GUIDELINES FOR ROAD DESIGN, CONSTRUCTION, MAINTENANCE AND SUPERVISION

Volume I: DESIGNING

Section 2: DESIGNING BRIDGES

DESIGN GUIDELINES (DG 1.2.5)

Part 5: DRAINAGE AND PIPING OF BRIDGES

INTRODUCTION

Drainage and piping of bridges comprise all required constructive measures for a fast and effective drainage of both, surface water and the water leaking up to the waterproofing surface, from the bridge. By an adequate bridge dewatering, traffic safety is ensured. Moreover, the bridge structure itself and the environment are protected in compliance with the water management requirements.

The bridge life period and maintenance costs are significantly affected by the drainage and piping system efficiency.

C O N T E N T S

1. SUBJECT OF DESIGN GUIDELINES

The intention of these guidelines is to present general guidelines for a correct design of drainage and piping of road bridges. Structural particularities and quality assurance requirements of individual elements of the dewatering systems shall be taken into consideration. Hydraulic calculation input parameters are given to specify dimensions and number of individual elements. For maintenance purposes, conditions of accessibility are given as well as procedures of cleaning of the drainage and piping system presented.

2. REFERENCE REGULATIONS

The DG 1.2.5 is based on the following regulations:

Technical regulations

- RVS 15.43 *Brückenausrüstung; Brückenentwässerung* (Equipment of bridges; Drainage of bridges) – Austrian guidelines

- ZTV-K, *Zusätzliche technische Vertragsbedingungen für Kunstbauten* (Supplementary technical contractual conditions for engineering structures) – German guidelines

- *Richtlinien für konstruktive Einzelheiten von Brücken; 6 Entwässerung* (Guidelines for design detailing of bridges; 6 Dewatering) – Swiss guidelines

- *Assainissement des ponts routes; evacuation des eaux, drainage...* (Improvement of road bridges; water evacuation, drainage...) – French guidelines.

Standards

- Gullies: DIN 1229, DIN EN 124

- Drainage pipes: ÖNORM B 2571, B 2570, DIN 19522

- Seepage water drainage pipes: C. B5. 226

- Fastening devices: DIN 17440, DIN 367, Part 11 – stainless steel

3. EXPLANATION OF TERMS

Drainage is leading away of both, the surface water and the water leaking up to the waterproofed surfaces, from the bridge.

Piping is collecting and leading away of the water from the bridge by means of drainage pipes.

Surface water is the precipitation water falling onto the upper surface of a bridge.

Seepage water is a portion of the surface water passing through the individual parts of the carriageway (asphalt layers, walkways, edge beams) up to the waterproofed surfaces.

Recipient is, for instance, a road drainage, river, lake or similar to which the water is led away from a bridge.

Gully is an element of the drainage system, into which the precipitation water from the carriageway flows.

Drainage pipe is an element serving for leading away the water from a bridge.

Fastening devices for drainage pipes are suspenders and supports serving for fixing the drainage pipes to the bridge structure.

Seepage water drainage pipe is a pipe with a specially shaped mouthpiece built-in into the superstructure below the protection of the waterproofing.

Unit intensity of rainfall is the quantity of precipitations in a time unit per unit of area.

Cleansing shaft is an opening on the drainage pipe to which a cleansing nozzle is placed for the needs of cleansing procedure.

4. GENERAL GUIDELINES FOR DESIGN OF DRAINAGE AND PIPING SYSTEM OF ROAD BRIDGES

4.1 General

The drainage and piping system of road bridges refers to the following:
- Drainage of upper (visible) surfaces of bridges;
- Leading away the seepage water from the waterproofed surfaces and relieving of vapour pressures;
- Dewatering and ventilation of hollows, dewatering of bearing surfaces;
- Dewatering of rear fills of abutments;
- Connecting of bridge dewatering system to recipient (road drainage) and maintenance of dewatering system.

The complete design of both, bridge cross and longitudinal section, and in particular of the bridge vertical alignment, shall follow the principles of a correct dewatering of the bridge.

All drainage and piping elements shall be designed to be easily replaced and accessible for regular maintenance.

The drainage and piping elements must not interfere with the load bearing structure, e.g. in the area of pre-stressed tendons, of main load bearing reinforcement etc.

A bridge must have its own separate drainage and piping system to be connected via road drainage or directly with the precipitation water recipient. However, this does not apply for short bridges where the bridge length is smaller than the required spacing between adjacent road gullies.

The dimensions and the number of structural elements of the dewatering system shall be specified on the basis of an adequate hydraulic calculation. As the input parameters for the hydraulic calculations, the meteorological data on the design precipitation quantities on the location of the planned structure are assumed.

In figure 4.1, a typical scheme of surface water drainage and piping on a road bridge is shown. Figures 4.2 and 4.3 present the position of drainage and piping elements with regard to the cross section.

4.2 Surface water drainage

The water from the bridge upper surface is led away via gullies and transverse drainage pipes into a collecting duct, which runs up to the recipients.

All the surface water falling onto the bridge deck shall be collected by means of bridge gullies in such a way that the water does not flow over expansion joints.

If the superstructure is a box girder, the longitudinal drainage pipes are placed to the box section interior for lengths $\geq$ 300 m, provided that the interior is accessible or that it is enabled by a sufficient clear height of minimum 1.60 m (figure 4.3).

In general, longitudinal, transverse and vertical ducts are not embedded in concrete.

Placing the vertical drainage pipes along or in piers of significant height and of bad accessibility shall be avoided.

Connections of pipes to the longitudinal ducts shall be designed hydraulically favourable. Bends of 90° shall be avoided. It is recommended to introduce a double bend of 45° with an intermediate piece.

Deformations of the piping systems must be taken into account.

At each change of direction of drainage pipes, a cleansing opening shall be foreseen.

4.3 Seepage water drainage and relieving of vapour pressures

A portion of surface water, leaking through individual carriageway elements (asphalt layers, walkways, edge beams) up to the waterproofed surfaces shall be led through the bridge superstructure in a controlled manner. Eventual condensed water shall be evacuated as well. Vapour and air pressures arising below and above the waterproofing layer shall be relieved.

The seepage water is drained by means by specially arranged gullies for surface water drainage and by small pipes with specially shaped mouthpiece to be built-in into the superstructure below the protection of the waterproofing.

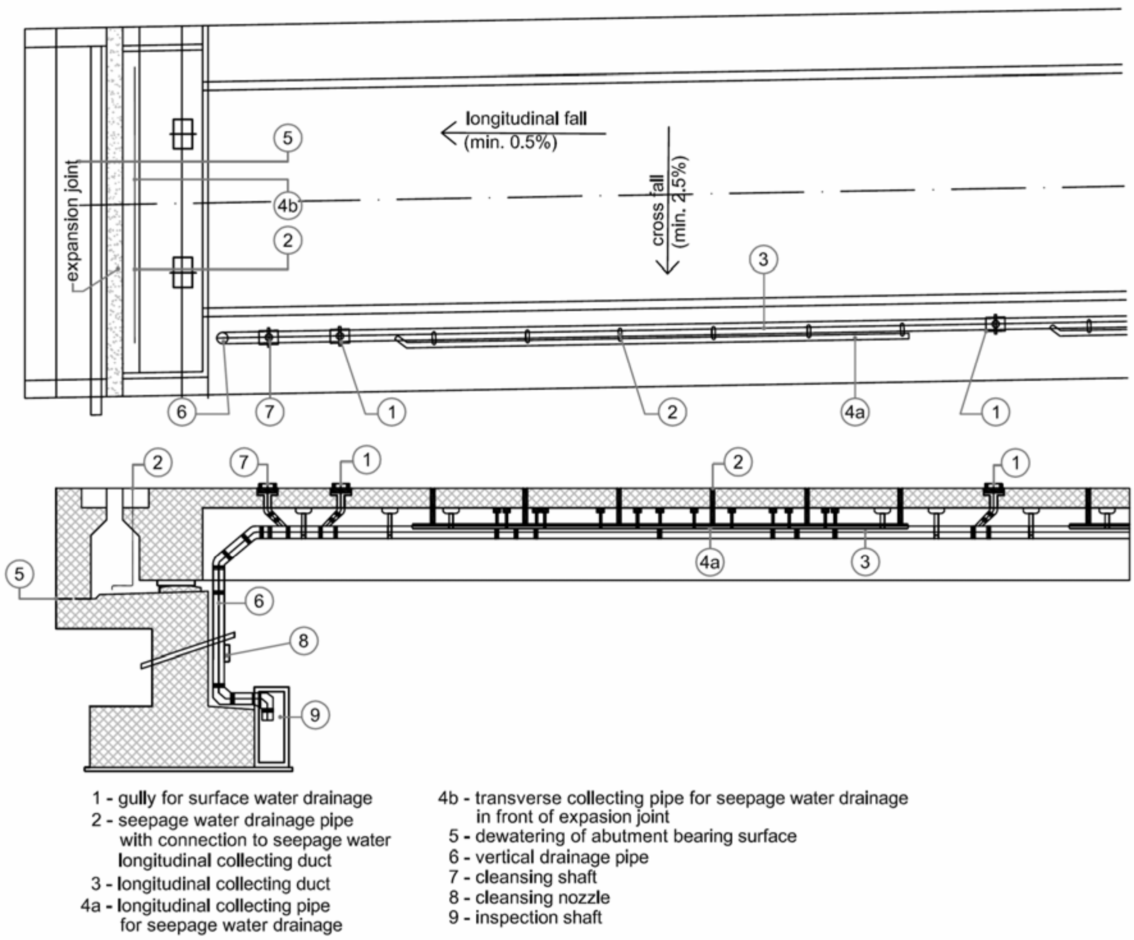


Fig.4 1: General scheme of bridge drainage and piping

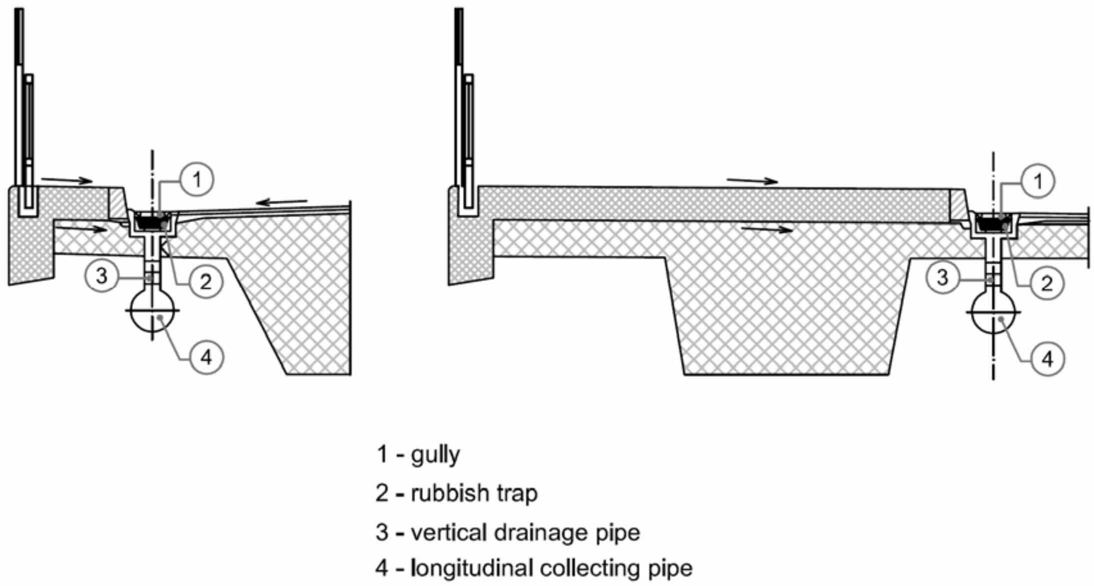
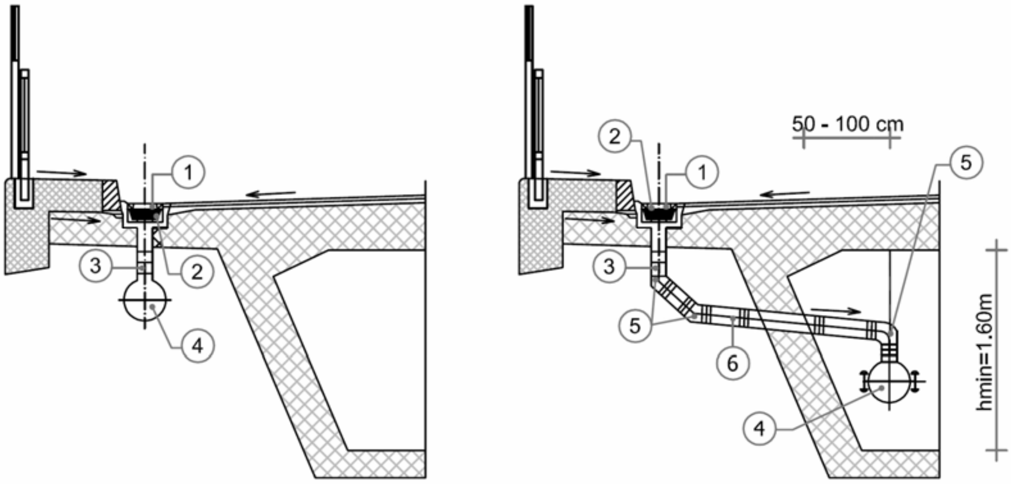


Fig. 4.2: Methods of placing drainage elements with respect to bridge deck cross section



1 - gully
2 - rubbish trap
3 - vertical drainage pipe
4 - longitudinal collecting pipe
5 - knee-pipe
6 - transverse drainage pipe

Fig. 4.3: Methods of placing drainage elements outside and inside of box section

4.4 Dewatering and ventilation of hollows

In case that the drainage system is placed in the interior of the superstructure box cross section, evacuation of water shall be ensured in the lowest point of each span using a corrosion resistant pipe of internal diameter of ∅ 200 mm (figure 4.4).
To equalize the outer and inner temperature, the superstructure box section shall be equipped with openings of ∅ 200 mm. In this way, formation of condensed water is prevented. The spacing between adjacent openings shall not exceed 20.0 m in longitudinal direction.

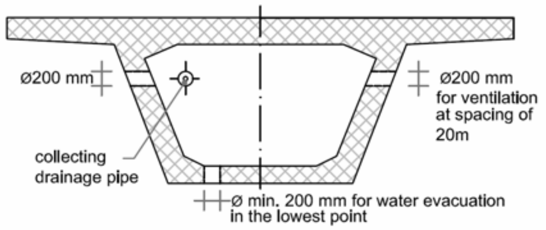
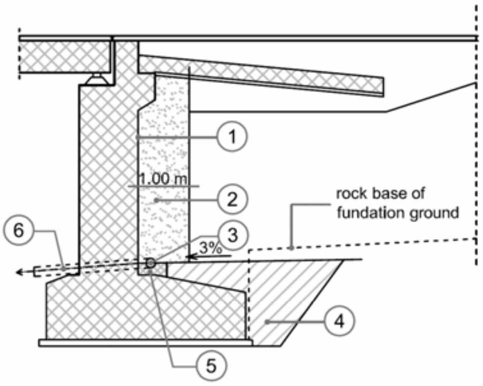


Fig. 4.4: Pipes for dewatering and ventilation of box cross section

4.5 Dewatering of rear fill behind abutment

Surface water which could, due to road longitudinal fall, flow onto the bridge, shall be captured before the beginning of the bridge and led away into a recipient (road drainage). In order to avoid hydrostatic water pressures in the layers of the rear fill acting on the abutment wall and wings, and to capture the surface water, which could eventually penetrate into that part, a 1.0 m thick filter gravel layer along the entire height of the abutment wall shall be foreseen. Instead of gravel, any backfilling material can be used, provided that flowing of water from the fill top up to the foundation upper edge is ensured (figure 4.5).



1 - waterproofing with protection
2 - gravel in layers of t=30 cm
3 - drainage pipe
4 - compact clay
5 - concrete base
6 - drainage pipe

Fig. 4.5: Dewatering of rear fill behind abutment

At the drainage layer base, the seepage water shall be led away through the rear fill by means of a drainage pipe. The drainage must be attached to an appropriate recipient.

4.6 Dewatering of bearing surfaces

On bearing surfaces located below expansion joints, a controlled system of water collecting and leading away shall be foreseen. At a waterproof expansion joint, the water penetrating on damaged places is evacuated by means of a collecting drainage gutter (figure 4.6) and a vertical pipe into a recipient.

The bearing surface must not be dewatered into the rear fill.

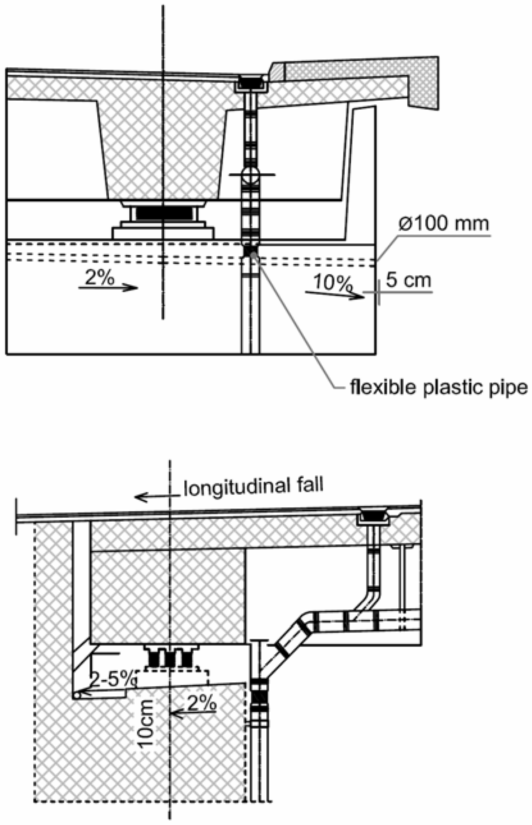


Fig. 4.6: Dewatering of bearing surfaces at waterproof expansion joint

4.7 Connecting bridge dewatering system to recipient (road drainage)

The bridge dewatering system shall be connected to a recipient in accordance with water economy requirements referring to the necessary measures for preventing and reducing water and soil pollution due to washing out of carriageways by the precipitation water.

Since bridges are constituent parts of roads, the fundamental dewatering principles shall be already determined for the road as well as defined in the design specification for the bridge.

In special cases, due to ground water protection, all the surface waters shall be drained from the roads via oil traps designed to function at the same time as sand traps as well.

For bridges of an area up to 2,000 m^2, it is usually sufficient to foresee a sand trap in a form of a shaft made of concrete pipes of ∅ 100 cm with a suitable cover. In case of bridges of an area greater than 2,000 m^2, a special sand trap design is required.

If there is no road drainage or public sewage in the bridge surroundings, special drainage system shall be foreseen conducting the water into a drain hole, road gutter or water stream.

For longer bridges, collecting or retarding basins shall be designed in the framework of the bridge, if this is foreseen by the road drainage conception.

4.8 Dewatering of smaller bridges

From the point of view of the dewatering design, a bridge is considered as a small one when its total length, including the wings and transition slabs respectively, is smaller than the required distance between two adjacent gullies. The latter amounts to 5 – 20 m depending on the bridge area as well as on both, the longitudinal and the cross fall of the carriageway.

Smaller bridges do not require a separate drainage and piping system. The bridge dewatering is carried out within the framework of the road drainage.

Where controlled road drainage by means of road sewage is designed (motorways, highways), road gullies are placed behind the transition slabs at both ends of the bridge where they are attached to the road sewage (figure 5.1a).

If the road drainage is uncontrolled, i.e. without road sewage (e.g. roads of a lower range), the surface water is led away form the carriageway by means of gutters placed next to abutment wing walls at both ends of the bridge (figure 5.1b).

The road sewage running in the area of the motorway central reserve shall be diverted before aside into the marginal strip area. This diversion shall be executed before the bridge.

5. STRUCTURAL PARTICULARITIES OF INDIVIDUAL ELEMENTS OF DRAINAGE AND PIPING SYSTEM OF ROAD BRIDGES

5.1 Gullies

Gullies are one of the most important elements of drainage and piping system. As a rule, they consist of three parts: a grate, a frame and an inflow piece. The latter has an inclined (lateral) or a vertical outflow pipe of minimum internal diameter of 125 mm. It must be equipped with distributing bars welded onto the steel reinforcement.

The shape and type of gullies shall be adjusted to the bridge structure (figures 8 and 9).

The gutters are placed on the carriageway edge, one-sided or two-sided, depending on the transverse fall. The distances between gullies and their number are determined by the hydraulic calculation (chapter 6).

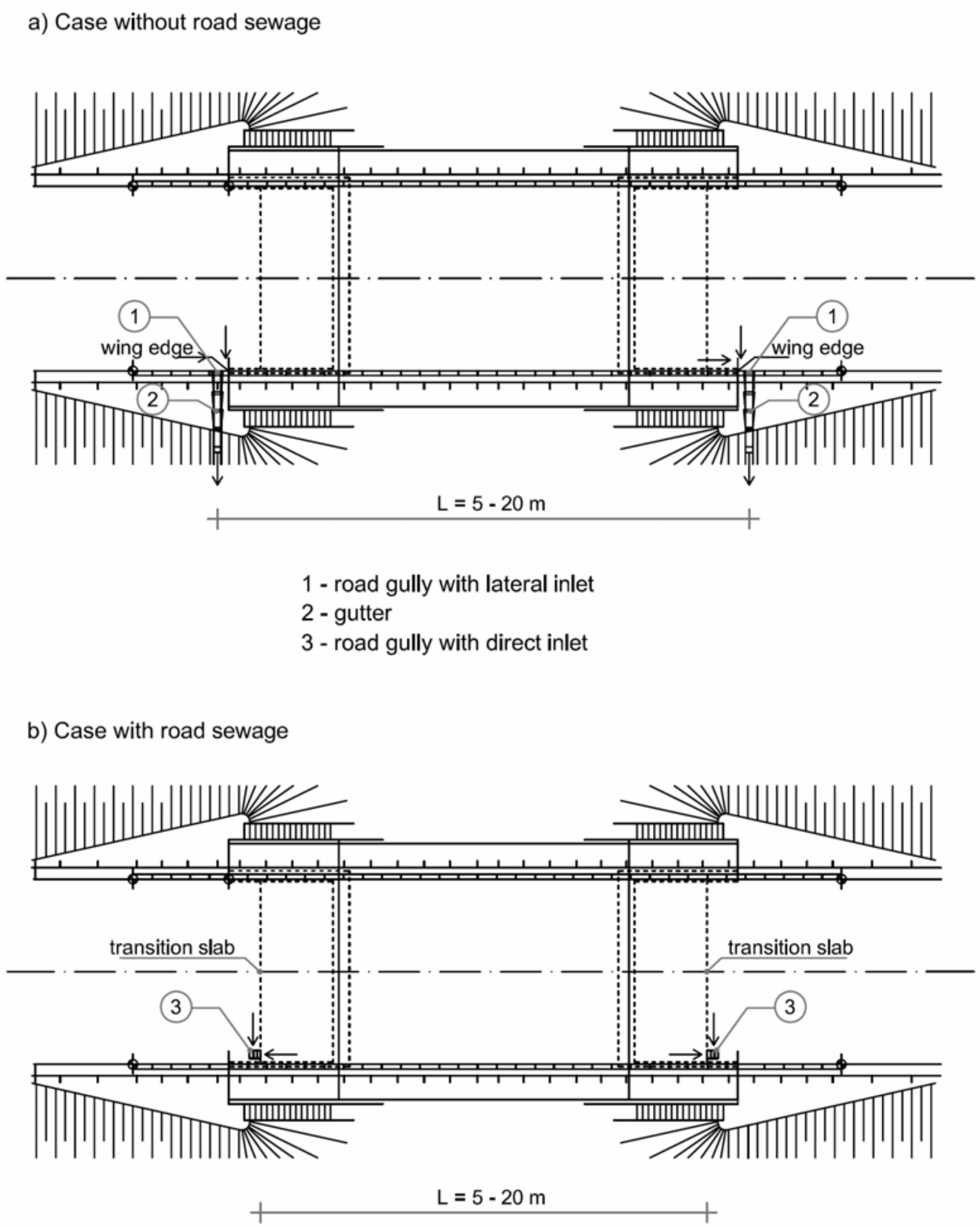
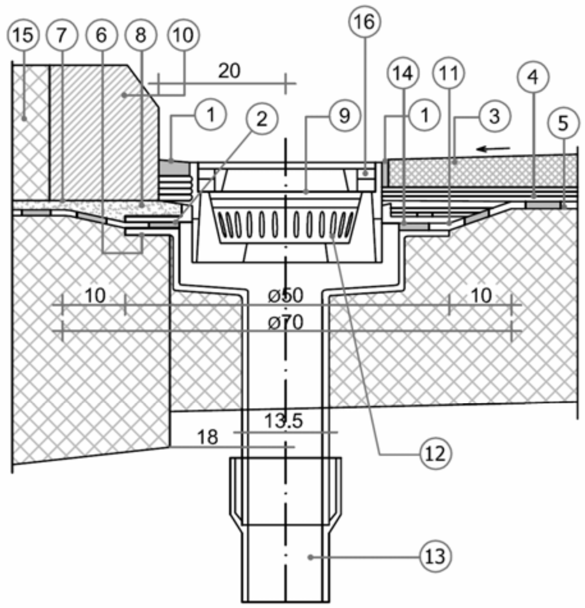
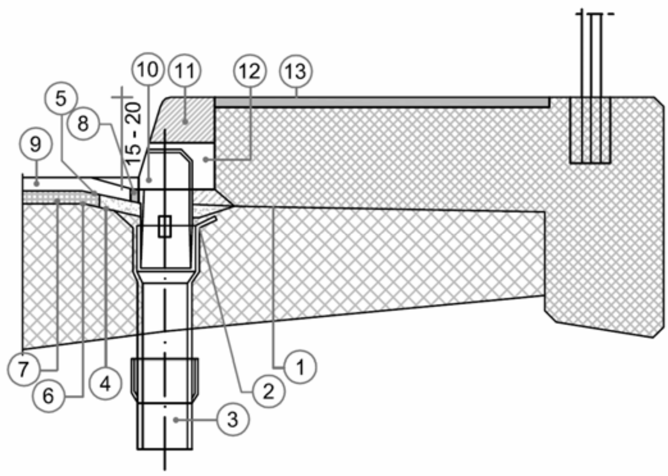


Fig. 5.1: Principles of dewatering of smaller bridges



1 - bituminous filling compound
2 - waterproofing below walkway
3 - wearing course
4 - protective layer of asphalt or asphalt-concrete
5 - waterproofing
6 - perforated steel plate
7 - filter of single-grain concrete with synthetic resin
8 - dividing layer of glass fabric
9 - gully with direct outlet (simultaneous building-in)
10 - granite kerb
11 - waterproofing pasted over gully flange
12 - rubbish trap
13 - plastic piece
14 - priming coat
15 - walkway
16 - stainless steel bolt for grate opening

Fig. 5.2: Gully with direct inlet arranged for simultaneous building-in



1 - waterproofing below walkway
2 - perforated steel plate
3 - plastic piece
4 - filter of single-grain concrete with synthetic resin
5 - dividing layer of glass fabric
6 - waterproofing pasted over gully flange
7 - waterproofing
8 - bituminous filling compound
9 - poured asphalt or asphalt-concrete below walkway
10 - gully with lateral inlet
11 - granite kerb
12 - cement mortar
13 - poured asphalt

Fig. 5.3: Gully with lateral inlet below walkway

Gullies with a free outlet can be used for bridges where dewatering by means of piping is not prescribed.

The gully elements shall be made of a quality grey cast iron and bituminized. The gully grate is of such a shape that also a safe cycling is ensured on the roads with a mixed traffic. The outer edge of the frame shall be at least 1 cm far from the kerb. This joint must be filled with an elastic bituminous compound.

For opening or lifting the grate, a stainless steel bolt shall be foreseen.

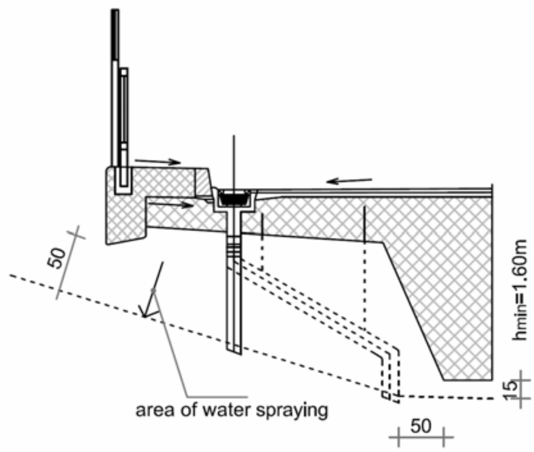


Fig. 5.4: Gully with a free outlet

The lower part of the gully is installed and concreted together with the reinforcement. Its subsequent concreting into an opening left in advance is allowed only in special cases.

The gully capacity depends in particular on the grate (size, inflow area, shape of grating bars), carriageway surface, falls, shape of gutter at the kerb, and the quantity of the water inflow into the gutter amounting to at least 10 l/s.

A gully can be accomplished in two ways: with a bottom inlet or with a lateral inlet. The latter can be exceptionally used for town bridges or those with a mixed traffic.

Only standardized gullies of proven capacity may be installed.

5.2 Drainage pipes

Drainage pipes are transverse pipes, longitudinal collecting pipes and vertical pipes (figure 4.1).

Through the transverse drainage pipe, the water collected in a gully is led away into the longitudinal collecting pipe at an angle of 45° in plan 60° from above.

The internal diameter of the transverse drainage pipe shall amount at least 150 mm or it has to be determined on the basis of hydraulic calculation (refer to chapter 6). The fall of that pipe shall be 5% minimum.

Longitudinal pipes collect the water from the transverse drainage pipes (carriageway with a two-sided cross fall) or directly from the gullies (carriageway with an one-sided cross fall).

The internal diameter of the longitudinal collecting pipes amounts to 200 mm minimum. The minimum inclination of the longitudinal collecting pipes is 1%.

Longitudinal collecting pipes must not be embedded in the bridge superstructure. When passing through cross girders or other structural elements, those pipes have to be separated from them.

All direction changes shall be carried out by means of adequate fittings of a minimum angle of 45°. A bend of 90° has to be achieved by two fittings of 45° and one intermediate straight pipe of 20 cm length.

For the selection of materials the following factors are decisive: durability, energy loss in the pipeline, cleansing, climatic influences, wearing of pipes due sand in the water flowing away, and aggressive action of chemicals in the pipe.

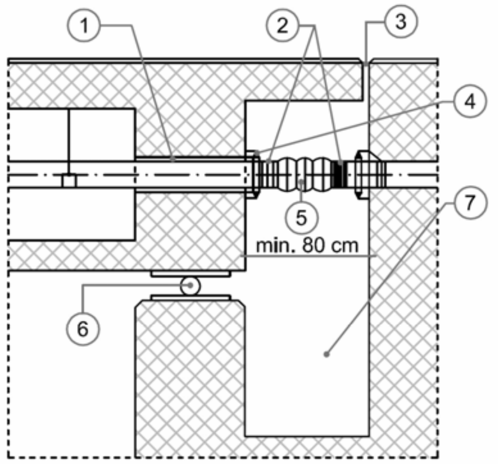
In the abutment area the collecting pipe can be led in the following ways:
- Through the fill behind the abutment, e.g. in case of short bridges (figure 5.5);
- Vertically downwards in front of the abutment (figure 5.6).

The diameter of the vertical collecting pipe shall be harmonized with the diameter of the longitudinal collecting pipe in such a way that the water is adequately accelerated when passing from the longitudinal collecting pipe to the vertical one. Therefore, for smaller heights of the vertical pipes and for minor water quantities, the profile of the vertical pipe shall be the same as of the longitudinal one.

The method of leading of those pipes, i.e. freely along the pier or in special grooves, is shown in the figure 5.7.

If vertical pipes are higher than 10 m, it is reasonable to foresee ventilation at the upper end of the pipe, for example an open inlet funnel serving for connection between both, the longitudinal and vertical pipe.

Into the vertical pipes bends of ≤ 60° may be only installed in order to prevent plugging of pipes.



1 - formwork pipe
2 - fastening of flexible pipe onto fixed pipe
3 - expansion joint
4 - fastening of fixed pipes onto structure
5 - flexible elastic pipe
6 - movable bearing
7 - lateral access min. 80/120 cm

Fig. 5.5: Leading of collecting pipe through the fill behind abutment

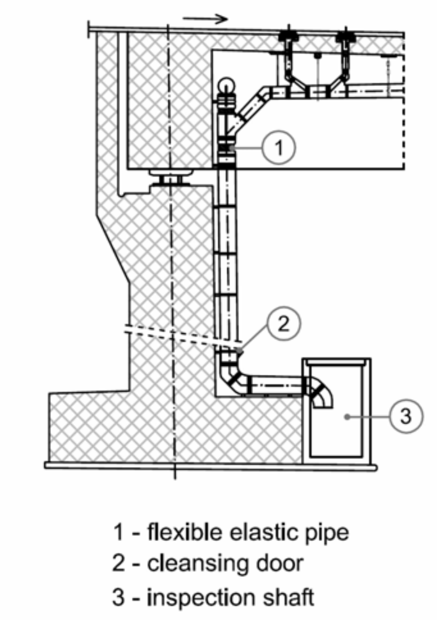


Fig. 5.6: Leading of collecting pipe downwards in front of abutment

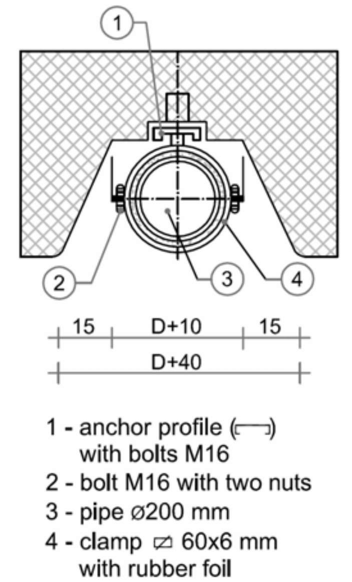


Fig. 5.7: Leading of vertical drainage pipe in a groove in the pier structure

5.3 Conditions for installation and fastening of drainage pipes to bridge structure

For fastening the pipes, suspenders and supports are used. They shall be manufactured and fixed in such a way that a sufficient support as well as both, contraction and extension of the pipes is ensured.

The supports and suspenders shall enable an adequate height regulation. The suspenders are carried out as movable or fixed (figures 5.8, 5.9, 5.10). A fixed fastening of pipes is executed at joints where transverse drainage pipes are connected to the longitudinal collecting pipe.

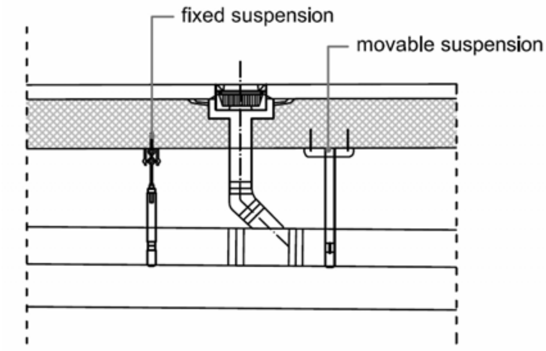


Fig. 5.8: Methods of suspending drainage pipes

Anchoring of suspenders and supports is performed by means of a special profile and bolts with T-heads. When carrying out a subsequent drilling and inserting of steel pieces attention shall be paid to pre-stressed tendons and reinforcement.

The suspenders and supports for fastening the pipes shall be protected from corrosion or made of stainless steel.
The distances between supports or suspenders depend on the pipe types and on the permissible sag (vertical flexure) of those pipes.

The length differences between the bridge structure and the pipeline are determined on the basis of material extensibility coefficients and of temperature differences: 40K for pipes inside and 60K for those outside of the box cross section.

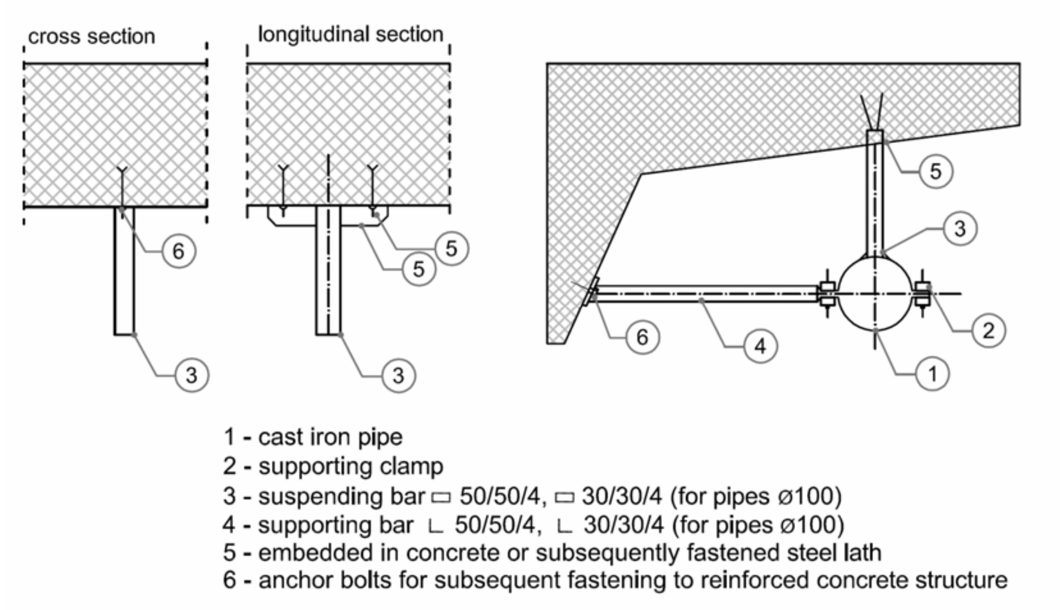


Fig. 5.9: Fixed suspension of pipes

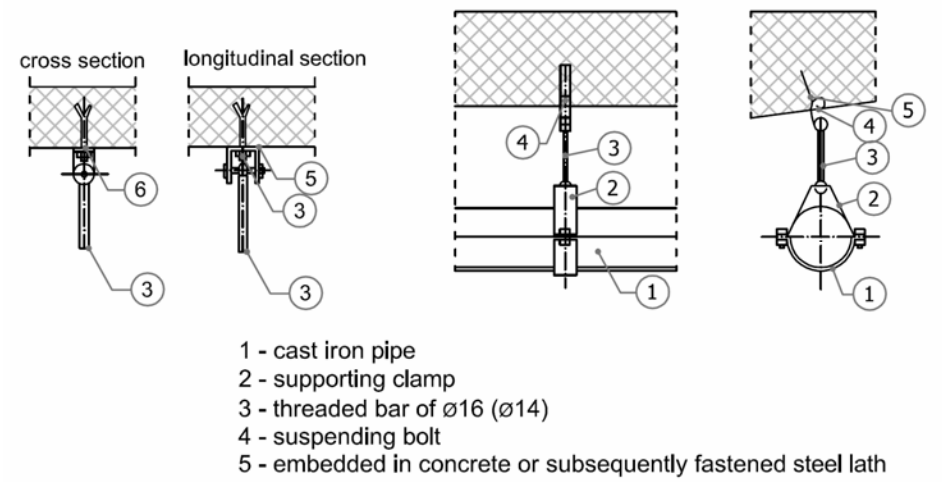


Fig. 5.10: Movable suspension of pipes

5.4 Elements for seepage water drainage and relieving of vapour pressures

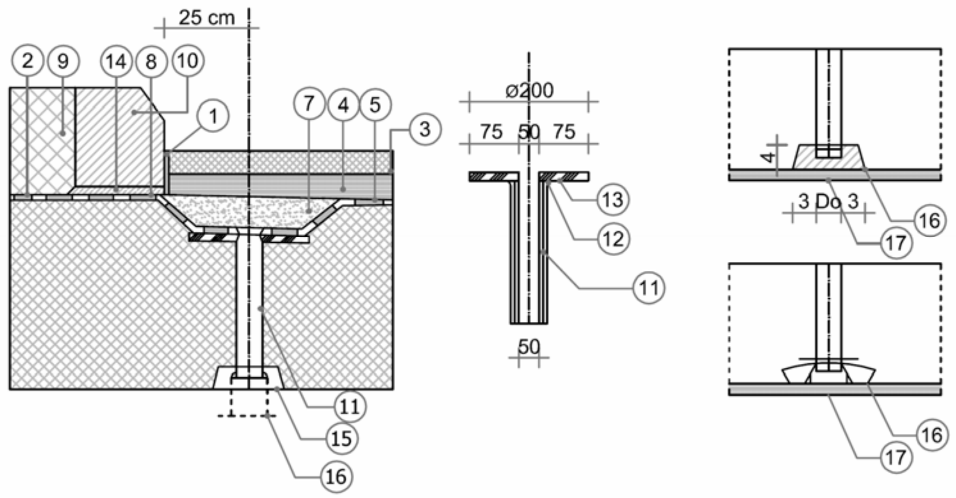
Seepage water pipes shall be distributed on the entire waterproofed surface in such a manner that they are placed in the carriageway lowest point, e.g. along the walkway (25 cm from the kerb), at spacing of 3.0 m to 10.0 m, depending on the carriageway longitudinal fall (figure 5.11). Each seepage water pipe shall cover about 15-25 m^2 of the carriageway.

In case of bridges that cross other roads, the seepage water shall be led to the collecting drainage pipe. The latter is then attached to the collecting pipe serving for evacuation of the surface water.

If the roads are of a lower range, a free outflow of the seepage water can be executed, however under condition that this will not represent any trouble under the bridge. An adequate method is shown in the figure 5.12.

Immediately before the lower expansion joint with regard to the bridge longitudinal fall, seepage water pipes shall be installed at distances of 3.0 m to 4.0 m (figure 5.13). The seepage water along the expansion joint must be evacuated by means of piping, if a free outflow of water might represent any disturbance below the bridge.

If a bridge has no inspection chamber, seepage water is collected along the expansion joint by the aid of a collecting channel built-in above the waterproofing and below the waterproofing protection layer. In the lowest point the water is brought away by means of a small pipe through the structure (cross girder) downwards to the bearing surface of the abutment. The mentioned bearing surface is inclined towards the rear wall. From that place, the water is led off from the bridge (figure 5.14).



1 - bituminous filling compound
2 - waterproofing below walkway
3 - asphalt wearing course
4 - asphalt or asphalt-concrete protective layer
5 - waterproofing
6 - plastic piece
7 - filter of single-grain concrete with synthetic resin
8 - dividing layer of glass fabric
9 - walkway
10 - granite kerb
11 - steel pipe of ø58 mm (internal diameter=70mm in case of dewatering)
12 - weld a=5 mm
13 - flange (circular steel plate)
14 - concrete poured under kerb
15 - fixing element of conical shape
16 - connecting pipe to main longitudinal drainage pipe
17 - shuttering lining

Fig. 5.11: Seepage water pipe

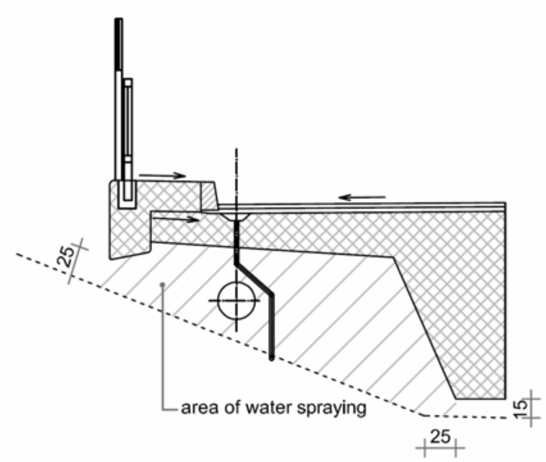


Fig. 5.12: Solution with free outflow of seepage water

In case that a bridge has an inspection walkway in the abutment, seepage water is led into the chamber and from there away from the bridge (figure 5.15).

For relieving the water vapour pressure below the waterproofing (where the waterproofing is protected by a layer of poured asphalt), additional pipes are installed at certain locations of the carriageway slab. These pipes are covered with waterproofing. However, in the outlet area, the waterproofing must not be stuck onto the concrete surface.

Dewatering of shafts in the walkways where service lines (e.g. electricity, ice announcing wires, water supply pipes, etc.) are located, as well as drainage of the holes for building-in the railing pillars, are shown in the figure 5.16.

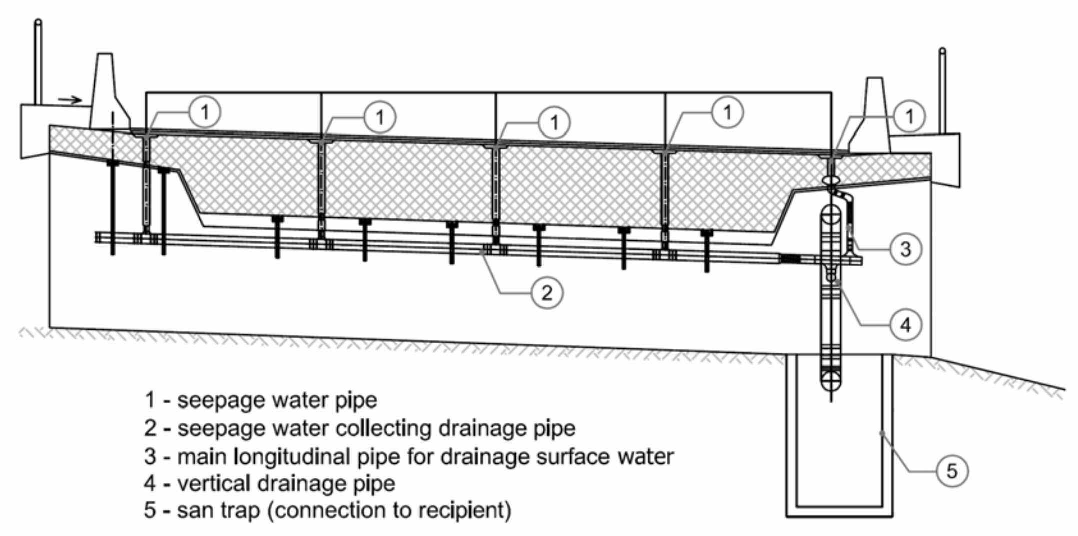


Fig. 5.13: Drainage and piping of seepage water before expansion joint

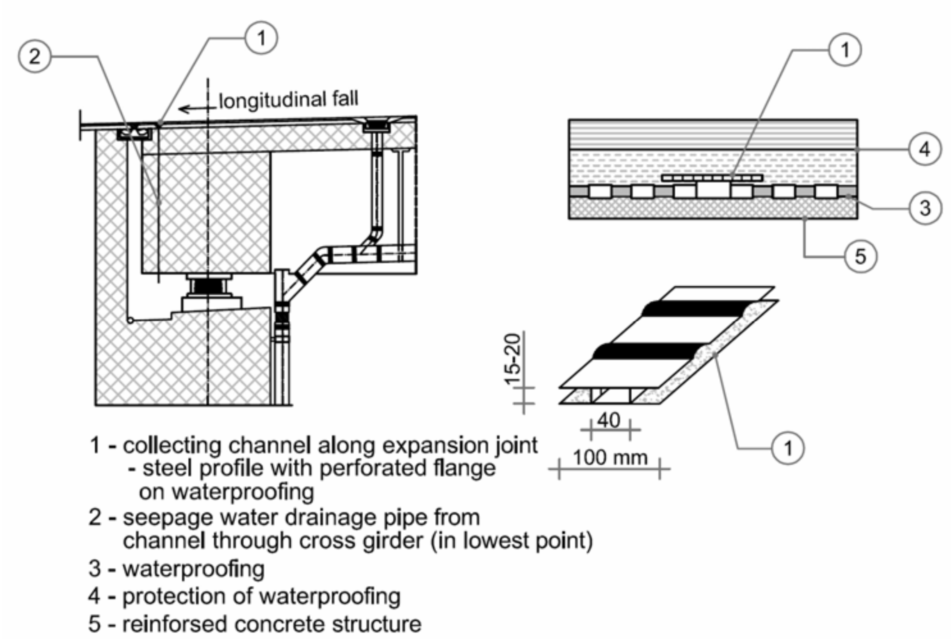


Fig. 5.14: Drainage of seepage water at expansion joint by means of piping in case of bridges without inspection walkway

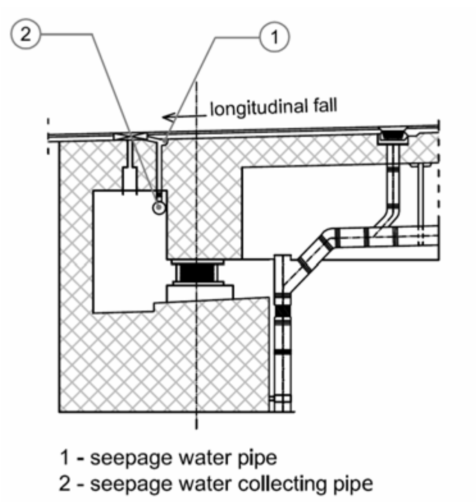


Fig. 5.15: Drainage of seepage water at expansion joint in case of bridges with inspection walkway

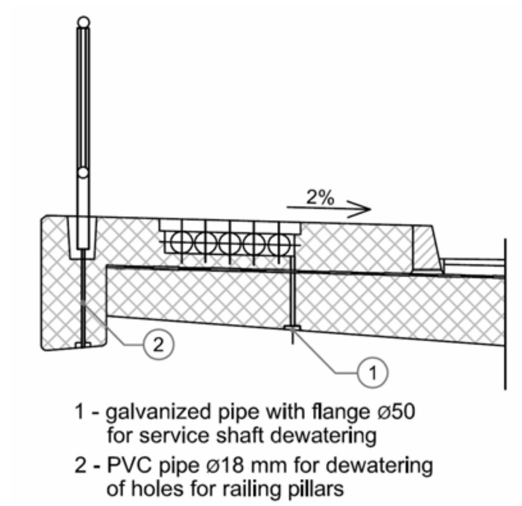


Fig. 5.16: Dewatering of service shafts in walkways and of holes for railing pillars

6. HYDRAULIC CALCULATIONS

Dimensions of individual drainage and piping structural elements are determined on the basis of hydraulic calculation being a constituent part of bridge dewatering design. In the present chapter, definitions of input parameters as well as formulae required for the design of individual elements of drainage and piping.

6.1 Precipitation water quantity and outflow

Rainfall and showers are the most important precipitations with regard to the drainage and piping system of a bridge. The intensity and frequency of the precipitations depend on the season, geographic position and momentary meteorological conditions. Other precipitations such as snow or fog are not essential for bridge drainage and piping.

The quantity of precipitation water outflow on a contributory area amounts to:

$Q_{out} = \varphi \cdot q'_{T(n)} \cdot F$

Q_{out} = quantity of precipitation water outflow [l/s]
φ = outflow coefficient, i.e. ratio rainfall quantity falling on contributory rea/water quantity flowing away into channel (for bridges φ = 1.0 is assumed)
q' = unit precipitation intensity (precipitation outflow at φ = 1.0); [l/ha·s]
F = contributory area to which the precipitation outflow refers to [ha]

The unit precipitation (outflow) intensity is equal to the precipitation quantity in time unit per area unit. It is determined with the help of precipitation intensity data:

$q' = i \cdot f = 166.6 \cdot i$ [l/s·ha]

$i = h/T$

i = precipitation intensity [mm/min]

h = precipitation level [mm]

T = precipitation duration

By processing of statistical data on precipitation obtained on the basis of long standing observations (10 – 20 years) by means of recording instruments (ombrographs) placed on individual areas, precipitation curves (ombrograms) or a series of those curves are determined. For a particular precipitation frequency n, the precipitation curves give a relation between the unit precipitation intensity q' and the precipitation duration T:

$q' = q'_{T(n)}$

The precipitation frequency n indicates how many times is a precipitation quantity reached or exceeded at certain precipitation (shower) duration.

Due to the traffic safety, a reliable bridge dewatering shall be ensured for design unit precipitation intensities at T = 5 min and n = 0.2.

A bridge drainage and piping system shall be, from the hydraulic point of view, designed in such a way that the duration time of collecting the water up to its outflow is shorter or equal to the duration time of the design shower:

$T \leq T_d$

$T = L/v$; duration time of collecting water up to its outflow at length L and velocity v

6.2 Determination of required number of gullies and spacing between adjacent gullies

The permissible contributory upper bridge area per one gully (F_{gul}) depends on the following:

- Longitudinal fall of the bridge edge dewatering
- Cross fall to be assumed 2.5% minimum
- Unit precipitation (outflow) intensity q'
- Permissible width of the water flow on the bridge edge
- Gully capacity.

The width of the water flow on the bridge edge (w) which must not be reached by vehicles even in case of heavy showers, may amount to:
- 1.50 m for bridges with a 2.5 m wide emergency lane,
- 1.00 m for all other bridges.

The contributory area to be drained per one gully:

$F_{gul} = e_{gul} \cdot b$

e_{gul} = spacing between gullies
b = width of drained area per one gully

The spacing between gullies is determined by the permissible inflow water quantity $Q_{gul,per}$ (l/s) per one gully or capacity of one gully.

$Q_{gul,per} \geq Q_{inf} = \varphi \cdot q' \cdot F_{gut}$

φ = outflow coefficient

The gully shall be designed for its capacity of 10l/s, provided that it is correctly built-in into the carriageway of 3% cross fall and 3.5% longitudinal fall (carriageway edge). In case of smaller cross and longitudinal falls, smaller gully capacities shall be taken into consideration when determining the area to be drained by one gully. In this way, a width of water flow along the carriageway edge greater than 1.5 m or 1.0 m is prevented.

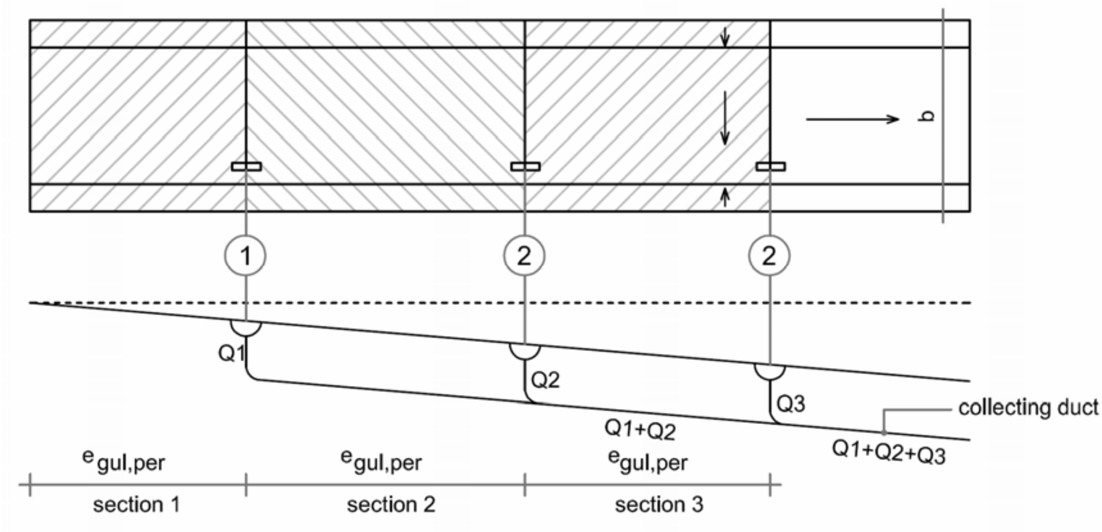


Fig. 6.1: Design scheme of contributory dewatered areas for determination of required number of gullies, spacing between adjacent gullies, and dimensioning of drainage pipes

At each gully, a portion of inflowing water flows ahead over the grid. However, that portion is small in case of hydraulically favourable grids, longitudinal falls below 5%, and water quantity not exceeding the gully capacity.

If longitudinal falls exceed 5%, a significant portion of water flows ahead over the grid even in case that the inflowing water quantity is smaller than the gully capacity. That water portion depends particularly on the gully grid structure. The latter shall be verified by a suitable test.

Values $Q_{gul,per}$ are shown in table 6.1 with regard to the carriageway cross fall, carriageway edge longitudinal fall, gully location (on the edge of traffic or emergency lane).

Table 6.1: Permissible inflow water quantity per one gully $Q_{gul,per}$ [l/s]

Longitudinal fall in % on the bridge edge in the line of gullies	Cross fall of 2.5%. Gullies located on the edge of emergency lane of 2.5 m width	Gullies located on the edge of traffic lane	Cross fall of 3.0%. Gullies located on the edge of emergency lane of 2.5 m width	Gullies located on the edge of traffic lane
1.0 – 1.5	10	3.5	10	5.5
1.6 – 2.5	10	5.0	10	7.5
2.6 – 3.5	10	6.5	10	9.5
3.6 – 4.5	10	7.5	10	10
4.6 – 5.0	10	8.5	10	10
5.0 Gully capacity taking into consideration its reduction due to the effect of significant longitudinal fall				

For the last gully on the bridge with regard to the water flow direction, a half the permissible inflow water quantity shall be taken into consideration. In this way, outflow of the water from the bridge over the expansion joint is prevented.

Under favourable conditions, the maximum distance between adjacent gullies may amount to 25.0 m. However, in unfavourable circumstances, that distance is reduced to 5.0 m (e.g. on the summits of convex or concave curvatures of the vertical alignment.

For assessment of an optimum spacing between gullies, taking into account their capacity, the a. m. values can be generally limited to:

- Minimum one gully per 400 m^2,
- Maximum spacing of 25.0 m for falls ≥ 1% and 10.0 m for cross-falls of 2.5% and longitudinal falls of 0.5% respectively.

6.3 Dimensioning of drainage pipes

The dimensioning of the longitudinal collecting duct is carried out in sections from one gully to another. A full pipe cross-section shall be taken into consideration. The following equations are used for dimensioning of drainage pipes:

- Flow-through quantity or conductibility of a pipe:

  $Q_c = v \cdot S$

  Q = flow-through quantity [m^3/s]
  S = internal cross section of the pipe [m^2]
  v = velocity of water in the pipe [m/s]

The velocity of water in the pipe (v) is calculated according to the De Chezy's formula where the friction coefficient (formula by Manning-Strickler) is inserted:

$$v = (1/n_G) \cdot R^{2/3} \cdot I^{1/2}$$

R = D/4 = hydraulic radius for circular cross section
I = pipe inclination (tan of angle)
n_G = roughness coefficient by Manning depending on the pipe type and amounting to:
0.011 for new steel pipes
0.013 for used steel pipes
$1/n_G$ = k; according to tables and manufacturers' information it amounts to 75-90.
Local losses in bends and joints are already taken into account.

The contributory water quantity per drainage pipe:

$$Q = q' \cdot F_{drain}/10{,}000$$

q' = unit precipitation intensity

F_{drain} = contributory drained area per one pipe

For a practical calculation tables or diagrams from the literature can be adopted. The latter have been elaborated for different materials and pipe roughness respectively. For dimensioning of pipes, data from the pipe certificate are used as a rule. In table 6.2, values for full circular pipe cross sections for mostly used diameters of 150, 200, 250 and 300 are given.

Table 6.2: Values of v and Q for circular pipes in accordance with the formula by De Chezy for velocity with friction coefficient C by Strickler-Manning taking into consideration the roughness coefficient m = 0.013

DN = pipe diameter; Q = outflow quantity (l/s), v = velocity (m/s), I = pipe inclination (%)

Inclination	DN 150		DN 200		DN 250		DN 300	
I	v	Q	v	Q	v	Q	v	Q
10	2.72	48.1	3.30	103.7	3.83	188.0	4.32	305.7
9	2.58	45.7	3.13	98.3	3.63	178.3	4.10	290.0
8	2.44	43.0	2.95	92.7	3.42	168.1	3.87	273.4
7	2.28	40.3	2.76	86.7	3.20	157.3	3.62	255.7
6	2.11	37.3	2.56	80.3	2.97	145.6	3.35	236.8
5	1.93	34.0	2.33	73.3	2.71	132.9	3.06	216.1
4	1.72	30.4	2.09	65.6	2.42	118.9	2.73	193.3
3	1.49	26.4	1.81	56.8	2.10	103.0	2.37	167.4
2	1.22	21.5	1.48	46.4	1.71	84.1	1.93	136.7
1	0.86	15.2	1.04	32.8	1.21	59.4	1.37	96.7
0.9	0.82	14.4	0.99	31.1	1.15	56.4	1.30	91.7
0.8	0.77	13.6	0.93	29.3	1.08	53.2	1.22	86.5
0.7	0.72	12.7	0.87	27.4	1.01	49.7	1.14	80.9
0.6	0.67	11.8	0.81	25.4	0.94	46.0	1.06	74.9
0.5	0.61	10.8	0.74	23.2	0.86	42.0	0.97	68.4

6.4 Practical example of calculation

Input data:

- Design duration time of shower: T_d = 5 min.
- Frequency of showers: n = 0.2
- Unit outflow intensity: q' = 528.6 l/(s·ha)
- Carriageway without emergency lane
- Width of carriageway to be drained: w = 15.0m
- Length of carriageway to be draine d: = 52.0 m
- Cross fall: 3.0%
- Longitudinal fall: 1.0%

Taking into consideration that the gully is located on the edge of the traffic lane, and both longitudinal and cross fall, the permissible outflow quantity of water per one gully can be read:

$Q_{gul,per}$ = 5.5 l/s

Determination of spacing between gullies

$e_{gul,per}$ (m) = (10,000 · $Q_{gul,per}$) / (q' · w) = (10,000 · 5.5) / (528.6 · 15.0) = 6.94 m

A spacing e_{gul} = 6.50 m between adjacent gullies is selected.

Determination of diameters of drainage pipes

Calculation of conductibility of cast iron pipes of ∅ 150 mm:
Pipe diameter D = 150 mm
Cross section area S = 0.018 m^2
Flow-through velocity v = 1.22 m/s (taken from table 6.2)

Pipe conductibility:
Q_c = 21.5 l/s (taken from table 6.2)
Calculation of conductibility of cast iron pipes of ∅ 200 mm:
Pipe diameter D = 200 mm
Cross section area S = 0.0314 m^2
Flow-through velocity v = 1.48 m/s (taken from table 6.2)

Pipe conductibility:
Q_c = 46.4 l/s (taken from table 6.2)

A tabular calculation of contributory water quantities Q in sections from one gully to another is shown in table 6.3.
A maximum contributory amount of water inflow Q_d from the entire drained area for the example considered:

Q_d = q' · l · b/10,000 = 0.0528 · 52 · 15.00 = 41.2 l/s, which is less than the pipe conductibility on the last section Q_c.

Table 6.3: Example of tabular calculation

Section from to	L_{sec} (m)	w (m)	F_{sec} (m^2)	Q_{out} (l/s) Gully	Q_{out} (l/s) Total	D_{pipe} (mm)	I (%)	v (m/s)	Q_{pipe} (l/s)	T_{out} (s) Section	T_{out} (s) Total
1-2	6.5	15.0	97.5	5.2	5.2	150	2	1.22	21.5	5	5
2-3	6.5	15.0	97.5	5.2	10.3	150	2	1.22	21.5	5	11
3-4	6.5	15.0	97.5	5.2	15.5	150	2	1.22	21.5	5	16
4-5	6.5	15.0	97.5	5.2	20.6	150	2	1.22	21.5	5	21
5-6	6.5	15.0	97.5	5.2	25.8	200	2	1.48	46.4	4	26
6-7	6.5	15.0	97.5	5.2	30.9	200	2	1.48	46.4	4	30
7-8	6.5	15.0	97.5	5.2	36.1	200	2	1.48	4.4	4	34
8-9	6.5	15.0	97.5	5.2	41.2	200	2	1.48	46.4	4	39

7. Maintenance of drainage and piping system of road bridges

7.1 Accessibility of drainage and piping system

All elements requiring maintenance or renewal must be accessible.

Longitudinal drainage ducts placed between superstructure longitudinal girders shall be accessible by means of special maintenance devices (special lifts) or by construction of special walkways.

Is the longitudinal drainage system placed within superstructure box cross section, an access opening of 0.80 m width and 1.20 m height shall be foreseen at least in one end cross girder. In the bottom slab, at least one opening of sufficient dimensions equipped with a cover shall be designed to enable replacement of the drainage duct.
If the collecting drainage pipes above the bridge piers are attached to the vertical drainage pipes, the transitions from the longitudinal pipes to the vertical ones shall be accessible to enable inspection and cleansing.

If possible, the grooves for placing vertical dewatering pipes shall be left uncovered to be inspected and maintained easier.
At the lower end of the vertical dewatering pipe, an inspection shaft shall be foreseen to allow accessibility and cleansing of the pipe.

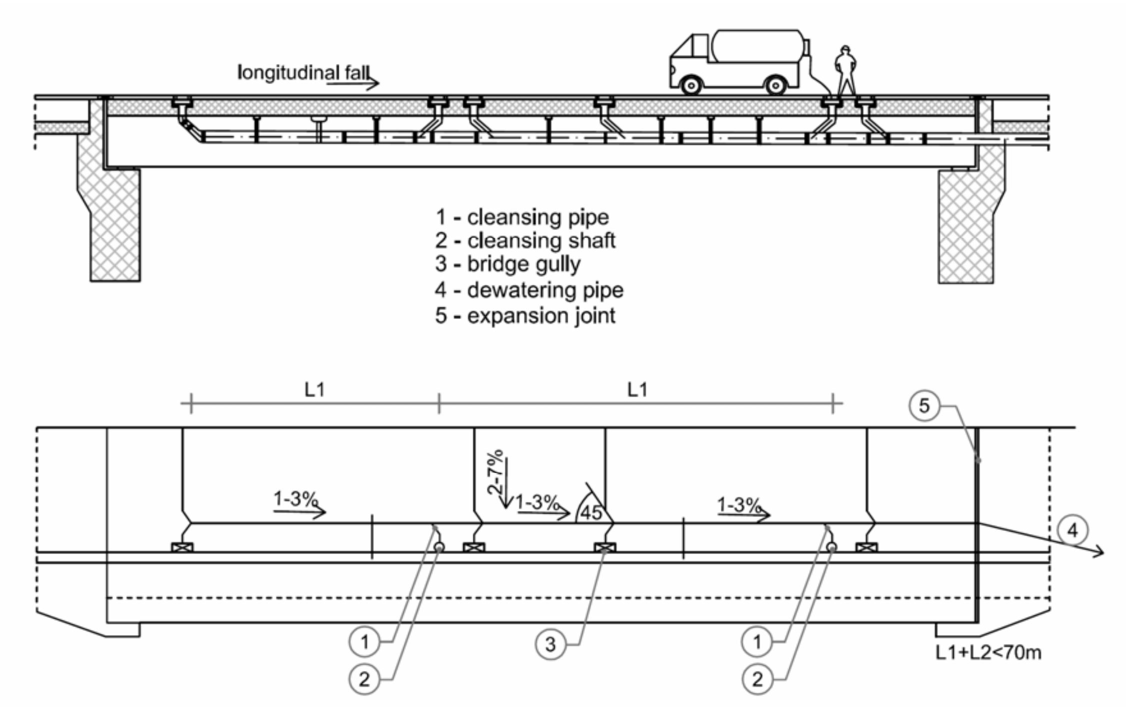


Fig. 7.1: Cleansing of longitudinal pipe

7.2 Cleansing and maintenance of drainage and piping system

The drainage and piping system shall be designed in such a way that economical maintenance and cleansing are possible.

Cleansing of the dewatering system is performed periodically as well as in case of stoppage. The periodical washing out of the dewatering system is carried out with the help of a high-pressure water jet. Cleansing in case of stoppage is performed by means of a high-pressure water jet as well, or by the aid of machines for mechanical cleaning with scrapers. In the first case, special cleansing pipes shall be foreseen (figure 7.1), while in the second case, high quality pipes are required.

When cleaning the pipes with a high-pressure water jet, the cleansing nozzle is introduced into the system in the counter-flow direction. In this way, water outflow is ensured. Therefore, special cleansing pipes with shafts are foreseen. The distance between the shafts is determined by the cleansing procedure allowing cleansing of 70 m of pipe from one shaft. Those shafts are located on the carriageway slab. They differ from the gullies in having a cover instead a grid.

At each inlet of transverse drainage pipes into the longitudinal collecting pipe, a cleansing opening shall be designed. These openings must be closed with a suitable cover. An access of the cleansing device through such an opening shall be made possible.

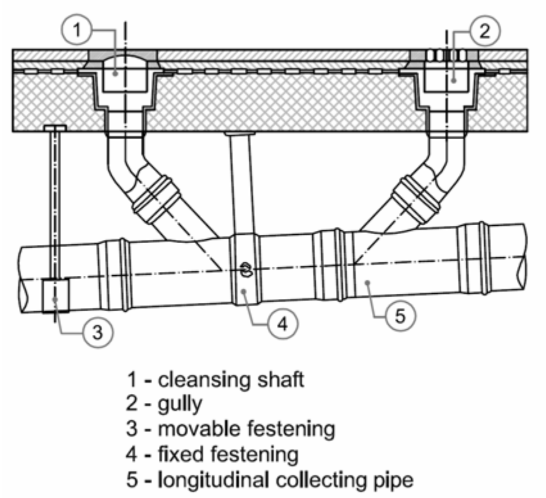


Fig. 7.2: Cleansing shaft and cleansing pipe

8. DESIGN OF DRAINAGE AND PIPING SYSTEM OF ROAD BRIDGES

The design of drainage and piping system of a bridge is a constituent part of the bridge design.
When planning and designing the drainage and piping system o a bridge, a permanent coordination with the road design and the water economy guidelines is required.

At the preliminary design stage, the drainage and piping system of the bridge shall be specified together with the bridge outline scheme.

In the building permit design and the execution design, the drainage and piping system of the bridge shall be elaborated as an independent design.

Contents of building permit design and execution design:
- Approved input documents such as water economy requirements and data, environment protection guidelines, hydro-meteorological data;
- Technical report (description of the system, installation and building-in, maintenance);
- Hydraulic calculation, static analysis;
- Drawings, details;
- Bill of quantities.

In the execution drawings, general arrangement of the piping network at an appropriate scale including all constituent parts of the drainage and piping system shall be presented. All details necessary for the execution shall be included, e.g. inclinations of transverse and longitudinal pipes, fastening devices, cleansing openings, description of materials for individual elements, fittings, etc.

Technical reports shall comprehend the execution technology for the drainage and piping system. Moreover, they must give material quality and performance requirements, they have to emphasize the need of attesting, and they shall specify conditions of attaching to recipients (sewage, river, etc.).

The bill of quantities must enable a due material purchase and balancing of the works carried out.

The hydraulic calculation shall include the necessary data on the selection of the rainfall intensity, the frequency of design shower, the unit precipitation intensity, the outflow coefficient and the outflow time. By the hydraulic calculation, arrangement of gullies and dewatering capacity of the entire drainage and piping system shall be verified.