Substructure: Design and construction. Stability

1 Purpose and scope

This chapter deals with the stability of embankments, earth cuttings, rock cuttings and other structures and solutions.

The design and construction of the substructure must provide the superstructure with the stability required by the regulations to ensure safe and regular traffic operations. The ballast bed must not be subject to unacceptable settlement or deformations and, in accordance with stipulations, must be safe from ground failure or landslides.

These factors are partly determined by the requirements regarding the ballast bed and its composition and construction, but also to a large extent by its interaction with and adaptation to the subsoil and terrain. It is therefore essential to have thorough knowledge of the ground conditions along the route of the line, and geotechnical surveys and calculations must form a natural part of the project.

2 Embankments

2.1 Stability

The inherent stability of an embankment will normally be assured if it has been designed and constructed in accordance with the guidelines provided in Underbygning/Prosjektering og bygging/Banelegeme. A stable slope gradient is a function of the type of material and embankment height. Guide values are provided in Tabell 1. In Tabell 1, the embankment height is considered to be its entire height from terrain to track, i.e. the embankment up to the formation, frost protection layer (if present), reinforcing layer and ballast.

Tabell 1: Guideline embankment geometry

Max. embankment gradient	Blasted rock, H (m)	Gravel, sand, H (m)	Clay/silt, H (m)
1 : 1.5	0–15	0–5	-
1 : 1.75	> 15	5–10	-
1 : 2	-	> 10	0–5
1 : 2.5	-	-	5–10
1 : 3	-	-	> 10

In Table 1 it is assumed that the subsoil has a satisfactory load-bearing capacity and does not present any stability problems.

As a rule, the total stability of the embankment will be determined by the ground conditions, and particularly by the ground's strength parameters. This may result in considerable limitations to the potential weight of the embankment and mean a change in the design conditions. Special measures will often be required to ensure that stability is satisfactory.

2.1.1 Stability calculations

Railway design loads that must be used in stability calculations for embankments are provided in Underebygning/Prosjektering og bygging/Generelle tekniske krav.

Recognised calculation methods must be used to document that the embankment is safe from landslides (material coefficient). The selection of the material coefficient must take into account the method by which the strength was determined, the action of the fracture mechanism, and recognised practice. The material factor must normally be set at no lower than 1.3. This may be increased when there is regarded to be a risk of progressive fracture development in brittle fracture materials, and when it is required in order to bring it into line with recognised practice for the analysis method being used for the problem in question.

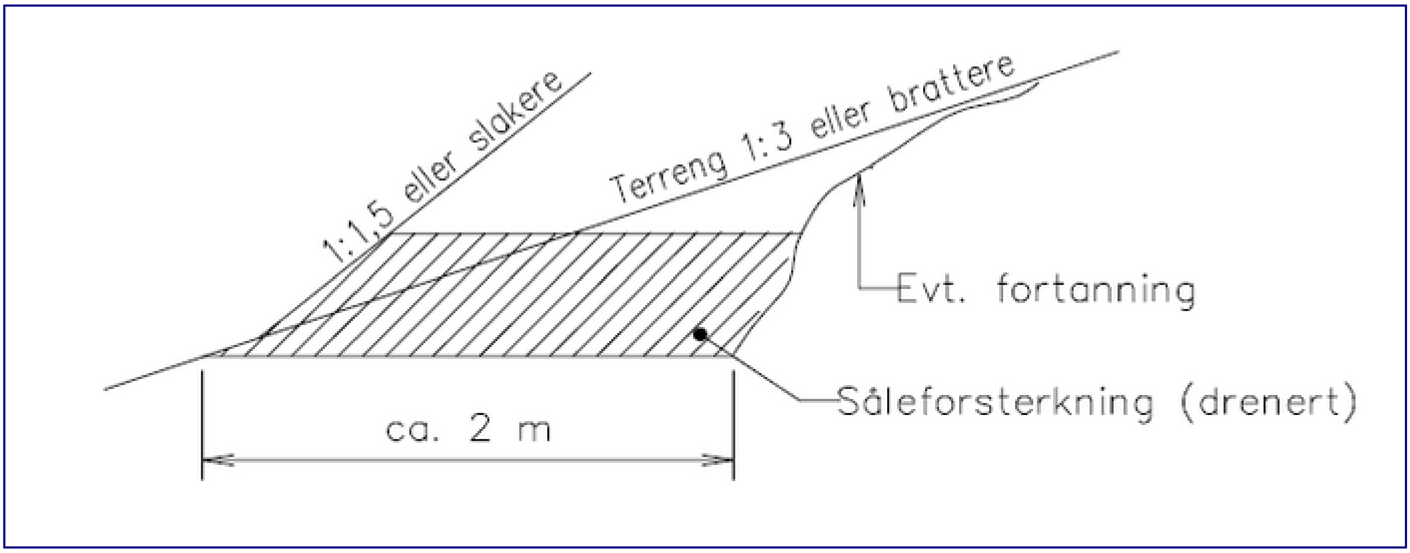
Guide material coefficients for stability calculations are provided in Tabell 2.

Tabell 2: Material coefficients for stability calculations

Analysis type	Damage consequence class	Fracture mechanism		
		Ductile	Neutral	Brittle
Effective stress analysis, aφ method	Moderately serious	1.20	1.30	1.40
	Serious	1.30	1.40	1.50
Total stress analysis, ADP method	Extremely serious	1.40	1.50	1.60
Total stress analysis, Su method	Moderately serious	1.40	1.55	1.70
	Serious	1.55	1.70	1.85
	Extremely serious	1.70	1.85	2.00

2.1.2 Embankment toe/bed reinforcement

When an embankment is constructed on terrain with a steep side slope, local stability at the embankment toe must be given particular attention. Good contact between the embankment and underlying terrain must be assured. When the terrain slope is steeper than 1:3, the bed must be reinforced in accordance with the principles shown in Figur 1. It may be necessary to abrade the rock in order to provide a key.



Figur 1: Bed reinforcement

2.2 Stabilisation measures

In principle, stabilisation measures may be divided into two main groups:

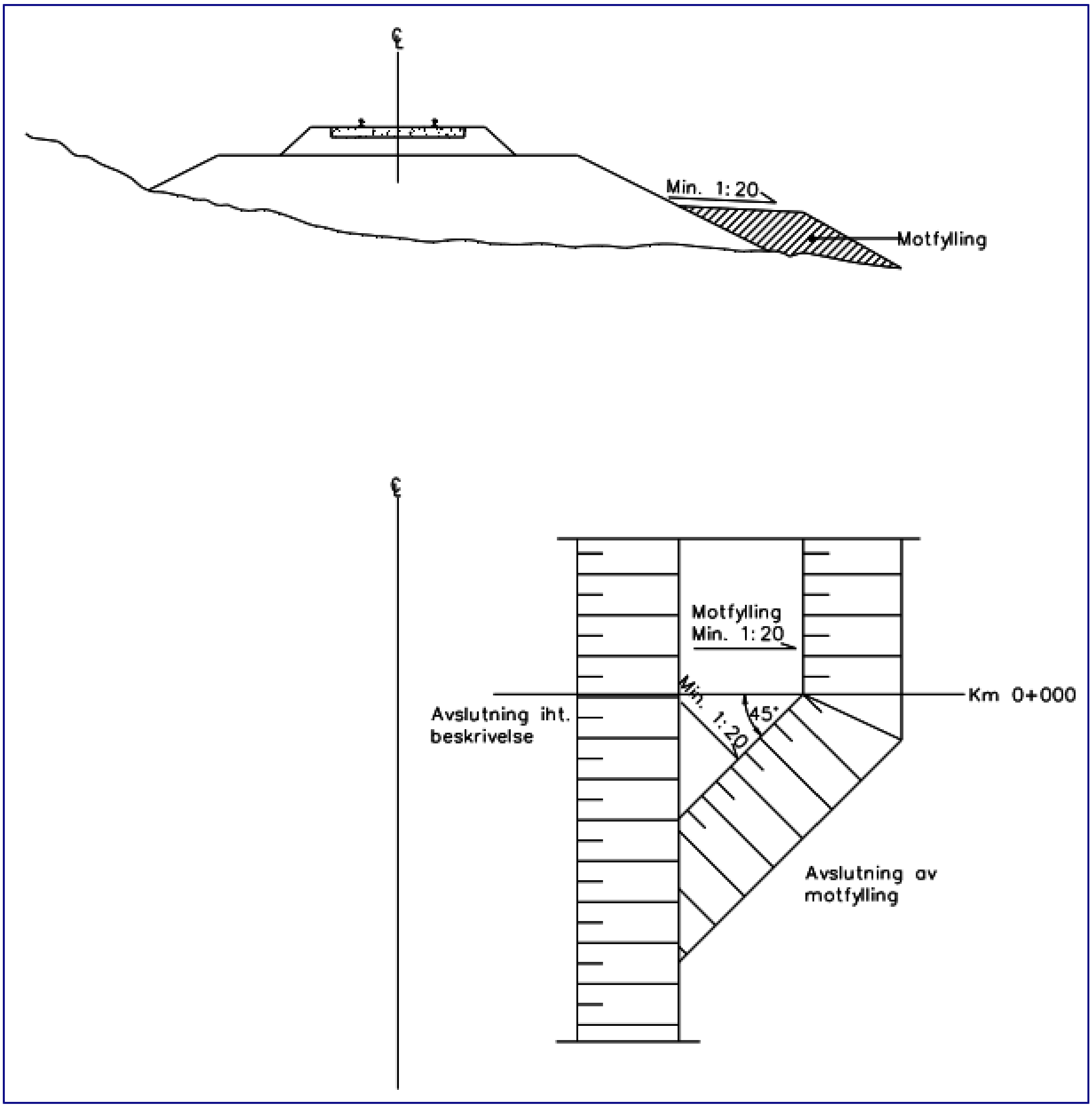
1. Measures to reduce stresses (shear stresses) in the ground. These can occur during the construction of berms or when the weight of embankments is reduced by the introduction of lightweight fill. The lightweight materials that may be utilised here must have the strength properties required to support the superstructure and traffic loads in the long term.

2. Measures to increase strength properties in the ground. This can be achieved using lime or cement stabilisation, electro-osmosis, salt diffusion, deep drainage, preloading, etc. It may also be necessary to construct supporting structures (e.g. piles and a pile cap) and supports (e.g. sheet piles anchored with stays).

Separate job specifications are normally prepared for any stabilisation measures that are required. These regulations only cover the basic provisions for measures within the first main group.

2.2.1 Berms

Berms are constructed with a crossfall of 1:20 out from the track, unless otherwise specified. See Figur 2.



Figur 2: Principles for berm construction

The entire berm must be constructed before the railway embankment level exceeds the level of the berm. Materials used in the embankment must consist of ordinary 'heavy' soil materials. Blasted stone materials containing large stones should not be used in the bottom layer. Materials such as organic soil or light construction waste must not be used.

2.2.2 Lightweight aggregate and foam glass

Tabell 3 shows parameters for the grading, density and unit weight of lightweight aggregate.

Tabell 3: Grading, density and unit weight of lightweight aggregate

Grading (mm)	**Dry density (kg/m3)**	**Design unit weight (kN/m3)**	
		above water	**under water**
0–32	400	6	8

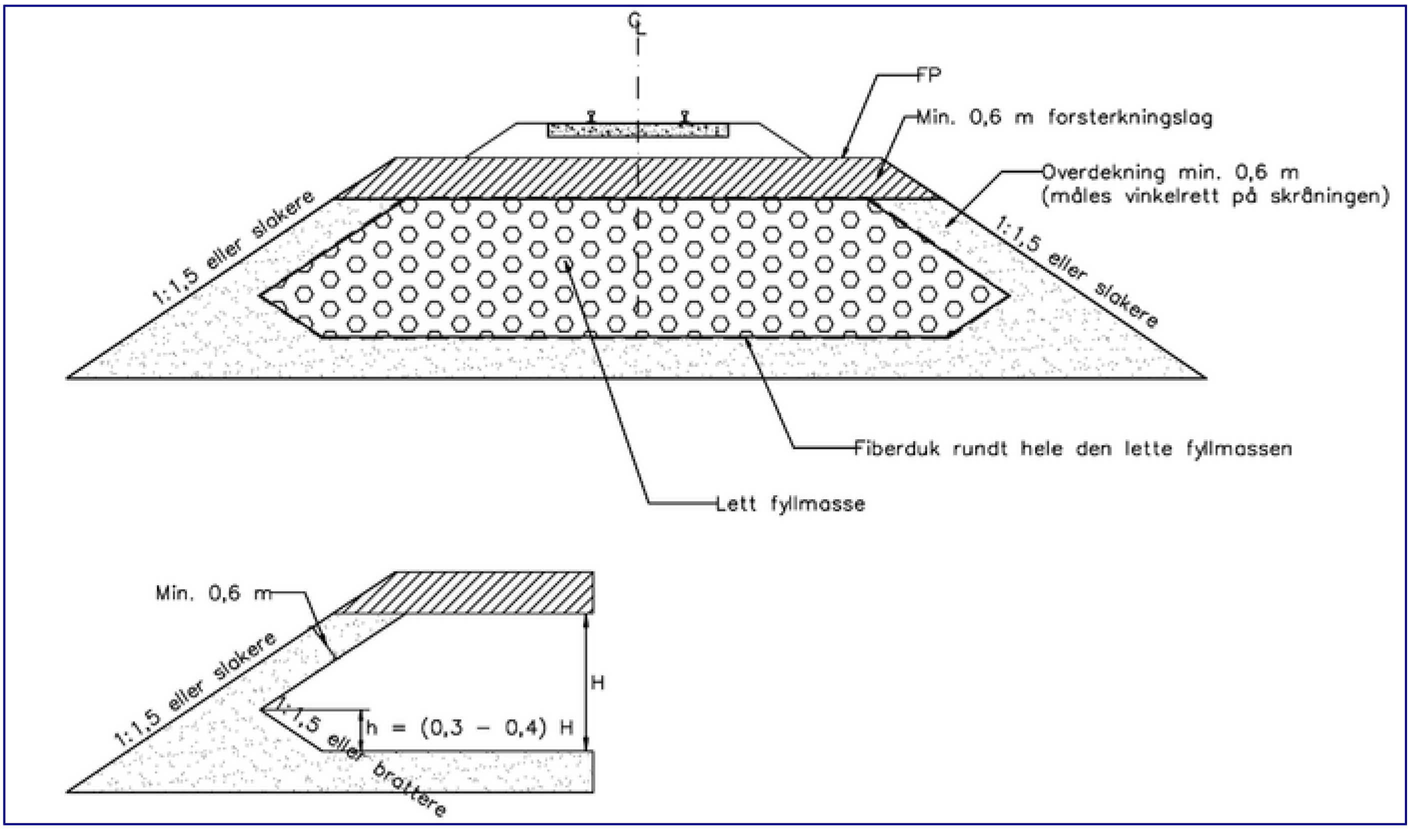
Tabell 4 shows parameters for the grading, density and unit weight of foam glass.

Tabell 4: Grading, density and unit weight of foam glass

Grading (mm)	**Dry density (kg/m3)**	**Design unit weight (kN/m3)**	
		above water	**under water**
10 – 50/60	180–300	3.5	4

2.2.2.1 Implementation

In principle, when lightweight aggregate or foam glass is used, it must be deposited and distributed as shown in Figur 3.



Figur 3: Principle. Lightweight fill.

Lightweight fill is normally laid to a maximum of 0.60 m below FL. A reinforcing layer of stones is then laid, see Underbygning/Prosjektering og bygging/Banelegeme. The layer of lightweight fill must be entirely enclosed by a fibre membrane, of a minimum Class III. (Cf. Underbygning/Prosjektering og bygging/Banelegeme). A cover layer must be laid on the side slopes. The cover layer must have a minimum thickness of 0.6 m, normally measured on the slope. For high embankments (higher than 3.0 m), the thickness of the cover layer must be increased, and the embankment's internal stability must be specially assessed to determine whether any reinforcement measures are required.

Embankments higher than 5 m made of lightweight aggregate or foam glass must be approved by the 'Infrastruktur, Teknikk, Premiss og utvikling' department ('Infrastructure, Technology, Conditions and Development').

When lightweight aggregate or foam glass is used in parts of an embankment, the lightweight materials must be laid as low as possible in the embankment.

2.2.2.2 Inspection

The following points must be inspected:

- acceptance check of material/grading supplied
- check that fibre membrane has been laid correctly
- layer thickness of the lightweight fills

2.2.2.3 Compacting

Lightweight aggregate and foam glass may be compacted using a tracked vehicle imposing a maximum load of 50 kN/m2. For areas adjacent to abutments, retaining walls, etc., a vibrating plate compactor with a maximum weight of 50–200 kg may be used.

2.2.3 Polystyrene

In principle, polystyrene fill is to be laid in accordance with the guidelines provided in forms 482–484, prepared by the Road Laboratory (Veglaboratoriet) regarding the use of this material in roads. Other than the general instructions regarding the levelling, distribution and construction of embankments (which will be the same for roads and railways), points in this regulation apply specifically to railways.

2.2.3.1 Stability

Any EPS fill used must lie entirely above the groundwater level or highest floodwater level.

The use of an EPS layer thicker than 3.5 m in embankments is not recommended. Special assessments of the embankment's inherent stability must be performed if the embankment is asymmetric.

The risk of water pressure at the rear edge of the embankment must be given particular attention.

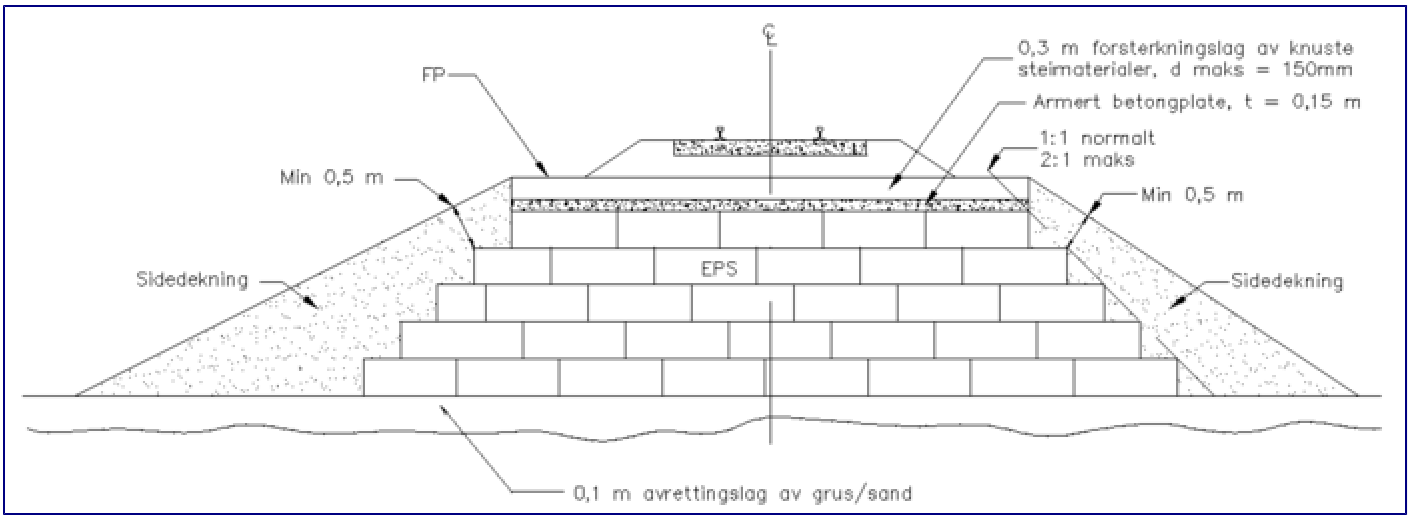
2.2.3.2 Materials

The material must be blocks of expanded polystyrene (EPS), with a minimum compressive strength of 200 kn/m2 (at 5% deformation) and a minimum density of 30 kg/m3. The outermost layer of blocks, if not the entire embankment, must be made of fire-retardant (self-extinguishing) material.

2.2.3.3 Implementation

The blockwork embankment must be constructed in courses, topped by a cast reinforced concrete slab with a thickness of 0.15 m, to the same width as the formation level (FL), with its upper edge a minimum of 0.30 m below the FL.

The principle for the construction of railway embankments using EPS is shown in Figur 4.



Figur 4: Principle for the use of expanded polystyrene blocks in railway embankments.

2.2.3.4 Inspection

Inspections must be carried out in accordance with the Road Laboratory's Form 484 regarding EPS embankments. Some of the points are shown here:

- Acceptance checks of EPS material: Weight, strength and deformation
- Geometry and distribution of blocks, inspections of gaps between blocks and uniformity of base
- Blocks must be laid in courses (using inter-block connectors, etc.)
- Outer layers (if not the entire embankment) must be made of fire-retardant material
- Concrete layer at top of embankment

3 Earth cuttings

3.1 Stability

The inherent stability of a cutting will normally be assured if it has been designed and constructed in accordance with the guidelines provided in Underbygning/Prosjektering og bygging/Banelegeme.

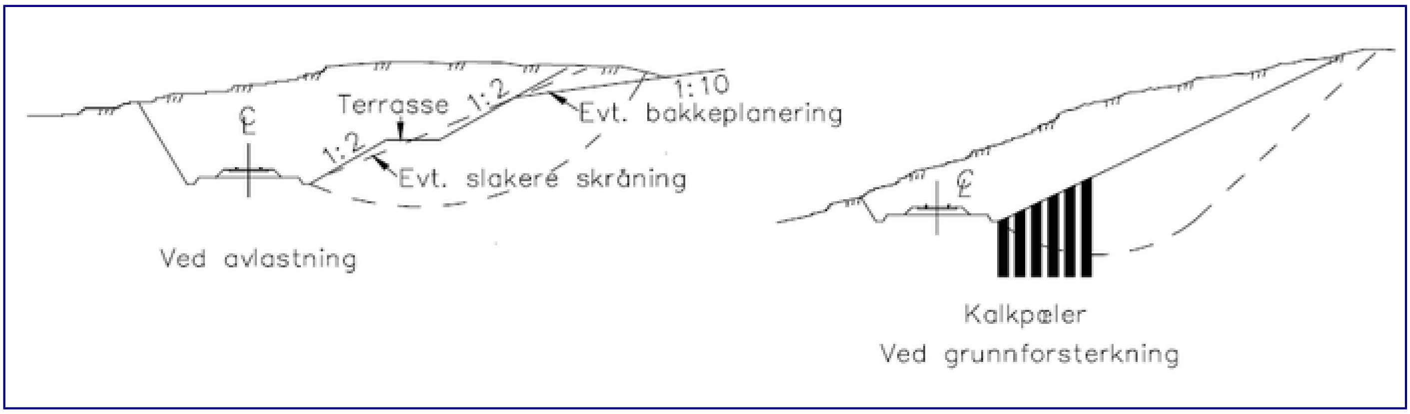
However, it is important to note that the gradient of a slope in soil must be suitable for the stability properties and erosion conditions of that soil type. If ground conditions are poor (soft clay and silt), with unfavourable terrain conditions, stability can quickly become critical, even in shallow cuttings. The materials contained in earth cuttings should therefore be identified early in the planning process. If there are any doubts about stability, special geotechnical surveys and calculations must be performed. Since the stability of a cutting usually diminishes over time, analyses of long-term stability are of particular interest here.

3.2 Stabilisation measures

Suitable stabilisation measures may be divided into two main groups described in Sikring mot dyperegående stabilitetsproblemer and Sikring mot overflateglidninger eller siginger/deformasjoner i de øvre sjikt i grunnen.

3.2.1 Protection against deeper stability problems

As a rule, measures require thorough geotechnical surveys, and as mentioned in item 2, are principally based on reducing ground stresses or increasing ground strength. Figur 5 shows several examples of stabilisation in accordance with these principles. However, stabilisation measures of this type will not be described in detail in this regulation.



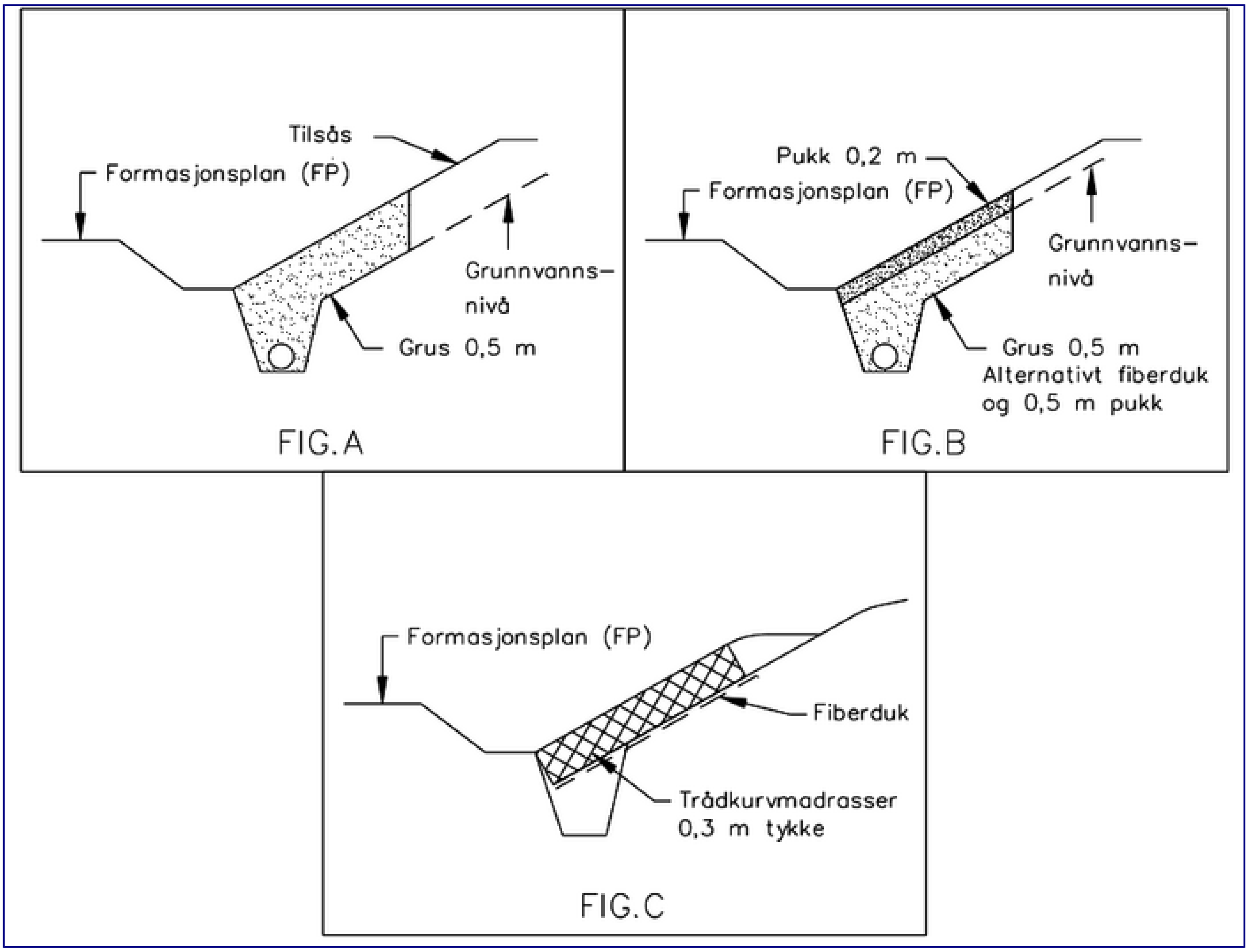
Figur 5: Stabilisation.

3.2.2 Protection against surface slides or subsidence/deformations in the upper ground layer

Separate job specifications are normally prepared for any stabilisation measures that are required. Sections 3.2.2.1–3.2.2.3 describe several basic provisions regarding the stabilisation of surfaces on slopes.

3.2.2.1 Soil replacement in cutting slopes

Soil replacement will be necessary in slopes in which soil stabilisation proves difficult. Alternative designs are shown in Figure 6. If climate conditions make it difficult to establish grass cover, alternatives b) and c) should be chosen. In locations where the soil type is considered to be particularly active in frost (susceptible to frost), measures in the form of soil replacement by heavy friction materials may also be considered in order to prevent later slides due to frost.



Figur 6: Soil replacement.

3.2.2.2 Drainage of cutting slopes

Refer to Underbygning/Prosjektering og bygging/Drenering.

3.2.2.3 Stabilising slopes during excavation

It may be necessary to stabilise slopes temporarily during the excavation process. This type of temporary stabilisation may be incorporated into permanent stabilisation measures. In most cases, it will be necessary to remove this temporary stabilisation before the installation is commissioned. Suitable temporary stabilisation measures could be:

- surface water diversion
- plastic sheet over surface to prevent drying out
- lowering groundwater level by means of ditches
- well points
- insulation, e.g. using winter mats to prevent capillary water absorption from freezing

4 Rock cuttings

4.1 Stability

For stability in cuttings, see Underbygning/Prosjektering og bygging/Banelegeme.

4.2 Stabilisation measures

There are several ways in which rock cuttings may be stabilised. The most appropriate methods are:

- scaling
- bolting
- meshing
- fibre-reinforced sprayed concrete
- supporting blocks of rock

This chapter provides a brief description of each method. For further descriptions of stabilisation categories, see Tunneler/Prosjektering og bygging/Stabilitetssikring.

4.3 Scaling

After rock has been blasted, cracks and fissures occur, even if the rock was previously solid and strong. It must always be meticulously scaled after any blasting work. In principle, this means that any loose stones that could present a hazard to safety on the line are removed if possible. This work should preferably be undertaken using scaling picks to prise out the stones.

Water in cracks and fissures has the effect of weakening connections between blocks of rock. During the winter, the freeze-thaw cycle of water in cracks can cause blocks to break loose. Particular attention must therefore be paid to any parts of cuttings where there is running water, or any parts of cuttings that are generally very damp.

4.3.1 Bolting

Bolting is an alternative to removing rock by scaling. Systematic bolting may be necessary in sections that are very prone to landslides. The positioning of the bolts must ensure absorption of tensile forces in preference to shear forces. This work must be performed by experienced professionals. Suitable bolt types are:

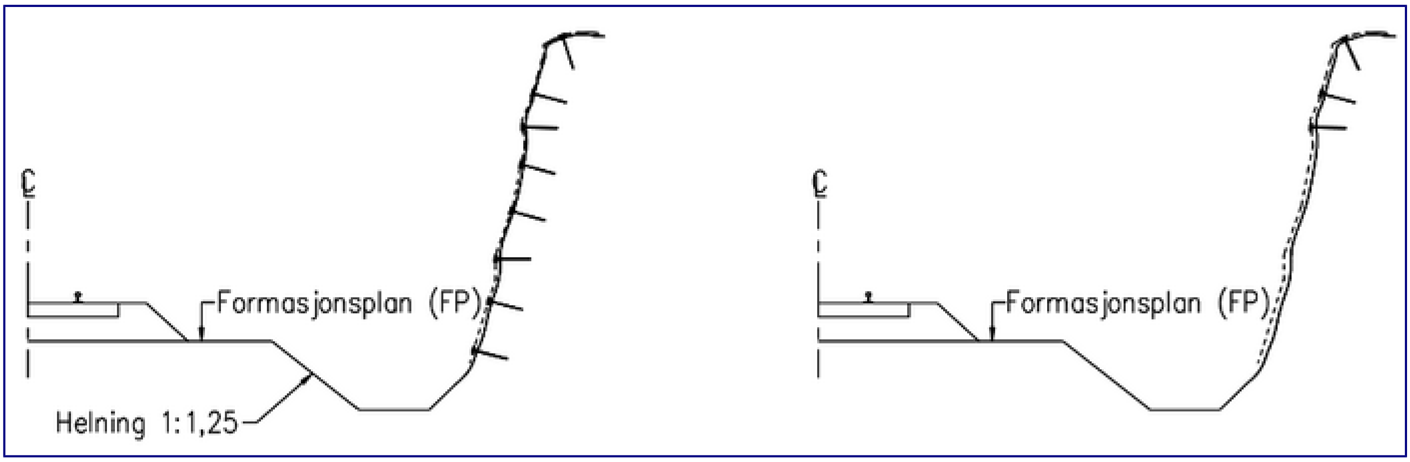
- grouted rebar bolts
- rebar bolts anchored by polyester resin

4.3.2 Meshing

In sections prone to landslides, it may not be practical to stabilise every single block using bolts. In such instances, it is possible to lay a mesh across the rock.

The mesh may be attached using one of two methods. The mesh may be attached using bolts across the entire rock surface, or it may be attached using bolts at the top, thereby remaining loosely suspended over the section of rock that is prone to landslides. If the first method is used, any loose stones that are trapped by the mesh must be periodically removed. This is achieved by breaking open the mesh and 'sewing' it closed again. If the second method is used, an area must be allocated at the base of the rock face for the collection of stones. (See Figur 7).

Mesh used for this purpose must be designed for rockslide protection (e.g. gabion mesh). The mesh must be galvanised and preferably also protected by PVC against corrosion (for environmental and aesthetic reasons).



Figur 7: Principle for stabilising a rock slope with mesh

4.3.3 Fibre-reinforced sprayed concrete

Fibre-reinforced sprayed concrete may be used as a means of stabilisation in cuttings where the rock is slightly crumbly.

4.3.4 Supporting blocks of rock

Overhanging blocks of rock may be supported. Timber props have been widely used, but must be regarded as a temporary solution. Permanent supports must be cast in concrete.

5 Retaining walls

5.1 Calculating

For design traffic loads, refer to Bruer/Prosjektering_og_bygging/Laster.

5.2 Different types of retaining walls

Slopes greater than those indicated in Underbygning/Prosjektering og bygging/Banelegeme should not be used without a retaining wall at the base. Suitable retaining walls are:

- concrete walls
- dry-stacked walls
- rock-filled baskets (gabions)

Figur 8 shows some examples of retaining walls. Various combinations of the solutions presented in armert jord may also be suitable.

5.3 Foundation

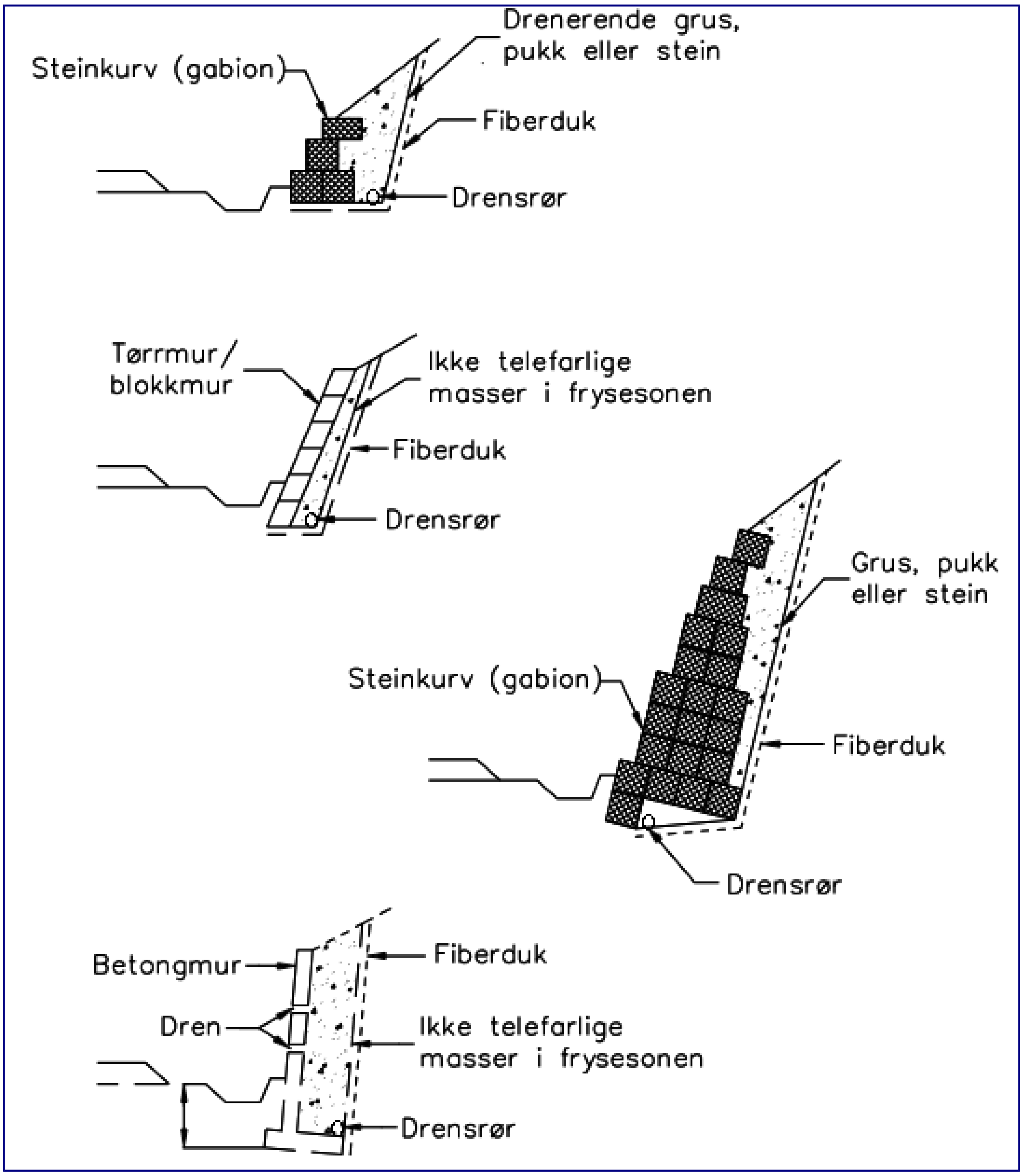
Foundations of rigid structures must be at a frost-free depth. The requirement for a frost-free foundation may be adjusted slightly if dry stacked walls and wire baskets are used.

Retaining walls must be on a solid base. If there is a reasonable depth of underlying rock, the foundation of the retaining wall must continue down to the rock. On steep rock faces, a base area for the wall must be blasted.

5.4 Fill material and drainage

Well-draining material such as gravel, crushed stone or stone must be used as backfill behind retaining walls. Before this is applied, the surface of excavated slopes should be covered by a fibre membrane. The fibre membrane may be omitted if the fill is composed of filter materials. For large or moderately large structures in the frost zone, the fill must be composed of non-frost-susceptible materials , cf. Underbygning/Prosjektering og bygging/Frost. The fill must normally be drained.

Sealed concrete structures must contain drainage outlets that pass through the wall, in order to protect the wall from water pressure.



Figur 8: Examples of retaining walls.

6 Soil reinforcement

7 =Principle/products/application

Soil reinforcement has been a recognised construction technique for hundreds of years. Brushwood, logs and, more recently, fibre membranes are among the reinforcement methods that have been used for road and railway construction across marshy ground.

The primary task of reinforcement is to compensate for the tensile strength that is not sufficiently present in soil. The method may be compared with the use of reinforcement in concrete.

The first type of reinforcement used timber materials. There are currently a vast number of products on the market that are designed for soil reinforcement. These fall into natural categories such as reinforcement with high-density membranes, reinforcement with mesh structures and reinforcement with steel strips. Within the first two groups there are products based on different raw materials and production techniques. Most of the products are based on polymer materials such as polyester, polyamide, polypropylene, polyethylene, etc.

Principle, product and application must be assessed by geotechnical specialists on an individual basis.

Correctly implemented soil reinforcement may provide:

- a way of utilising local/ inexpensive materials in railway embankments
- a more stable substructure
- reduced deformations resulting from loads, and thereby reduced maintenance and extended useful/service life
- improved access to areas with a soft subsoil
- a smaller area requirement, since ,for example, steeper slopes can be used
- a way of building earth structures that would not be possible using conventional construction methods

Soil reinforcement is suitable for use in conjunction with lightweight fill (lightweight aggregate).

The technical area of soil reinforcement naturally falls into two subject groups:

- retaining structures
- embankments

7.1 Retaining structures

Retaining structures refer to angular retaining walls, block retaining walls and abutments.

A retaining structure containing reinforced backfill is basically made up of cladding in front of backfill that is reinforced in layers. The most common backfill materials are sand and gravel, but this is not a requirement. The reinforcement will reduce the pressure exerted by the soil on the retaining structure. The reinforced backfill may be designed to be inherently stable. The task of the front cladding is to cover and protect the structure against external forces, to prevent soil erosion between the reinforcing layers, and to provide an aesthetically appealing exterior.

Drainage is normally provided behind the structure, and frost-susceptible materials are not used in the frost zone, cf. Støttemur.

In some instances, structures may also be constructed without the front cladding; this is known as a geosynthetic retaining wall. This type of structure may be considered to be both a retaining structure and a slope.

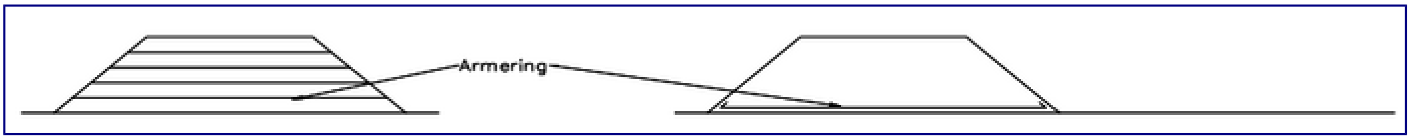
The design of the complete retaining structure must take into account:

- load-bearing capacity
- stability of the area
- settlement
- internal stability
- tensile failure of reinforcement
- anchoring failure in filler

7.2 Embankments

Reinforcement in an embankment serves two main purposes:

- improved internal stability and/or steeper embankment slopes
- improved distribution of subsoil loads



Figur 9: Schematic drawing of reinforced embankment.

If embankments are constructed on subsoil with a good load-bearing capacity, it may be preferable for the embankments to have steeper slopes for reasons of space.

If embankments are constructed on ground with a poor load-bearing capacity, soil reinforcement may be used to reduce the transfer of shear stresses from the embankment to the subsoil.

The design is as indicated in Støttekonstruksjon.

8 Stability of adjacent terrain

8.1 General

The stability of a railway line depends on the stability of the adjacent terrain. It is therefore essential for this to be given sufficient consideration during the planning phase of new railway installations. For reasons of safety and cost, the potential route of a line may be greatly influenced by terrain that is prone to landslides. If a line has been laid in active landslide or avalanche zones, measures to protect it from events such as avalanches or rockfalls will often be extremely expensive. In some instances, the NNRA may find it necessary to impose stringent restrictions on the use of adjacent terrain, and/or find it necessary to secure ownership rights or intervention rights to adjacent terrain that may be at some distance from the track, in order to be able to control the stability of this terrain.

A new railway installation may itself constitute a significant encroachment on the terrain. During the planning and design phases, a thorough assessment is required regarding the potential impact of the installation on the surroundings and to neighbouring parties. In addition to an assessment of the direct risk that cuttings and embankments can pose to adjacent land and property, there must also be an assessment of potential settlement risks that may arise as a result of groundwater lowering (pore pressure reduction), water wells draining dry, etc. Assessments of the stability of adjacent terrain should also include the study of any available maps that show quick clay deposits.

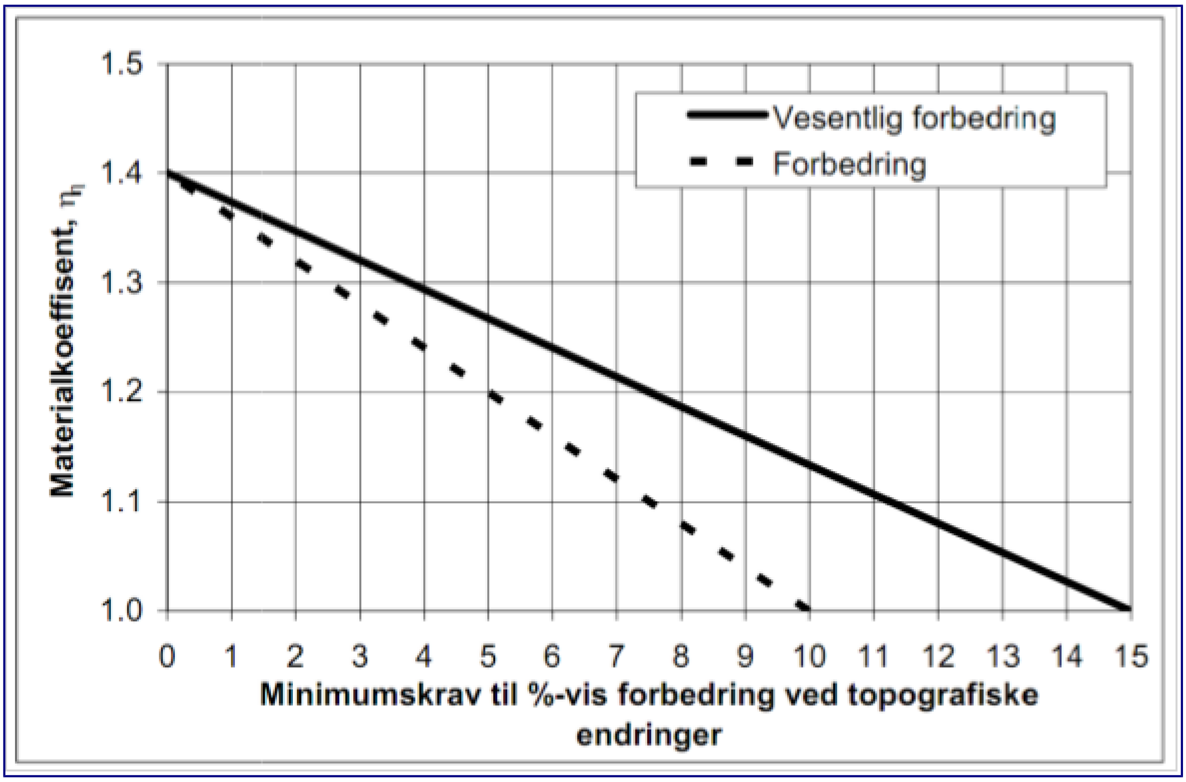
8.2 Soil terrain

Ballast bed stabilisation measures must be designed and implemented so as to ensure that the railway installation will not impact the adjacent soil terrain in the form of landslides or landslips. This problem is dealt with in Fylling and Jordskjæring.

The planning and design of any measures necessary to secure the inherent stability of soil terrain, thereby protecting the railway installation from landslides and landslips, requires a thorough knowledge of the geotechnical/hydrological conditions, and not least requires reliable data regarding local landslide activity (landslide statistics, local knowledge, etc.). This may involve extremely diverse landslide types, and the resultant stabilisation measures involved will be equally complex and very much determined by local conditions. In principle, protection methods may be categorised according to the way in which they work. The various protection methods are described in sections 7.2.1–7.2.3.

The table and figure below must be consulted in the event of construction work in hazard zones alongside existing railway lines.

Category of measure	**Class of hazard level prior to construction work**		
	Low	Moderate	High
K3. Measures that involve relocation of persons and measures that concern essential societal functions: Homes, institutions, schools, business premises, water, sewerage and waste installations, key power grids, etc.	**Hazard level evaluation Stability analysis:** a) $\gamma_M \geq 1.4$ or b) improvement **Enhanced monitoring** (Project Class 3, NS 3480)	**Hazard level evaluation Stability analysis:** a) $\gamma_M \geq 1.4$ or b) significant improvement **Enhanced monitoring** (Project Class 3, NS 3480)	**Hazard level evaluation Stability analysis:** a) $\gamma_M \geq 1,4$ or b) significant improvement **Enhanced monitoring** (Project Class 3, NS 3480)



Figur 10: Requirement for percentage improvement during topographic changes

8.2.1 Preventive measures

Preventive measures, i.e. measures to prevent landslides being triggered

- support structures
- ground reinforcement
- drainage, channelling

8.2.2 Barriers

Barriers, i.e. measures to stop landslide debris or prevent it reaching the railway line

- earth mounds or cones
- catch fences
- catching dams (concrete or stone)
- landslide sheds

8.2.3 Landslide warnings

Landslide warnings, i.e. measures to prevent trains running into landslide debris

- landslide warning fence (see Fjellskjæring)

8.3 Rock terrain

Measures to stabilise the ballast bed against landslides from adjacent rock terrain is dealt with in Fjellskjæring.

Measures that may be used to ensure that the railway installation is not vulnerable to landslides and landslips are described in sections 7.3.1–7.3.3.

8.3.1 Preventive measures

Preventive measures, i.e. measures to prevent landslides being triggered

- Cf. Fjellskjæring

8.3.2 Barriers

Barriers, i.e. measures to stop or divert landslide debris or prevent it reaching the railway line

- Cf. Fjellskjæring

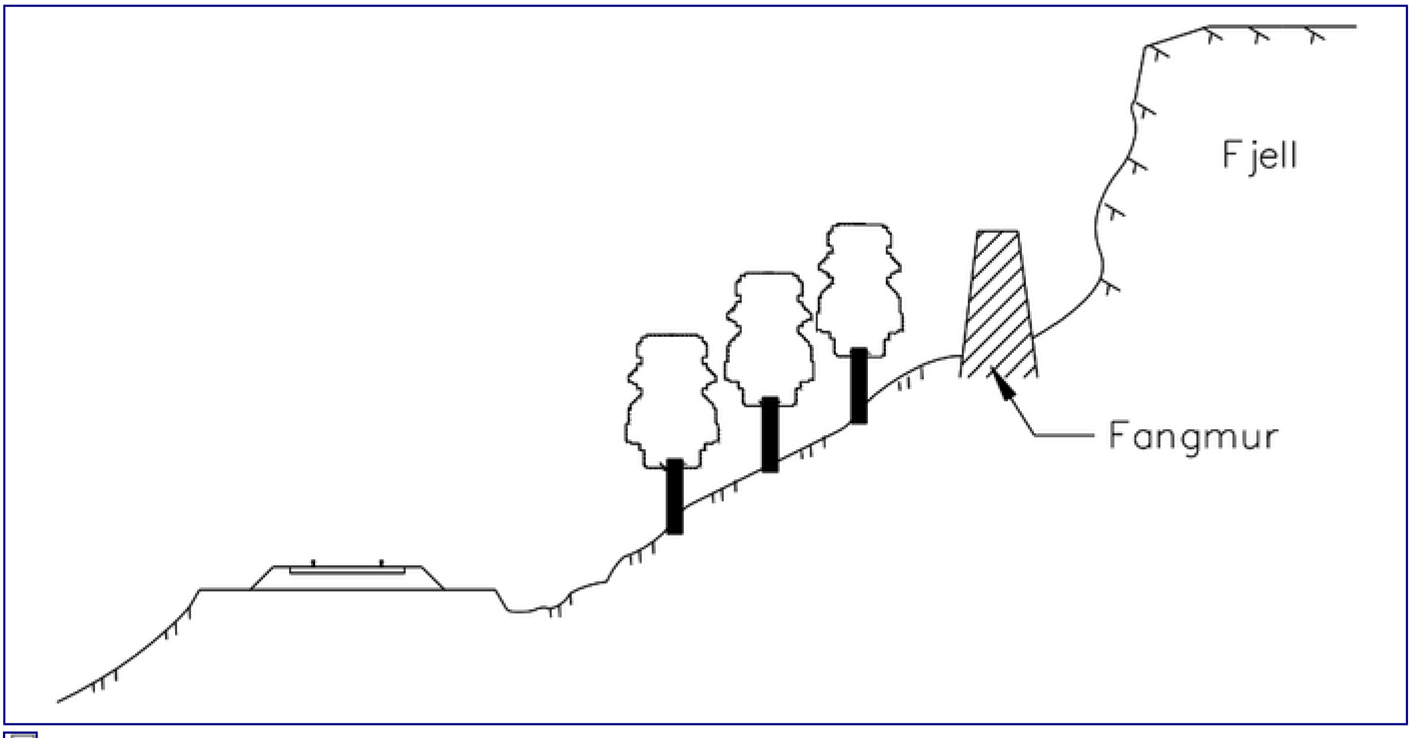
8.3.3 Landslide warnings

Landslide warnings, i.e. measures to prevent trains running into landslide debris

- Landslide warning fence At locations where it would be impossible or would involve an unreasonable cost to prevent rockfalls, landslides or landslips, a landslide warning fence may provide a reasonable degree of safety.
- A landslide warning fence is not designed to offer any physical resistance to rockslides. Thus, it does not guarantee the safety of any train that runs past the signal into an area that is prone to landslides. These fences should therefore only be erected in locations that experience minimal traffic, and where other safety measures would be too wide-ranging and expensive.
- The erection of a landslide warning fence does not exempt the designated line personnel of their responsibility to undertake routine inspection and maintenance of the rock slopes.

8.4 Combination of soil and rock terrain

A landslide and landslip hazard will often be constituted by both soil and rock terrain. Figur 11 shows a typical situation, in which a catching dam may be capable of preventing a rockfall from the rock slope from triggering a landslide in the soil slope.

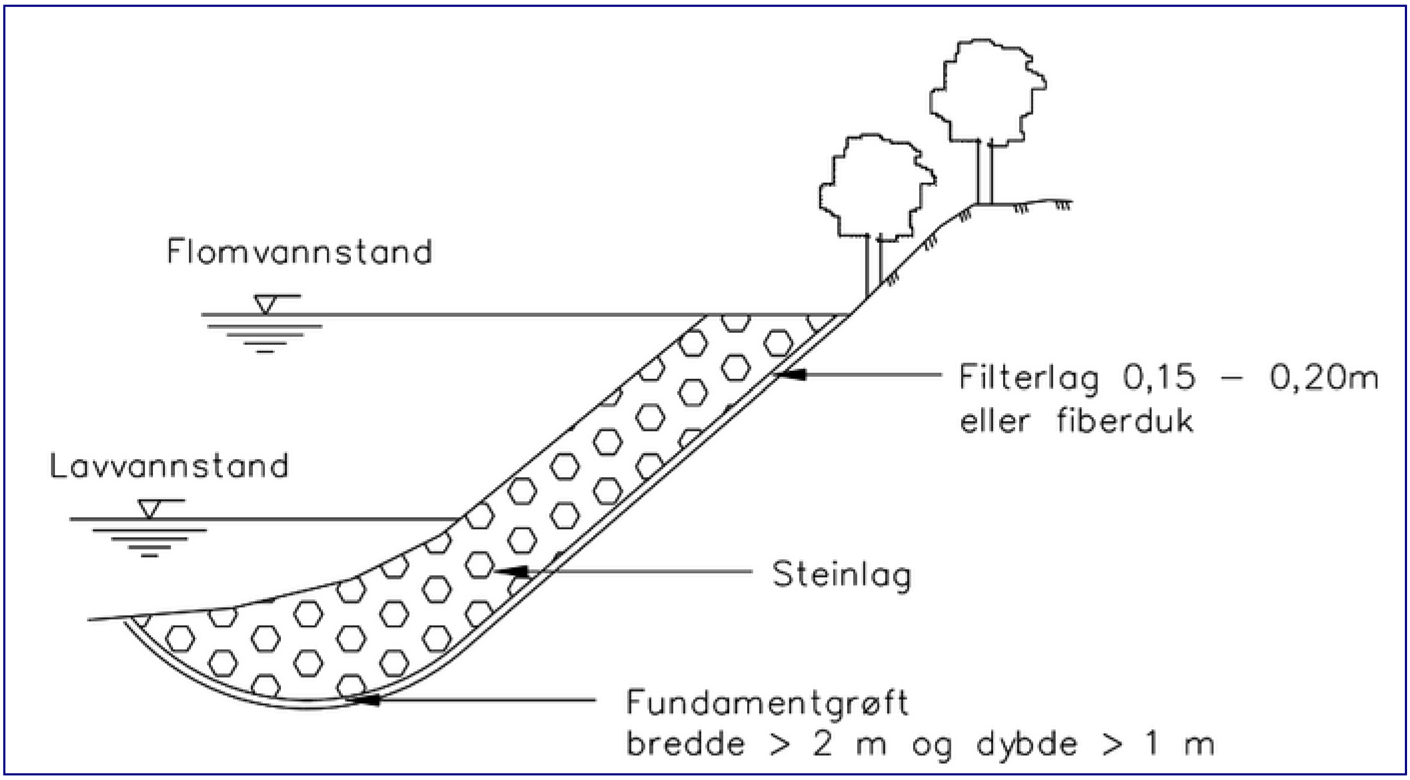


Figur 11: Stabilisation measure.

9 River walls

Incursions into watercourses are covered by a number of legislative provisions. Changes to flow conditions and the construction of barriers to protect against rivers and watercourses are not permitted without contacting the Norwegian Water Resources and Energy Directorate (NVE).

In principle, a barrier against a river or body of water with breaking waves must be constructed as shown in Figur 12. A filter layer or filter membrane must be used when the slope is formed of sand, silt or clay. The filter layer may be made up of natural gravel or crushed material with an even grain distribution. If a fibre membrane is used, this must be of usage class IV (cf. Underbygning/Prosjektering og bygging/Banelegeme). The fibre layer is not necessary if the stone cladding is at least 1.5 m thick and comprised of unsorted stone (material containing quarry dust). New installations require a stone dimension designed on the basis of the flow velocity. Refer also to NVE's provisions.



Figur 12: Principle design of barrier against river or lake.
Protection against wave erosion follows the same principles as for river walls. Depending on the wave height, average stone dimensions will normally be 0.5–1.0 m. If the waves are large, the use of well-graded stone on top of a filter layer is recommended. Stone cladding must extend well above the design wave crests. Stone dimensioning must be performed by technical specialists.