Substructure: Design and construction. Ballast bed

1 Purpose and scope

This chapter describes the design and construction of the ballast bed, i.e. the substructure of the line including embankments, cuttings and associated structures. Bridges are described in Bruer/Prosjektering og bygging.

The substructure has the following functions:

- Constitute a load-bearing, stable and evenly elastic foundation capable of absorbing the forces and resisting the long-term erosive effects to which the line may be exposed during its economic service life.
- Prevent frost penetration to susceptible material beneath the substructure.
- Draw away water from precipitation and adjacent terrain.

2 Construction of the formation

The formation is the finished level base for the substructure.

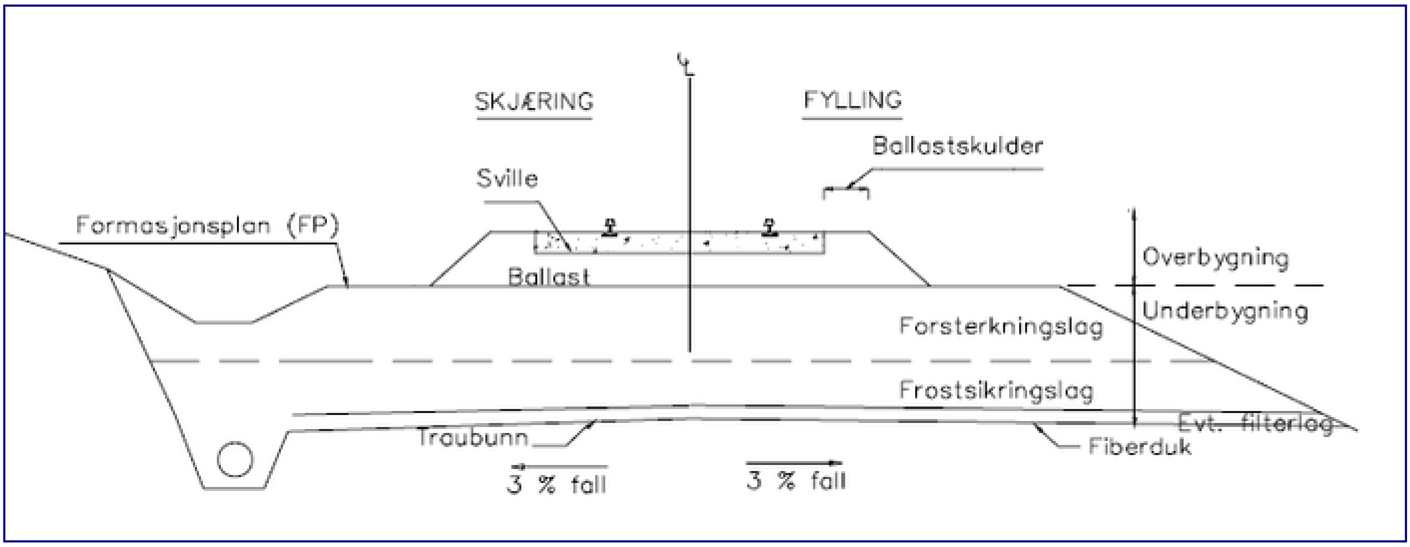
'Formation' is used to describe the reinforcing layer, frost protection layer and any filter layer.

The filter layer must prevent fine subsoil particles from penetrating and degrading the formation materials and ballast.

The frost protection layer, together with the reinforcing layer and superstructure, must prevent the penetration of frost to the formation and subsoil.

The reinforcing layer must form a pressure-distributing layer between the ballast and the deeper, less load-bearing materials, safeguard the substructure's draining capacity and strength, and have even elasticity.

The formation level is the top of the reinforcing layer.



Figur 1: Principle sketch of construction of railway embankment and cutting

2.1 Formation

The formation is the finished level base for the reinforcing layer or frost protection layer, and any filter layer.

The formation must be trimmed and adjusted in accordance with the requirements specified in avsnitt 2.5.1.

Between the fine-grained subsoil and the formation, a filter must be used to prevent fine subsoil particles from penetrating into the overlying materials. The filter layer may comprise sand and gravel and/or fibre mesh.

2.1.1 Filter layer on natural ground

A filter layer beneath rock spoil may be made up of gravel or sand. The layer must be constructed in accordance with the filter criteria. For a description of the filter criteria, refer to NPRA Manual 018.

2.1.2 Fibre mesh as filter/separation

Fibre mesh may be used as a filter/separation in the following transition zones:

- formation/subsoil
- formation/embankment
- embankment/subsoil
- around an embankment of light, granular materials (lightweight aggregate, foam glass)

In non-trafficked areas, e.g. drainage ditches, for erosion-protection of slopes and for traffic loads in relatively dry conditions, fibre mesh may completely replace the gravel filter.

Fibre mesh used on a ballast bed must be of usage class IV, and of the 'needle felt' or 'felted and thermally treated' type. Woven fibre mesh must not be used as a filter, although strong versions may be used as soil reinforcement.

For use of fibre mesh, reference is made to [NS 3420 del I4] and Statens Vegvesen håndbok 018.

Tabell 1: Fiberduk

Usage class	To be used against	Area density of mesh (g/m²)
I	Drainage materials in ditches	90-110
II	Sand and gravel	120-180
III	Crushed stone and ballast	190-300
IV	Ungraded blasted rock	≥ 300

2.1.3 Filter layer on soft ground

If the ground is particularly soft, fibre mesh on its own will not be a satisfactory filter material for this purpose due to the long-term effect of dynamic rail traffic. In such cases, fibre mesh may be used as a supplement to mineral filter materials, and, where applicable, in combination with geonet:

- together with a minimum 200 mm gravel filter layer
- beneath stone embankments comprising blasted rock containing quarry dust

2.2 Frost protection layer

For requirements regarding the frost protection layer, refer to kapittel 9 Frost.

Any reductions to the frost protection layer may be undertaken in accordance with avsnitt 2.4.

2.3 Reinforcing layer

The reinforcing layer is the upper layer of the substructure. The top of the reinforcing layer forms the formation level (FL). The reinforcing layer must form a pressure-distributing layer between the ballast and the deeper, less load-bearing materials and must safeguard the substructure's draining capacity, as well as provide strength and even elasticity to the superstructure.

The reinforcing layer must have a minimum thickness of 700 mm. Exceptions to this requirement are reinforcing layers in tunnels, refer to Underbygning/Prosjektering_og_bygging/Tunneler, on bridges, refer to Overbygning/Prosjektering/Spor_på_bruer, and on non-mainline tracks, refer to avsnitt 2.4.

The upper part of the reinforcing layer may comprise a levelling course of gravel/crushed stone as a base for the ballast.

The reinforcing layer must be drained.

2.3.1 Materials in the reinforcing layer

The reinforcing layer must be made up of load-bearing, well draining and non-frost susceptible materials (T1- materials, cf. Chapter 9, Frost, table 9.1). Approved materials are described in sections 2.3.1.1 - 2.3.1.5.

The materials must be in accordance with [NS 3420 I54 "Forsterkningslag"].

2.3.1.1 Blasted rock

A reinforcing layer of blasted rock must have a maximum stone dimension of 300 mm, though not greater than half the layer thickness that is distributed.

Stones must be well graded, with the grain uniformity coefficient $C_u = d_{60}/d_{10} \geq 15$.

Filling with quarry dust to the extent that the stones 'shift' is not permitted, and no more than 3% of material may be less than 0.02 mm, based on material less than 20 mm.

2.3.1.2 Crushed stone

For reinforcing layers comprising machine-crushed stone, the same requirements for grading and stone dimension apply as for sprengstein. Machine ballast without a sand/gravel fraction is unsuitable for use in the reinforcing layer for technical reasons relating to frost.

2.3.1.3 Gravel

A gravel reinforcing layer must comprise well graded materials from natural gravel deposits. The material may contain stone but the maximum grain size must not exceed 150 mm.

2.3.1.4 Lightweight aggregate and foam glass

Lightweight aggregate and foam glass are primarily used as a stabilising measure to reduce ground stresses (shear stresses), and for load reduction as a subsidence-reducing measure on poor ground. It is also appropriate to use such materials when building adjacent to existing lines/structures where the excavation depth must be restricted, and also for frost insulation. Also refer to kapittel 8 Stabilitet.

2.3.1.5 Expanded polystyrene (EPS)

Expanded polystyrene (EPS) is used for the same purpose as lightweight aggregate and foam glass.

EPS must not be used if there is a risk of uplift or major water pressure on the embankment. Also, EPS must not be laid down when subsoil frost is present. Also refer to kapittel 8 Stabilitet.

2.4 Reduction in layer thickness

Depending on the type of track, the thickness of the reinforcing and frost protection layers may be reduced as indicated below:

- Main line tracks and goods terminals, 100%

Sidings, industrial sidings, goods lines, shunting lines, other lines at stations, 80% Holding sidings, etc, 50%

In practice this means that when, for example, the reinforcing and frost protection layer for a mainline track is dimensioned to 1.0 m, the equivalent dimensions for a siding and holding siding will be, respectively, 0.8 m and 0.5 m.

2.5 Implementation

2.5.1 Formation

The formation must be trimmed and adjusted in accordance with the following requirements:

- maximum vertical deviation from projected height, + 0 mm
- maximum horizontal deviation from projected width, ± 100 mm
- cross-fall, minimum 3%

2.5.2 Frost protection and reinforcing layer

The reinforcing layer must be built up layer by layer with approved materials. The layer thickness must be adapted to the grain size.

Laying and compaction must be in accordance with [NS 3420 I54 "Forsterkningslag"].

The infill is concluded on a level that permits trimming/wedging out the surface in order to establish the formation level.

2.5.3 Formation level (FL)

At no point must the formation level have a greater deviation than + 0 and - 50 mm from the projected height. The formation level must not have a greater deviation than + 100 mm from the projected width.

Requirements for the formation level's width are specified in Overbygning/Prosjektering/Ballast.

The formation level may be laid with a declivity or cross-fall.

2.6 Inspection

As a minimum, the formation, reinforcing layer and formation level must be inspected. If the scope of the inspection has not been specified, it should be determined by the individual project.

2.6.1 Formation

The formation must be inspected in accordance with the following points:

- Geometry, i.e. height, width and cross-fall
- Filter materials and fibre mesh

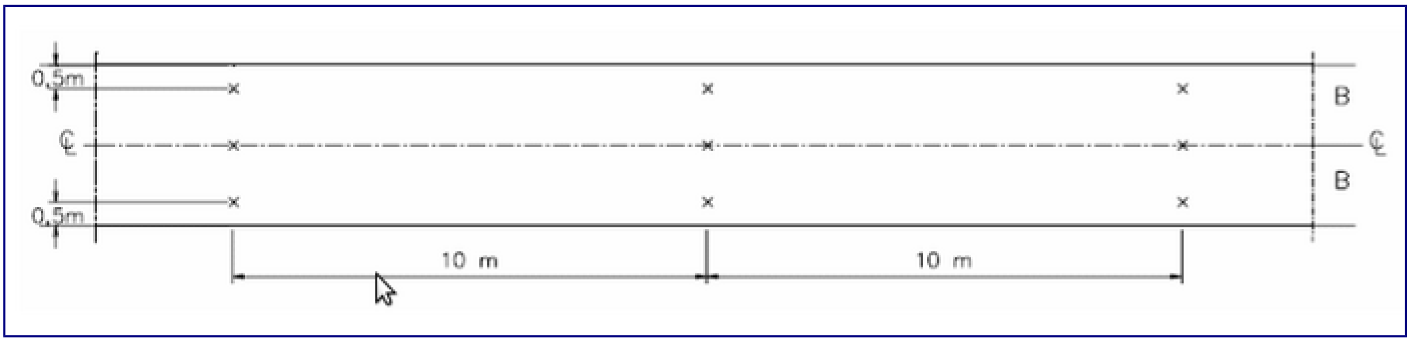
2.6.2 Reinforcing layer

The reinforcing layer must be inspected in accordance with the following points:

- Materials
  - visual acceptance check (grading, max. stone dimension, rock type)
  - grading curves (max. grain size, fines content) per 2000 m3 distributed material
  - rock type
- Compaction/layer thickness
  - distributed thickness per layer
  - separation/filter
  - number of overpasses
  - total layer thickness

2.6.3 Formation level (FL)

An inspection of the formation level must be conducted every 10 metres in the centre line of the track and 0.5 m inwards from the edge of each side of the formation level. The inspection points are marked with an x on figure 2. The inspection must be carried out in accordance with the requirements of formasjonsplan



Figur 2: Inspection of formation level

3 Embankment

This section describes the embankment up to the formation.

3.1 General

The embankment must form a solid base for the substructure and superstructure and otherwise perform the function of adjusting the line to the desired height above the terrain.

The embankment geometry must generally be as specified in the plans, usually determined by the line's standard profile, as well as local terrain and soil conditions.

If the embankment is made up of the same materials as the reinforcing layer, it will not be necessary to level the formation with cross-falls in the transition. At the base of the embankment it may be appropriate to introduce a gravel filter layer on the subsoil.

Before the embankment is laid out, a degree of pre-treatment and preparation of the terrain surface will generally be required, including removal of top soil, replacement of organic soil types such as peat and mud, as well as forest felling and the removal of other kinds of vegetation.

3.2 Materials

Ideally, friction materials should be used for embankments. However, subject to certain guidelines, the following materials may also be used:

- all soil types not classified as clay, silty loam, loamy silt and organic soil
- dry crust clay, in exceptional circumstances, and always in conjunction with a drainage layer

The embankment slope, up to 0.5 m below the formation level (FL), measured vertically, must be covered as specified in Tetting_av_sideskråninger_og_etablering_av_grasdekke.

3.3 Light embankments

For light embankments, refer to Underbygning/Prosjektering_og_bygging/Stabilitet.

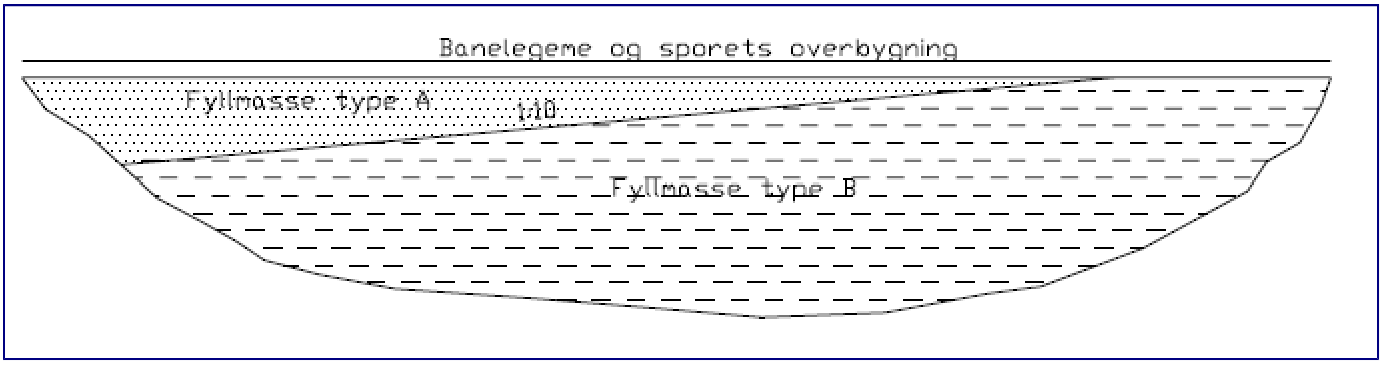
3.4 Implementation

3.4.1 Filter layers/separation layers

For filter layers/separation layers, refer to Filterlag_mot_naturlig_grunn.

3.4.2 Wedging out

If different types of material are used for the embankment, these must be joined together by wedging out in the longitudinal direction of the line in order to prevent unacceptable unevenness. Refer to the principle drawing in figure 3.



Figur 3: Wedging out materials in embankments. Principle sketch of longitudinal section

3.4.3 Compaction

The embankment must be built up and compacted layer by layer. The maximum permitted stone dimension is 2/3 of the thickness of the layer. The requirements for embankment construction will normally be satisfied by implementation in accordance with NS 3458 Compaction. Requirements and implementation.

3.4.4 Slope protection

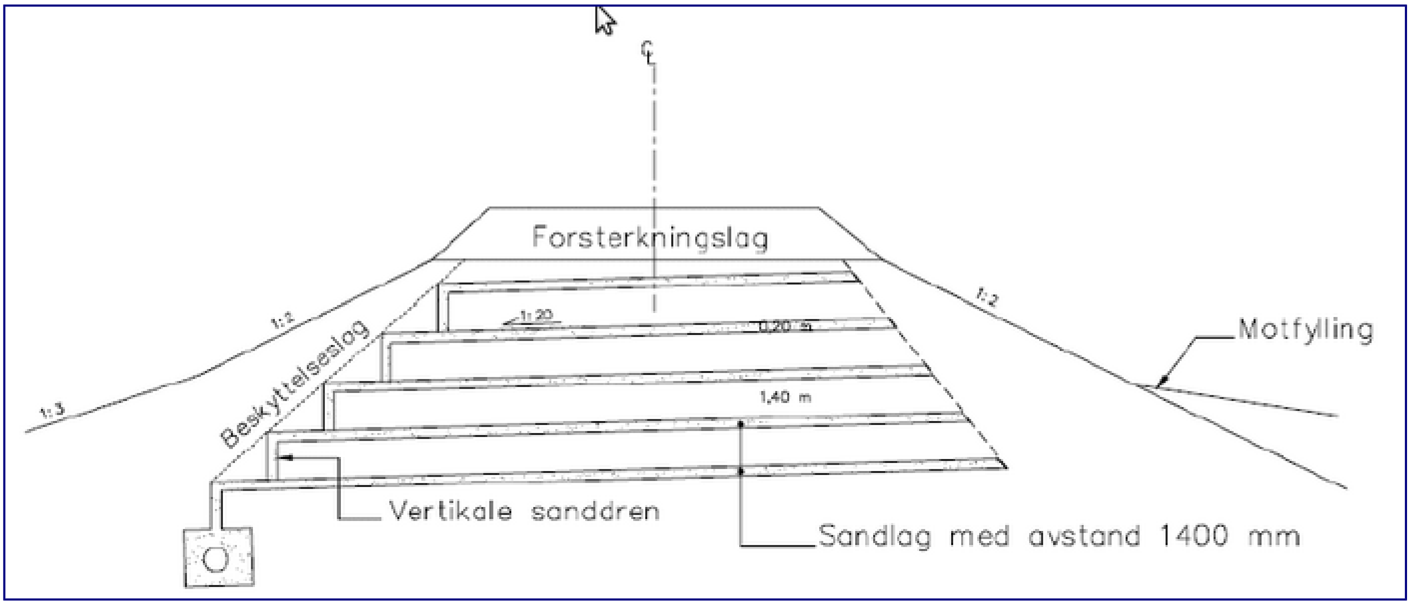
When using frost-susceptible mixed soils (e.g. moraine, silty sand/gravel) in the embankment, it is assumed that the slopes will be protected with well graded friction materials.

3.4.5 Embankment toe/bed reinforcement

For embankment toe/bed reinforcement, refer to Underbygning/Prosjektering_og_bygging/Stabilitet.

3.4.6 Clay embankment

Clay embankments must be constructed in favourable weather conditions with minimal or zero precipitation. The clay must be laid to a thickness of 0.2 m and compacted into an homogeneous mass with minimum possible air content. For each 1.4 m layer of clay, a 0.2 m draining sand layer must be laid. The embankment slope must not be steeper than 1:2, refer to figure 4. Reference should also be made to Statens Vegvesens håndbok 274 "Grunnforsterkning, fyllinger og skråninger".



Figur 4: Principle sketch of clay embankments

3.5 Inspection

3.5.1 Backfill and compaction

During inspection, measuring and analysis of selected samples, it must be ensured that the prescribed quality requirements have been fulfilled. Table 2 shows the minimum requirements for the inspection of works that are well under way. It is assumed that stricter inspections will be conducted during the startup phase.

The soil extraction site must be independently inspected and approved before the operation commences. Testing of rock spoil removed from tunnels and rock cuttings must be undertaken on a regular basis when requirements for filtration properties are necessary.

Tabell 2: Kontroll av fyllmasser

Fyllmasse	Tilsyn	Classification of backfill Sample of each	Compaction testing Sample of each
Stones	Inspection	Not conducted	Number of passes
Sand and gravel	Inspection	1000 m^3	1000 m^3
Silt	Continuously	1000 m^3	1000 m^3

Clay and loamy moraine	Continuously	Special requirements	Special requirements

3.5.2 Geometry

It must be ensured that the geometry of the embankment (i.e. angle of side slopes, embankment top) is in accordance with the specifications.

4 Earth cuttings

The cut is carried out through uncompacted materials in order to establish sufficient space through the terrain to construct the line.

The design and size will be primarily determined by the requirements for minimum infrastructure gauge specified in Chapter 5 Clearance gauges, as well as local factors associated with soil conditions, amount of snowfall, snow accumulation, danger of landslides/avalanches, drainage, water outlets, noise and terrain adaptation.

The cutting should generally be designed in accordance with standard profiles in Underbygning/Prosjektering_og_bygging/Profiler_og_minste_tverrsnitt

Table 3 specifies the maximum permissible slope gradient for different types of soil.

Tabell 3: Maximum permissible slope gradient for different types of soil

Soil condition, soil type	**Stone**	**Gravel, coarse sand**	**Fine sand/silt**		**Clay**
			Dry	**Layered, hydromorphic**	
Maximum slope	1:1.25	1:1.5	1:2	Individual assessment	1:2

For deep cuttings in fine-grained soil, silt-clay, particular consideration must be given to the stability of the cutting, usually based on completed ground surveys. Matters concerning the stability and support of the cutting are dealt with in Underbygning/Prosjektering_og_bygging/Stabilitet.

4.1 Implementation

The top soil must be removed before the actual cutting work is carried out. The formation must be levelled and built with a 3% declivity to prevent the accumulation of water.

The cutting must include side slopes that are suitable for the soil type, shear strength, groundwater conditions and terrain. Erosion protection in accordance with the plans must be carried out at each natural excavation level before the next level is excavated. Necessary consideration must be given to adjacent conditions, e.g. greater loads that occur near the cutting.

4.2 Inspection

4.2.1 Geometry

It must be ensured that the geometry of the earth cutting (i.e. angle of side slopes, formation) is in accordance with the specifications.

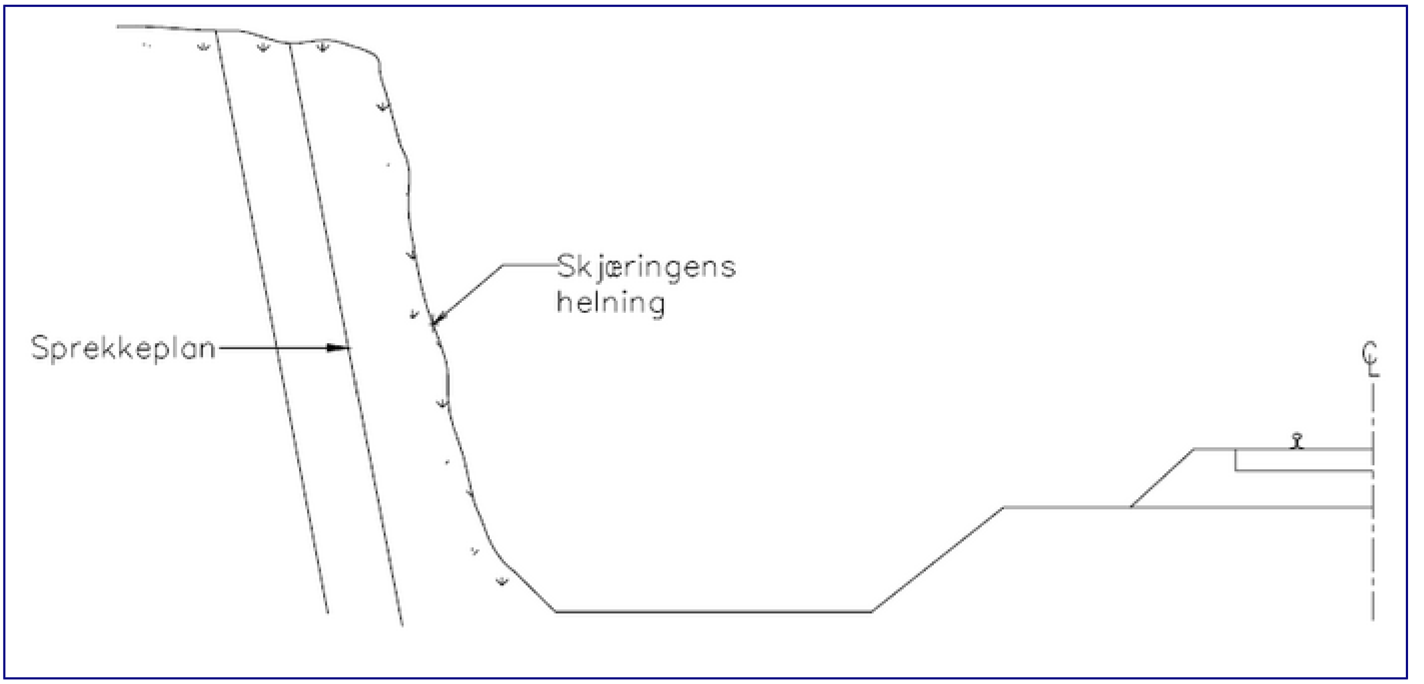
5 Rock cuttings

The cut is carried out through rock in order to establish sufficient space through the terrain to construct the line.

The design and size will be primarily determined by the requirements for minimum infrastructure gauge specified in Underbygning/Prosjektering_og_bygging/Profiler_og_minste_tverrsnitt, as well as local factors associated with soil conditions, amount of snowfall, danger of landslides/avalanches, drainage, water outlets, noise and terrain adaptation.

It is assumed that an engineering geological assessment of the rock and implementation of safety measures will be conducted for new infrastructure. In order to achieve the minimum extraction of spoil, virtually vertical cutting walls must be used. Equally, stratification and fractures in the bedrock will often determine the gradient of the cutting. Blasting should be conducted in accordance with the fracture analysis. Refer to figure 5.

On sections of line where drifting snow may cause problems, the gradient must also be considered on the basis of such conditions.



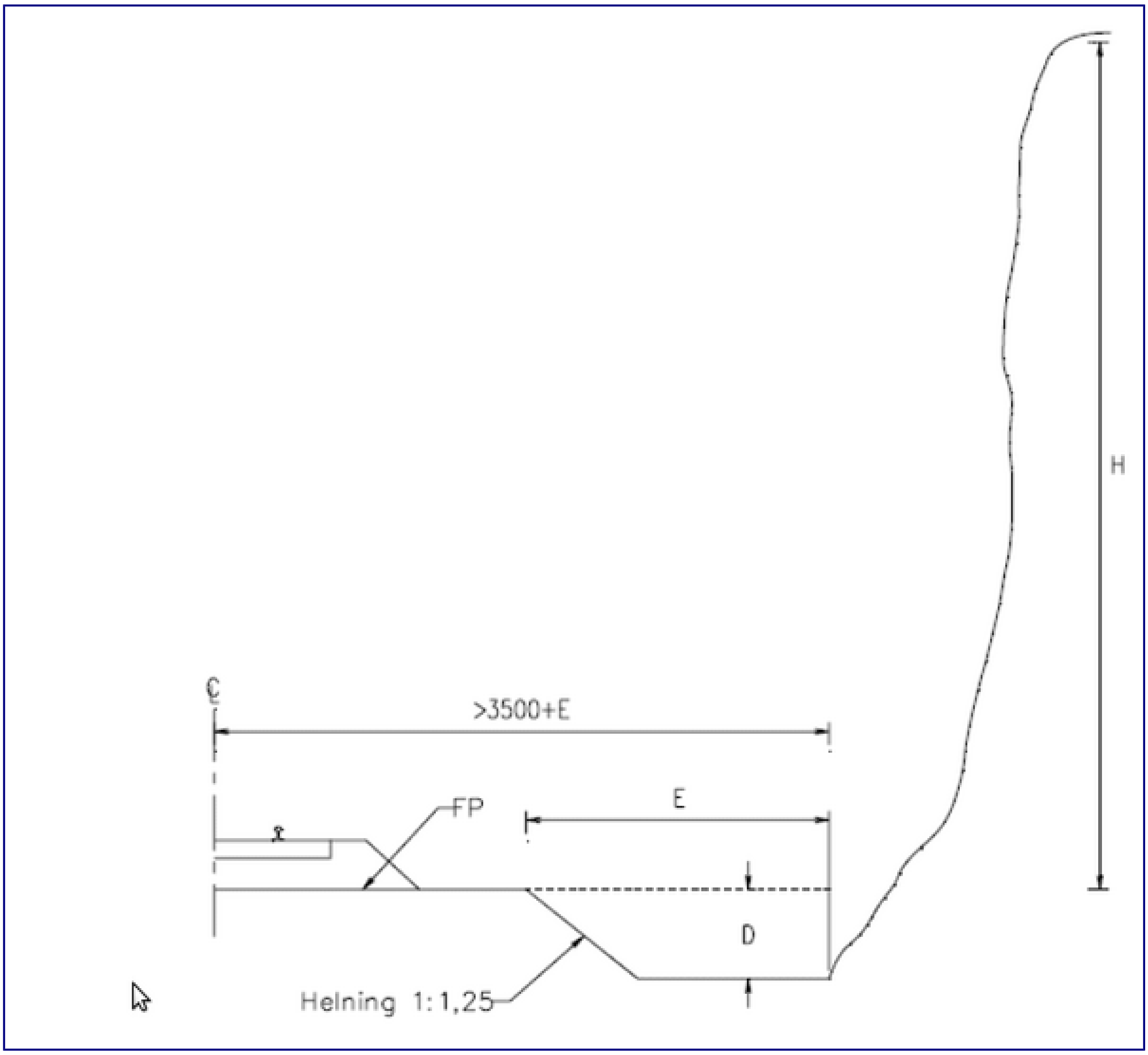
Figur 5: Adaptation of cutting slope to fracture analysis

5.1 Catchment ditch

To protect the line from falling rocks, a catchment ditch must be constructed between the cutting wall and the line. Refer to figure 6. Height H, width E and depth D may be found in table 4. Where the topography permits, the catchment ditch may also be placed up the slope at a greater distance from the line. This type of catchment ditch may be combined with a barricade of earth or stones.

In certain cases it may be appropriate to include an avalanche/landslide warning fence/catch fence at the top of the slope/cutting.

The need for an extended cutting with catchment ditch must be assessed rock quality, topography and also in relation to other methods of protection. If extensive permanent protection is used (with bolts, nets, etc.), the width and depth of the ditch may be reduced in relation to the guide values in table 4.



Figur 6: Rock slope with catchment ditches

Tabell 4: Guide dimensions for catchment ditches

Slope (α)	**Height H (m)**	**Width of ditch E (m)**	**Depth of ditch D (m)**
Vertikal	5-10	3.0	1.0
	10-20	5.0	1.5
approx. (80^{o}-90^{o})	> 20	6.5	1.5
4:1 to 3:1	5-10	3.0	1.0
	10-20	5.0	1.5
approx. (75^{o})	20-35	6.5	2.0
	> 35	8.0	2.0
2:1	5-10	3.0	1.0
	10-20	5.0	2.0
approx. (65^{o})	20-35	6.5	2.0
	> 35	8.0	3.0
4:3	0-10	3.0	1.0
	10-20	3.0	1.5
approx. (55^{o})	> 20	5.0	2.0

1:1	0-10	3.0	1.0
	10-20	3.0	1.5
(45°)	> 20	5.0	2.0

5.2 Deep blasting

In rock cuttings, continuous deep blasting (subterranean blasting) must be conducted to a frostproof depth beneath the track bed.

5.3 Implementation

Deep blasting must be conducted in such a way that it is at its deepest towards the ditch side, cross-fall approx. 1:20. This should be undertaken simultaneously with other blasting work in the cutting.

5.4 Inspection

Deep blasting must be inspected through point-by-point excavation. Fixed rock nodules higher than 0.2 m above the projected base level should not be permitted.

Requirements for inspection of the formation level are the same as for a reinforcing layer of blasted rock, cf. sections 2.5.3 and 2.6.3.

6 Sealing of side slopes and establishing grass cover

Grass cover must be established on all earth cuttings and side slopes along the ballast bed.

For environmental reasons, grass cover must also be established on stone embankments. These must then be covered with quarry sand or soil and thereafter sown.

When using blasted rock, the side slopes must always be sealed with graded gravel/stones. This should be undertaken before covering with any clay or soil, so that the clay/soil cannot penetrate the rock materials. The covering will also prevent cold air from penetrating through the side slopes of the blasted rock embankment.

Clay, soil or grass cover must be established up to 0.5 m below the formation level (FL), measured vertically.

In regions where the climatic conditions make it difficult to establish grass cover, an alternative slope protection should be selected (moss/lichen vegetation, other types of erosion protection).