GUIDELINES FOR ROAD DESIGN, CONSTRUCTION, MAINTENANCE AND SUPERVISION

Volume I: DESIGNING

Section 3: DESIGNING STRUCTURES

DESIGN GUIDELINES (DG 1.3.2)
Part 2: CULVERTS

INTRODUCTION

Culverts are structures designed for roads crossing water impediments such as ditches, rivulets or channels. They can also serve animals, pedestrians and minor vehicles or a combination of those users to pass under roads. By definition they are smaller bridges of spans up to 5 metres.

Roads of higher category, especially motorway, brutally divide the natural and urban space. Therefore, the need for culverts of various purposes below those roads becomes significantly greater.

As a consequence, culverts represent a very large group of structures, which, due to their significant length and the fact that they cut the road body, influence the construction technology, road body stability and exploitation conditions. Therefore, those structures are very demanding regarding the structural design and foundations.

C O N T E N T S

1 SUBJECT OF DESIGN GUIDELINES

Culverts are very important and frequent road and motorway elements.

The intention of this design guideline is to present general guidelines and details for a correct culvert conception and design.

A special chapter (4) refers to a correct preparation of culvert design bases. The chapter 6 (Culvert design) comprehends all details related to foundation, transversal expansion joints, reinforcing, de-watering and waterproofing. In addition, that chapter also contains instructions for the culvert bottom design (bottom protective revetment) as well as for the shaping of inlet and outlet part.

By unifying the types, openings, dimensions and design methods it is intended to support water managing experts, designers and contractors. By limiting the culvert minimum clear openings, which depends on culvert length, particularly inspection and maintenance of those structures are facilitated.

2 REFERENCE REGULATIONS

As it is usually for all kinds of bridges, the design, construction and maintenance of culverts is based on numerous rules, standards and guidelines as well.

For actions arising from the traffic loads, relevant regulations dealing with the actions on road bridges shall be considered logically;

- Law of public roads;
- Rulebook of technical norms for concrete and reinforced concrete, Official Gazette of SFR Yugoslavia No. 11/1987,
- Rule Book of technical provisions and conditions for the design and construction of concrete and reinforced concrete structures in environments exposed to aggressive water and soil actions (Yugoslav Official Gazette No. 32/70);
- Rule Book of technical norms for the design and construction of foundations of structures (Yugoslav Official Gazette No. 15/90)
- Rulebook of basic conditions to be fulfilled by public roads and their elements out of settlements from the point of view of traffic safety (Yugoslav Official Gazettes No. 35/81 and No. 45/81).

3 EXPLANATION OF TERMS

Safety height is the minimum distance between the maximum possible water level and the minimum lower edge of the structure.

Hydraulic conductibility is the maximum possible quantity of water that can flow through the culvert in a certain time unit.

Clear width is the horizontal distance between the culvert walls.

Clear height is the vertical distance between the culvert bottom revetment and the culvert upper slab or arch.

Overlay is the thickness of the fill and carriageway pavement structure above the culvert upper slab or arch.

Transverse expansion joint is a discontinuity of the structure in transversal direction enabling independent movements and rotations of both structural parts.

Nonlinear differential settlements are a non-continuous course of settlement magnitudes along the culvert axis.

Transition slab is a reinforced concrete slab placed on the bridge connecting fill in order to prevent an eventual height step between the carriageway and the connecting fill.

Internal friction angle is a measure for the dependence of the soil shear strength on the effective normal stress.

Compressibility modulus or **deformation modulus** is a characteristic value of deformability of the built-in material determined on the basis of the slope of the curve loading/settlement at the load plate test.

4 CLASSIFICATION OF CULVERTS IN VIEW OF THE HYDROTECHNICAL CHARACTERISTICS AND PURPOSE

With regard to the functionality and characteristics the following culvert types can be distinguished:

4.1 Culverts to evacuate the water arising from the road and cut slopes area.
4.2 Culverts to drain depressions with periodically running water. The culvert dimension depends on the largeness of the area crossed by the road running on a fill.
4.3 Culverts on melioration ditches with periodically stagnant or slowly running water towards the drain.
4.4 Culverts in inundation areas with stagnant water are particularly intended for the communication of the flood water and for the possibility of outflow after the flood has terminated (where a road runs on larger inundation areas, within dry retarding basins or karst fields).
4.5 Culverts in inundation areas with slowly running water (inundation culverts) in inundation areas of river valleys.
4.6 Culverts on gently sloping brooks where the water flows in a tranquil hydraulic regime (the water flow depth in the bed is greater than the critical depth: $h_v > h_{cr}$). The longitudinal fall of the stream is less than 0.5%.
4.7 Culverts on steep brooks and torrents where the water flows in a transitional or torrential hydraulic regime (the water flow depth is approximately equal or less than the critical depth:: $h_v \leq h_{cr}$). The longitudinal fall of the stream is greater than 0.5%.

5 HYDROLOGY – HYDRAULIC DESIGN OF CULVERTS

5.1 Hydrology – assessment of relevant water quantities

For the hydraulic design of culverts it is mandatory to assess relevant water quantities (water flow-through) to be led away by a culvert. The relevant flow-through for different culvert types is assessed introducing different methods.

For the culverts of the types 4.1 and 4.2 mainly intended for precipitation water, the water quantities (flow-through) shall be assessed adopting drain methods where the relevant rainfall with a suitable return period (n=1 to n=0.01) is taken into consideration. The selection of the rainfall return period depends on the intended protection of the road (road body) from flooding.

The rainfall duration is relatively short (5 minutes) as a rule. The information on rainfalls can be obtained from the hydro-meteorological institute; the data are based on the statistical analyses of observations carried out at ombrographic stations. The run-off coefficients depend on the contributory areas. For road surfaces they amount to φ=0.8 to φ=0.95, while for green surfaces from φ=0.1 to φ=0.3.

The water flow-through in melioration ditches (type 4.3) shall be assessed on the basis of the analysis of the area drained by means of the particular ditch. The water amounts can be assessed introducing drain methods, adopting empirical hydrological methods, or on the basis of an engineering analysis. To assess the flow-through, low run-off coefficients (φ=0.1) are taken into account as a rule.

In culverts with stagnant inundation water (type 4.4) the relevant flow-through is assessed in view of the water volume running through the culvert, and of the flow (run-off) time. As a rule, the flow-through quantities are small due to a longer period.

Inundation culverts (type 4.5) are a part of bridging a major inundation area (at larger brooks and rivers with broad inundation areas). As they are a constituent part of the bridging system, the belonging flow-through depends on the hydraulic characteristics of the particular brook, including inundation areas and bridging system. As a rule, the water quantities for major water streams are assessed on the basis of hydrological analyses of the river and brook basin.

Culverts on natural streams (type 4.6 and 4.7). As culverts are generally designed in contributory areas of $F < 1$ km^2 (conditionally of up to 5 km^2), an approximate relevant flow-through Q_{100} can be assessed introducing empirical hydrological equations. The following empirical equations to assess the relevant water flow-through Q_{100} are used in practice:

Pintar: $Q_{100} = q_{100} \cdot F^k$

Where:

Q_{100} = flow-through with a hundred-years return period
q_{100} = specific run-off with a hundred-years return period [$m^3/s/km^2$] from the basin of 1 km^2
F = size of the contributory area [km^2]
k = coefficient of the river and brook basin [-]; it depends on the shape of the basin, overlay, slopes and geological substrate, and amounts to 0.65 – 0.85

Kresnik: $Q_{max} = \alpha \cdot F \cdot \frac{30}{0,5 + \sqrt{F}}$

Where:

F = size of the contributory area [km^2]
α = roughness coefficient (generally α = 1; in case of greater retention it can amount up to 0.6)

If F < 1 km^2, $\sqrt{F}$ = 1 shall apply

Empirical formulae have been derived in individual areas. Therefore, their application is limited to those and similar areas, both meteorologically and geographically. In practice such a formula shall be used, which has been developed in regions similar to that of the particular project.

In karst regions as well as in areas of high permeability of the ground, the actual water quantities are generally smaller than the calculated ones. Roughly they shall be assessed by analysing the conductivity of a wider area, by the river/brook bed morphology, and by the data obtained in the past.

5.2 Hydraulic design of culverts

Culverts are simple structures, but extremely complex in view of hydraulic. Due to the change of the flow-through cross section, as well as of the fall and roughness, hydraulic properties of the water flow such as depth, width, and velocity change at short distances.

The flow-through capacity of a culvert depends on the energy difference (hydraulic losses) between the inlet and outlet. In general, the following three types of hydraulic losses occur in the culvert area:

- local losses at the inlet, which result from the reduction of the flow-through cross section, of the fall change, of the roughness, and, in certain cases, of the inlet immersion as well;
- local losses within a culvert of a uniform cross section, which particularly depend on the roughness of the culvert walls;
- local losses at the culvert outlet, which result from the cross section widening, change of depth, and roughness.

The hydraulic conditions depend on the following:

- **Conditions at the outlet**

  The outlet can be either immersed or non-immersed. In a non-immersed outlet, a tranquil flow regime or a torrential flow regime is possible. In case of an immersed outlet, as well as in case of a tranquil regime at a non-immersed outlet, the water level below the outlet (“lower water”) affects the culvert capacity. In a non-immersed outlet with a critical depth or a torrential flow the lower water does not affect the culvert capacity.

- **Hydraulic conditions in the culvert interior**

  In the culvert interior, the water can flow at a full cross section (flow under pressure) or with a free water level. The latter can be divided in a tranquil and torrential flow. The water flow regime depends on the hydraulic conditions at the outlet as well as on the culvert geometry and fall. The torrential flow within the culvert does not affect the culvert capacity at the inlet.

- **Hydraulic conditions at the culvert inlet**

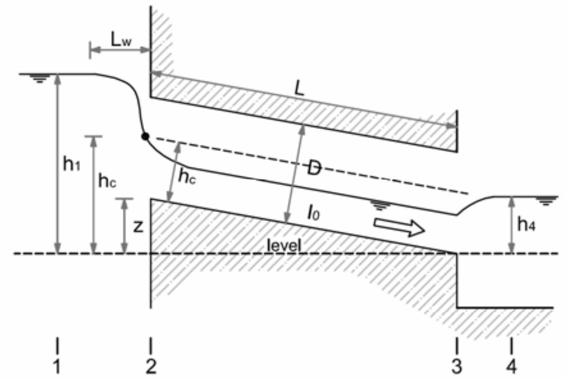
  A culvert inlet can be either immersed or non-immersed. In view of the water flow regime, a non-immersed inlet is divided in a tranquil and torrential one.

Examples of individual types of the flow through a culvert are presented below. In addition, conditions to assess the flow type, equations to determine the flow-through, and the explanation of variables are given. The equations and the meaning of variables are of an informative character only.

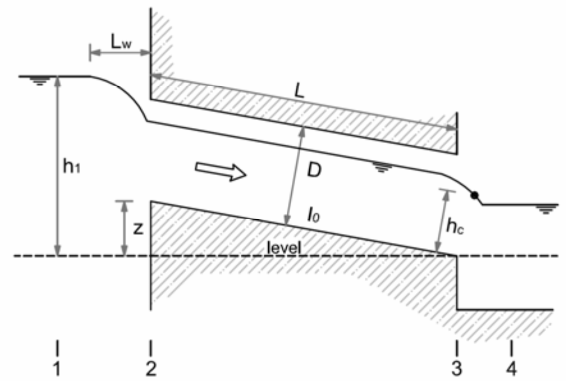
Adequate software for the hydraulic design of culverts is available. In complex software for constant and inconstant non-uniform water flow in natural beds different modules are added for the design of culverts of different shapes as well as of multi-pipe culverts (“batteries”), allowing the calculation of spilling over the road fill.

In culverts of greater dimensions, which also serve for crossing, the hydraulic design of the part intended for the water flow shall be carried out introducing the methods applicable to open riverbeds. Approximate results can be obtained by means of simple equations for a constant uniform flow (Manning’s equation).

TYPE 1



TYPE 2



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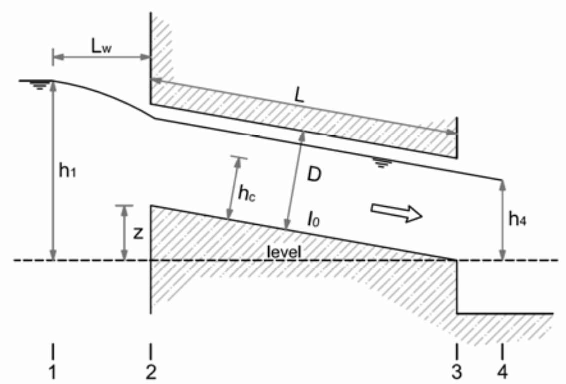
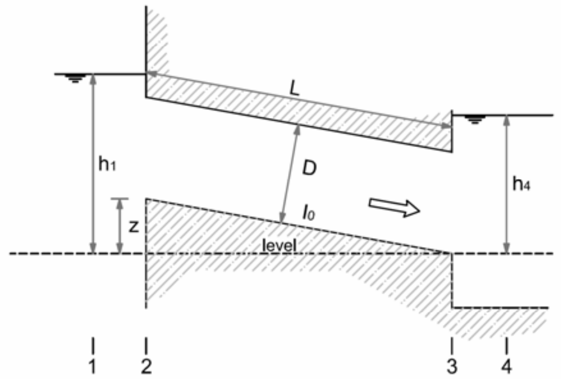
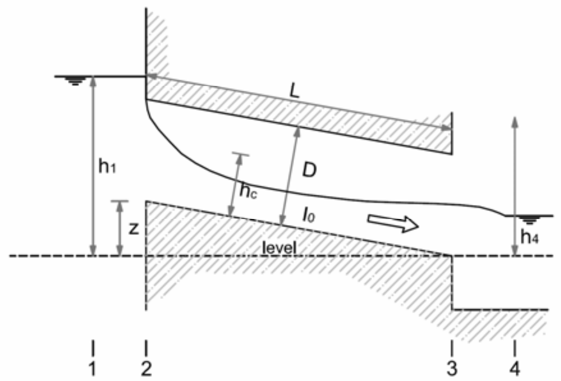


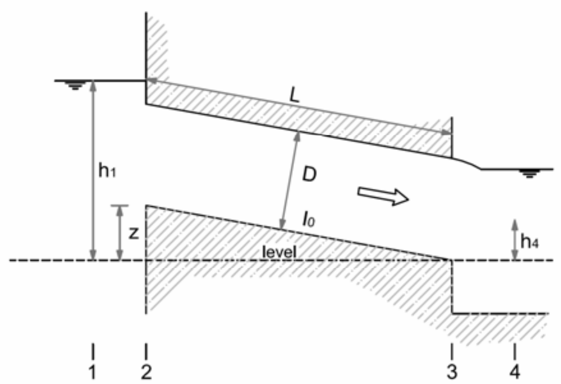
TYPE 4



TYPE 5



TYPE 6



Water flow type		Equation
TYPE 1	Critical depth at inlet $(h_1 - z) / D < 1.5$, $I_0 > I_c$, $h_4 / h_c < 1.0$	$Q = C_D \cdot S_c \cdot \sqrt{2g \cdot (h_1 - z + \alpha_1 \cdot \frac{v_1^2}{2g} - h_c - \Delta h_{1-2})}$
TYPE 2	Critical depth at outlet $(h_1 - z) / D < 1.5$, $I_0 < I_c$, $h_4 / h_c < 1.0$	$Q = C_D \cdot S_c \cdot \sqrt{2g \cdot (h_1 + \alpha_1 \cdot \frac{v_1^2}{2g} - h_c - \Delta h_{1-2} - \Delta h_{2-3})}$
TYPE 3	Tranquil flow through entire culvert $(h_1 - z) / D < 1.5$, $h_4/ D<1.0$, $h_4 / h_c < 1.0$	$Q = C_D \cdot S_c \cdot \sqrt{2g \cdot (h_1 + \alpha_1 \cdot \frac{v_1^2}{2g} - h_3 - \Delta h_{1-2} - \Delta h_{2-3})}$
TYPE 4	Immersed outlet $(h_1 - z) / D > 1.0$, $h_4/ D>1.0$	$Q = C_D - S_0 \cdot \sqrt{\frac{2g \cdot (h_1 - h_4)}{1 + (18.08 \cdot C_D^2 \cdot n_g^2 \cdot \frac{L}{R_0^{4/3}}}}$
TYPE 5	Torrential flow inside culvert $(h_1 - z) / D > 1.5$, $h_4/ D<1.0$	$Q = C_D - S_0 \cdot \sqrt{2g \cdot (h_1 - z)}$
TYPE 6	Free culvert outlet, full cross section $(h_1 - z) / D > 1.5$, $h_4/ D<1.0$	$Q = C_D - S_0 \cdot \sqrt{2g \cdot (h_1 - h_3 - \Delta h_{2-3})}$

Explanation of symbols and terms:

Q flow-through

H_1 water level in the upstream profile No. 1 (measured from primary plane)

z culvert inlet level (measured from primary plane)

C_D flow-through coefficient

S_c flow cross section at the location where critical depth occurs (inside the culvert)

$\alpha_1 \cdot \frac{v_1^2}{2g}$ kinetic energy at inlet

v_1 velocity at inlet

α correction factor of the kinetic energy

g gravitational acceleration

h_c critical depth

Δh_{1-2} losses at inlet

$$\Delta h_{1-2} = \frac{L_w \cdot Q^2}{K_1 \cdot K_c}$$

L_w distance between inlet and undisturbed level

$$K_1 = \frac{1}{n_g} \cdot S_1 \cdot R_2^{2/3}$$

conductibility at upstream profile

$$K_C = \frac{1}{n_g} \cdot S_C \cdot R_C^{2/3}$$

conductibility at critical profile

N_g Manning's roughness coefficient

Δh_{2-3} losses through the culvert

$$\Delta h_{2-3} = \frac{L \cdot Q^2}{K_2 \cdot K_3}$$

L culvert length

$K_2 = K_3 = \frac{1}{n_g} \cdot S \cdot R^{2/3}$ culvert conductibility

The conductibility is in fact a modified Manning's equation, from which the slope of the energy line is excluded or the energy difference due to lineal losses:

$$\frac{Q^2}{K^2} = \left(\frac{\frac{1}{n_g} \cdot \sqrt{I \cdot S \cdot R^{2/3}}}{\frac{1}{n_g} S \cdot R^{2/3}}\right) = I_E$$

S_3 cross section at culvert outlet

h_3 water depth at culvert outlet

S_0 culvert cross sectional area

h_4 water depth at outlet

R_0 hydraulic radius at full cross section

5.3 Design guidelines taking account of hydraulic and hydrodynamic conditions

In view of hydraulic and hydrodynamic conditions as well as culvert types the following guidelines shall be taken into consideration in the culvert design:

5.3.1 Culvert fall

In culverts for the precipitation water (type 4.1), the fall I_0 shall be similar or slightly greater than the critical fall ($I_0 \geq I_c$) in order to ensure sufficiently high velocities and tractive forces.

The fall in culverts of types 4.2, 4.3, and 4.4 shall be specified in view of the ground conditions and always oriented in the water run-off direction. In culverts of type 4.5 the fall shall be determined simultaneously with the flood water level. In natural water streams, the culvert fall shall be equal to the natural fall of the bed (culverts of type 4.6). In very steep beds under a torrential regime (torrents – refer to 4.7), the fall shall be greater than the critical one ($I_0 > I_c$).

5.3.2 Inlet design

From the hydraulic conditions it is evident that the culvert capacity predominantly depends on the conditions at the inlet, and the local losses at the inlet are prevailing in most cases.

The following recommendations are given in view of the culvert types:

In precipitation water culverts (type 4.1) the inlet is usually designed in a shape of a sand capture with a deepened bottom. Due to the inflow through a gully, the free fall into the sand capture, and the culvert inlet, the water flow often exceeds the critical depth, the hydraulic losses at the inlet are high, and the flow type 4.1 or 4.5 occurs. It is essential that the sand capture basins, which are intended for the reduction of the water flow energy, are as large as possible. In case that an inlet is not executed with a sand capture, it shall be shaped as continuously as possible.

In the culvert types 4.2, 4.3, 4.4, the shape of both inlet and outlet have is not essential, as the flow velocities are small. The losses at the inlet depend on the shape of the inlet head and wings. Continuously shaped transitions and oblique wings diminish the losses at the inlet. Sudden reductions of the cross section and exposed culvert heads at the inlet increase the hydraulic losses.

In the culvert type 4.5 (inundation culverts), the inlet part shall be designed with oblique wings and continuous transitions, as the water flow velocities are quite high.

Culvert inlets for natural water streams (culvert type 4.6 or 4.7) shall be designed as continuous with a longer transition from the open profile to the culvert profile. At the culvert inlet the velocity shall be kept equal or even increased, and the flow lines shall be adequately oriented.

In culverts located on torrent beds where $I_0 > I_c$ (culvert type 4.7) it is mandatory to prevent the water flowing beyond the critical depth (water jump). The velocities and tractive forces in the area of the inlet as well as of the culvert itself shall be greater than in the normal profile to prevent formation of deposits. The water flow velocities are regulated by both fall and width. In torrential beds where the inflow of shoved sediments, branches, and leaves is expected, a barrage shall be constructed before the culvert inlet to allow retaining of those materials. In addition, a rake for collecting such undesired stuff shall be provided.

5.3.3 Culvert outlet

Due to increased velocities and, therefore, greater kinetic energy, erosion can be expected at culvert outlets. Particularly in culverts with torrential water flow inside the culvert as well as with a natural (non-consolidated) bed beneath the culvert, suitable structures for energy dissipation shall be foreseen (e.g. packed rockfills).

5.3.4 Culvert interior design

In culverts on natural water streams and torrent beds, a bottom lining resistant to abrasion shall be foreseen. The abrasion depends on both water flow velocity and portion of solid particles travelling with the water.
The width of the wetted cross section shall increase with the culvert depth.

The width of the bottom inside the culvert shall always be smaller than the width of the bottom of the natural bed ($w_{culv} \leq 0.8\ w_{np}$).In case that a culvert is designed to enable passage of humans as well, an at least 0.6 m wide footway shall be provided 20 cm above the normal mean water level (Q_{sn}).

In culverts of substantial falls ($I_0 > I_c$), a rough bottom, e.g. quarry stone in concrete, shall be foreseen.

In long culverts of major falls it is necessary to take account of the possibility of water flow oscillations. Namely, due to different velocities of the boundary layer and the water level, waves can occur whose depth is considerably greater than the normal depth. In such cases, in order to prevent the pulsation of pressures, it is obligatory to provide a larger flow-through cross section, a greater roughness of the bottom and walls, and, if necessary, an additional ventilation of the culvert.

5.3.5 Safety height

In precipitation water culverts (culvert type 4.1) the maximum filling at the inlet shall amount to 2/3 of the flow-through cross section height.
In culverts of types 4.2, 4.3, and 4.4, the safety height is not required; it is however wished-for.

In inundation culverts (type 4.5) the safety height at the inlet shall preferably be equal to the energy potential of the water flow ($v^2/2g$). If a satisfactory safety height is ensured at the main bridging and the distance is not too big, an inundation culvert can also be executed without the safety height. In such a case, however, the possibility of jamming is much higher.

In culverts on natural brooks and torrents (culvert type 4.6 or 4.7), the safety height shall amount to 0.5m or to the energy potential ($v^2/2g$). In circular culverts, the safety height shall be greater than or equal to the culvert radius.

6 TYPES AND CONSTRUCTION OF CULVERTS

6.1 General

In case of periodical and minor water streams the culvert should be perpendicular to the road, although a correction of the stream might be required.

By cross section shape, the culverts are divided in three types:

- Pipe culverts
- Box culverts
- Arch culverts.

The selection of the culvert type depends on the height of the fill in the profile where a culvert is located, and on the water quantity to be led away. In case of another purposes, the choice of the culvert type is subjected to the traffic requirements.

The culvert clear opening (width and height) depends on the foreseen water quantity to be led through the culvert, and on the longitudinal fall. The clear opening is specified in the hydrological – hydro-technical guidelines issued by a relevant institution. Those guidelines are based on the hydrological data and hydraulic calculation.

Pipe culverts suitable for leading away the precipitation waters, draining the melioration ditches and conditionally draining the natural streams, where this is allowed by hydraulic and dynamic conditions, below fills being usually higher than 3.0 m (exceptionally higher than 1.0 m).

Box culverts are recommended for streams where major water quantities have to be led through the culvert, and at relatively small heights of the overlay (0.40 to 5.00 m). That culvert type is suitable also in case of small differences between the road and stream vertical alignment.

For major water quantities and greater overlay heights, as a rule more than 3.00 m (only exceptionally above 1.00 m), it is recommendable to introduce arch culverts. In these cases, such shape is more rational due to major earth pressures.

Where a large amount of water must be led off, where the difference between road and stream vertical alignment is small and where it is impossible to carry out a culvert of larger dimensions, two or more parallel circular pipes can be foreseen (figure 6.1).

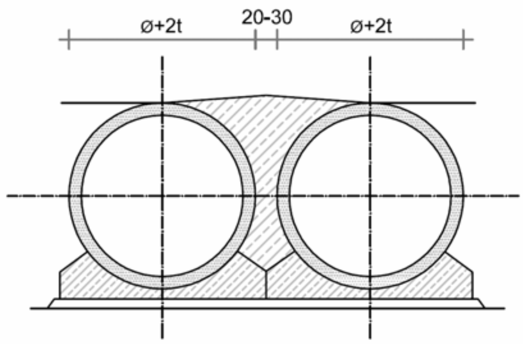


Fig.6.1: Example of solution of a culvert with two pipes

The culvert overlay heights can be smaller or greater. A direct contact between the asphalt layer and the box culvert structure shall be avoided. As a rule, the overlay height should not amount less than 40 cm.

The culvert clear height must be sufficient to enable cleaning of the culvert as well. Therefore, the diameter of pipe culverts must not be less than 100 cm for culvert lengths up to 15.00 m. The minimum diameter for culverts of lengths between 15.00 m and 30.00 m should amount to 150 cm, while it must be at least 200 cm for culverts longer than 30.00 m. The clear height and width of box and arch culverts must not be under 200 cm. Only for box culverts shorter than 15.00 m, the clear height and width may amount to 150 cm.

6.2 Pipe culverts

As it is already evident from their name, pipe culverts consist of pipes of circular cross section.

The circular cross section and, due to prefabrication, a smooth internal surface of the pipe, increase the culvert capacity. Therefore, pipe culverts are very favourable from the hydraulic point of view.

Despite a. m. fact, a crushed stone revetment in concrete or in another material (e.g. abrasion resistant fibrous concrete) shall be applied to the culvert bottom since significant abrasion may be expected in case of major falls where the theoretical velocity of water flow exceeds 10 m/s. Such revetment can only be carried out in culverts of diameter greater than 150 cm.

Pipe culverts are generally made of pre-cast standard pipes, reinforced or not, but obligatory of waterproof concrete.

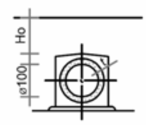
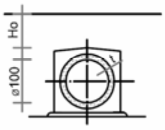
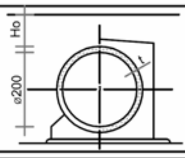
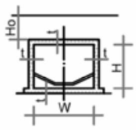
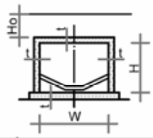
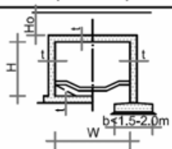
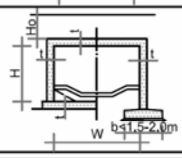
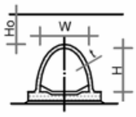
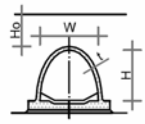
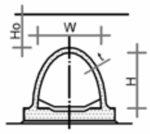
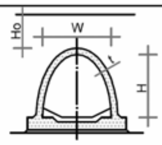
The usual profiles are ∅ 100, 150, and 200 cm. Intermediate profiles are available as well, e.g. ∅ 110, 140, 180, 210, and 240 cm.

To the exterior of standard prefabricated pipes (reinforced or non-reinforced), encasing concrete can be applied depending on the overlay height, on the fact whether the pipes rest in a fill, a wide excavation (excavation width on the bottom exceeds 3 ∅ of the pipe) or a trench (excavation width on the bottom is smaller than 3 ∅ of the pipe), and on the traffic load on the carriageway.

The minimum overlay above the pipe culverts shall not be smaller than 100 cm. Lower values are not allowed since the traffic load distribution would be insufficient meaning that the traffic loading would be excessively concentrated.

Figures 6.2 and 6.3 show examples of layout of pipe culverts with an opening of ∅ 200 cm. In cross section, two alternatives are presented: pipes with and without external encasing concrete.

Since pipe culverts are mainly used for minor water streams, their clear openings are small as well, which is unfavourable for maintenance. Therefore, the culvert cross section shall have sufficient dimensions to allow the maintenance worker to inspect and clean the pipe interior.

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

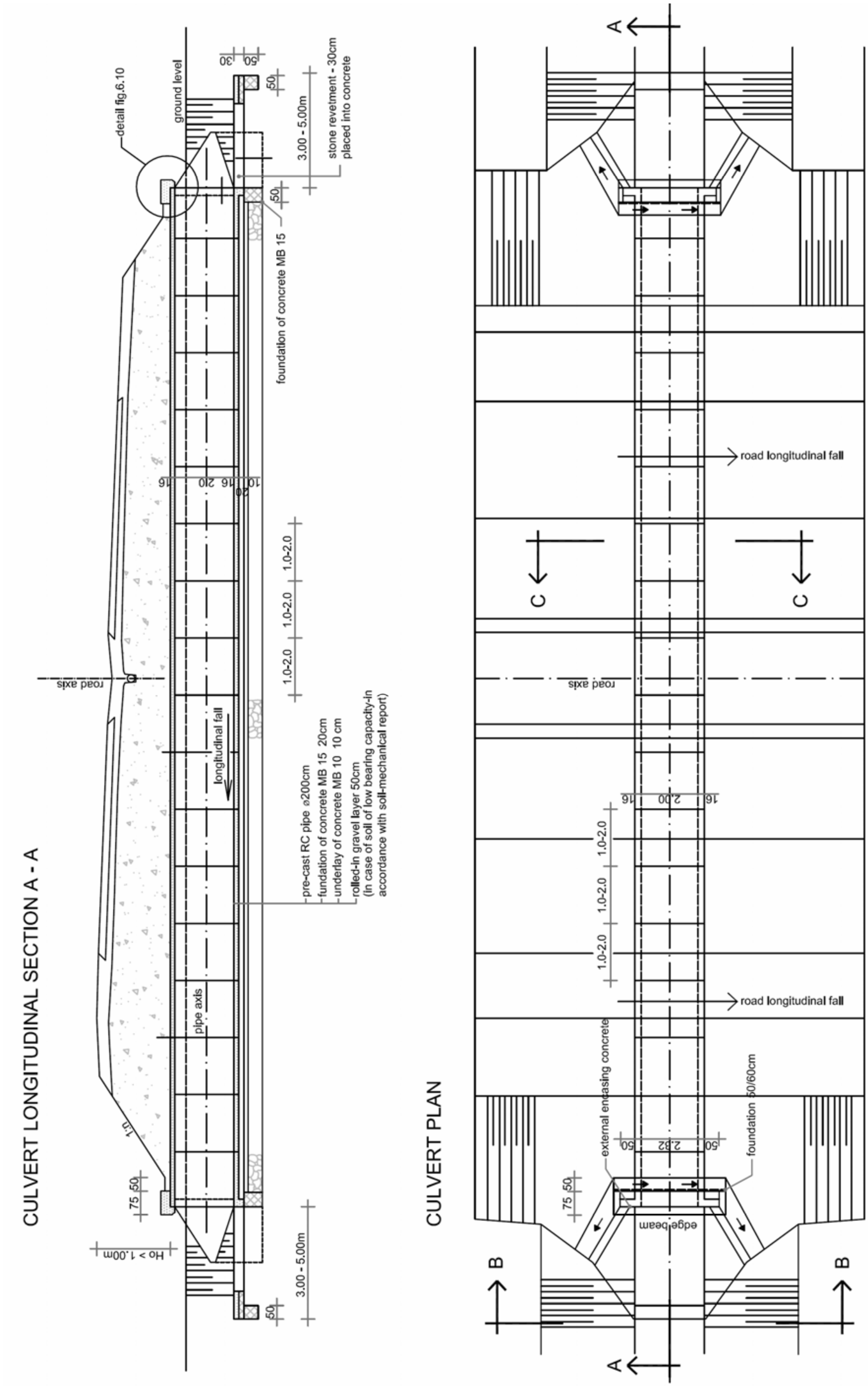
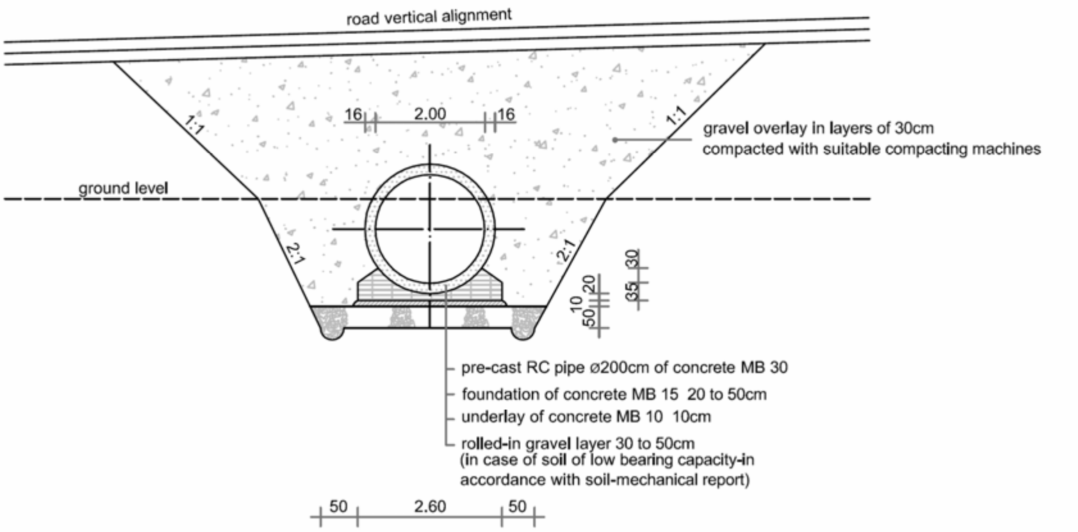
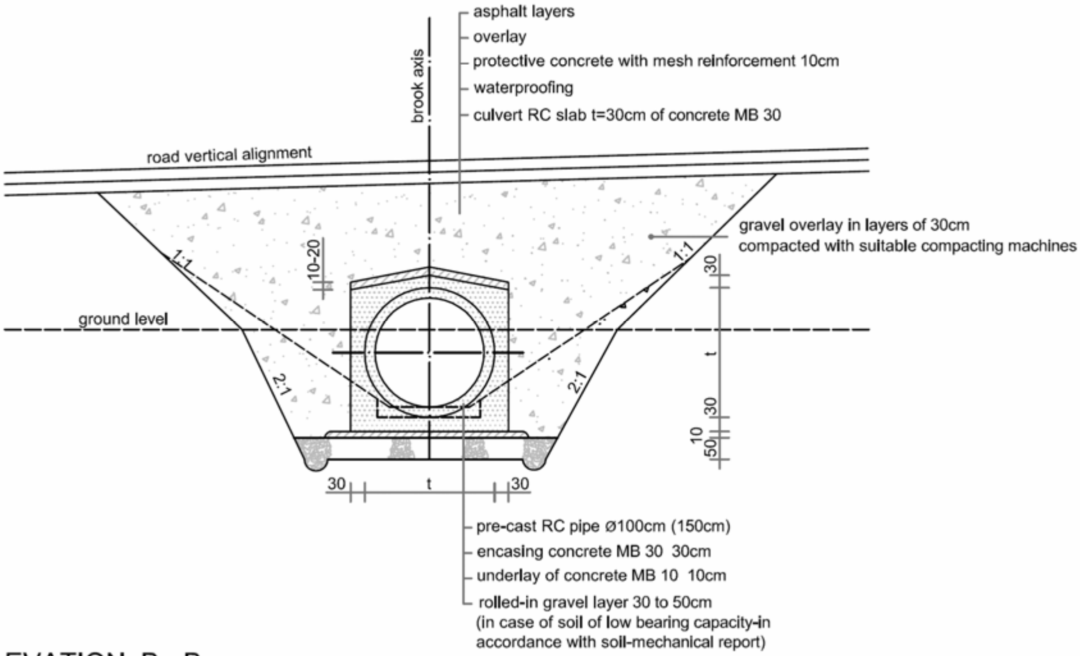


Fig. 6.2: Plan and longitudinal section of pipe culvert with openings of ∅200 cm

CULVERT CROSS SECTION C - C - pipes without external encasing concrete



CULVERT CROSS SECTION C - C - pipes with external encasing concrete



ELEVATION B - B

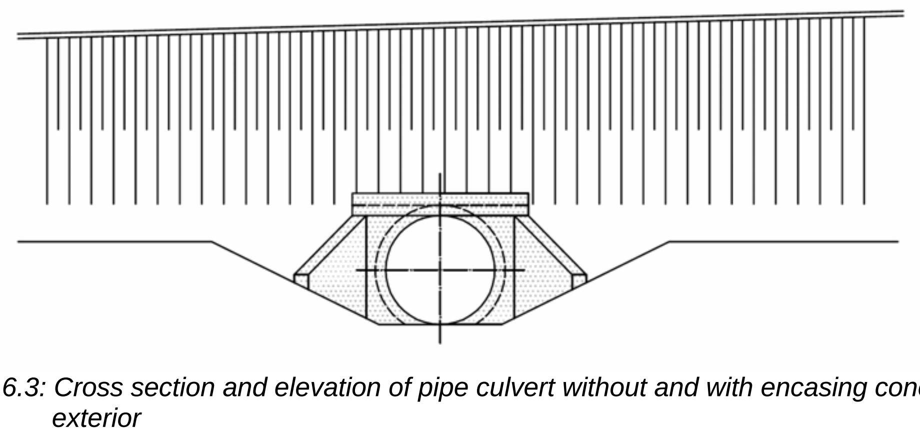


Fig. 6.3: Cross section and elevation of pipe culvert without and with encasing concrete at pipe exterior

6.3 Box culverts

The load bearing structure of a box culvert is a closed reinforced concrete frame of clear span (opening) between 2.0 m and 5.0 m. It can be constructed either in segments of pre-cast elements or monolithically in situ.

Figures 6.4 and 6.5 present an example of layout of a box culvert with an opening of 3.00/2.50m.

For this culvert type, normal inspection and cleaning must be ensured as well, therefore its clear height shall amount at least 1.50 m. However, box culverts can be up to 7.00 m high, depending on the needs and requirements.

A carriageway placed directly onto the upper culvert slab shall be avoided. Such a solution is allowed only exceptionally. As a rule, the minimum overlay above the upper slab shall be at least 40 cm thick.

For box culverts of 2.00 m width, the height varies between 1.50 m and 3.50 m. The wall and slab thickness shall be 25 cm or more. In case that culverts have to be protected from moisture and shall be watertight, which is achieved by waterproof concrete according to the “white tub” principle, the wall and slab thickness must amount to at least 30 cm. The overlay height can vary from 0.40 m to 5.00m.

For box culverts of 3.00 m width, the height varies between 2.00 m and 5.00 m. The wall and slab thickness shall be 30 cm or more. The overlay height can vary from 0.40 m to 5.00 m.

For box culverts of 4.00 m width, the height varies between 2.50 m and 6.00 m. The wall and slab thickness shall be 35 cm or more. The overlay height should be between 0.40 m and 4.00 m. If the load bearing capacity of the foundation ground is good, such culvert can be founded on strip foundations.

For box culverts of 5.00 m width, the height varies between 3.00 m and 7.00 m. The wall and slab thickness shall be 40 cm or more. The overlay height should be between 0.40 m and 3.00 m. In case of higher overlays, it is recommendable to foresee an arch culvert. If the load bearing capacity of the foundation ground is good, such culvert can be founded on strip foundations as well.

6.4 Arch culverts

The bearing structure consists of a bottom slab and an upper arched part. The latter can have a shape of a partial circular line, parabolic line, some other curve or a combination of those curves. The connection between the bottom slab and the arch can be fixed or by means of a hinge, depending on the construction method (monolithic or with pre-cast elements).

In figures 6.6 and 6.7 a layout drawing of an arch culvert with an opening of 2.00/2.00 m is presented.

The clear width and the clear height of arch culverts vary from 2.00 m to 5.00 m.

For arch culverts of 2.00 m or 3.00 m width and height, the arch thickness shall be equal or greater than 20 cm. For arch culverts of 4.00 m clear width and clear height, the arch thickness must amount to at least 25 cm. In case that the clear width and clear height are 5.00 m, the minimum arch thickness shall be 30 cm.

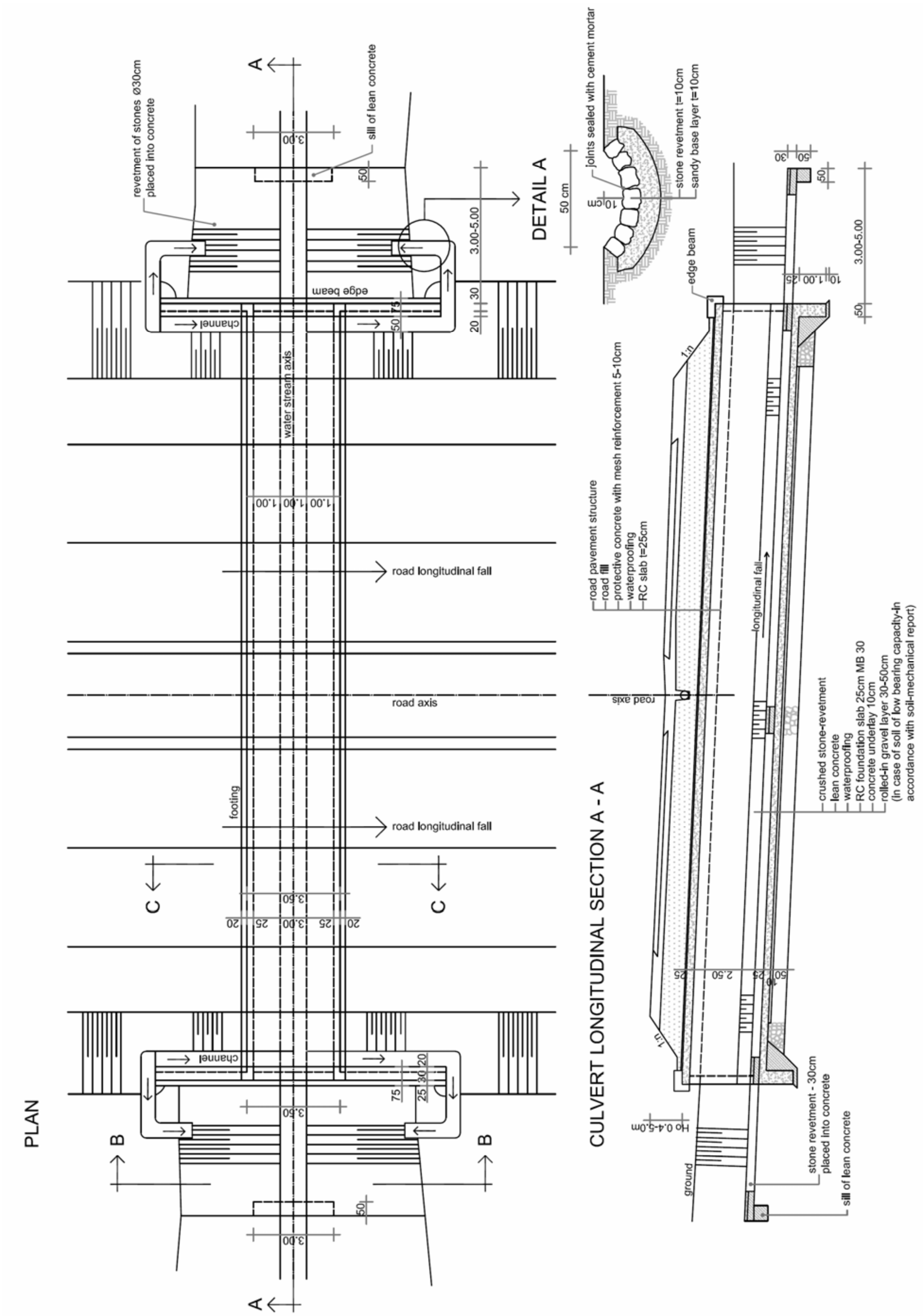


Fig. 6.4: Example of layout of a box culvert with an opening of 3.00/2.50 m with parallel wings

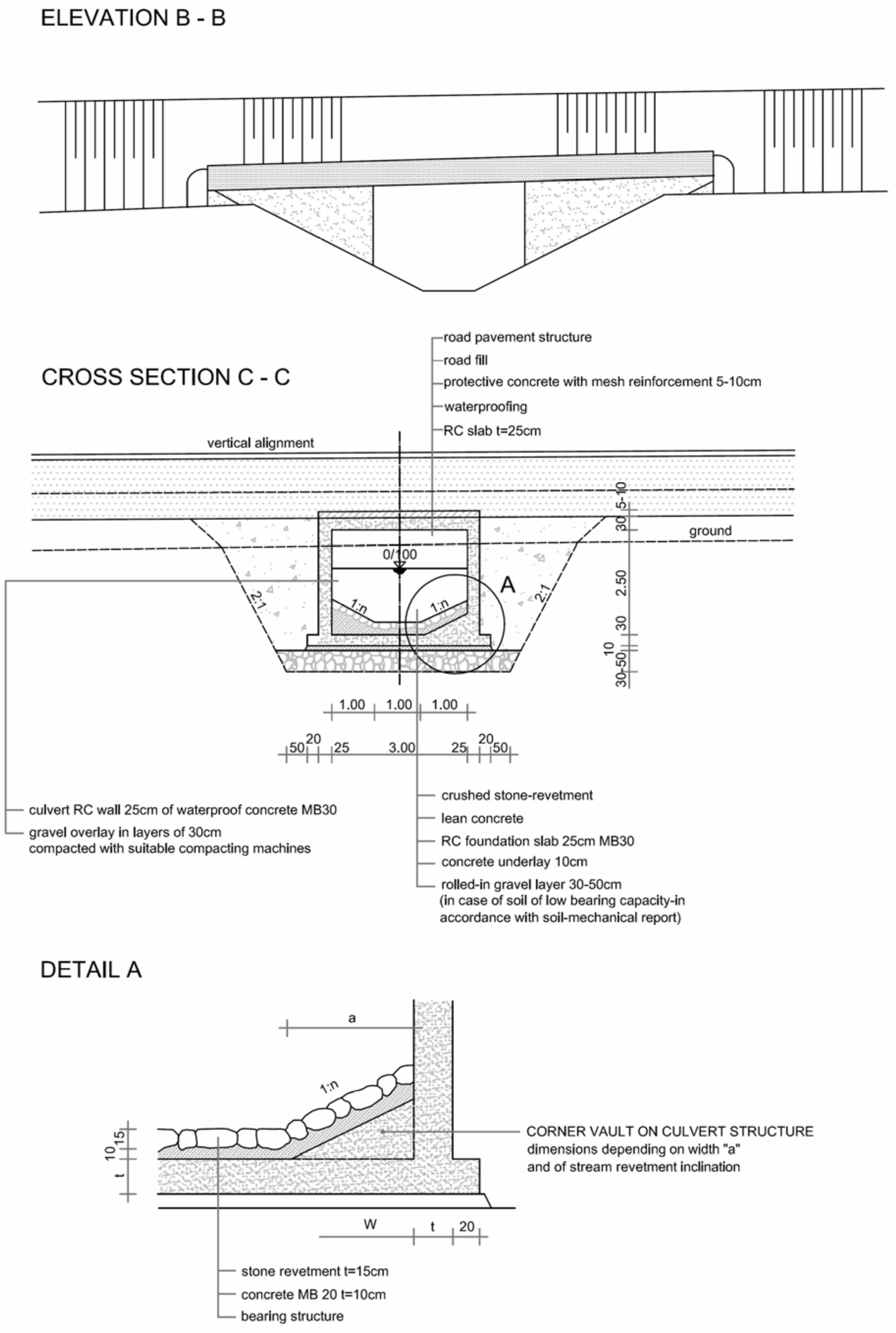


Fig. 6.5: Elevation B-B and cross section C-C belonging to figure 6.4 including detail A of box culvert bottom revetment

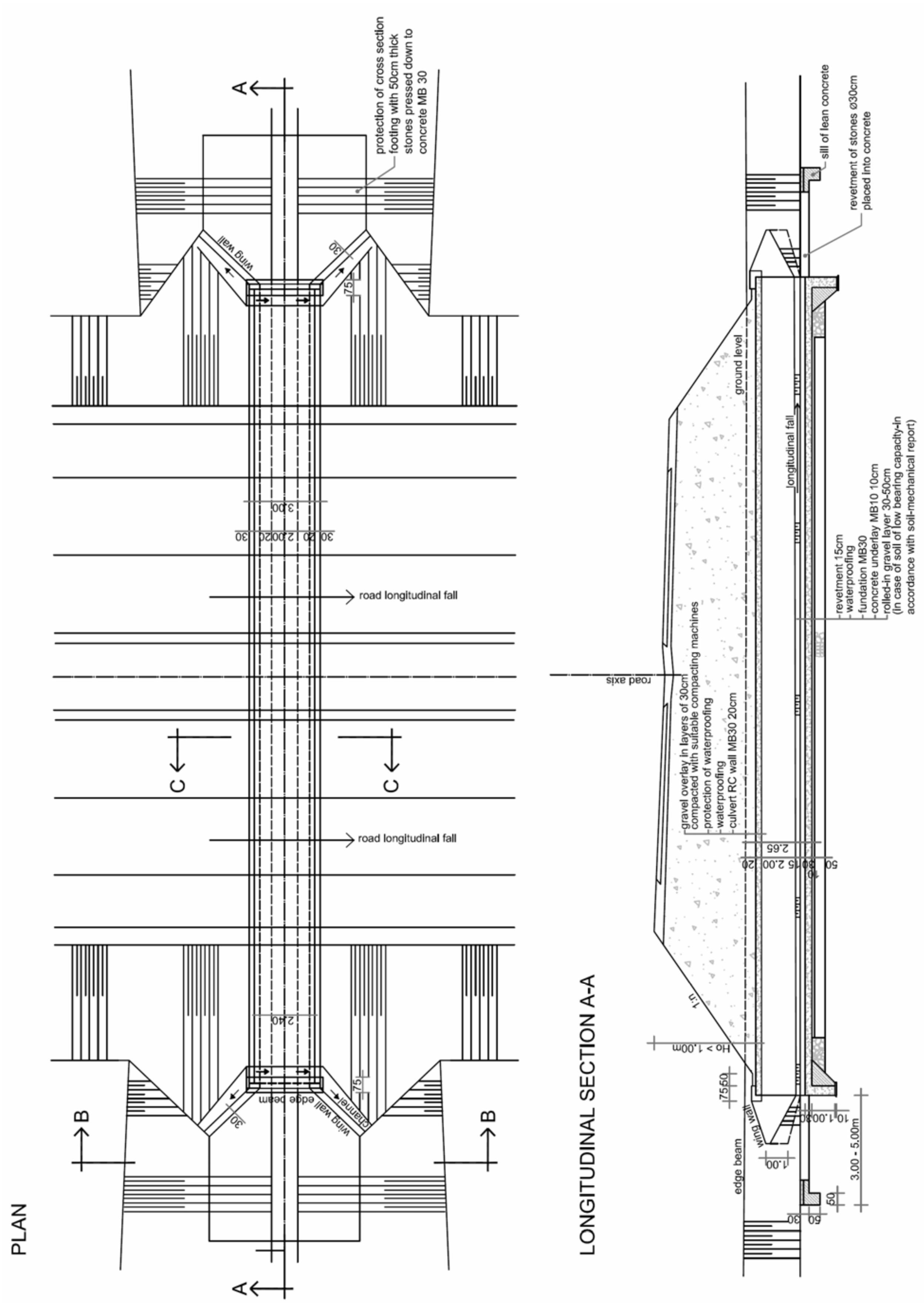
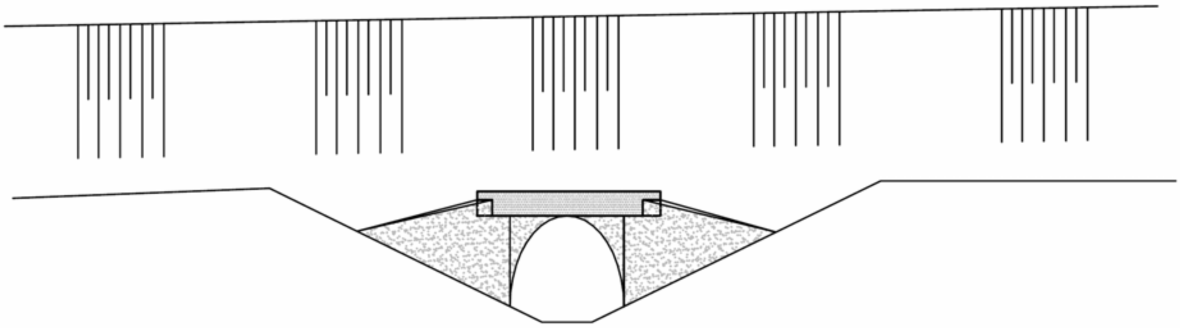
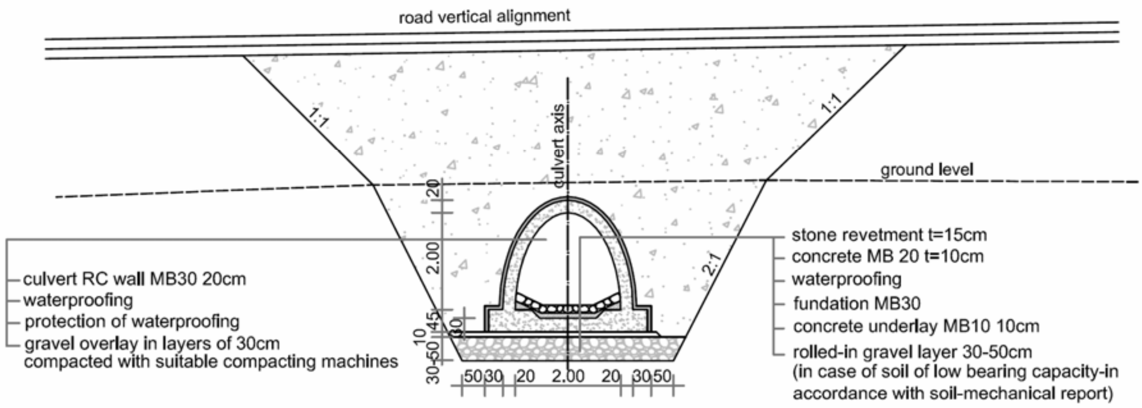


Fig. 6.6: Example of layout of an arch culvert with an opening of 2.00/2.00 m

ELEVATION B - B



CROSS SECTION C - C
MONOLITHIC ALTERNATIVE



CROSS SECTION C - C
PRE-CAST ALTERNATIVE

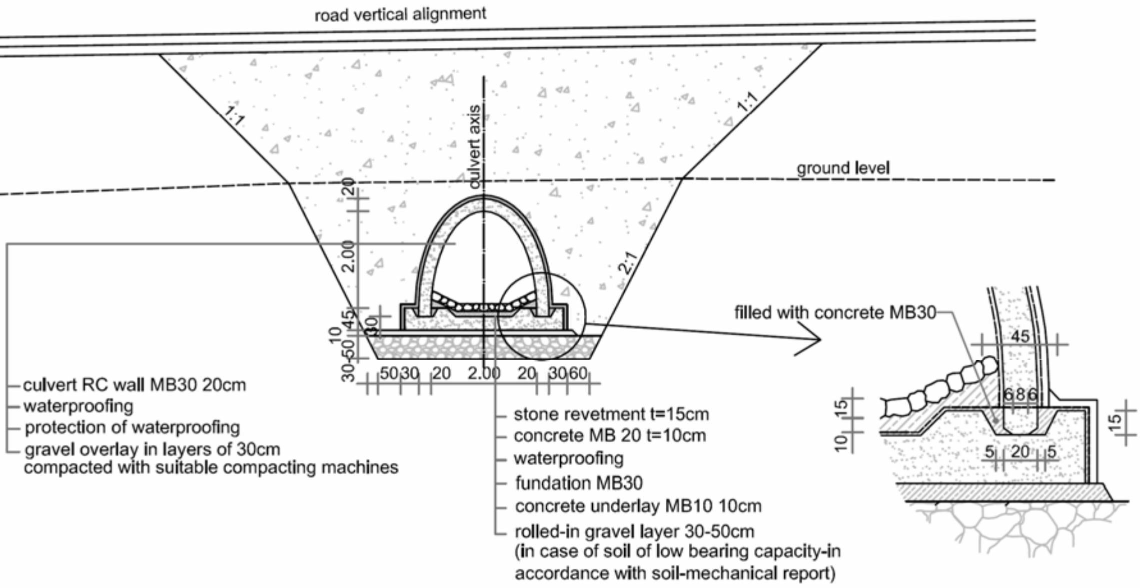


Fig. 6.7: Elevation B-B, cross section C-C for monolithic and pre-cast execution of arch culvert shown in figure 6.6 including detail of joint pre-cast arch – bottom slab

7 CULVERT DESIGN

7.1 Foundation

The bottom of the foundation or of the bottom slab is generally determined by the vertical alignment of the stream, road or footpath running through the culvert.

As a rule, culverts are founded on shallow foundations, since they are mainly located below the fills meaning that culvert and fill settlements are simultaneous.

In general, culverts must not be founded in fills, but always in a solid ground. The situation is even worse if a culvert is founded partly in a fill and partly in a solid ground. If this cannot be avoided, all necessary measures shall be foreseen in both, the fill and the culvert structure.

At both, the inlet and outlet part of a culvert, a transverse sill has to be constructed in order to avoid erosion of culvert foundations.

If pipe culverts are founded on soil of good quality and load bearing capacity and if there is no danger of erosion, foundations need not be executed on the entire culvert length, bur only at the inlet and outlet part. In case of doubtful or poor soil quality, the culvert structure is placed onto a thicker concrete base while the encasing concrete is cast at the pipe exterior.

Box culverts of clear openings 2.00 m and 3.00 m are always founded on a bottom slab irrespective of the soil bearing capacity. Box culverts of clear openings 4.00 m and 5.00 m are founded on a bottom slab or on separate strip foundations, depending on the soil bearing capacity.

Arch culverts must always be founded on a bottom slab.

The culvert bottom can have a major or a minor longitudinal fall. The latter shall be specified in the stream regulation design and by water-economy guidelines fulfilling the water-economy conditions and requirements. However, the longitudinal fall must not be smaller than 0.5%.

If the longitudinal fall does not exceed 5%, the foundations are smooth. In case that the longitudinal fall is greater than 5% and smaller than 15%, the lower surface of the foundations shall be executed stepwise (figure 7.1). If the longitudinal fall lies between 15% and 30%, transversal anchor sill shall be foreseen at intervals of 2.0 m to 3.0 m (figure 7.2).

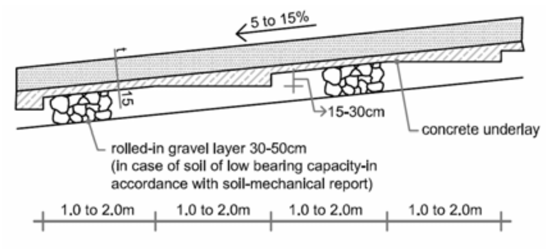


Fig. 7.1: Stepwise execution of culvert foundation for longitudinal falls between 5% and 15%

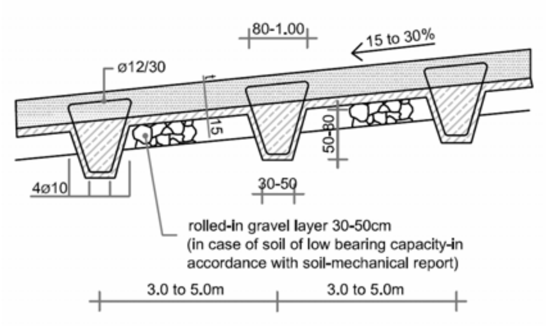


Fig. 7.2: Execution of culvert foundation for longitudinal falls between 15 % and 30 %

7.2 Transversal expansion joints

The arrangement of transversal expansion joint depends on the culvert length, on the overlay height above the culvert, and on the foundation soil characteristics (particularly on compressibility).

For longer monolithic culverts executed transversal expansion joints are obligatory. The number of those joints shall be as small as possible. Internal forces and moments must be calculated for the longitudinal direction and the necessary longitudinal reinforcement shall be verified as well.

In case of pipe culverts being generally constructed of pre-cast pipes as well as of prefabricated box and arch culverts, the site joints play a role of transversal expansion joints. It is essential to devote special attention to those joints.

Some details of transverse joints of pre-cast pipe culverts are shown in figure 7.3.

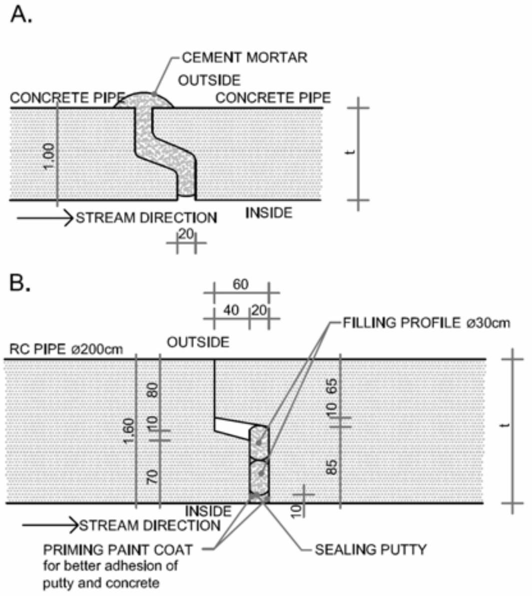


Fig. 7.3: Prefabricated pipe culverts – detail of joint
A. for ∅100 cm (∅150 cm)
B. for ∅200 cm

Where non-linear differential settlements are expected due to different thicknesses of compressible foundation soil layers, transversal expansion joints at adequate intervals shall be foreseen as well.

For monolithic execution of box and arch culverts, some details of transversal expansion joints are shown in figure 7.4. Under A., an example of sealing strip in the middle of the wall is shown, which is more demanding for execution, in particular due to formwork and reinforcement. Under B., an example of so-called formwork sealing strip is presented.

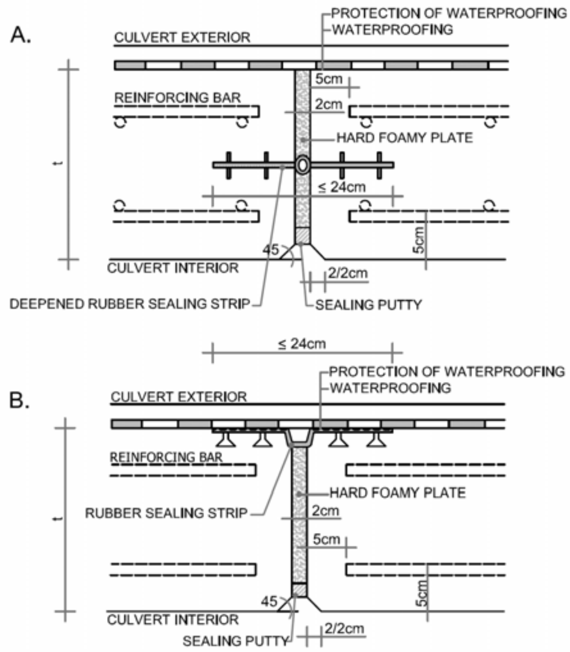


Fig. 7.4: Detail of execution and sealing of expansion joint in case of monolithic construction of box and arch culverts

7.3 Reinforcing

Reinforcing shall be carried out in accordance with DG 1.2.1.

All the reinforcement must be verified by an adequate design calculation.

Special attention shall be paid to the details and protective concrete cover, which is essential for a long service life of the particular structure. Therefore, the thickness of the protective concrete cover on both, external and internal side, shall amount to at least 5.0 cm.

In the pipe culverts of ∅ 100 cm and ∅ 150 cm, a single reinforcement in the cross section centre serves for taking the load during transportation and erection as well as for taking the load of fresh concrete during application of the encasing concrete to the culvert exterior, while the reinforcement in the encasing concrete at the pipe exterior must take the overlay weight and the traffic load.

Pre-cast pipes of culverts ∅ 200 cm are reinforced with a double reinforcement on the entire circumference. They can also be reinforced with a single reinforcement with variable position and with an extra reinforcement in the opposite zone.

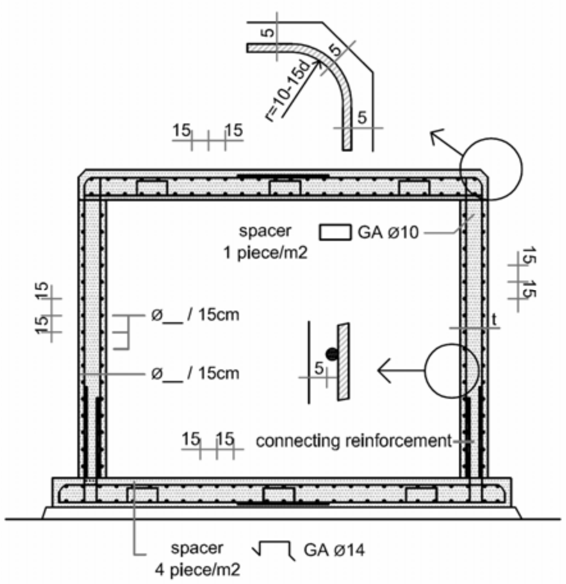


Fig. 7.5: Principle of box culvert reinforcing

If the required reinforcement cannot be built-in into the pre-cast pipe itself, the latter shall be encased with concrete. In such a case, reinforcing must be carried out as described for culverts ∅ 100 cm and ∅ 150 cm.

An example of box culvert reinforcing is shown in the figure 7.5, while the figure 7.6 shows an example of arch culvert reinforcing.

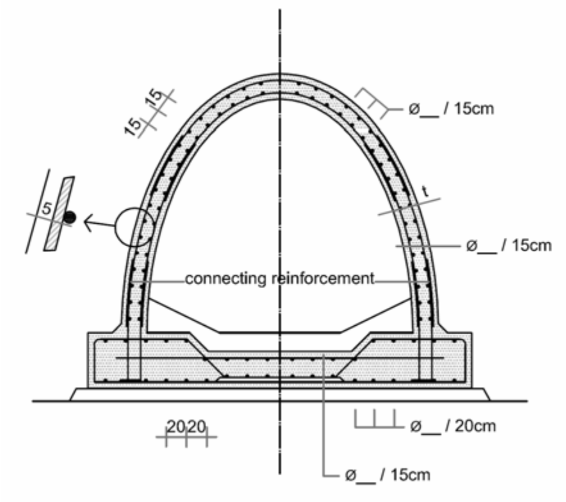


Fig. 7.6: Principle of arch culvert reinforcing

7.4 Transition slabs

Pipe and arch culverts do not require transition slabs.

When designing the transition slabs for box culverts, provisions of DG 1.2.8 shall be taken into consideration.

In exceptional cases, where the surface course of the carriageway structure is directly on the culvert structure, where a lower rank road runs over the culvert, where the culvert is founded on a good soil and where the overlay is not high, the transition from the road carriageway to the culvert carriageway can be carried out as shown in the DG 1.2.8.

When a motorway is directly on the culvert structure (i.e. without an overlay), or the culvert is founded on a ground of low bearing capacity, or the overlay is high, the transition slabs shall be executed as presented in DG 1.2.8.

In usual cases that have to be our aim as often as possible, where the overlay thickness amounts to 40 cm or more, the transition from the culvert carriageway to the road carriageway has to be performed as described in DG 1.2.8.

7.5 De-watering and waterproofing

In case of pipe culverts that are not encased in concrete at their exterior, and of arch culverts, the water can flow away from the structure quite rapidly, since the shape of those culverts in favourable. However, in case of encased pipe culverts and of box culverts, de-watering of upper culvert surface shall be ensured by sufficient cross and longitudinal fall of the latter. Generally, this can be achieved by a roof slope of the culvert upper slab (minimum 2.5 %).

In order to prevent accumulating the water on the culvert, which may cause a hydrostatic pressure, a filter layer shall be executed and the water must satisfactorily flow away from the culvert rear. When the foundation bottom is located in a permeable soil, it is sufficient if the filter layer is directly connected with the permeable solid ground. In case that the foundation is situated in an impermeable soil, drainage shall be carried out along the culvert.

All culvert structures must be protected from moisture. The upper slab is protected by “black” waterproofing, while the water-tightness of walls, lower slab and wings is ensured by introducing the waterproof concrete.

The entire non-encased pipe culverts and arch culverts, as well as the upper surfaces of box culverts and encased pipe culverts are protected from moisture by a waterproofing consisting of single welded bituminous strips.

The latter shall be mechanically protected from damages. In case of non-encased pipe culverts and arch culverts, the protection of waterproofing is carried out by means of felt or profiled plastic foil. For box culverts and encased pipe culverts where the upper surface in more or less even, such a protection is executed with a 10 cm thick protective concrete reinforced with mesh reinforcement Q 133 (∅ 4.6 mm/10 cm).

The essential provisions to ensure the water-tightness are as follows:

- Design provisions (construction joints, expansion joints, anticipated locations of cracks);
- Measures related to concrete technology;
- Careful execution and an adequate, sufficiently long care of fresh concrete;
- Limiting of cracks to 0.20 mm by means of suitable reinforcing.

Notwithstanding ensuring of watertight walls according to the “white tub” principle, additional waterproofing with strips shall be carried out at locations of vertical joints and of expansion joints, in a width of 1.00 m (0.5 m both, left and right from the joint).

7.6 Bottom protective revetment

In order to ensure a more favourable hydraulic profile at minor flows as well as to protect the culvert bottom from abrasion, a bottom protective revetment is generally carried out. The revetment can be made of natural stone or of wear resistant concrete (aggregate of silicate stone, fibre concrete).

The revetment roughness depends of the culvert longitudinal fall. For falls up to 5%, the revetment can be smooth or the joints between stones are filled up to the top (figure 7.7). If the longitudinal fall amounts to 5-15%, the joints between stones shall be 5-15 cm deep (figure 7.8). For falls of 15-30%, the shape and execution method must be specified in the hydrological – hydro-technical documents for each individual case. Culverts having a longitudinal fall greater than 30% are not constructed.

In general, the bottom protective revetment is of trapezoidal shape. The revetment sides at the bottom are placed at an inclination of 1 : n.

To achieve an additional protection from erosion of both, inlet and outlet part, the protective revetment shall be extended by 3.0 m to 5.0 m out of the culvert. That revetment shall end with a transverse sill, as it is the case for the culvert foundations.

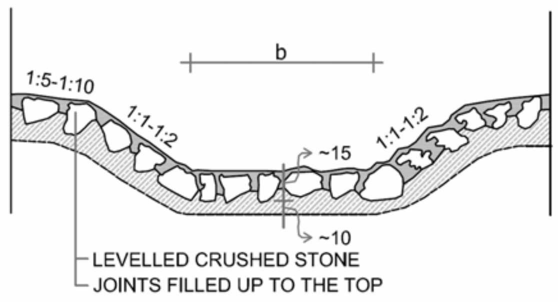


Fig. 7.7: Culvert bottom protective revetment for falls up to 5%

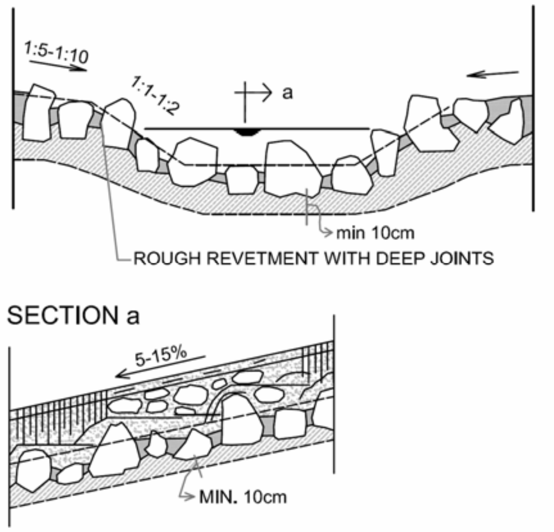


Fig. 7.8: Culvert bottom protective revetment for falls of 5-15%

A bottom protective revetment is not necessary for the pipe culverts, since the shape of pipes itself ensures a sufficient flow even at low water levels. From this case shall be removed if the water flow velocities are great.

7.7 Inlet and outlet part

On both, the inlet and outlet part, the culvert must end with side wings. The latter shall be designed to ensure an optimum water inflow and a fastest possible water outflow. The function of those wings is also to prevent efficiently falling of embankment material into the stream bed.

The upper slab or the front wall of box, arch and pipe culverts of ∅ 200 cm, shall end with an edge beam ensuring an effective de-watering of the embankment above the structure and preventing falling of the overlay material over the culvert edge into the stream bed. Figure 7.9 shows an example of an edge beam when the overlay is thicker than approx. 40 cm.

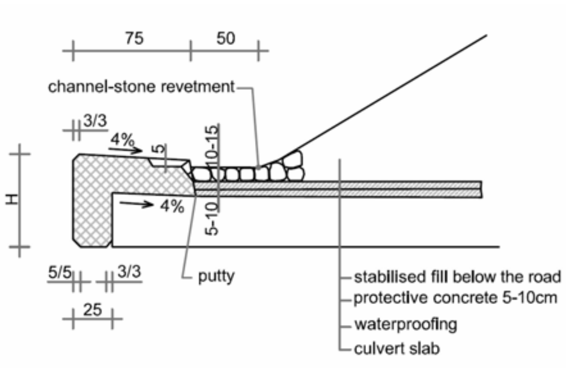


Fig. 7.9: Detail of edge beam

In case of smaller pipe culverts the wings are replaced by an inclined end head, formed in the embankment inclination (figure 7.10).

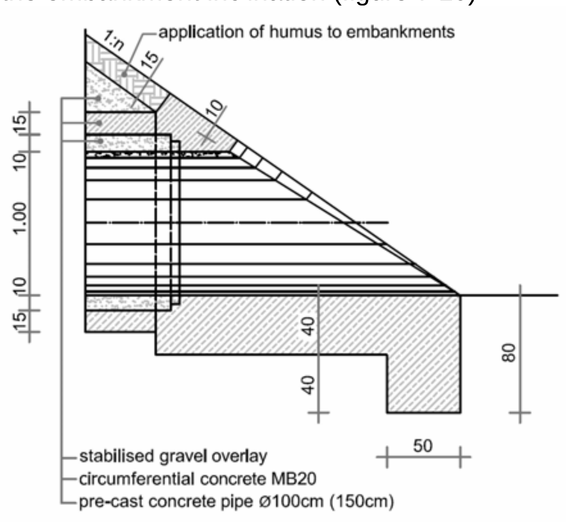


Fig. 7.10: Detail of end of pipe culverts ∅100 cm (∅150 cm)

8 STATIC ANALYSIS OF CULVERTS

The load and actions on culverts shall be taken into consideration in accordance with DG 1.2.1.

The static analysis of culverts is carried out according to principles being valid for other bridges.

For the static analysis of culverts, the following loads shall be considered:

- Dead weight;
- Vertical earth pressure;
- Horizontal earth pressure;
- Traffic load;
- Action due to settlement.

The dead weight is considered in the same way as for other bridges. However, in case of culverts with a high overlay, the dead weight has only a minor influence on internal forces and moments.

The most essential and the most difficult work is to determine the most realistic vertical earth pressure. The latter depends on the following:

- Overlay height;
- Soil characteristics (specific gravity, internal friction angle, compressibility modulus);
- How the culvert is dug in the solid ground;
- Culvert position in the overlay.

The horizontal earth pressure is dependent on the same factors as the vertical one.

In case of high overlays, the vertical and horizontal earth pressure acting on culvert can differ one of another by factor 2 or more, depending on calculation method (Terzaghi – Birbaurmer). As a consequence, the method of earth pressure calculation shall be selected extremely carefully and the calculation itself must be performed in at least two ways.

When performing the static analysis of culverts, one must consider the same traffic load as for other bridges. However, in case of culverts, the traffic action is transferred to the structure via soil. Here, the load distribution has to be taken into consideration, which again depends on the soil characteristics and the position of culvert in the overlay.

The effect of settling on the structure must be studied particularly in the longitudinal direction of the culvert. If the differential settlements are so significant that the structure cannot take occurred deformations, longitudinal expansion joints must be foreseen.

9 CONDITIONS FOR CULVERT CONSTRUCTION

Pipe culverts are exclusively constructed of prefabricated pipes, reinforced or not, encased in concrete or not.

Box and arch culverts can be built on site or assembled of pre-cast elements. The selection of construction method depends in particular on the extent of work, contractors' capability as well as on the distance between the pre-cast workshop and the construction site. A criterion is also the culvert cross section. In case of major cross sections, construction of prefabricated elements is not reasonable, since the elements can be too large and too heavy for transportation and assembling.

To a great extent, the selection of construction method depends on the geology as well. If a great number of expansion joints is required, it is reasonable to think over the pre-cast construction method, if such possibility is given at all.

If the culvert is constructed according to the pre-cast method, special attention shall be paid to the site joints.

Culverts of minor openings and with thin overlays are generally constructed in such a way that an already executed overlay is dug through and the culvert is placed into the trench. For culverts of major openings and thicker overlays, first the structure is constructed followed by the execution of the backfill and later on of the overlay.

Backfilling of culverts shall be carried out parallel on both sides in layers of 30 cm that have to be compacted extremely carefully with minor compacting machines.