radius, $O\,[m]$ is wetted perimeter, and S_y is a friction slope that is assumed to be equal to longitudinal bed slope.

The following table contains typical channel cross sections and geometry parameters used in Chezy-Manning's equation.

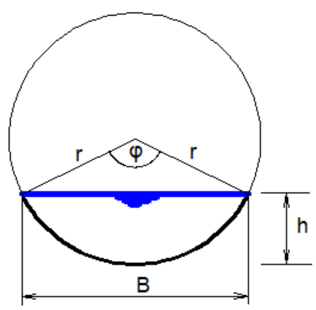
Table 10 Typical open channel cross sections and geometry characteristics



$$A = (B_0 + m \cdot h) \cdot h$$
$$O = B_0 + 2y\sqrt{1 + m^2}$$
$$B = B_0 + 2 \cdot m \cdot y$$



$$A = B \cdot h$$
$$O = B + 2 \cdot h$$



$$\varphi = 2 \cdot \arccos\left(1 - 2\frac{h}{2r}\right)$$
$$A = \frac{r^2}{2} \cdot \left(\frac{\pi \cdot \varphi}{180} - \sin\varphi\right)$$
$$O = \frac{r \cdot \pi \cdot \varphi}{180}$$
$$B = 2\sqrt{h \cdot (D - h)}$$
$$h = \frac{B}{2} \cdot \mathrm{tg}\left(\frac{\varphi}{4}\right)$$

where $B_0\,[m]$ is bottom width, $B\,[m]$ is top width, m is side slope, $h\,[m]$ is water depth, $r\,[m]$ is cross section radius.

After the depth of water in the channel has been calculated, it is necessary to check stability of channel in regard to erosion. This is done by calculation of maximum allowable velocity for particular soil type:

$$v_{max} = \frac{1}{n} \cdot R^{\frac{1}{6}} \cdot \frac{\sqrt{\tau_d}}{\sqrt{\rho \cdot g}}$$

where $\tau_d\,[N/m^2]$ is tangential shear for particular soil type.

Table 11 Allowable tangential shear for unlined and lined channels, modified from [3]

Category	Description	N/m^2

Cohesive soil (Plasticity index PI=10) (*source: USDA*)	Sandy clay Inorganic dast Dusty sand	1,8-4,5 1,1-4,0 1,1-3,4
Cohesive soil (Plasticity index PI≥20) (*source:USDA*)	Sandy clay Inorganic dast Dusty sand Inorganic clay	4,5 4,0 3,5 6,6
Nevezana zemljišta[2] (Plasticity index PI<10) (*Soource: USDA*)	Fine-grained sand D_{75}<1,3 mm Fine-grained gravel D_{75}=7,5 mm Gravel D_{75}=15 mm	1,0 5,6 11
Gravel	Coarse gravel D_{50}=25 mm Cobble D_{50}=50mm	19 38
Rock riprap	D_{50}=0,15 m D_{50}=0,30 m	113 227

Curbs and gutters

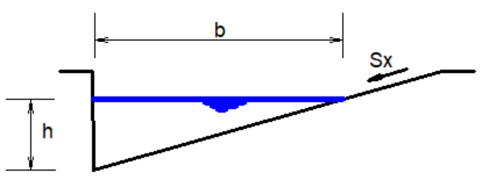
If road section contains curb then runoff from the road surface flows along the curb in gutters. Gutters usually has triangular or composite cross section. Flow capacity of the gutters is calculated using standard Chezy-Manning's equation.

Flooding width, $b\ [m]$, is calculated on a basis of calculated depth, $h\ [m]$, and lateral slope S_x:

$$b = \frac{h}{S_x}$$

Typical gutter cross section and associated geometry characteristics and discharge equations are given in the following table.

Table 12 Typical gutter cross sections and geometry characteristics

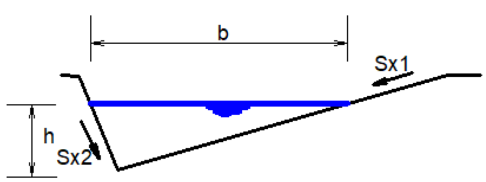


$$b = \frac{h}{S_x}$$

$$A = \frac{b \cdot h}{2} = (\frac{h}{S_x}) \cdot \frac{h}{2}$$

$$R = \frac{A}{O} \approx \frac{A}{b} = \frac{h}{2}$$

$$Q = \frac{(1/2)^{5/3}}{n \cdot S_x} h^{8/3} \sqrt{S_p} = \frac{0.315}{n \cdot S_x} h^{8/3} \sqrt{S_p}$$

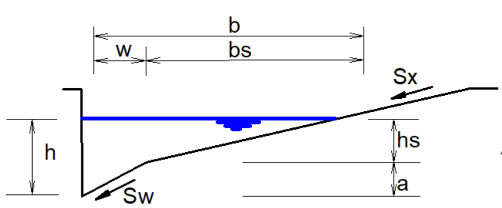


$$S_x = \frac{S_{x1} \cdot S_{x2}}{S_{x1} + S_{x2}}$$

$$A = \frac{b \cdot h}{2} = (\frac{h}{S_x}) \cdot \frac{h}{2}$$

$$R = \frac{A}{O} \approx \frac{A}{b} = \frac{h}{2}$$

$$Q = \frac{(1/2)^{5/3}}{n \cdot S_x} h^{8/3} \sqrt{S_p} = \frac{0.315}{n \cdot S_x} h^{8/3} \sqrt{S_p}$$



$$S_w = S_x + a/w$$

$$E_0 = \left[1 + \frac{S_w/S_x}{\left(1 + \frac{S_w/S_x}{\frac{b}{w} - 1}\right)^{8/3} - 1} \right]^{-1}$$

$$Q = Q_w + Q_s$$

$$Q_s = \frac{0.315}{n \cdot S_x} h^{8/3} \sqrt{S_p}$$

$$Q_w = Q_s \frac{E_0}{1 - E_0}$$

Recommended Manning values for road surfaces ranges from 0.012 $m^{-1/3}s$, for asphalt smooth surface, to 0.016 $m^{-1/3}s$, for asphalt rough surface. Manning's coefficient for gutters with small longitudinal slopes, where sedimentation is being expected, is recommended to be 0.020 $m^{-1/3}s$. Standard values for Manning's coefficients are given in Table 3.

Water from gutters is being discharged through either openings in curbes, or through gullies.

Storm water inlets

Runoff on the road surface spreads along the road and is of main concern for risks associated with difficult traffic conditions and accidents. Stormwater inlets should be designed and spaced to allow reduction of runoff spread to satisfactory conditions.

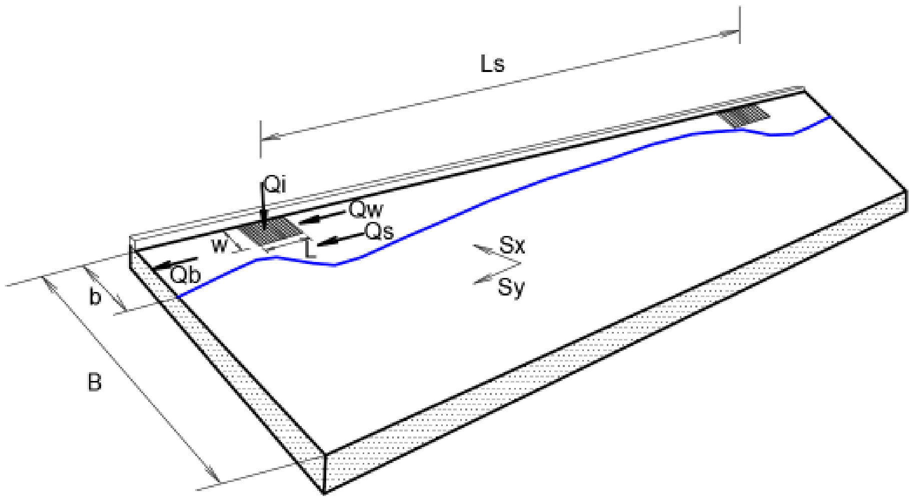


Figure 8 Collecting of runoff flow in storm water inlets

Inlet capacity (Q_i) is discharge that could be intercepted by an inlet. Remaining discharge, that is not intercepted by the inlet, is being transferred to the downstream inlet. The inlet type determines its capacity, as it is presented hereinafter.

Inlet efficiency (E) is a relation between the discharge that could be received by the gully inlet (Q_i) and total runoff that reaches the gully (Q): $E = Q_i/Q$

Gully capacity

Capacity of gully (Q_i) depends on type of gully and runoff velocity.

Several types of gullies could be used [1]. Further text refers to the gully type 1 (Figure 18), that is the most common used in country.

Total discharge that approaches the gully consists of the frontal discharge, that comes directly to the gully of widht ω, Q_ω, and the side discharge Q_s:

$$Q = Q_w + Q_s, \qquad Q_\omega = Q \cdot E_0 \qquad \text{and} \qquad Q_s = (1 - E_0) \cdot Q$$

Gully efficiency is calculated using the following formula: $E_o = 1 - \left(1 - \frac{\omega}{b}\right)^{8/3}$, where $\omega\ [m]$ is gully width, and $b\ [m]$ is flooding width.

Gully inlet capacity, Q_i , is equal to a sum of effective frontal and side discharges:

$$Q_i = R_w \cdot Q_w + R_s \cdot Q_s$$

where, R_w is efficiency of frontal discharge reception and is equal to:

$$R_w = \begin{cases} 1 - 0.295 \cdot (v - v_0), & v \geq v_0 \\ 1, & v < v_0 \end{cases}$$

where v is velocity of flow Q that approaches the gully, v_0 is maximum velocity that depends on gully type ($v_0 = 0.676 + 4.03 \cdot L - 2.13 \cdot L^2 + 0.598 \cdot L^3$ for gully type 1 with distance between gully openings $d_0 = 50\ mm$) and L is gully length.

Efficiancy of gully regarding side flow, R_s, is calculated as follows:

$$R_s = \frac{1}{1 + \frac{0.0828 \cdot v^{1.8}}{S_x \cdot L^{2.3}}}$$

<u>Gully distance</u>

Capacity of gully depends to a large extent of lateral and longitudila slope of gutter, as well as on the permissible depth of water. The basic criterion for determination of gully distance is that the allowable flooding width for precipitation of the required return period is not exceeded.

Runoff (Q) that reaches the gully should be received by the gully (Q_i), but in a case that intensive rainfall part of the flow could not be accepted, it is being transferred to the downstream gully (Q_b):

$$Q_b = Q - Q_i$$

The discharge that is transferred downstream from the gully could not be greater than one third of total runoff upstream of the gully.

Distance between gullies $L\ [m]$ is calculated:

$$L = \frac{Q_i}{B \cdot i_k \cdot C}$$

where $B\ [m]$ is width of road surface, $i_k\ [m/s]$, is design rainfall intensity, and $C\ [-]$ is runoff coefficient.

Calculation of gullies' distance is an iterative procedure because the rainfall intensity depends on rainfall duration that changes depending on the calculated travel time of the rain runoff to the gully, t_{01}. Travel time, $t_0 [min]$, is calculated using the kinematic wave model:

$$t_{01} = 1.36 \cdot \frac{B_s^{0.6} \cdot n^{0.6}}{i_e^{0.4} \cdot S^{0.3}}$$

where S is slope in flow direction, $S = \sqrt{S_x^2 + S_y^2}$, $B_s [m]$ is the length of runoff to curb, $B_s = B \cdot \sqrt{1 + \left(S_y/S_x\right)^2}$, and $B[m]$ is width of the road surface that is being drained, $n\ [m^{-1/3}s]$ is Manning's coefficient (Table 3), $i_e\ [mm/min]$ is effective rainfall intensity ($i_e = i_k \cdot C$). Recommended value of runoff coefficient for asphalt surface is 0.9, while values for other surfaces are given in chapter Hydrology, Table 4.

Travel time of runoff t_{02} along the curb of length L_{12}, is calculated as

$$t_{02} = L_{12}/v_a$$

where $v_a [m/s]$ is average water velocity between two cross sections, $v_a = \frac{0.63}{n} \cdot (b_a \cdot S_x)^{2/3} \cdot \sqrt{S_p}$, $b_a\ [m]$ is average width of runoff between upstream (with width marked as $b_1\ [m]$), and downstream sections (with width marked as $b_2\ [m]$):

$$b_a = 0.65 \cdot b_2 \cdot \left(\frac{1 - (b_1/b_2)^{8/3}}{1 - (b_1/b_2)^2}\right)^{3/2}$$

Procedure for calculation of travel time is iterative – rainfall intensity, $i_k\ [m/s]$, is taken depending on rainfall duration, $t_k\ [min]$. For the first iteration, rainfall duration t_k is adopted to be 2 min. After implementation of above equation travel time t_0 is calculated and is further used in repeated calculation as a new rainfall duration t_k.

It is commone practice to adopt 5 minutes for runoff travel time.

Example of calculation of distance between gullies is given in literature [3].

6.2.3 Underground Sewage Systems

Runoff collected in gullies is being conveyed through the underground sewer system toward the outlet structure. These systems are usually used in urban areas but could be also used in rural areas in situations where surface drainage is not possible to build (excavated sections, tunnels, bridges, etc.). Flows in pipes (sewers, culverts, etc.) are mostly with a free water surface but could change to surcharged/pressurised flow.

Size of circular pipes with a full profile is calculated using Chézy-Manning's equation:

$$Q_{pp} = \frac{0,312}{n} \cdot D^{8/3} \cdot \sqrt{S}$$

where $Q_{pp}\left[\frac{m^3}{s}\right]$ is discharge in full profile, $n\left[m^{-1/3}s\right]$ is Manning's Roughness Coefficient, $D[m]$ is inner pipe diameter, and S is longitudinal pipe slope. Values of Manning's Roughness Coefficient is given in Table 3, and for pipes ranges between 0.011 and 0.013 $m^{-1/3}s$, and 0.013 $m^{-1/3}s$ is usually most common used in projects.

The following table (Table 13) contains discharges, $Q_{pp}\left[\frac{l}{s}\right]$, and velocities, $v_{pp}\left[\frac{m}{s}\right]$, for full profile in circular pipes, for various longitudinal slopes.

Discharge capacity of partially filled pipes is calculated on a basis of the discharge capacity of full profile:

$$\frac{Q}{Q_{pp}} = \frac{3 \cdot 4^{2/3}}{\pi} \cdot \left(\frac{h}{D}\right)^2 \cdot \left(1 - \frac{7}{12} \cdot \left(\frac{h}{D}\right)^2\right)$$

where $h[m]$ is water depth. This equation is applicable for relative fullness, $\frac{h}{D}$, up to 0.82, that refers to relative discharge, $\frac{Q}{Q_{pp}}$, close to 1.

Detailed calculation of flow in pipes that are partially filled and pipe sizing is available from the literature [1,3].

Table 13 Flows and velocities in the full profile of circular channels for different slopes, modified from [3]

(Manning's Coefficient 0.013 m-1/3s, or the corresponding absolute pipe wall roughness of 1.5 mm)

S	Pipe diameter in cm													
	30		*40*		*50*		*60*		*70*		*80*		*100*	
	Q_{pp}	v_{pp}	Q_{pp}	v_{pp}	Q_{pp}	v_{pp}	Q_{pp}	v_{pp}	Q_{pp}	v_{pp}	Q_{pp}	v_{pp}	Q_{pp}	v_{pp}
(‰)	*(l/s)*	*(m/s)*	*(l/s)*	*(m/s)*	*(l/s)*	*(l/s)*	*(m/s)*	*(m/s)*	*(l/s)*	*(m/s)*	*(l/s)*	*(m/s)*	*(l/s)*	*(m/s)*
0.5									204	0.53	290	0.58	523	0.67
1					119	0.61	193	0.68	289	0.75	412	0.82	741	0.94
1.5			80.8	0.64	146	0.74	236	0.84	355	0.92	505	1.0	909	1.16
2	43.5	0.62	93.5	0.74	169	0.86	273	0.97	410	1.07	584	1.16	1050	1.34
5	69.1	0.98	148	1.18	268	1.36	433	1.53	650	1.69	925	1.84	1664	2.12
10	98	1.39	210	1.67	378	1.93	613	2.17	921	2.39	1309	2.6	2355	3.0
12	107	1.52	230	1.83	415	2.11	672	2.38	1009	2.62	1435	2.85	2581	3.29
14	116	1.64	249	1.98	449	2.28	728	2.57	1090	2.83	1550	3.08	2788	3.55
16	124	1.75	266	2.12	480	2.44	776	2.75	1166	3.03	1657	3.3	2981	3.8
18	132	1.86	282	2.24	509	2.59	824	2.91	1237	3.21	1758	3.5	3162	4.03
20	139	1.96	297	2.37	537	2.73	868	3.07	1304	3.39	1853	3.69	3333	4.24
25	155	2.2	333	2.65	600	3.06	971	3.43	1458	3.79	2072	4.12	3727	4.75
30	170	2.41	364	2.9	657	3.35	1064	3.76	1597	4.15	2270	4.52	4084	5.2
40	196	2.78	421	3.35	759	3.87	1229	4.35	1845	4.79	2622	5.22		
50	220	3.11	471	3.75	849	4.32	1374	4.86						
60	237	3.35	510	4.06	924	4.71	1504	5.32						
70	256	3.62	551	4.38	999	5.09								
80	274	3.87	589	4.69										
100	306	4.33	658	5.24										

6.2.4 Culverts

Culverts are installed at locations of intersection of road structure and natural watercourses and are used for transfer of rainfall runoff from one side of the road to other side. Sizing of culverts and their positioning in horizontal and vertical planes depends on size of catchment area, design runoff, terrain characteristics (elevations, slopes) and possibilities for discharge in water recipients.

Quantity of runoff is calculated as shown in section 6.1.2.

Culverts that are part of closed drainage systems are sized using procedure/equations given in previous Chapter 6.2.3.

Culverts that are connected to natural watercourses or open channels are sized taking into account timing and variation of natural runoff and runoff from road structure.

The slope of the culvert is usually adopted to follow the slope of the terrain.

Flow in culvert could be free surface flow or submerged flow. Hydraulic conditions in culvert depend on the culvert slope and downstream and upstream conditions. Generally, calculation of culvert size is an iterative procedure because culvert size is adopted assuming certain conditions at the inlet and outlet (submerged or unsubmerged) and culvert slope (steeper or less steep than critical slope). Those assumptions must be checked for the design discharge and if preconditions are not met, the initial conditions must be adjusted and calculation must be repeated. Summary of the sizing of culverts for the most common cases is given hereinafter, while detailed calculations are given in literature [3].

Free flow in culvert with critical depth at inlet occurs when flow in culvert is supercritical, due to culvert steep longitudinal slope (steeper than critical slope), culvert outlet is not submerged (if relation between energy at section 1 and culvert height is less than 1.2, $e_1/D < 1.2$) and culvert inlet is not submerged ($h_4 < h_k$).

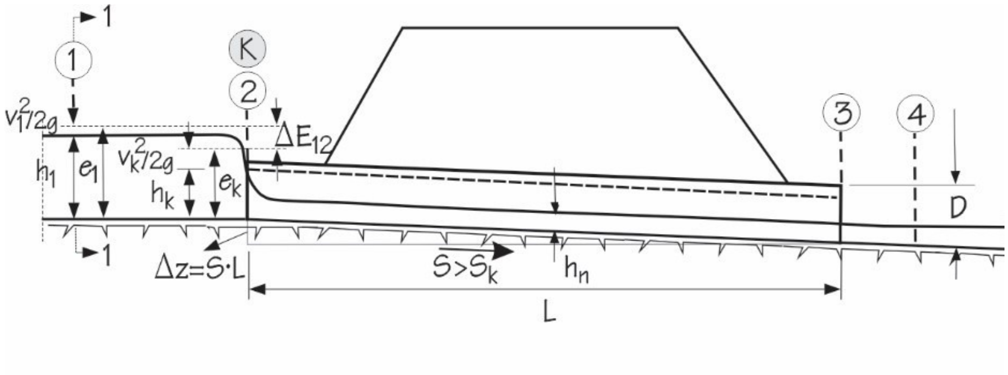
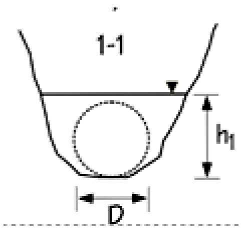
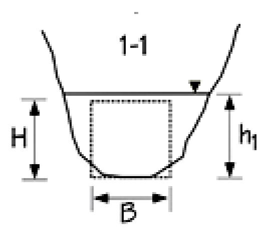


Figure 9 Culvert with free flow and critical flow at inlet [3]

Sizing of the culvert with circular and rectangular cross sections is done using following equations:



$$Q = \frac{16}{9\pi} \cdot \frac{D^2\pi}{4} \cdot \sqrt{gD}$$



$$Q = C_B \cdot B \cdot \sqrt{g} \cdot \left(\frac{2}{3} \cdot e_k\right)^{3/2}$$

where $D[m]$ is culvert radius, $B[m]$ is culvert width, C_B is jet contraction coefficient ($C_B = 1$ for hydraulically shaped inlets, $C_B = 0.9$ for unshaped inlets), $e_K = 3/2h_k$ is specific energy for rectangular cross section.

Free flow in culvert with critical depth at outlet occurs when culvert slope is less than the critical slope, resulting in subcritical flow in culvert, and culvert inlet is not submerged (if relation between energy at section 1 and culvert height is less than 1.2, i.e. $e_1/D < 1.2$) and free flow occurs at outlet.

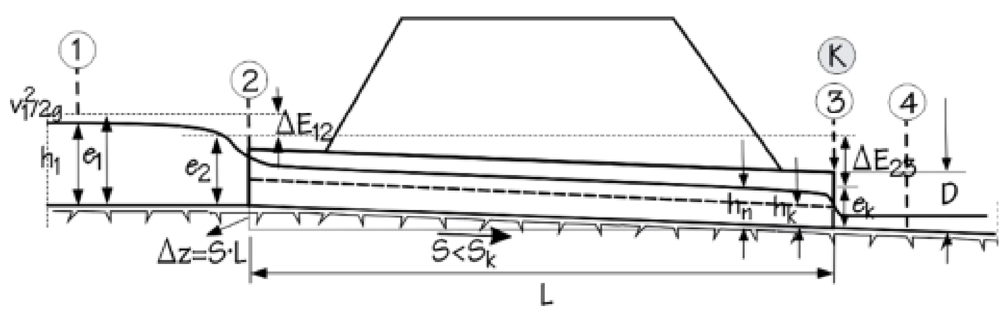


Figure 10 Culvert with free flow and critical flow at outlet [3]

Calculation is identical to previous case, but specific energy, e_k , is calculated from Bernoulli equation for sections 1 and 3:

$$e_k = h_1 + \Delta z + \frac{v_1^2}{2g} - \Delta E_{12} - \Delta E_{23}$$

Where ΔE_{12} is energy loss at the inlet, and ΔE_{23} is energy loss due to friction.

Narrowed section at inlet is a control section when culvert outlet is not submerged, and free flow with free surface occurs at the inlet (if relation between energy at section 1 and culvert height is between 1.2 and 2, i.e. $1.2 < e_1/D < 2$). Narrowed inlet is control section relevant for calculation of culvert capacity.

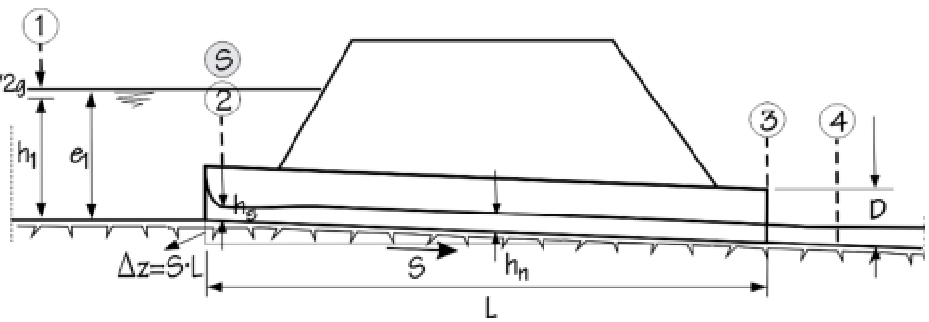
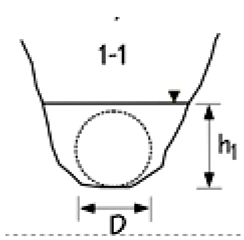


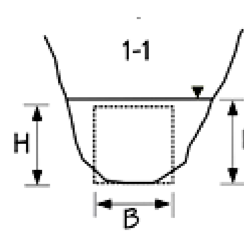
Figure 11 Culvert with free flow and narrowed water depth at inlet [3]

Sizing of the culvert with circular and rectangular cross sections is done using following equations:



$$Q = C_d \cdot \frac{D^2\pi}{4} \cdot \sqrt{2g(e_{1-}C_d D}$$

$$C_d = 0.96/(1 + 0.5\exp(-15\frac{r_d}{D})$$



$$Q = C_H \cdot B \cdot H \cdot \sqrt{2g(e_{1-}C_H H}$$

where C_d and C_H are coefficients that depend on the roundness of the culvert invert (r_d) [3].

Pressurized flow in culvert occurs when inlet submergence is greater than 2 ($e_1/D > 2$).

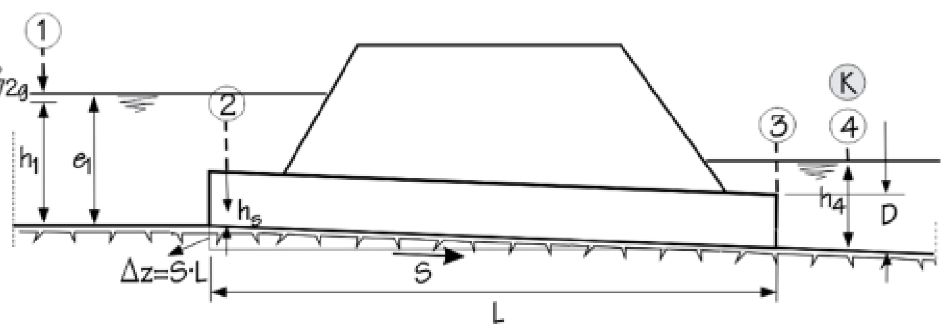


Figure 12 Culvert with full flow [3]

Culvert capacity is calculated as follows:

$$Q = \frac{D^2\pi}{4} \cdot \frac{1}{\sqrt{1 + \sum \xi}} \sqrt{2g(e_1 + \Delta z - h_k)}$$

where $\sum \xi$ is a sum of losses, including local losses at the culvert inlet and friction losses, and h_k is relevant depth at section 4.

If the outlet is submerged, than depth h_k is the same as h_4, ($h_k = h_4$), but if free flow occurs at the outlet, then water depth at section 4 must be calculated. For the first calculation iteration it could be assumed that the water depth is equal to culvert radius ($h_k = D$).

6.2.5 Water Retention

There are various types of flow retention measures that serve to control quantity and quality of runoff: detention basins, retention basins, infiltration basins and other.

Detention basins are small water impoundments with a capacity up to 16 ha. Outflow from the detention basins is usually uncontrolled. They are used for temporarily detention of runoff and they empty after the storm. Usage of detention basins for deterioration time greater than 24 hours is considered to be reasonable. Part of detention basins is used for sedimentation. Maintenance is moderate if properly designed, with low maintenance costs.

Retention basins has usually larger volumes and controlled outflow discharge. They are used for prolonged (dry retention basin) or permanent (wet retention basin) storage of inflow that inter alia results in removing pollutants by settling dissolved pollutant biochemically. Maintenance is relatively low-cost after first year except for major cleanout that is planned once in ten years.

Infiltration basin could be designed as a flood detention basin, for reduction of flow, or as a water quality control basin, for improvement of water quality. The most common use of infiltration basins is in a situation where there are no natural water recipients in which collected runoff could be discharged.

Runoff from the catchment depends on previous soil moisture – if considered rainfall was preceded by other rainfall episodes, infiltration will be less due to already increased soil moisture.

Prolonged use of infiltration systems could cause occurrence of colmation, i.e. deposition of suspended sediment particles at the bottom of infiltration basin. This leads to reduction of filtration coefficient and thus reduction in functionality of the system.

Simplified calculation of infiltration basin filling and emptying dynamics is given i literature [3].

6.2.6 Sedimentation

Sedimentation is a process of sinking of suspended solids having a density greater than 1000 kg/m^3. Particle will sink in still water until sinking resistance is equal to effective weight of the particle.

Scheme of sedimentation process is given in the following figure.

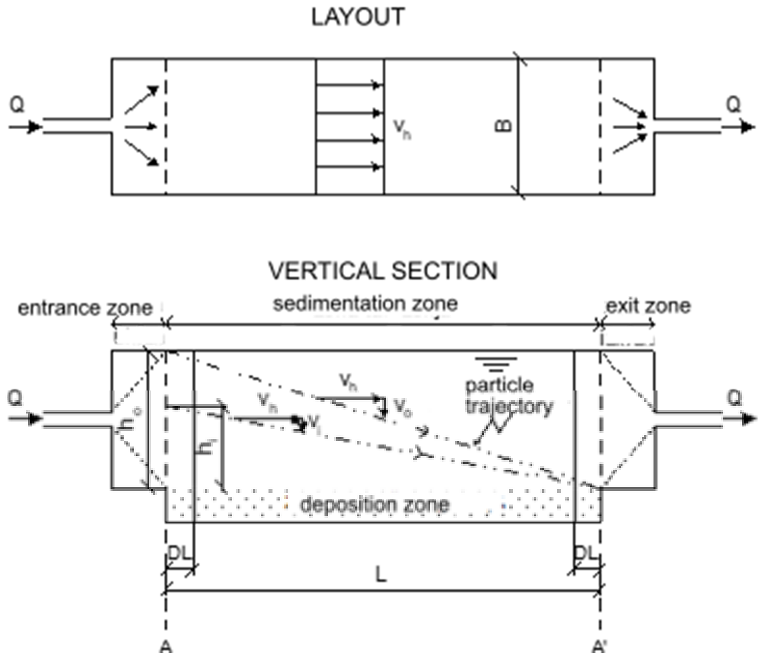


Figure 13 Ideal rectangular settling basin with horizontal flow, modified from [3]

Sinking velocity, $v_o\left[\frac{m}{s}\right]$, depends on water velocity, $v_h\left[\frac{m}{s}\right]$, and length of sedimentation basin, $L[m]$, and could be calculated as follows:

$$v_o = \frac{h_0}{t_0} = \frac{Q}{A}$$

where $h_0[m]$ is sedimentation tank depth, $A = B \cdot L[m^2]$ is area of sedimentation basin base, $t_o[s]$ is water retention time, calculated as a ratio of sediment basin volume, $A \cdot h_0\ [m^3]$, and design flow, $Q\left[\frac{m^3}{s}\right]$, $t_o = \frac{A \cdot h_0}{Q}$, and $B[m]$ and $L[m]$ are width and length of the sedimentation tank.

All practices with sinking velocity greater than $v_o\left[\frac{m}{s}\right]$ will be settled down in the sedimentation tank.

More information on the design of sedimentation tanks could be found in literature [3].

7 FACILITIES

7.1 Surface Drainage

Traffic areas

Minimum longitudinal and lateral slopes of road surfaces and road facilities should be adopted together with the road designer. Recommendations from the drainage point of view are given hereinafter.

Longitudinal slope (S_y) should be minimum 0.5 %, and in exceptional conditions and on shorter sections minimum slope 0.3 % could be acceptable.

Lateral slope (S_x) should be minimum in a range of 1.5 % to 2.5 %. If the road consists of more than one lane in one direction, the lateral slope increases in each subsequent lane toward the stop lane (road edge) for 0.5 % to 1 %, up to maximum lateral slope of 4 %.

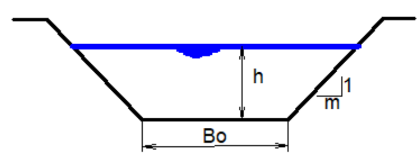
If road consists of a dividing lane, runoff should not be directed toward the dividing lane. If previous is not possible, drainage system must be designed to collect entire runoff so that maximum width of flooding does not exceed the dividing zone.

In the case of road junctions driving conditions are adjusted to lower traffic speeds. Road surfaces of intersecting roads must be drained prior to the intersection area. Rules applicable for drainage of roads is applicable also to drainage of roundabouts. Sample of drainage of roundabout is given in Appendix.

Paved secondary traffic areas (hard shoulder, parking lane, bicycle path, pedestrian path) are mostly separated from the road, in terms of position and/or level, thus usually common longitudinal drainage could be designed. Lateral slopes of secondary traffic areas should be equal to the lateral slopes of traffic areas. Parking areas usually have lateral slope of 2.5 %.

Unpaved shoulders must ensure free drainage of the road surface. It usually has lateral slope of 12%, toward the outside, and elevation of shoulder surface at connection to road edge should be about 3 cm lower than the road surface. If the shoulder is not used for road drainage, lateral slope could be 6 %.

Open channels are installed along the road and within the dividing zone of roads. The most common cross section of channels is trapezoidal with defined bottom width B_0 $[m]$ and side slope m. Bottom width at the most upstream section should be 30 to 50 cm, and the side slope m depends on soil type and ranges between 1 and 3. Total heigh from the top to bottom of channel is usually equal to water depth plus 15 cm.



Maximum allowable velocities are determined by allowable shear stress for specific longitudinal channel slope and particular channel lining material (Chapter 6.2.2).

For channel side slopes greater than 3 $(m > 3)$, slope stability check is usually not necessary.

Open channels must be placed low enough to allow free discharge of runoff water collected in the drainage systems located in the road structure.

Whenever possible, when design water velocities permit, bottom and side of channels should be unlined or grassed. If velocities are higher, channel must be covered with gravel or stone, or, for high velocities, with concrete. Typical cross sections of channels lined with stone in cement mortar or concrete are given on the following Figure.

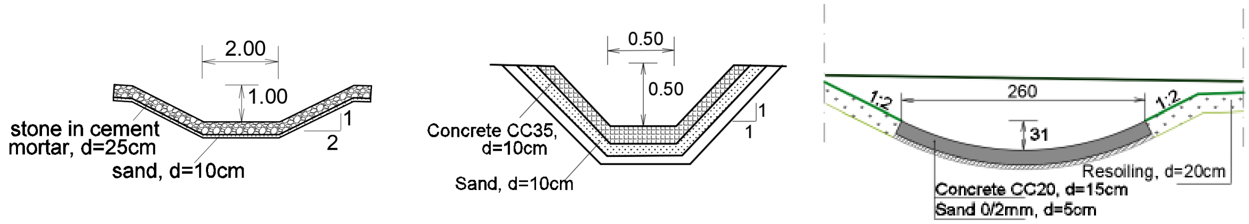


Figure 14 Typical lined channel cross sections

Slope drain flumes are open channels perpendicular to contour lines, placed on embankments. They are used for transfer of collected surface runoff from the road surface to the open channels located at foot of the embankment. Since that the side slopes channels usually have steep longitudinal slopes, they are lined with stone or concrete, and are made in cascades. Sometimes it is necessary to anchor the channel into the embankment slope, depending on the subsoil conditions.

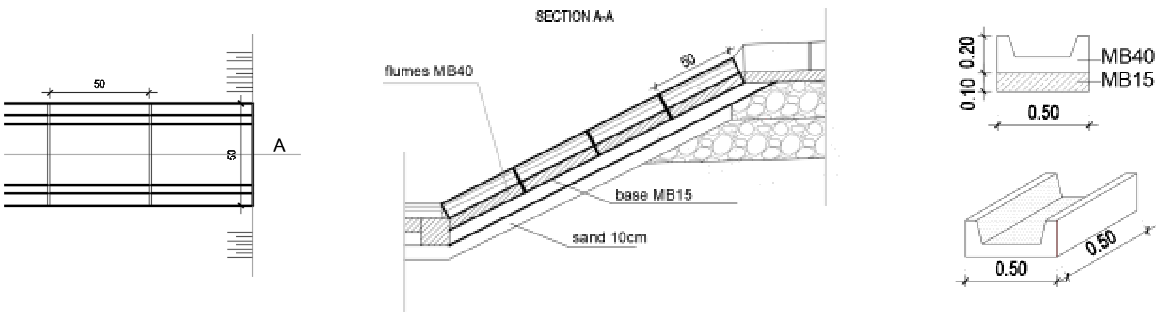


Figure 15 Typical drain flume channel

Cascades are used when open channel is placed in a section with high elevation difference at short distance causing significant longitudinal slope of open channel and, consequently, high water velocities that can lead to erosion of the channel lining. The purpose of cascade is to converse kinetic energy at the cascade to other type of energy (potential, sound, heat), that result in a decrease in velocity. Cascades are usually covered with stone in mortar, or with concrete, and could be also made of pre-cast concrete. Special attention should be taken to a stability of cascades and ensuring that undercutting of the structure will not happen. Inlet of cascades is exposed to a risk of erosion due to a turbulence, and must be protected by stone, paving, or similar lining.

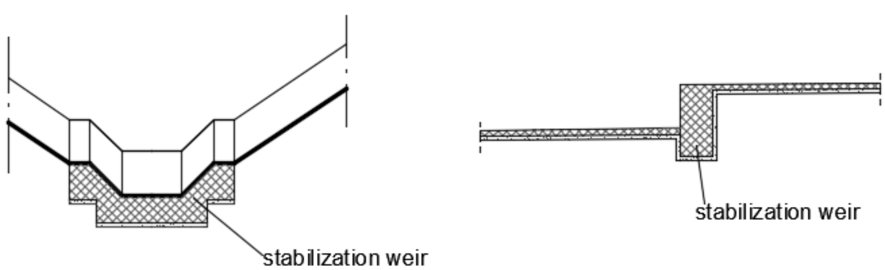


Figure 16 Typical cascade

Gutters are placed next to the road surface edge or edge of stop line. Gutters are made of asphalt or concrete and are bordered with the curb, often used prefabricated. Width of the gutter depends on road width and ranges from 0.5 m, for roads with two lanes, to 0.75 m, for roads with more than two lanes. Depth of gutters are usually 0.10 m. Gutter cross section depends on type of curb (Chapter 6.2.2). The following figure presents possible solution for gutter design and recommended geometric characteristics [1]. Longitudinal slope of gutter should be equal or greater than 0.5 %. If the longitudinal slope falls below the minimum value, distance between gullies must be decreased. At external side of gutter, it is necessary to design berm of minimum 0.5 m.

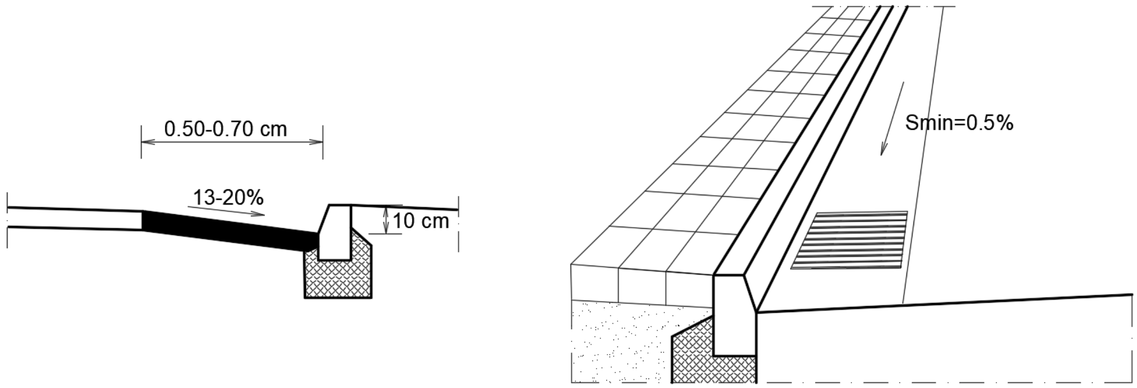


Figure 17 Typical gutter

Gullies intercept runoff collected in gutters and transfer it to the underground drainage systems, i.e. to pipelines. There are several types of gullies, as shown in literature [3].The most used gully in the country is type 1, with openings parallel to the curb. Next figure presents disposition of two gullies of type 1 placed in a row next to each other.

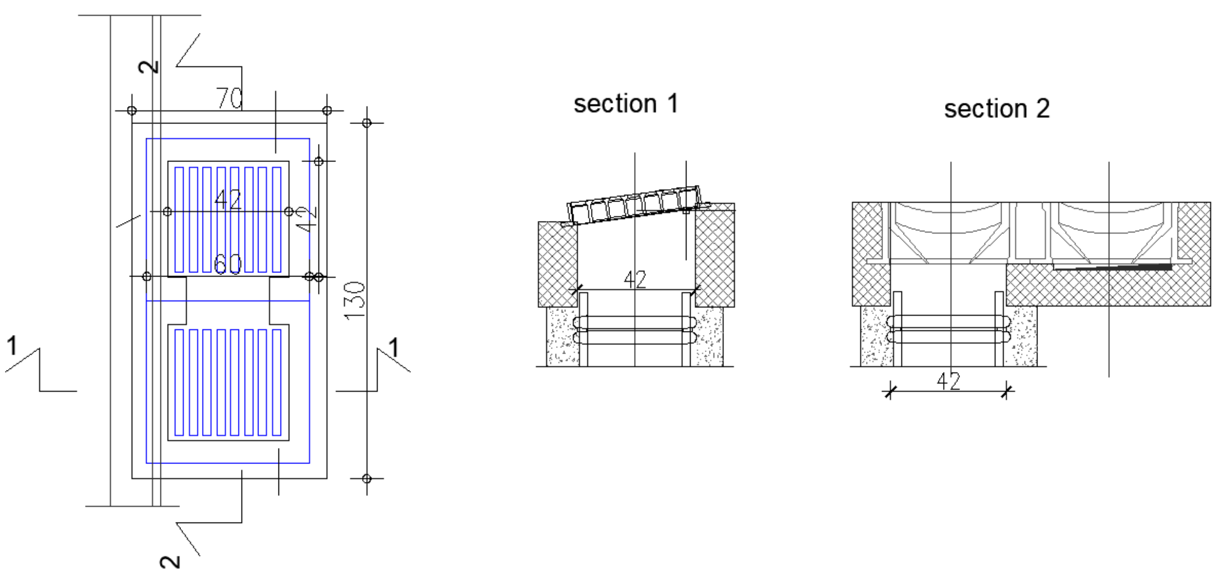


Figure 18 Two gullies type 1 installed in a row

Slot channel is a street gutter made of prefabricated parts in which water intercepts into the channel through a slot. It should be used in special cases where usage of other drainage facilities is not possible. Slotted channels are usually circular or oval, with minimum diameter 20 cm. The slot is minimum 13 mm wide, and maximum 30 mm. Exact sizes of slot channels could be obtained from manufacturers.

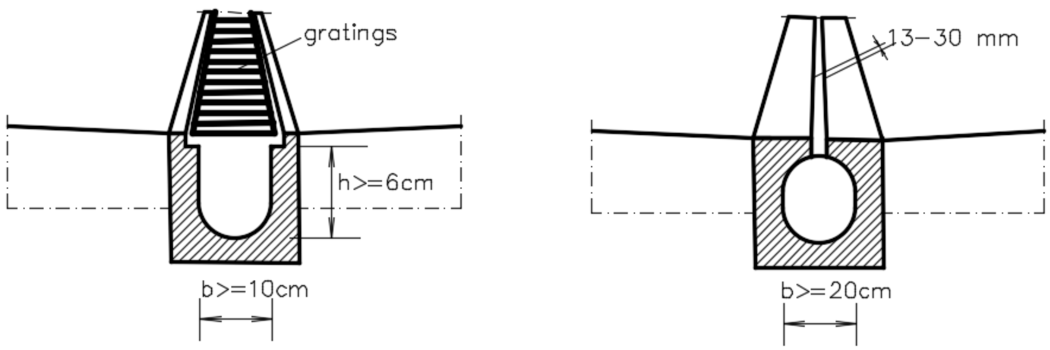


Figure 19 Samples of box gutter (left) and slot channel (right)

The slot channels are suitable for use in drainage of tunnels.

Segmented channel could be used instead of gutters and provides higher safety on road. They can be placed immediately along the road surface or could be separated by shoulders. Surface of segmented channel is lined with asphalt, concrete elements or grass. At external side of the segmented channel, it is necessary to design a berm of minimum 0.5 m [1].

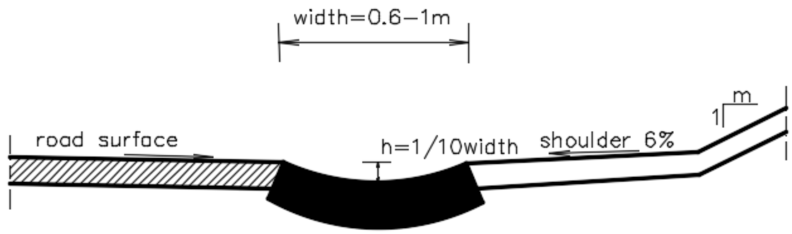


Figure 20 Segmented channel

7.2 Underground Sewerage System

Underground drainage system consists of straight pipelines and manholes.

Pipes

Pipelines are used for underground transfer of collected runoff that enters the underground drainage system through gullies.

Dimensions and other characteristics of manufactured pipes are defined in numerous standards (ISO, EN, DIN, BS, SRPS, and etc.) and recomendations. Nevertheless, each manufacturer of sewerage pipelines has products' brochures with necessary information on produced pipes.

Minimum pipe diameter is set to enable access for inspection, cleaning and maintenance. The most common minimum pipe size is 300 mm, while connection pipes to gullies have smaller sizes.

Minimum and maximum slopes are defined in order to ensure minimum transport water velocity to achieve pipe self-cleaning and prevent wear and damage of pipes due to excess velocities.

Minimum velocity should be 0.4 m/s for water depth 2 to 3 cm, or 0.7 to 0.8 m/s for full pipe flow. Maximum allowable velocity is 3 m/s for full pipe flow and/or heigh water depth, or 5 to 6 m/s for occasional short term situation.

Minimum and maximum slopes could be calculated on a basis of minimum/maximum velocities (using for example Darcy Weisbach formula) or for engineering practice using formula $S_{min} = 1/D$ and $S_{max} = 15/D$, where $D\ [mm]$ is pipe diameter. Minimum and maximum slopes for circular pipes, for various minimum and maximum velocities in full pipe profile, are given in following table.

Table 14 Minimum and maximum slopes of circular sewers for various minimum and maximum velocities in full profile [3]

	S_{min}		S_{max}	
	0,6 m/s	0,8 m/s	3 m/s	5 m/s
D (mm)	S_{min} (‰)	S_{min} (‰)	S_{max} (‰)	S_{max} (‰)
300	1,86	3,30	46,43	128,98
400	1,28	2,27	31,98	88,83
500	0,96	1,71	24,00	66,68
600	0,76	1,35	19,02	52,83
700	0,63	1,11	15,63	43,43
800	0,53	0,94	13,20	36,67
1000	0,40	0,71	9,97	27,68

Pipe materials

Pipes could be made of various materials, such as plastic, concrete, reinforced concrete, steel, etc.

Plastic pipes are most commonly used in practice due to simple handling and relatively low cost. The most used pipe material is PVC (diameters up to 500 mm, segment length 1 to 6 m), HDPE (smooth pipes up to 600 mm and corrugated pipes for larger sizes, segment length 6 to 12 m), PP (for high durability and resistance to mechanical impacts) and polyester (for large sizes).

Concrete pipes are used for free flow in pipes and in a case where large pipe size is required and when high bearing capacity is required. Concrete pipes could be either prefabricated or made on site. Prefabricated pipes usually have circular or egg shaped/ellipsoid cross sections, up to diameter of 1200 mm. If reinforced concrete is used, pipe diameter could be maximum 2000 mm. Length of prefabricated pipes are usually 1 m (less common 2 m).

Steel pipes are used in specific situations where installation of pipes made of other materials would not be acceptable (significant dynamic loads, underwater collectors, siphons, etc.) or would require complex structures (i.e. big number of cascades).

Excavation depths

Minimum excavation depth should meet all conditions listed below:

- 0.8 m to pipe top – for frost protection (in our country);
- 1.0 to 1.5 m – for protection from traffic load;
- depth that allows connection of gullies, upstream pipes and culverts by gravity.

Maximum excavation depth is limited by conditions for excavation and depends on soil characteristics, groundwater level and construction technology. Maximum excavation depth is usually about 7 m, if no groundwater is present, or 4 to 5 m, if groundwater exists.

Minimum trench width $B_r\ [m]$ depends on outer pipe size $D_s\ [m]$, as follows:

D_s [mm]	B_r [m]
$300 - 800$	$B_r = D_s[m] + 0.6$
$800 - 1200$	$B_r = D_s[m] + 0.8$
≥ 1200	$B_r = D_s[m] + 1.0$

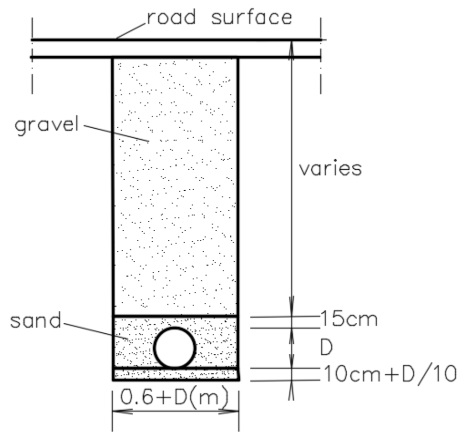


Figure 21 Typical excavation trench

Typical excavation trench for pipe size up to 800 mm is shown on Figure 21. Thickness of bottom sand layer is either 10 cm deep or *10+ D/10*.

Manholes

The main role of manholes is to provide access to the drainage system (i.e. pipelines) that will enable maintenance and cleaning, as well to ensure ventilation of sewerage system. Manholes are installed at a point of connection of straight pipelines, particularly in following cases:

- at commencement of section;
- at change of pipe size, pipe direction and pipe slope;
- at rectilinear sections at a distance up to $160 \cdot D$, where D is pipe diameter;
- at connection with gullies.

Maximum distance of manholes could be also requested based on requirements of system cleaning and maintenance equipment.

Manholes are usually made of reinforced concrete, polypropylene or HDPE.

Reinforced concrete manhole for sewer size up to DN600 mm are made of prefabricated parts height 0.5-1 m, that has circular cross section with diameter of 1 m. Top prefabricated part has variable diameter, from 1 m do 0.6 m on top of the manhole (Figure 22).

For sewer sizes greater than DN600 mm, bottom of the manhole is rectangular and is made on site. Upper part of the manhole is made of prefabricated parts (Figure 23).

Polypropylene and HDPE manholes are convenient for usage due to easy and fast installation (Figure 24).

General disposition of manholes defers on relative position of gully – manhole and gully consist unique facility, or manhole and gully are separate facilities connected with a pipe. Standard manholes for circular pipe are shown on following figures.

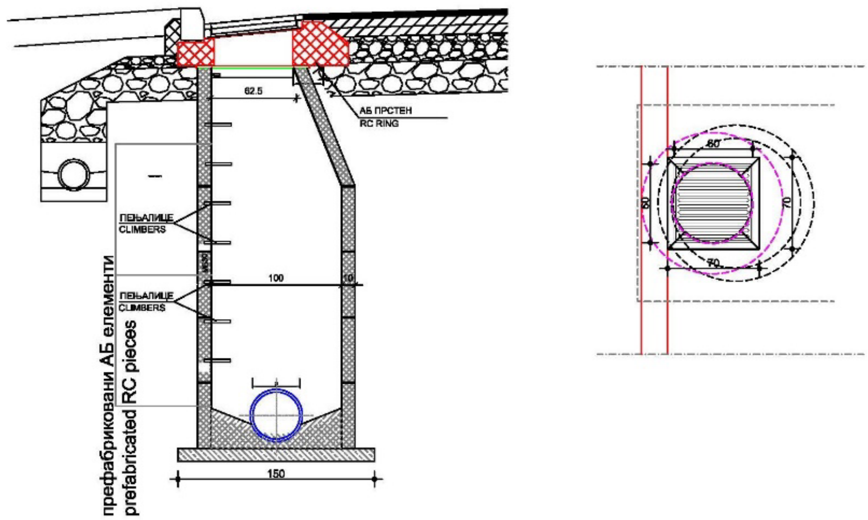


Figure 22 Prefabricated manhole-gully for pipes DN300-400-500-600

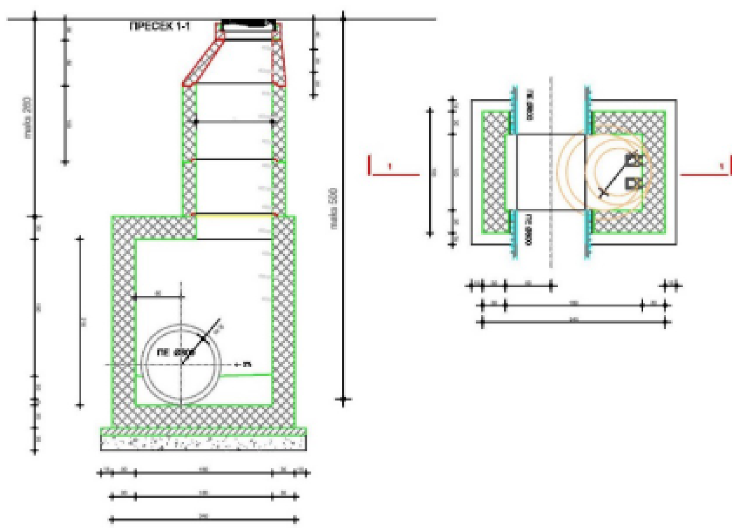


Figure 23 Prefabricated manhole-gully for pipes DN800

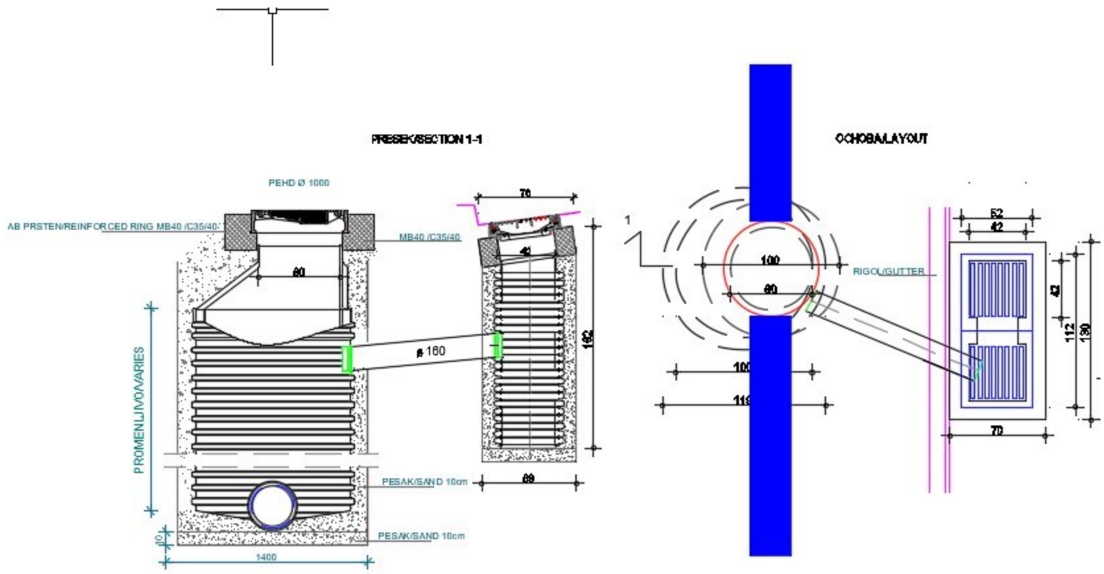


Figure 24 Detail of connection of gully to manhole

Cascade manholes are used to limit flow velocities at either junctions or sections where great elevation difference should be overcomed at short distances, i.e. with great longitudinal pipe slopes.

Standard cascades are made in manhole and type of structure depends on cascade height. For height up to 0.4 m and diameter up to 400 mm, ordinary cascade is used, and for height between 1 and 10 m and diameter greater than 400 mm cascade with safety wall is used (Figure 25).

Examples of other types of cascades could be found in literature [1,3].

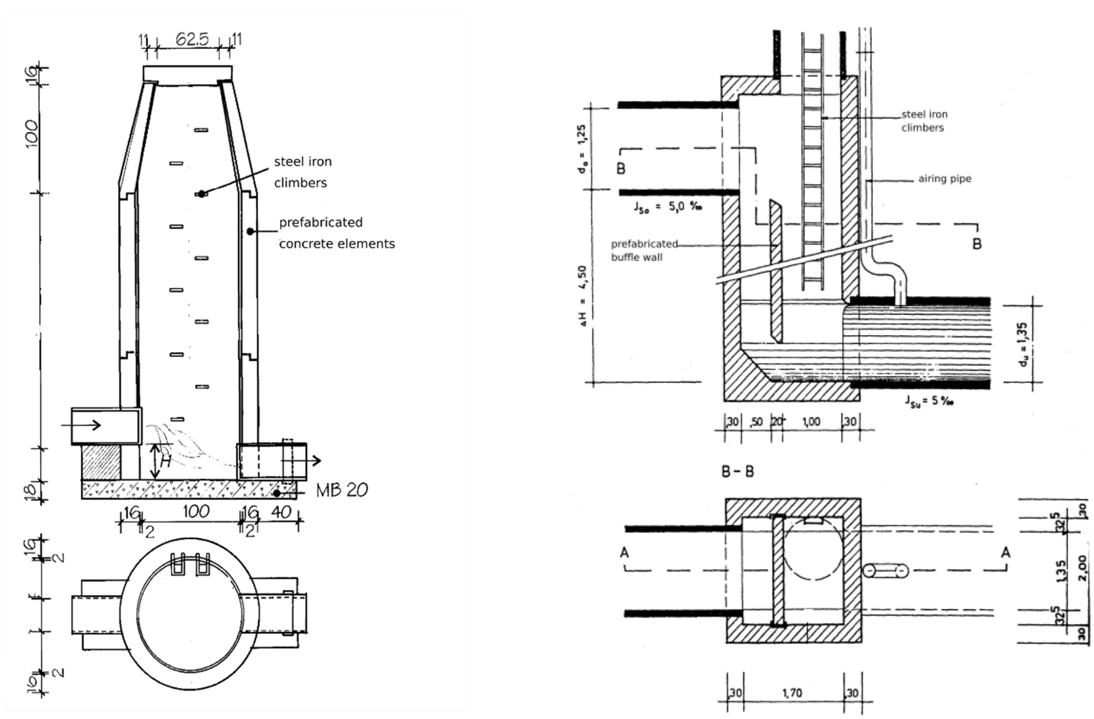


Figure 25 Samples of standard cascade (left) and cascade with a safety wall (right), modified from [3]

7.3 Subsurface Drainage

Subsurface drainage is intended for preventing water from entering the road base and to ensure drainage and lowering of groundwater level. Also, surface drainage enables faster consolidation, stabilisation and improvement of bearing capacities of highly compressible, low permeable and low bearable coherent soil. It is executed through installation of longitudinal or lateral drainage pipes and vertical drainage/drainage wells.

Drainage pipes for low and deap longitudinal and lateral subsurface drainage are made of polimers (flexible of rigid) or of cementous concrete. Pipes must be perforated and usually circular or horseshoe pipe cross sections are used. Required types of perforation are TP (360^o), LP (220^o), MP (120^o) and UP (without perforation). Category of pipes depending on the required circumferential stiffness should be ND or SD.

Perforated pipes must be either covered by geotextile or by backfilling material (stone grain mixtures) of defined granulation.

Details on sizing of subsurface drainage is given in literature [1,3].

Drainage of road structure

Measures against frost damage on the road structure imply removing of water from the road subsurface. Water is drained over graded subsurface layers toward the edge of road and drainage pipes - minimum lateral slope of sublayer should varies between 2.5 and 4 %. Drainage pipes are usually used for further longitudinal transfer of collected water.

Examples of drainage solutions for subsurface road layers are shown in following figure [2].

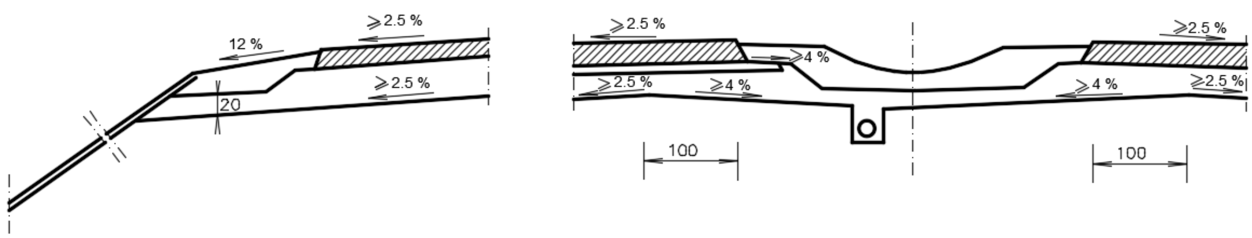


Figure 26 Subsurface drainage

7.4 Culverts

Culverts could be shaped as a pipe, box or arch. Selection of shapes depends on the design discharge and overburden thickness in the profile at culvert location.

Box culverts are used for greater design discharge and for small overburden thickness (0.4 to 5.0 m). Arch culverts are used for greater design discharge and greater overburden thickness (more than 3.0 m).

Recommended size of culverts:

Pipe culverts:	
D (cm)	max Length (m)
100	up to 15.0
≥ 150	15.0 to 30.0
≥ 200	> 30.0

Box culverts:	
Width and Height (cm)	max Length (m)
≥ 150	15.0

Arch culvert:	Minimum size = 200 cm

Tabular review of culvert types is given in Table 15[1].

Inlet of the culvert could present a severe restriction to water flow, thus shaping of the inlet could have a significant effect on its functional capacity. Standard culvert inlets are shown on Figure 27.

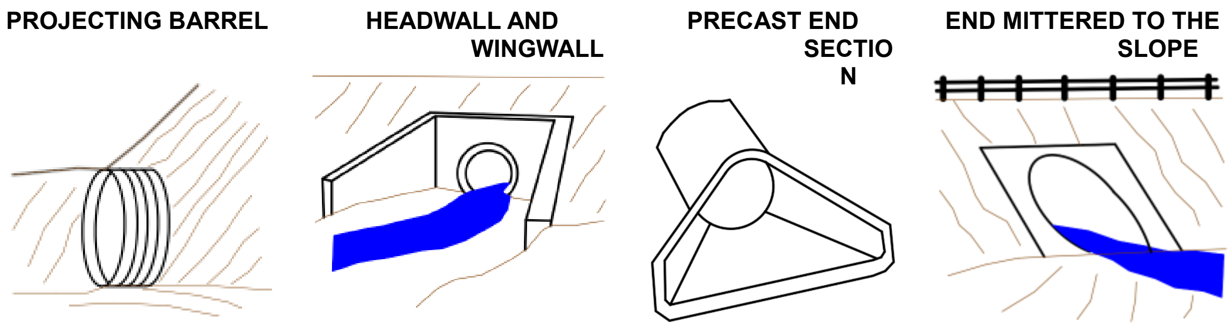


Figure 27 Standard culvert inlets

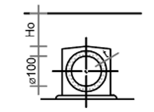
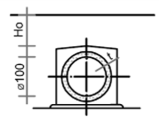
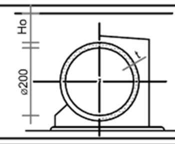
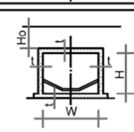
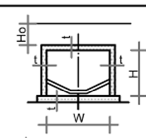
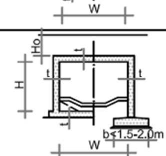
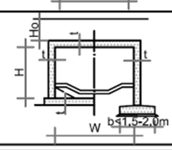
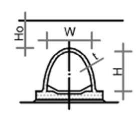
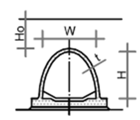
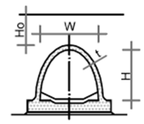
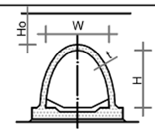
Outlet section of culvert could be affected by high velocities that could cause excessive erosion of downstream channel in the vicinity of the outlet. Depending on soil type of natural water recipient, various protection measures could be applied:

- cut-off walls - for velocities up to 1.3 times the average natural recipient velocity;
- armouring riprap (concrete riprap, rock riprap, vegetation, etc.) - for velocities between 1.3 and 2.5 times the average natural recipient velocity;
- velocity control device - for velocities greater than 2.5 times the average natural recipient velocity.

Culverts could be made of various materials: prefabricated pipes, corrugated pipes, in-site made concrete, etc.

More information on culverts is available from the literature [1].

Table 15 Culvert types [1]

TABULAR REVIEW OF CULVERT TYPES					TABLE 1
TYPE	DIMENSIONS overlay height Ho width W height H thickness t	MATERIAL	CROSS SECTION	PURPOSE	• Construction method • Botton protection
PIPE CULVERTS	Ho > 1.00m ø100 (110) t ≥ 10cm	pipe concrete MB 30 external encasing concrete MB 20 reinforcement RA 400/500-2		- for water	- pre-cast elements - without revetment
	Ho > 1.00m ø150 (140,180) t ≥ 13cm	pipe concrete MB 30 external encasing concrete MB 20 reinforcement RA 400/500-2		- for water	- pre-cast elements - revetment at V theor.>10m/s
	Ho > 1.00m ø200 (210,240) t ≥ 10cm	pipe concrete MB 30 external encasing concrete MB 20 reinforcement RA 400/500-2		- for water	- pre-cast elements - revetment at V theor.>10m/s
BOX CULVERTS	Ho=0.40-5.00m W = 2.00m H = 1.50-3.50m t ≥ 25cm (30)	concrete MB 30 RA 400/500-2 MGA 500/560		- for water - for minor animals	- monolithic or pre-cast elements - revetment
	Ho=0.40-5.00m W = 3.00m H = 2.00-5.00m t ≥ 30cm (35)	concrete MB 30 RA 400/500-2 MGA 500/560		- for water - for pedestrians - for animals	- monolithic or pre-cast elements - revetment
	Ho=0.40-4.00m W = 4.00m H = 2.50-6.00m t ≥ 35cm (40)	concrete MB 30 RA 400/500-2 MGA 500/560		- for water - for pedestrians - for animals - for minor vehicles	- monolithic or pre-cast elements - revetment
	Ho=0.40-3.00m W = 5.00m H = 3.00-7.00m t ≥ 40cm (45)	concrete MB 30 RA 400/500-2 MGA 500/560		- for water - for pedestrians - for animals - for minor vehicles	- monolithic or pre-cast elements - revetment
ARCH CULVERTS	Ho > 1.00m W = 2.00m (220) H = 2.00m t ≥ 20cm (25)	concrete MB 30 RA 400/500-2 MGA 500/560		- for water - for minor animals	- monolithic or pre-cast elements - revetment
	Ho > 1.00m W = 3.00m H = 3.00m t ≥ 20cm (25)	concrete MB 30 RA 400/500-2 MGA 500/560		- for water - for pedestrians - for animals	- monolithic or pre-cast elements - revetment
	Ho > 1.00m W = 4.00m H = 4.00m t ≥ 25cm (30)	concrete MB 30 RA 400/500-2 MGA 500/560		- for water - for pedestrians - for animals - for minor vehicles	- monolithic - revetment
	Ho > 1.00m W = 5.00m H = 5.00m t ≥ 30cm (35)	concrete MB 30 RA 400/500-2 MGA 500/560		- for water - for pedestrians - for animals - for minor vehicles	- monolithic - revetment

7.5 Drainage of structures (bridges, retaining walls, tunnels)

The principles for surface drainage of roads also apply to the drainage of bridges, retaining walls, tunnels and other structures. Functioning of drainage systems affect the lifespan and maintenance costs of structures.

Drainages systems at structure aims at collection and transfer of unavoidable water away from the structure, aiming at preventing water to penetrate the structure, securing the structure from additional loads caused by water, preventing erosion, and others.

Design of drainage facilities is done in accordance with Chapter 6.2.

Bridges

Runoff from the surface of bridge is collected in closed drainage system consisting of gutters, gullies, manholes, sewers, water treatment facilities, if needed, and outlet structure. Drainage system shall be provided from any low points located within the underbridge. Immediate approach to the drainage system must be enabled from from the carriageway, footways and other paved surfaces.

Drainage system should be designed to operate by gravity, if possible, to avoid pumping that require extended maintenance. Water collected in gullies is transferred in pipelines that are mounted on the bridge structure and at pillar or abutment at appropriate location, for transfer of water to the ground level. The runoff is either transferred to the ground level below the bridge or is transferred to the sewer system on adjacent road section.

Sewers used for the drainage of bridges must be made of high durable material that can withstand static and dynamic loads and weather conditions. Sewers made of polyester or steel are commonly used on bridges.

Detailed explanation of design of drainage systems on bridges could be found in literature [1].

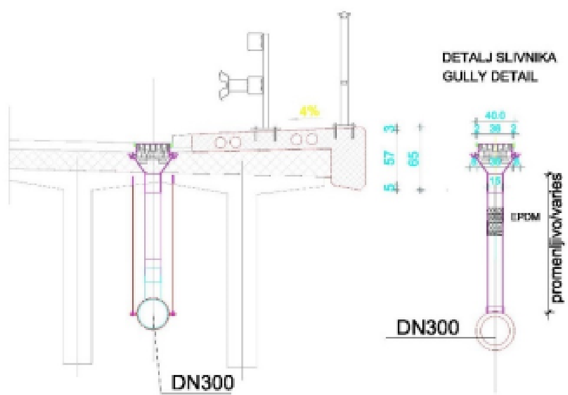


Figure 28 Sewer and gully placed on bridge

Tunnels

Water from the road surface in tunnels, galleries and covered cuts, and water drained from the rock mass must be collected and transferred in a safely manner to area outside of the tunnel. Runoff is usually collected in slot channels and sewers placed in longitudinal direction (Figure 19).

Retaining Walls

Proper design of drainage system behind the retaining walls enables collection of penetrated water from the soil and its transfer to a safe place where discharge of water will not endanger the facility. By this, hydrostatic water pressure on the retaining wall, from stratified water, will be avoided.

In a case where retaining wall is situated on impermeable soil, the drainage system could be composed of drainage of filtering layer or of drainage pipes placed along the retaining wall (Figure 29, left), at the lowest point of the retaining wall, in a backfill material that allows free drainage (gravel, rubble). Minimum pipe diameter should be 200 mm, and minimum longitudinal slope should be 1 %. At a suitable location drained water should be transferred outside of the retaining wall through the pipes built into the wall (Figure 29, right).

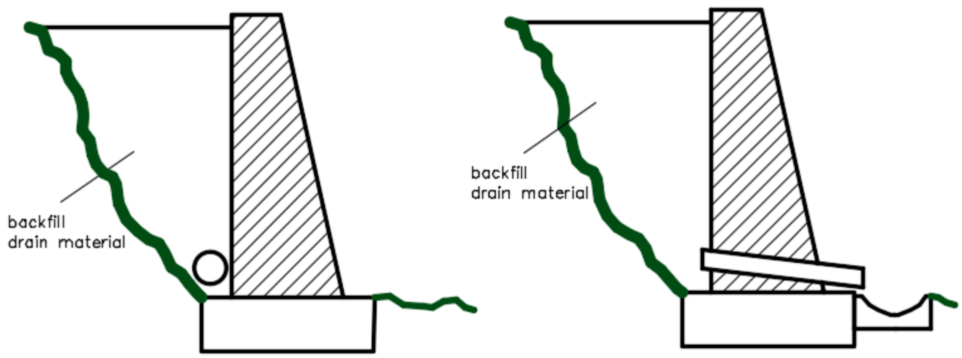


Figure 29 Drainage of retaining walls

Design of various types of retaining walls' drainage could be found in the literature [1].

7.6 Facilities for water retention

Design principles for water retention facilities are given in Chapters 6.1.4 and 6.2.5.

Detention Basins

Sizing of detention basin is done using criteria that outflow structure should limit the peak outflow rates to allowable rates and that basin provide sufficient volume for temporary storage of runoff. All side slopes should be 3H:1V or flatter. The channel bottom should be sloped minimum 2% towards the outlet. Length to width ratio should be minimum 3. Emergency spillway should be planned to provide overflow for storms (100-year storm).

The following figure shows sample of detention basin [6].

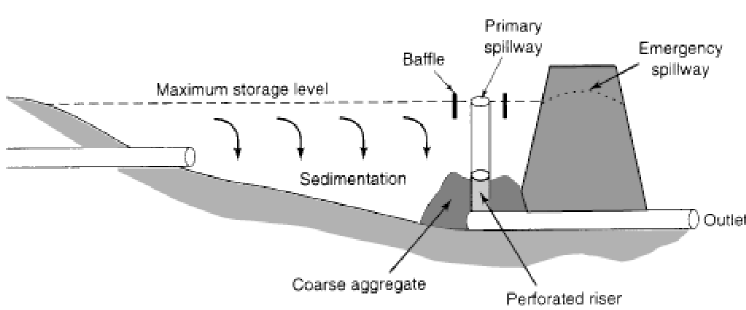


Figure 30 Detention basin [6]

Retention Basins

Retention basins (Figure 31) consist of inlet structure, outlet structure, for controlled discharge, and emergency outlet (spillway), that is designed for selected extremely large flood.

Unlike dry retention, which temporarily retains water and then empties, wet retention has a constant water level that can be designed to improve water quality through the sedimentation of pollutants and their transformation, including the binding of nutrients and other substances in aquatic vegetation. In the rainless period, the runoff that reaches wet retention basins leaves the area only by infiltration and evaporation, and in the rainy period, through the outlet structures.

The retention basin must have sufficient volume to meet the conditions for reducing the maximum flow. The required volume of retention basin is determined through the transformation calculation of the inlet hydrograph.

Design of retention basin and sizing of basin is given in Chapter 6 and in literature [3].

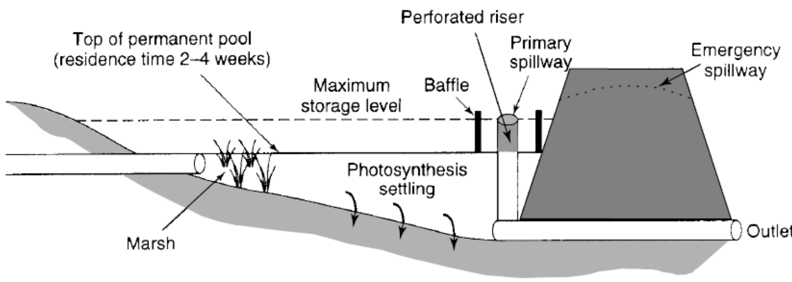


Figure 31 Retention basin [6]

7.7 Water treatment

Pollution from runoff originated on road structures could be possible threat for water resources and environment. Traffic that takes place on roads could pollute water resources and environment on permanent or occasional basis. Permanent pollution includes particles caused by wear of vehicles, tires and brakes, consequences of road maintenance procedures (e.g. sprinkling salt on roads, etc.), and others. Occasional pollution is caused as a result of emergency situations, such as spillage of pollutants due to the accidents, vehicle failure and others. Pollution extent depends on the traffic density and characteristics of the road surface.

All water that drains from the road structure is considered to be contaminated water. Waters from surrounding terrain adjacent to the road are considered unpolluted. Wastewater from other locations (gas stations, motels, etc.) must not be connected to the road drainage system. The only exception is water from the surface of parking area next to the road. Unpolluted and polluted waters should be drained independently, in separated systems.

Design of road must include assessment of area sensitivity that refers to hydrogeological characteristics of soils and rocks in which groundwater is formed and characteristic of the aquifer.

In areas with sensitive and moderately sensitive water sources, drainage of polluted waters from channels and sewers should be directed toward the collection tanks or retention facilities. In areas with highly sensitive water sources, construction of reservoirs is not allowed and polluted runoff from roads should be directed to the area outside of the water source zone. Collection tanks and retention basins also serve as media for mechanical treatment of runoff water drained from the road surface, as described hereinafter. Prior the runoff enters the retention facility, it is desirable to provide an oil separator in order to partially protect the tank from backfilling with coarse sediment and pollution from oils.

Responsibility for drainage systems in roads located outside settlements belongs to the company in charge for management of roads, while local authorities are responsible for management of roads, and belonging drainage systems, located in settlements.

Protection of surface waters (rivers, channels, lakes) may include the application of various measures and procedures, and should be in accordance with the conditions for a particular section of the road, obtained from the authorities responsible for water management and environmental protection.

Concept of protection of surface water should be based on collection and partially treatment of first flush, i.e. initial runoff from impervious surfaces, since that the initial runoff contains the greatest amount of pollution and the quality of runoff after the initial one is being improved. Initial runoff could be calculated as a result of initial 10-25 mm of rainfall (10-25 litres per square meter), using discharge coefficient for impervious surface of 0.90. Remaining runoff is considered to be relatively clean and is being discharged directly in water recipients through specific overflow structures.

The first flush should be treated in oil separators where free oils, grease and suspended particles will be removed. If runoff is discharged in sensitive water courses, additional treatment should be applied (lagoons, filtration), in accordance with the requirements set by the regulation and relevant authorities.

Protection of soil from pollution includes protection of groundwaters through prohibition of pollution discharge into the groundwater. This approach for protection is completely justified since that the groundwater is a valuable resource, often used as a source of potable water, and its pollution always has long-term consequences.

If this is applied to the drainage systems for roads, conditions for the required level of watertightness of facilities for collecting and transporting runoff should be set, depending on the characteristics of the land and underground aquifers over which the road route passes.

Control of quantity and quality of runoff from local roads outside of settlements is done by use of several measures including:

- Providing required level of water resistance of the surfaces over which the rain runoff is carried out.
- Retention of runoff has an impact on a runoff quantity but also on a quality of runoff through prolonged time for water retention that enables sedimentation of suspended practices and filtration prior to discharge, if applicable.
- Sedimentation of suspended particles that are pollution carriers results in decrease of pollution. Sedimentation is achieved with decrease in water velocity in particular reservoirs.
- Filtration and biofiltration of runoff results in pollution decrease. Soil, aggregate layer, plants or geotextile layers could be used as filtering materials.

More information on design principles for road runoff treatment options could be found in literature [3].

7.7.1 Retention basins

Retention basins could be used for enhancement of water quality, besides their role in decrease of flood peaks prior to discharge in recipients. The sedimentation process for solid particles requires a sufficient residence time which dictates the operation of the basin.

Prior to the inlet of basin, it is recommended to instal sand catcher and/or oil separator that will partially treat the runoff.

Design principles for sizing of retention basins are given in Chapters 6 and 7.6.

7.7.2 Infiltration basins and drainage trenches

In a case where water recipient does not exist, it is necessary to design infiltration basin or drainage trenches that will temporarily store the runoff on the surface and infiltrate it gradually into the ground. The infiltration basins and drainage trenches are usually vegetated depressions which are dry except in periods with heavy rainfall. The infiltration basin must have the capability to drain off stored water between storm events.

There are several advantages of usage of infiltration basins and drainage trenches: reduction of runoff volume, removal of pollutants by means of filtering through the soils, contribution to groundwater recharge, simple and cost-effective to construct. Prerequisite for the long term functionality of infiltration systems is existence and care of vegetation and soil layer through which the runoff infiltrates, thus protecting the groundwater from pollution.

Selection of infiltration device is dictated by the type of pollutants. For example, removal of oils and grass in stormwater will be more efficient by sand filter than vegetable beds.

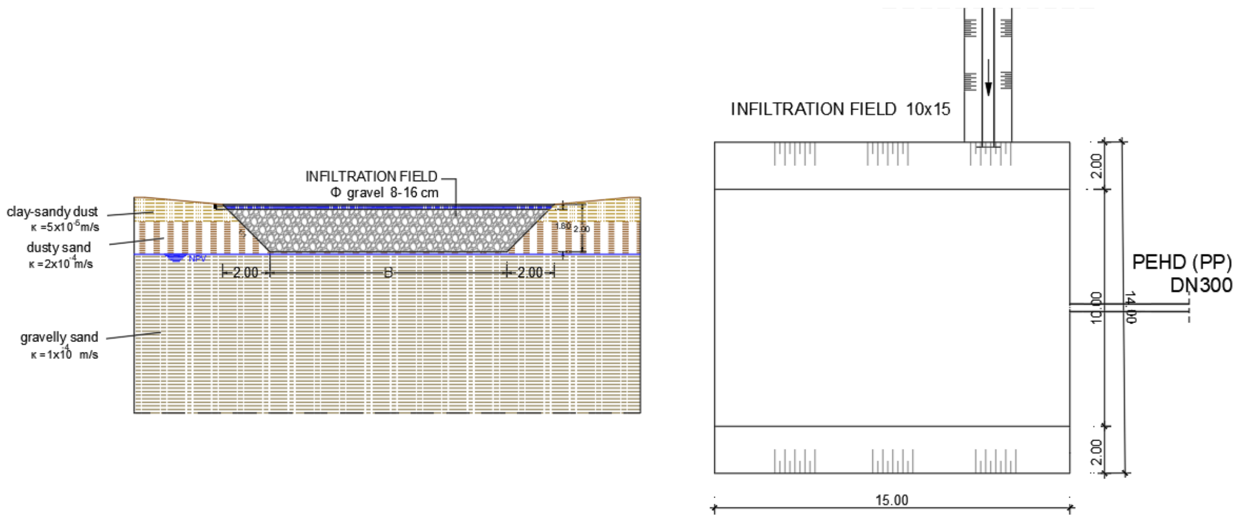


Figure 32 Infiltration basin

Infiltration basins should be built in relatively flat terrain with slope not exceeding 5.0 %. Infiltration basins should be avoided in fill areas due to possibility of creating an unstable subgrade.

Minimum distance between bottom of the infiltration basin and groundwater surface is 0.2 m. The basin floor of the basin should be as flat as possible. To enhance the infiltration amount, a large and shallow basin is preferred to a small and deep basin. Depth of infiltration basin/trench should be minimum 20 cm, and side slopes should vary between 1:1 to 1:5. At low point on the basin floor additional drainage facility may be placed (drainage wells, high infiltration medium like sand, drainage pipes).

The infiltration basin is very vulnerable to sediment clogging, thus preventing measures must be implemented upstream of the basin that will prevent sediment from reaching the basin (grass filter strips, sediment forebay, etc.).

Depth of top soil should be at least 20 cm. Soil infiltration rate depends on type of soil and contribution of clay. Roughly, if soil consists of 25% of clay, it is not suitable for infiltration.

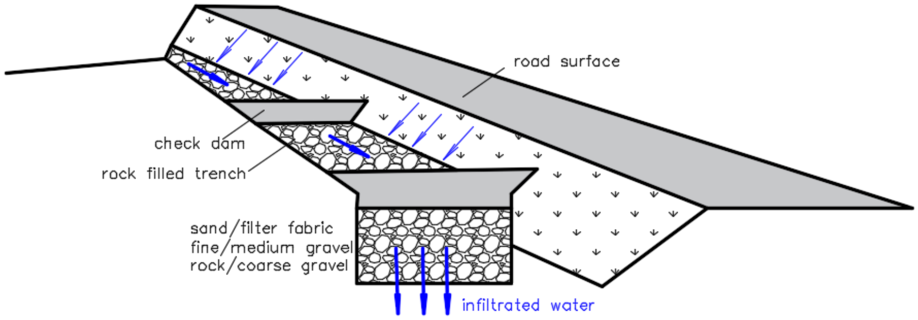


Figure 33 Infiltration trench design

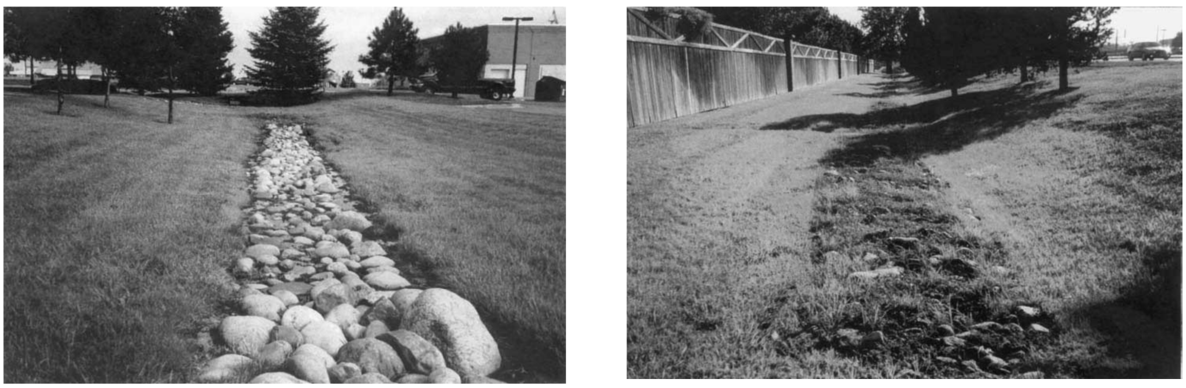


Figure 34 Infiltrated trenches built in urban area (left) and along highway (right)

Removal of pollutants in infiltration basins could be done for catchment areas up to 4 ha.

Construction of infiltration basins is not allowed in areas where the quality of groundwater and water sources may be endangered. Monitoring of level and quality of groundwater should be done in piezometers installed in a vicinity of basin, thus negative changes in groundwaters, if any, could be detected in a timely manner.

7.7.3 Sedimentation facilities

Due to vehicle breakdowns or accidents on the surface of roads, fuels or motor oils can be spilled and reached the road drainage system on their own or together with rainwater runoff. Fuels and oils are pollutants and their emissions into the environment should be minimized or eliminated.

To prevent pollution of environment, the following facilities could be used, alone or in combination, sometimes together with the retention basins:

- sedimentation tanks for the removal of suspended solids (and together with them most of the heavy metals and other pollutants);
- oil separators for the removal of insoluble matter lighter than water (various light hydrocarbons, fats and oils).

Design principles for sizing of sedimentation facilities are given in Chapter 6.2.6.

When designing the sedimentation tank, special attention should be paid to the ease of access and removal of sludge and waste retained in the sedimentation tank.

Oil-water separators

Additional sedimentation could be achieved if sand catcher is installed prior to separator entrance. The sand catcher is made in a form of shaft that allows retention of coarse material, sand, sludge and other impurities that can cause wear or clogging of separators and other downstream facilities for rainwater treatment. The precipitated material needs to be periodically removed and disposed, in accordance with local regulations.

When choosing a separator, in addition to the requirements regarding its capacity and efficiency of oil removal, special attention should be paid to the installation conditions and the need for easy access for maintenance and cleaning. At the separator outlet, or directly downstream from it, a place should be provided for taking samples of treated water.

Separators are installed below ground surface at elevation that will induce neither backwater effect in the upstream section nor submergence due to heigh water levels in recipients.

Samples of separator design is given in following figure. Figure A is standard separator, while separators B and C contain coalescing filters (taken from reference [3]).

Oil separators must meet the requirements of EN858. According to EU standard EN858, there are two classes of separators – class I, that treat runoff to fuel/oil concentration in treated water of 5 mg/L, and class II, that treat the runoff to fuel/oil concentration in treated water of 100 mg/L. Selection of oil separator class is dictated by local conditions and requirements of relevant authorities.

More information on design of oil separators could be found in literature [3].

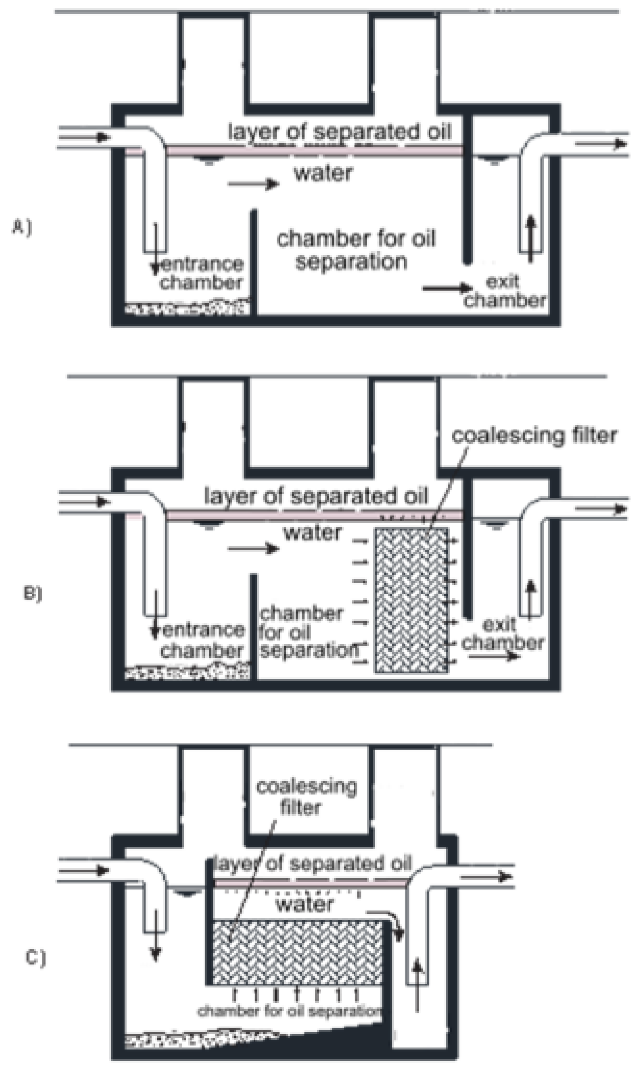


Figure 35 Typical oil separators: A) standard separator with three chambers, B) and C) separators with three chambers and coalescing filters, modified from [3]

Sample of designed oil separator is given in Appendix.

8 GREENING OF DRAINAGE SYSTEMS

Drainage systems should be incorporated in natural landscape with appropriate plants typical for particular region. Plants, together with soil layer, contribute to stabilization of soil in riparian zones, reduce risk of erosion and affect improvement of runoff quality. Selection of plants depends on a potential for interaction with water, i.e. whether plants will be permanently under water, or temporarily flooded, or above the changing water level.

Areas intended for infiltration (infiltration basins, trenches) should be greened immediately with seeds typical for region. If potential for erosion exists, special seed plant mixtures should be used, as well as sods, seed mats or ready-made turf.

Drainage system landscape must be design in a way that require minimum maintenance.

9 DRAINAGE OF ROADS DURING CONSTRUCTION

The principles for drainage of roads apply accordingly for each phase of the construction. Application of drainage measures during construction is necessary in order to avoid damage of works on site. Optimal economic solution is to use design of finale drainage system (for completed/built facilities) during construction phase, if possible.

Runoff from the adjacent terrain that flows toward construction site should be collected in open channels prior to the site and transferred out of the site. In order to achieve this, it is necessary to build the drainage system before the commencement of works. In erosion-sensitive soils it is necessary to provide longitudinal drainage using lined channels or pipelines. Design of drainage facilities should be done in accordance with Chapter 6.

Special attention should be made if polluted runoff is expected and, hence, adequate measures must be applied, including sedimentation facilities, as described in Chapter 7.

10 PRECAUTIONARY MEASURES

If retention facilities are located close to the road, fall protection measures for motor vehicles and pedestrians must be applied.

If water depth in retation facility is less than 1.3 m, and slope is 1:2 or flatter, exit aids (handrails, staircases) are not required. For steeper slopes exit aids are required to be installed. In a case of paved slopes, no exit aids is required for slopes equal or flatter than 1:5.

If water depth in retention facility is higher than 1.3 m, exit aids should be planned in a distance maximum 15 m.

11 MAINTENACE

Maintenance of roads must be in accordance with the Rulebook on Works on Regular Maintenance of Public Roads

This rulebook regulates the types of works, technical conditions and the manner of performing works on regular maintenance of public roads. Regarding road drainage system, regular maintenance includes cleaning and maintenance of ditches, gutters, culverts and other parts of the road drainage systems, and replacement of deformed, worn-out or temporary culverts.

Inspections

Conditions of public roads are determined by inspections that are performed regularly, seasonally, systematically and extraordinary. Regular inspections are realized minimum two times per week (state roads IB), minimum ones per weak (state roads IIA), minimum two times per month (state roads IIB) and once per month on other roads. Seasonal inspection is done minimum twice per year, in spring and autumn, with the intention of assessment of the condition and functionality of road elements, including drainage systems. Systematic inspection is done if regular inspections reveal damages that endangers carrying capacity and functionality of certain road elements. Extraordinary inspections are performed after extraordinary events, such as natural disasters (earthquakes, flood, landslides, major ice strikes on rivers, avalanches, debris, etc.).

Regular inspections of tunnels include functioning of surface and groundwater drainage systems, seasonal inspection is done after summer and winter periods and includes recording the possible occurrence of water in a tunnel or gallery and inspection of manholes. Drainage systems in tunnels is systematically inspected minimum once in five years. Special inspection of the tunnel is performed with specific equipment and measuring instruments every ten years with the aim of controlling the condition of the tunnel structure. Extraordinary inspections of tunnels and galleries are done in a case of natural disasters (earthquake, flood, fire, etc.), impermissibly high concentrations of exhaust gases and major damage to the tunnel pre-sections or pre-section structures.

Drainage systems on bridges are inspected regularly, seasonally (minimum twice per year, before and after winter season), systematically (minimum once in five years) and main inspection is done minimum once in ten years. Extraordinary inspections are performed after extraordinary events that could impair carrying capacity and functionality of bridge, such as natural disasters (earthquakes, slides, floods, heavy precipitation, storms, and others), severe damage from the impact of a vehicle or vessel, fire, explosion, etc., following crossing exceptional loads over the bridge (exceeding the allowed loads or dimensions of vehicles) and sudden damages of bridge or individual elements.

Maintenance of drainage facilities, slope drains/flumes, shoulders, bridges, tunnels and galleries

Drainage facilities are maintained to enable their functionality. Works on the maintenance of drainage facilities include:

a) maintenance of surface water drainage facilities: open ditches, gutters, slope drains/flumes and channels, with concrete or stone linings, and culverts;

- maintenance of open ditches is done so that the level of the ditch bottom is always lower than the lowest elevation of the sub-grade by 20 cm and that longitudinal slope enables gravity drainage of waters;

- maintenance of open ditch cross section to have designed cross section area or area that enables normal inflow and gravity drainage of surface waters;

- repair of damaged parts of channels and slope drains/flumes with concrete lining;

- maintenance of concrete or stone culverts is done by removing sediments that interferes with normal water flow through culvert and repair of damaged parts. Maintenance includes cleaning of culvert inlet and outlet and repair of damaged parts, if any.

- maintenance of gutters include gutters made of crushed stone, concrete and asphalt and are done in order to enable withstanding of pressure of truck's wheels and to provide gravity drainage of surface water from the road and cut slope.

- maintenance of shoulders include maintenance of vegetated shoulders, stabilized shoulders (mechanically stabilized, stabilized with bitumen or cement), concrete shoulders and shoulders made of crushed stones. Shoulder should always be able to withstand pressure of truck wheels, should not be higher than road surface level and should have transverse slope to allow easy drainage of surface water from roadway. Vegetation on shoulders is maintained to have adequate heigh that does not endanger the visibility of signalization and equipment.

b) maintenance of groundwater drainage facilities: all types of pipes, manholes, water inception chambers, etc.

Flushing of drainage systems and other closed drainage systems is performed twice a year (in spring and autumn).

c) Regular maintenance of bridges include cleaning and/or repair of gullies and drainage pipes.

d) Regular maintenance of tunnels and galleries include cleaning of drainage channels in the tunnel.

Maintenance of oil separators

Oil separators must have regular supervision and maintenance. Regular removal of separated light liquids and sediments from the separator and their final treatment or disposal must be done carefully and in the prescribed manner so the environment will not be endangered.

Maintenance of landscaped drainage systems: retention basins, infiltration basins, drainage trenches, etc.

Regular maintenance of green areas should be done, such as weeding, mowing and pruning.

All surfaces covered with plants must be regularly inspected several times per year, including facilities that are integral part of the drainage system.

If necessary, cleaning of surface areas, removing of sediments, replacing of clogged filtering material must be done, etc.

Care of plants must be done on regular bases. When maintaining planting areas and laws, plant population should not be damaged. No herbicide are allowed in the drainage system area.

Additional inspections and maintenance of road drainage systems may be stipulated in accordance with current legislation and technical standards that include adaptation to climate change.

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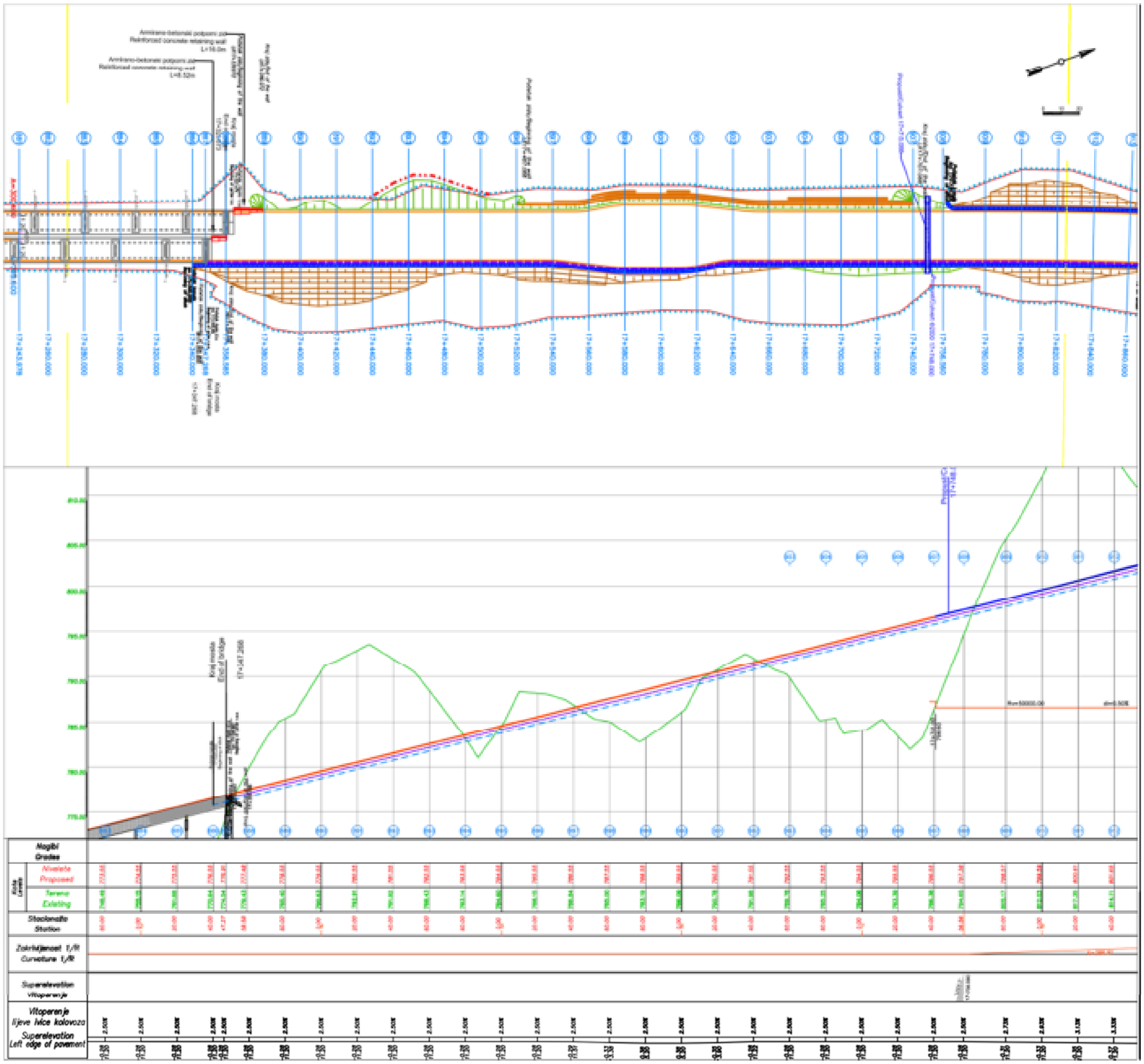
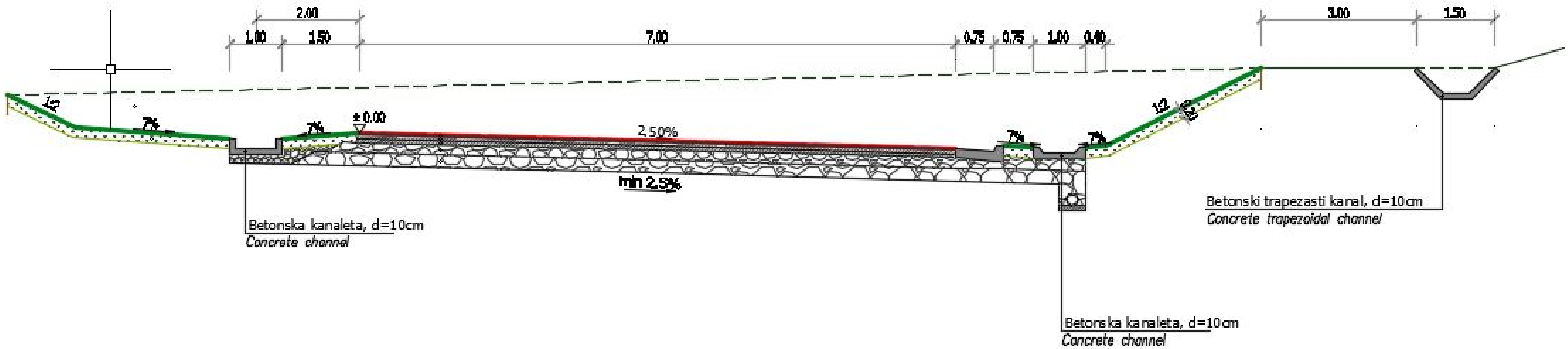
13 Appendix

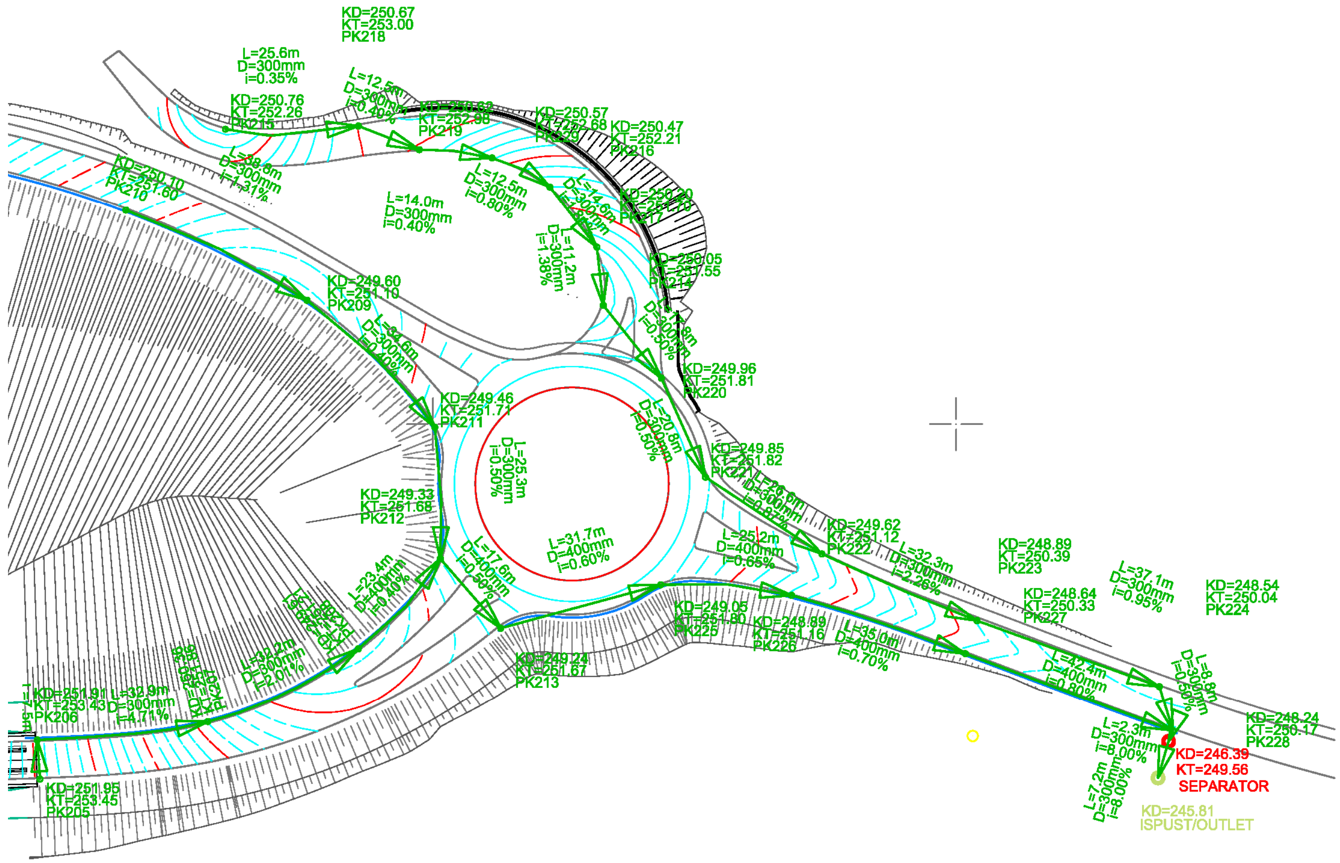
13.1 Drainage system layout and longitudinal profile



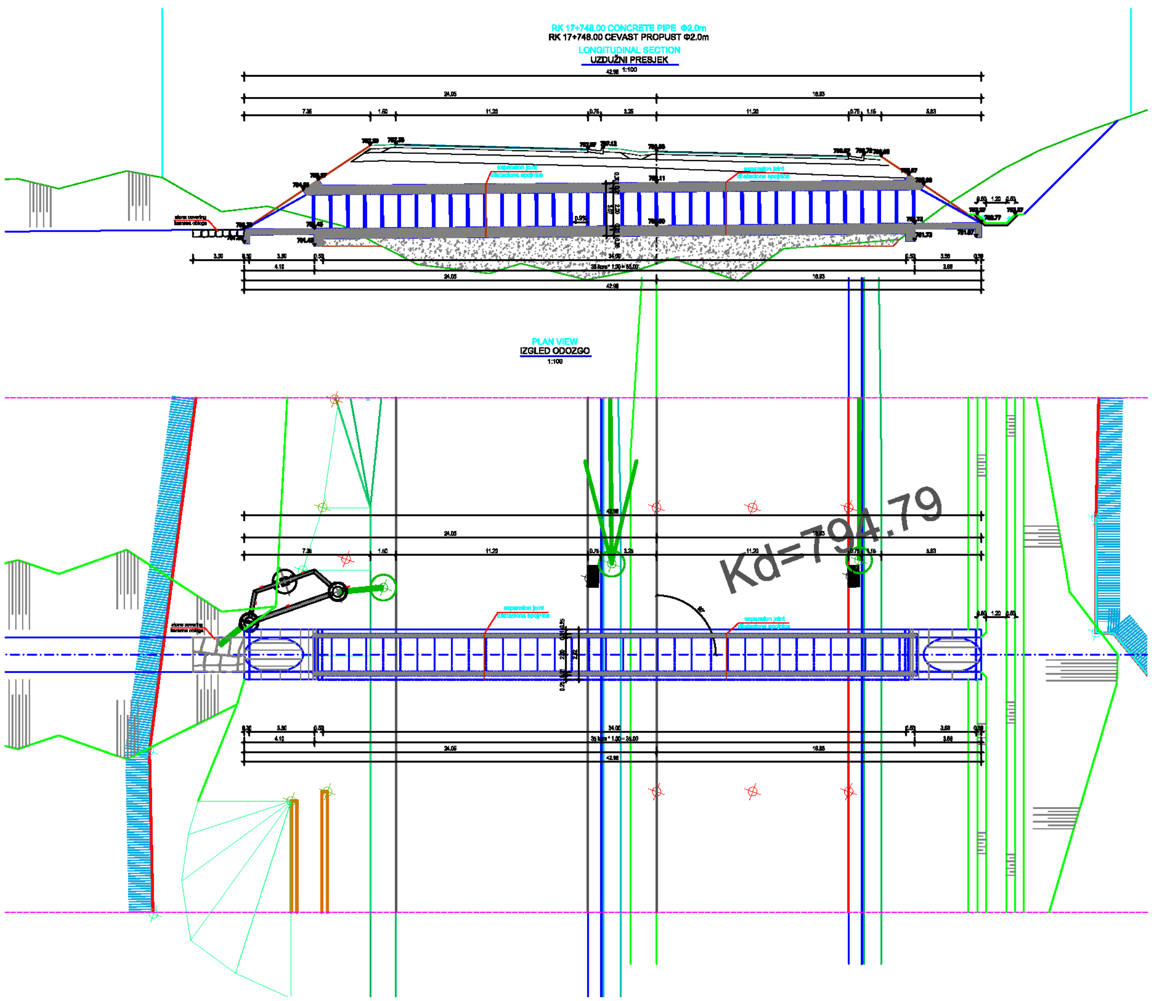
13.2 Road cross section with drainage system



13.3 Drainage of intersection (roundabout)



13.4 Culvert



RK 17+748.00 CONCRETE PIPE Φ2.0m
RK 17+748.00 CEVAST PROPUST Φ2.0m
LONGITUDINAL SECTION
UZDUŽNI PRESJEK
PLAN VIEW
IZGLED ODOZGO
Kd=794.79

13.5 Oil separator