Substructure: Design and construction. Drainage

1 Purpose and scope

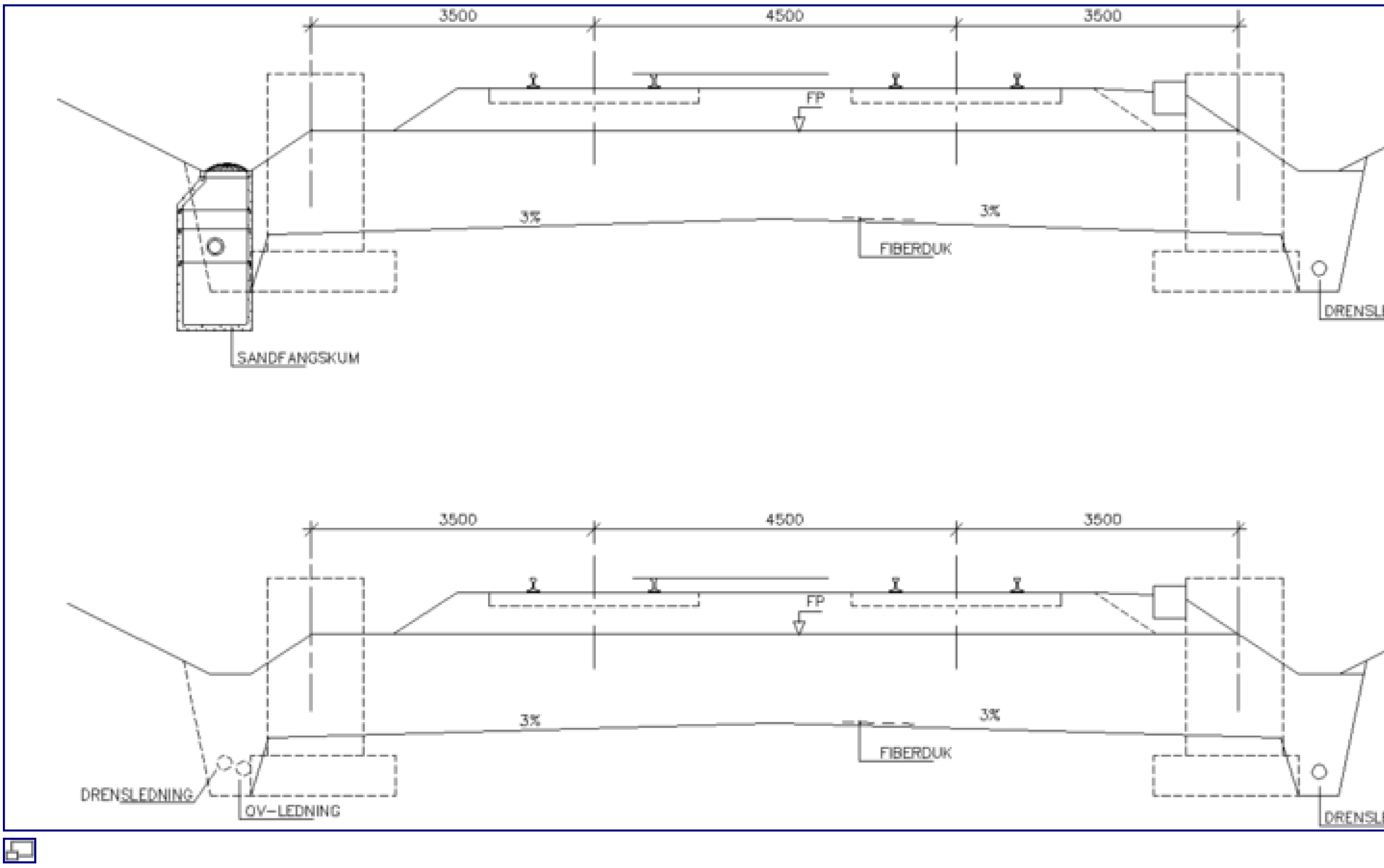
This chapter describes substructure drainage.

A drainage system will include all the components needed to ensure that the substructure is properly drained, and may be formed of components such as open ditches, closed ditches with pipe drains and drainage through stormwater drainage pipes, channels and culverts.

Where there are changes in the terrain or water flow (e.g. where streams are diverted), the drainage system must be planned with particular care. Overloading can result in major damage in the form of erosion and landslides.

2 Functions of the drainage system

One of the drainage system's functions is to collect surface water and/or ground water and direct it away, thereby keeping the ballast bed drained. The drainage system must also protect the substructure from erosion, from becoming sodden, and from losing its load-bearing capacity and stability. Figure 1 shows the principle for the location of ditches, basins, stormwater drainage pipes and pipe drains, cf. sections for Åpen linjegrøft, Lukket linjegrøft, Lukket drensgrøft and Overvannsledning.



Figur 1: Principle sketch of location of drainage in cross-section
For technical reasons relating to frost, it is advisable for closed drainage ditches to be positioned slightly higher than the base of the formation, cf. lukket drensgrøft.

3 Design water flow

Mal:Textbook material The formula should not be used for areas larger than 2,000 hectares. For larger catchment areas, the maximum water flow is determined on the basis of the Norwegian Water Resources and Energy Directorate's (NVE's) flood water observations.

Surface water must be directed away in open ditches along the line, in water channels, culverts or under open bridges.

A 200 year return period must be used as a basis for calculating the dimensions of water channels and other drainage installations, as well as an additional climate factor of 20%. The climate factor will be used to take into account the fact that the intensity and frequency of intense episodes of precipitation will increase in future years as a result of climate change. The NPRA (Manual 018) and NVE have introduced an equivalent climate factor of 20% for small catchment areas.

When calculating the dimensions of water flow, extra measures must also be considered if there are:

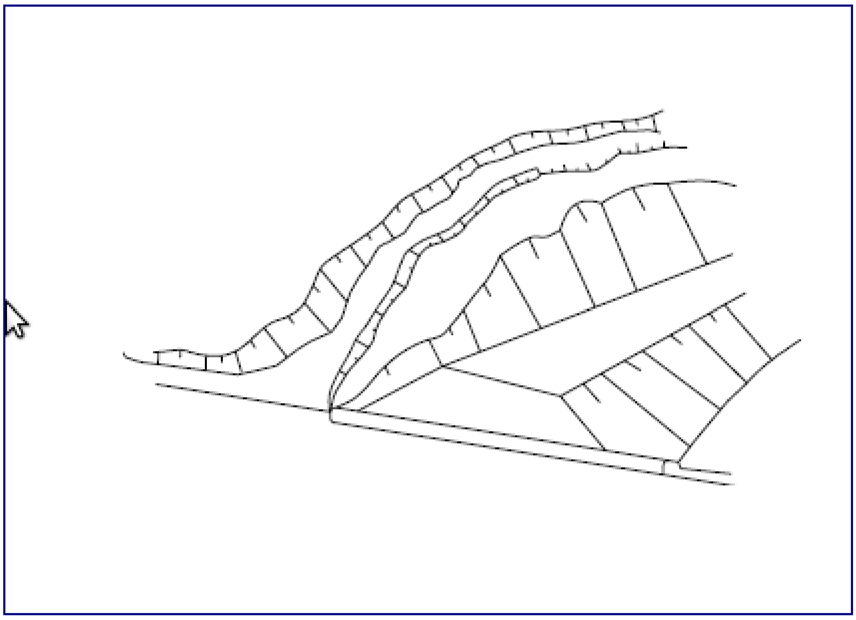
1. capacity problems for water channels
2. problems of excessive sediment transport
3. ice problems

Possible measures include:

- alternative floodways – an extra water channel higher up the embankment, slightly to the side of the existing channel
- retention/sediment basin (for 1 and 2)

4 Ditches in natural terrain and slopes

If the ballast bed cuts across the natural drainage flow of any terrain, flood ditches must be installed to prevent the water running out uncontrolledly and down the slope of the cutting, thereby causing erosion. The flood ditch must be designed to suit the local conditions, both in terms of design and location. A common location would be just inside the top of the cutting. However, there should be at least 1.0 m between the ditch and the edge.



Figur 2: Location of flood ditch

If the ditch or natural course of a stream flows into the slope of a railway cutting, channels must be constructed that direct water down to the culvert or lineside ditch.

If the volumes of water are large, these channels must have a frost-free or virtually frost-free foundation, and must be protected from erosion, for example by being properly paved with stone. If there is a severe fall in steep cuttings, it must be possible to reduce the water velocity along the channel, or at the latest, where the water flows out of the channel. It may be necessary to interrupt the flow by installing basins at intervals along the channel. The dimensions of the cross-section should be sufficient to ensure that there is no danger of flood water erosion outside the channel. The water must feed directly from the channel into a water channel or basin and closed stormwater drainage pipe; see overvannsledning.

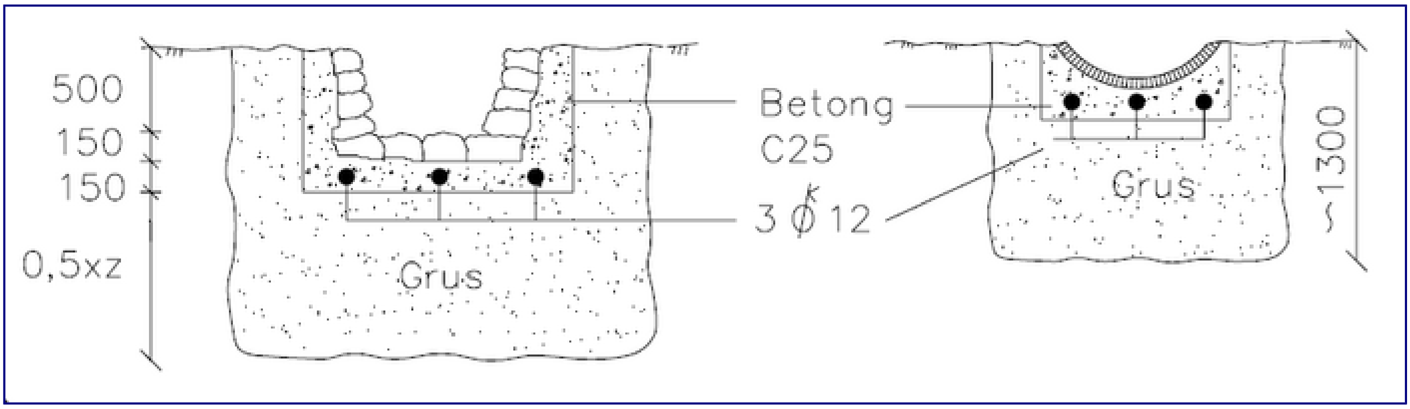
4.1 Channel with frost-free foundation

At locations where the ground is susceptible to frost, where there are major water flows and/or severe falls, the channel must be solidly constructed, with a frost-free foundation. Where the channel contains water or is covered with snow, the frost foundation may be calculated at a thickness = 0.5 • Z below the base of the channel. Z is taken from Figure 3 in Underbygning/Prosjektering_og_bygging/Frost.

For the base of the channel, the following should be used:

- pre-cast concrete half-pipe
- cast-in-place concrete, if necessary lined with natural stone to reduce the water velocity
- stone paving

The concrete should be reinforced to prevent damage from cracking; see Figure 3.



Figur 3: Channel with frost-free foundation
Constructing the channel as a stepped construction is recommended if there is a severe fall or major water flow. Such channels must have the same kind of frost-free foundation as frost-free channels.

5 Open lineside ditch

This form of drainage will be formed of open, usually shallow ditches, whose primary function is to intercept and divert floodwater, thereby preventing such water from leaking into ballast and reinforcing layers.

Longitudinal ditches form part of the cutting profile, and their design is specified in Underbygning/Prosjektering og bygging/Banelegeme, Table 3. The base of the ditch must be at least 0.5 m under FL, and for new installations, the standard (practical) width of the base has been set to 0.5 m. At any point, the ditch must have a fall of at least 5‰ (1:200). In instances where the line effectively falls in the opposite direction to the ditch, surface water in the lineside ditch may be fed down into basins and away in closed pipes.

In instances where the cutting and its lineside ditch transition into an embankment, surface water must be fed into a channel or into the natural terrain in a controlled manner. As in the case of the lineside ditch, the construction of outflows along the slope of the embankment must be such that surface water is prevented from penetrating the backfill material.

Deep lineside ditches will make the ballast bed more susceptible to frost penetration from the side. Therefore, lineside ditches must not be designed deeper than necessary based on prevailing conditions.

Longitudinal ditches should have watertight bases, and be watertight up to 0.2 m below formation level.

6 Closed lineside ditch

Special conditions may make it necessary to enclose the lineside ditch. There may be locations where, for extraordinary reasons, the route of the ditch is interrupted by permanent structures (e.g. acoustic barriers, various foundations for pylons, cabinets, retaining walls, etc.). In new installations, this will usually only apply to short sections. A pipe must then be laid around the 'obstacle', in order to ensure continuity in the lineside ditch. Recommended pipe dimension in such cases is 400 mm.

If longer sections need to be enclosed (e.g. at stations/stops, platforms built in deep cuttings, etc.), in principle this must be constructed as a closed ditch with pipe drains or a combined drainage/stormwater ditch. The minimum permissible dimension of the pipe drain is 150 mm. The ditch must be filled to the top with open, water-permeable material that allows stormwater to pass down easily to the pipe. To reduce the risk of soil penetration, fibre membrane must be laid along the bottom and sides of the ditch.

7 Closed drainage ditch

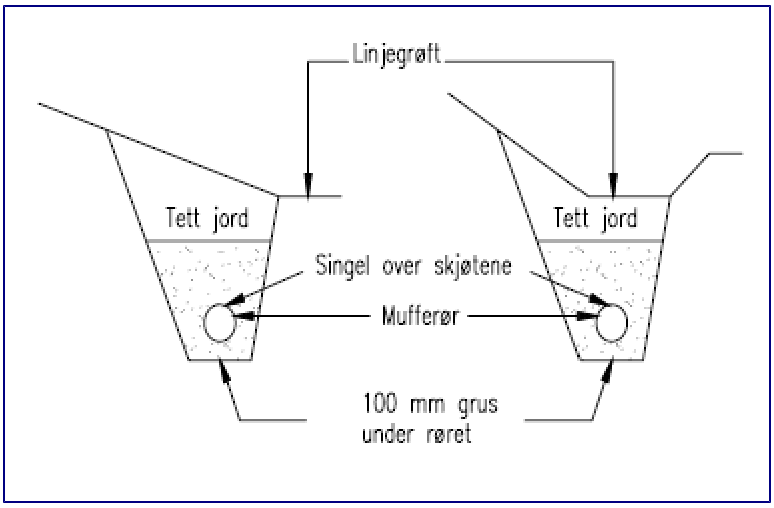
'Closed drainage' refers to closed ditches containing drainpipes and/or drainage material that must be capable of drawing in/collecting groundwater and directing it along the bottom of the ditch to a secure outlet. The purpose of this system is primarily to lower groundwater to a controlled level, and keep it at this level. The need for closed drainage must be evaluated on the basis of local geotechnical/hydrological conditions.

Longitudinal drainage lines in earth cuttings must be laid at the edge of the cutting or under the lineside ditch. Refer to Figure 4.

The pipe drain must have a fall in the right direction for its entire length, minimum 5‰. Permitted deviation from theoretical height is normally ± 50 mm.

It is not normally necessary to have both closed drainage and a closed lineside ditch.

For technical reasons relating to frost, it is not advisable to drain the formation completely dry. In order to ensure that there will be some water in the formation, closed drainage ditches may be laid slightly higher than the base of the formation, but no higher than the base of the reinforcing layer.



Figur 4: Closed drainage along the track

7.1 Ditch materials

In the drainage zone, the ditch must be filled with permeable material that either has filtration properties itself or is protected with suitable filters. In more secondary ditches over short sections, it may occasionally suffice if the ditch is filled with coarse drainage materials protected with fibre membrane. However, the general rule is for pipes to be laid, packed around with drainage and filter materials.

The upper part of the ditch normally contains densely compacted materials, such as compacted clay and/or black peat, in order to prevent stormwater penetrating down into the groundwater drainage.

7.1.1 Drainage materials

The area around drainpipes must be filled with materials that allow water to pass through easily, yet at the same time have the necessary filtration properties to protect against penetration of fine-grained soil. The filter layer must have a minimum thickness of 100 mm, and must satisfy certain grain uniformity coefficient requirements in relation to the pipes' drainage outlets ((NS 3420, part H). The filter materials must be non-frost-susceptible and must have a maximum grain size of 22 mm for plastic pipes and 63 mm for concrete pipes. Backfill materials above the pipe zone must be non-frost- susceptible and must also satisfy the filter criteria regarding adjacent soil. In practice, good foundry sand will be satisfactory for any types of soil that requires drainage.

It can often be difficult to obtain materials that satisfy the filtration property requirements and also the high drainage capacity requirements. In such cases, an alternative may be to use fibre membrane between the drainage and the soil. The drainage materials can then be formed of relatively coarse material in shingle or crushed stone fractions. The fibre membrane must be of a lighter type that is suitable for drainage purposes, normally class I/class II (cf. Table 1, Underbygning/Prosjektering og bygging/Banelegeme).

7.1.2 Pipe materials

Concrete and plastic pipes may be used in pipe drains. The drainpipes must let water enter through holes/slits in the pipe wall or through open joints. They must have sufficient mechanical strength to tolerate design loads from traffic and soil, as well as being capable of resisting local climate and environmental stresses. In most cases, drainpipes with an inner diameter of 100–150 mm will be sufficient. Possible dimensions of the types of pipe mentioned are shown in Table 1.

Tabell 1: Pipe dimensions

Pipe material	Length (mm)	Diameter (mm)	
		Minimum	Maximum
Concrete	1-2	100	600
Plastic PVC/PE	5-250	48	350

- Copolymer

7.1.2.1 Concrete pipes

Concrete socket pipes must satisfy the requirements of [NS 3121] as a minimum. The pipes must be laid without rubber packing washers, allowing drainage to occur through open joints. When the pipes are laid, sufficient room for the sockets must be excavated, ensuring that the body of the pipe lies evenly against the foundation. Socket pipes with male and female ends must be laid with the male end following the direction of the ditch's fall. A 4 mm spacer may be used to ensure that there is a gap between the pipe and the edge of the socket. In acidic water conditions (pH < 5), pipes of sulphate resistant cement must be used.

7.1.2.2 Plastic pipes

In plastic pipe drains, pipes used must satisfy the requirements and specifications of [NS 3065]. The material may be of PVC, PP copolymer or PE. The pipes may be moulded or flat extruded. The pipes may be round/circular or tunnel-shaped. The material and construction of the pipes must be assessed from a strength perspective. With these objectives in mind, double-walled pipes should preferably be used, with corrugated outer walls and smooth inner walls.

The pipes should be laid in straight lengths with a controlled fall; normal lengths of 6 m with socket joints/jointed sockets. For simpler and more secondary drainage purposes in terrain outside the levelled area, corrugated pipes in smaller dimensions may be used, if these are available in long lengths on coils.

7.1.3 Basins

7.1.3.1 Inspection basins

Inspection basins, usually with sand traps, must be installed in long pipe drains. The distance between these basins may vary, depending on geometry and local conditions, but should be between 50–100 m. Prefabricated concrete basin sections may be used, provided that these satisfy the requirements of the current Norwegian standard [NS 3139], or plastic basins that satisfy diameter and sand trap volume requirements. Prefabricated base sections with watertight bases may be used, or suitable standardised sand trap basins with submerged outlet pipes. The base may also be cast in situ. The minimum diameter of such basins is 650 mm, but the sand trap section on new installations must not be less than 1,000 mm.

7.1.3.2 Catch basins

Two or more pipe drains can feed into a shared outlet from a catch basin. These basins normally have a minimum diameter of 1,000 mm. Prefabricated basin sections with watertight base sections are normally used, although the basins may also be cast in situ. They should be fitted with ladders.

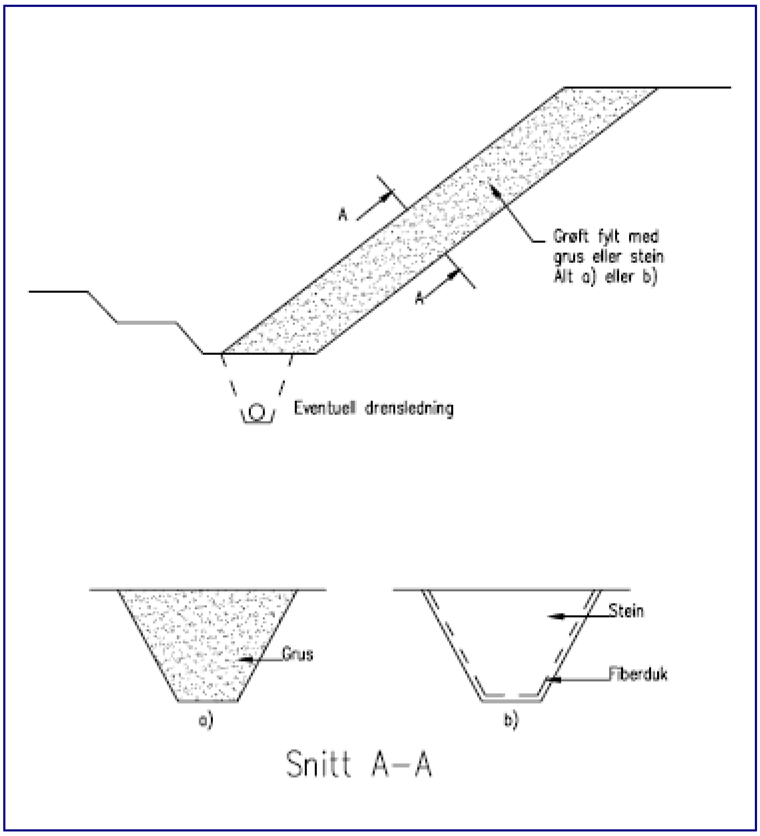
7.2 Drainage in rock cuttings and tunnels

In rock cuttings and tunnels, the drainage ditch is laid along the lowest edge, since the levelled area has a fall of 1:20. The ditch must be a minimum of 0.5 m wide, the depth depending on the fall of the line. In the longitudinal direction, the ditch must have a fall of at least 3.0‰ over its entire length. The drainpipes should be laid in a levelling course and backfilled with ballast chips. For rock cuttings less than 100 m in length, the ditch may be constructed without drainpipes.

The main task of drainage ditches in rock cuttings is to prevent frost heave resulting from ice formation. Since the ditches are generally covered in snow, and the drainage water contains a certain amount of heat, frost penetration will be moderate. A frostproof depth 'a' (Z + 0.5) m may be anticipated. Z is taken from Figure 3 in Underbygning/Prosjektering og bygging/Frost.

7.3 Drainage in cutting slopes

In most instances, the drainage effect of the lineside ditch and any longitudinal pipe drain is sufficient to protect the slope. In order to avoid groundwater erosion and surface slides in particularly water-bearing slopes, the slope must be protected with suitable drainage ditches. Refer to Figure 5.



Figur 5: Ditches in slopes at right angles to longitudinal direction

8 Stormwater drainage pipes

This includes all pipes whose purpose is to ensure that stormwater and drainage water, primarily water from sand trap basins, is drained away to outlets in water channels or culverts, streams or rivers. The pipes must consist of pipes with watertight joints, with dimensions that can withstand the volumes of water that may be generated by the associated catchment area. Inspection/flushing basins should be installed at intervals equivalent to those for pipe drains, 50–100 m. At any given point, the pipe must have a minimum fall of 5‰.

8.1 Ditch materials

8.1.1 Fill materials

The following materials may be used as foundation for pipes and for filling around the pipe zone up to 0.25 m above the pipe top:

- well-graded gravel, sand or crushed stone of an equivalent grading and maximum grain size to that specified for drainage pipes in drensmaterialer
- open-graded crushed stone in shingle/fine aggregate fractions 8–16 mm

Ditches can normally be backfilled above the pipe zone with local materials that should not contain stones larger than 300 mm. Also refer to instructions from pipe suppliers.

8.1.2 Pipe materials

Concrete and plastic pipes may be used in stormwater drainage pipes. The measurements, tolerances and material properties of joint material must ensure that watertightness can be achieved in accordance with current Norwegian standards.

8.1.2.1 Concrete pipes

In concrete pipelines, pipes must be used that satisfy requirements and specifications in accordance with [NS 3121] (unreinforced socket pipes, available dimensions 100–250 mm and reinforced corrugated pipes, available dimensions 300–2,000 mm). When concrete socket pipes are used, the sockets must be laid in the downstream direction. Rubber sealing rings should be used in the joints.

8.1.2.2 Plastic pipes

In plastic pipelines, pipes may be made from PVC in accordance with [NS 2963], PP copolymer in accordance with [NS 2962] and PE in accordance with [NS 2961]. Similarly, moulded or smooth plastic pipes may be used, provided that they are approved in accordance with the DnP standard (equivalent to former NPF standard 8001, class C).

Available dimensions, N100–N800. In pipes close to or below the railway, it is assumed that pipe materials used will be of high strength and ductility, and with a ring stiffness in accordance with DnP standard (minimum equivalent class C in former NPF standard 8001).

8.1.3 Basins

Prefabricated concrete basin sections may be used, normally with watertight base sections or gutter sections in accordance with current standards.

9 Water channels

Water channels are deliberately located passages for water through the line. In new installations, circular pipes are generally used. The term 'culvert' is often used to describe larger passages.

9.1 Dimensions

The dimensions of water channels are as stated in Section 2. The minimum nominal diameter is 600 mm (N600).

9.1.1 Pipe materials

9.1.2 Concrete

Prefabricated pipes are normally used, of the reinforced corrugated type [NS 3121], dimension 600–2,000 mm. Cast-in-place concrete may also be used, or prefabricated concrete sections.

9.1.3 Plastic

Pipes made from PE, PP, copolymer or PVC may be used.

These must be smooth internally and may be profiled externally, or double-walled with dimensions up to 1200 mm. The pipes must have a minimum class C stiffness.

The pipes must be certified either in accordance with Norwegian Standards or with [NPF product norm 8001].

9.1.4 Steel

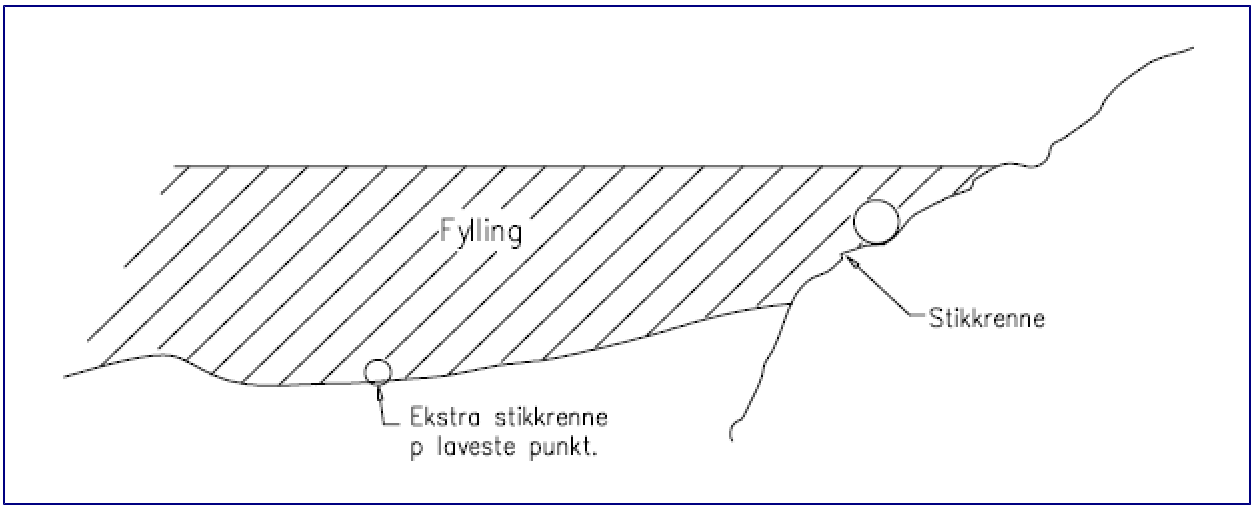
Corrugated steel pipes may be used (spiral corrugated or bolted steel multi-plate). The pipes must be protected against corrosion. Minimum corrosion protection is a 60 µm zinc coating on each side (hot dip galvanised) plus a 200 µm epoxy coating on the inner side. Relevant pipe dimensions are shown in Table 2.

Tabell 2: Permitted settling of ballast bed in operational phase

Internal diameter (mm)	Plate thickness (mm)	Weight/m (kg)
500	1.9	30
600	1.9	36
800	2.0	49
1,000	2.3	70
1200	2.6	90
1400	3.0	126

9.2 Route and fall

Water channels are normally laid at the bottom of valley depressions. However, local conditions may indicate that it is more practical (or necessary) to lay the water channel to one side. In such cases, the inlet to the water channel must be so designed that water from the adjacent line or flood ditch and stream is really directed into the water channel. An extra water channel, with smaller dimensions, must also be laid at the bottom of the valley depression. This water channel must intercept meltwater and floodwater that may cause erosion under the embankment. This is particularly important under stone embankments comprising silt or fine sand. Refer to Figure 6.



Figur 6: Extra water channel at lowest point

In order for the pipe in the water channel to be self-cleaning with regard to sand and gravel, the water channel should have a minimum fall of 4‰. In cases where water velocity at outlets is expected to be so high that it will cause erosion problems, the maximum fall should not exceed 10‰.

9.3 Inlets and outlets

Inlets must be designed so as to enable water channels to fulfil their function, which is to collect and direct water through the embankment and prevent undermining. Drop manholes or foundation walls and wing walls must be installed to prevent water finding its way around the water channel and through the embankment. Sheet piling may also be used if necessary. This is particularly important for stone embankments that are laid on fine-grained, easily erodible ground. If flood water is expected to carry driftwood, windthrow, ice, etc. that could partially or completely block an inlet, a grating or trash rack must be installed.

If the fall is greater than the recommended maximum value and the ground at the outlet is susceptible to erosion, the outlet must be protected from erosion. In terrain that slopes steeply to the side, it may be necessary to protect the outlet by constructing a drop manhole. Otherwise, if the fall is severe, it may be necessary to construct a front wall, in order to prevent the pipe section from sliding out. This particularly applies to water channels made from short concrete pipes. The front wall must have a frost-free foundation. In places where it is not possible to build a front wall or manhole, the outer sections of pipe must be fastened together, for example with tie rods.

The water channel should be of a sufficient length to ensure that the ends lie completely outside the slope of the embankment. If they do not, a front wall must be installed. If oblique end pieces are used, the water channel must be constructed to such a length that it protrudes approximately 150 mm from the slope. This is a routine method when corrugated steel pipes are used.

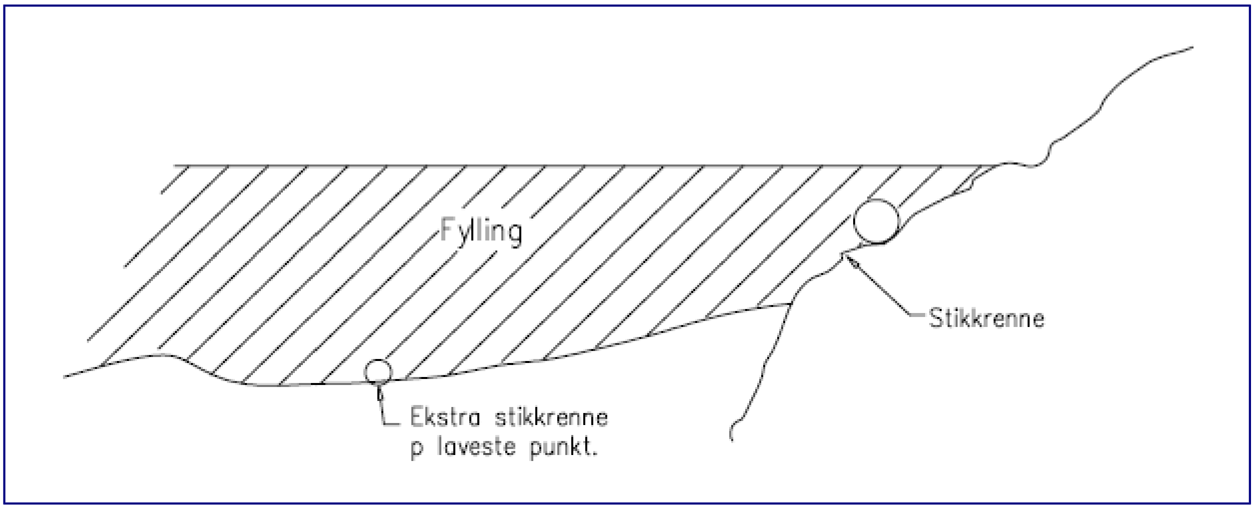
9.4 Foundation

Irrespective of the type of approved pipe used, before the water channel can be laid, a ditch must be dug that is sufficiently wide as to allow at least 0.75 m free space between the water channel and the ditch wall. For pipes with $d < 1.0$ m, this distance is reduced to 0.5 m.

The foundation itself depends on the load-bearing capacity of the ground. On firm ground such as rock, gravel, sand or dry crust clay, the water channel is laid directly on the bottom of the ditch, with a thin levelling course of gravel or broken ballast. Geotechnical surveys must be conducted on soft ground. Measures such as soil replacement, piling, preloading or the use of lightweight fill may be necessary.

If the ground is susceptible to frost, and the water channel can be expected to dry up and freeze in winter, frost protection must be used as stated in Chapter 9, Frost, Figure 9.7.

On moderately firm ground, the water channel's foundation must comprise a 0.3–0.5 m thick bed of gravel or shingle. The width of the bed should be at least 1.0 m wider than the widest diameter of the pipe. Refer to Figure 7.



Figur 7: Foundation of water channel with d < 1.0 m on moderately firm ground

9.5 Laying, packing around the pipe and backfilling

Packing around and above the pipe must be performed in accordance with current regulations and the pipe supplier's instructions for laying and installation. Irrespective of the type of pipe used, if the embankment is low and the pipe dimensions are moderate, once the pipe has been laid, the area around may be filled with gravel/crushed stone fractions. The areas around both sides of the pipe must be filled at the same time and in the same manner. Fill material must be added in layers and properly but carefully compacted. Particular attention must be given to the fill material around the bottom half of the pipe, ensuring that it gets well underneath the pipe and is properly compacted. The area above the pipe must be filled in even layers and compacted according to regulations. The layer directly above the pipe must only be compacted using light equipment. Heavy mechanical compaction is only permitted when the covering layer is at least 0.5 m thick.