GUIDELINES FOR ROAD DESIGN, CONSTRUCTION, MAINTENANCE AND SUPERVISION

Volume I: DESIGNING

Section 3: DESIGNING STRUCTURES

DESIGN GUIDELINES (DG 1.3.4)

Part 4: ANCHORED RETAINING AND SUPPORTING WALLS

INTRODUCTION

Anchored walls are up-to-date geotechnical structures enabling road planning and construction in severe geomorphologic conditions and urban settlements. Taking into account their size and cost, anchored walls essentially influence the construction progress and costs, the traffic safety and functionality, and the acceptability of planned interventions in space from the point of view of ecology and environment protection.

The use of anchored walls to secure the cuts during the road construction is relatively effective and frequent, in particular for the reliability and safety as well as for the possibility of selecting among alternative solutions, depending on the required securing degree.

The present Design Guidelines 1.3.4 are divided in nine chapters, which, beside the introductory part, discuss in detail the selection and conception, the design, geostatic analysis, construction, and supervision of construction, quality assurance and maintenance of anchored walls.

In a special chapter (9), ground anchors are discussed. They represent a special and an extremely delicate element within the group of geotechnical structures. They are situated in the ground and cannot be directly controlled due to their inaccessibility. The ground is heterogeneous, never sufficiently known and, as a rule, containing water where aggressive substances may circulate.

These Design Guidelines take account of the up-to-date professional and theoretical knowledge by planners, soil mechanical experts, designers, contractors and maintainers, of the current regulations and standards in the field of civil engineering, as well as of the European pre-standards of the geotechnical design.

C O N T E N T S

1 SUBJECT OF DESIGN GUIDELINES

The present design guidelines are intended for all participants in the processes of planning, designing, constructing, and maintaining of anchored retaining and supporting walls.

The goal of these design guidelines is to introduce, to deal with and to analyse general geo-mechanical, structural, technological, and organizing comprehensions that might essentially influence the investment process, conception, design, construction, and maintenance of anchored walls.

The present design guidelines ensure a fusion of profound theoretical and professional knowledge, of data indicated in the literature including practical experiences, technical regulations, and standards.

The design guidelines are mainly intended for construction of new anchored retaining and supporting walls. However, they are so commonly conceived as to be applicable to renewals, reconstructions, and repairs of existing anchored walls as well.

To anchored walls such supporting and retaining reinforced concrete structures belong where the structural stability and load bearing capacity are ensured by means of a tensile tie, i.e. a ground anchor, which is anchored to a load-bearing stratum. Without this element, stability and safety of the structure cannot be ensured during construction stages as well as in the service life.

Those anchored wall types are discussed, which have proven themselves as the most suitable ones, and which have been mostly used both in our and international practice. However, other anchored wall types depending on the ground morphology and geological composition of the soil are mentionable as well.

A specific anchored wall is a pile wall; this is a flexural supporting or retaining structure consisting of reinforced concrete piles of 80 cm to 150 cm in diameter. It is connected with beams by means of ground anchors or without them. Pile walls belong to structures, which, by their flexural resistance and embedment in ground, fulfil their purpose, i.e. to protect fill or cut slopes, and construction pits.

2 REFERENCE REGULATIONS

Design, construction, and maintenance of anchored retaining and supporting walls are based on the provisions of different regulations, standards, and guidelines.

The following groups of regulations shall be taken into account in constructing anchored walls on roads:
- Regulations in the field of construction and structures on the whole;
- Regulations for design, construction, use, and maintenance of roads;

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

Regulations for materials and reliability verifications of geotechnical structures;

In the field of materials, reliability verifications, and designing of retaining structures, the following rulebooks and standards from the former Yugoslavia apply:

Rulebook of technical norms for foundation of structures, Official Gazette of SFR Yugoslavia No. 15-295/90;

Rulebook of technical norms for concrete and reinforced concrete made of natural and artificial lightweight aggregate filler, Official Gazette of SFR Yugoslavia No. 15-296/90;

Rulebook of Yugoslav standards for bases of structural design, Official Gazette of SFR Yugoslavia No. 49-667/88;

Rulebook of technical norms for concrete and reinforced concrete in structures subjected to aggressive environment actions, Official Gazette of SFR Yugoslavia No. 18/92;

Rulebook of technical norms for steel wires and strands for pre-stressed structures, Official Gazettes of SFR Yugoslavia No. 41-530/85 and No. 21-276/88;

The goal of the present Design Guidelines is, among others, both comprehension and application of provisions of the European Norms also relating to the anchored retaining and supporting walls.
- EN 1990:2002 Eurocode 0 Basis of design;
- prEN 1991 Eurocode 1 Actions on structures;
- prEN 1992 Eurocode 2 Design of concrete structures;

- prEN 1997 Eurocode 7 Geotechnical design;
- prEN 1998 Eurocode 8 Design of structures for earthquake resistance;
- EN 12063:1999 Execution of special geotechnical work – Sheet-pile walls;
- EN 12699:2000 Execution of special geotechnical work – Displacement piles;
- EN 1538:2000 Execution of special geotechnical works – Diaphragm walls;
- EN 1536:1999 Execution of special geotechnical works – Bored piles;
- EN 1537:2002 Execution of special geotechnical work – Ground anchors (July 2002);
- EN 206-1:2003 Concrete-Part 1 Specification, properties, production, and conformity;

The European Norms prEN are still at the supplementing, testing and ratification stage.

3 EXPLANATION OF TERMS

Anchored wall is a retaining or supporting structure composed of reinforced concrete elements and ground anchors ensuring structural stability, load bearing capacity, and safety.

Rear side is the unexposed part of a retaining or supporting anchored wall.

Rear ground is an intact rock or soil to be retained or secured by an adequate wall.

Rear wall is the unexposed wall side in contact with the soil to be retained.

Front wall is the exposed wall side.

Front foundation toe is a part of foundation extended from the front wall.

Foundation ground is a rock or soil, into which the loading is transferred.

Wall element is a vertical load-bearing element, which makes the transfer of the rear earth pressures to the foundation ground and ground anchor feasible.

Wall inclination is the angle of the front or the rear wall to the vertical.

Crown is the retaining or supporting wall upper part.

Block is a reinforced concrete element through which the anchor force is transferred to the ground.

Column is a load bearing reinforced concrete element, placed onto the ground predominantly in vertical direction. It enables a transfer of the anchor force to the ground.

Beam is a load bearing reinforced concrete element, placed onto the ground predominantly in horizontal direction. It enables a transfer of the anchor force to the ground.

Grid structure is a system of interconnected columns and beams.

Filling element is material filling up the space between columns and beams.

Drainage is intended for an effective dewatering of the anchored wall rear, thus for preventing hydrostatic pressures.

Drain concrete, which is permeable to water, is made of an aggregate of a single grain size of ϕ 16 mm.

Drainage geo-textiles, which is permeable to water, is predominantly made of synthetic fibres or strips.

Working field is an area where an anchored wall or a wall segment is executed.

Vertical segment is a retaining or supporting wall part between vertical joints, i.e. the length of the particular construction stage.

Longitudinal stage is the height of the particular construction stage of a retaining or supporting wall.

Access road is a communication enabling access of the mechanization and transport means to the working field.

Bored pile is a cast-in-situ reinforced concrete pile executed in a preliminarily bored or excavated borehole in the foundation ground.

Pile wall is a flexural structure composed of piles and linking beam; its purpose is to protect cut and fill slopes.

Linking beam is a structural element linking pile heads in the pile wall longitudinal direction.

Intermediate anchor beam is a structural element serving to place the anchors and to link the piles in the pile wall longitudinal direction.

Filling elements between piles is a part of the pile wall structure protecting the soil between the piles.

Pile wall facing is a subsequent finishing of the pile wall exposed surface under certain circumstances.

Ground anchor is a load-bearing element capable of transmitting an applied tensile force from a structure to the load-bearing stratum.

Test anchors are anchors subjected to an assessment test.

Assessment test is an in-situ test to determine the characteristic anchor resistance.

Control anchors (measuring anchors) are installed at the anchored structure; measurements are carried out on these anchors during the service life of the structure.

Fixed anchor length is the length of an anchor over which the load is transmitted to the surrounding ground.

Free anchor length is the length of an anchor between the fixed anchor length and the tendon anchorage at the anchor head.

Anchor head is the component of a ground anchor, which transmits the tensile force from the tendon to the bearing plate or structure.

Monitoring is a series of activities required to monitor structural appearance and behaviour, with an aim to control the safety of the structure and to prolong its service life.

4 SELECTION AND CONCEPTION OF ANCHORED WALLS

Anchored walls are retaining or supporting structures composed of concrete elements and ground anchors. The latter take the entire load or a portion of the load to ensure both safety and stability at all the construction stages as well as in the service life. The function of concrete elements, such as blocks, columns, beams, grid, wall, etc., is to ensure the load transfer from anchors to the ground, and to protect the slope locally.

On the basis of preliminary acquired soil mechanical and other characteristics of the ground, structural designer conceives an anchored wall structure. For this purpose the following shall be taken into account:
- reliability,
- serviceability,
- construction conditions,
- economy,
- aesthetic appearance and landscaping features.

In the technical report on the conceived anchored wall, the available bases, selection of the structure, stability verifications, and feasible construction methods shall be appropriately explained.

The selection, conception, and constructive solution of anchored walls shall follow hydro-geological properties of soil, shape and size of the cut, as well as contractor’s available mechanization and equipment.

Anchored wall can be executed in two ways. In case of a soil of a high load bearing capacity, anchored walls are constructed directly onto the excavated slope. Where a soil of a low load bearing capacity is in question, anchored wall shall be executed from above downwards. The height of an excavation stage depends on the soil properties and structural type.

Both conception and selection of the constructive solution of an anchored wall are directly connected with the soil quality/properties at the wall location. In view of that, anchored walls can be divided in the following types:

- anchored blocks (Fig. 4.1)
- anchored columns (Fig. 4.2)
- anchored columns with filling elements in-between (Fig. 4.3)
- anchored beams (Fig. 4.4)
- anchored columns and beams – grid structure (Fig. 4.5)
- anchored columns and beams – grid structure with filling elements in-between (Fig. 4.6)
- anchored walls (Figs. 4.7, 4.8)
- special anchored walls constructed from above downwards (Fig. 4.9)
- anchored pile walls (Figs. 4.10, 4.11, 4.12).

The sequence of the abovementioned wall types corresponds to a decrease of soil mechanical properties of the ground, thus to an increase of complexity of cut protecting measures.

All the aforementioned wall types can be executed either by the cast-in-situ or pre-cast/cast-in-situ construction method.

A typical feature of the wall types listed from the first to the fifth line above is that they are not founded habitually.

A stage to follow the selection of the structure is to verify, whether it is realistic to execute the selected structure at the location foreseen. In addition to adequate stability analyses and drawings, the structural designer shall work out and suitably check the fundamental technological conditions of the wall construction. For this purpose, all the procedures required to construct a certain anchored wall type shall be analysed. The following shall be foreseen:

- possible access roads,
- working fields for construction,
- earth works technology including adequate protection,
- protection from factors, which impede the construction or make it more difficult (rear water inflow, unstable sandy slope layers, etc.),
- ensuring traffic flow and functioning of other infrastructural flows,
- feasibility of construction in stages in the spirit of defining the access/starting point and the work progress direction,
- mandatory method statements for the individual construction stages,
- definition of appropriate details as well as of solutions in connection with those details,
- requirements in connection with the current quality control of materials and building-in the materials,
- requirements in view of survey control.

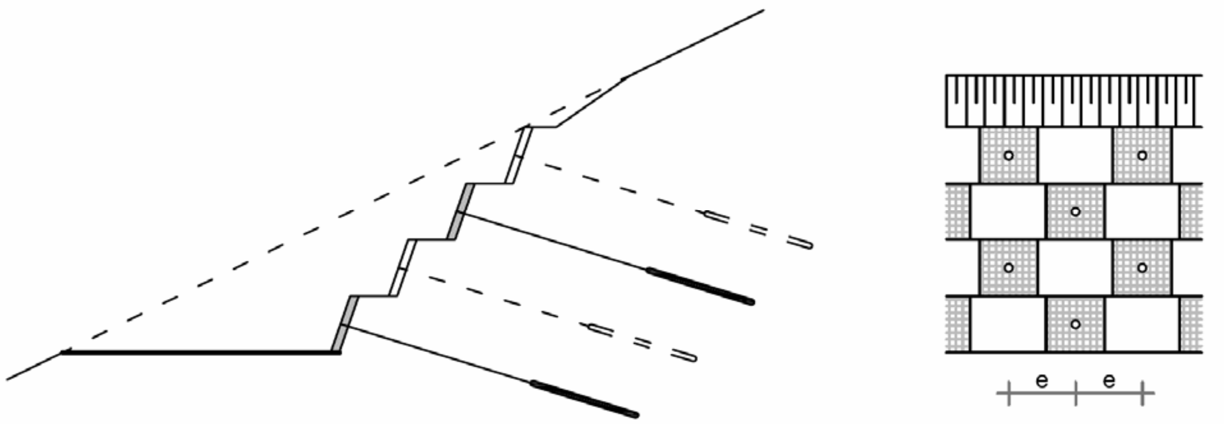


Fig. 4.1: Anchored blocks

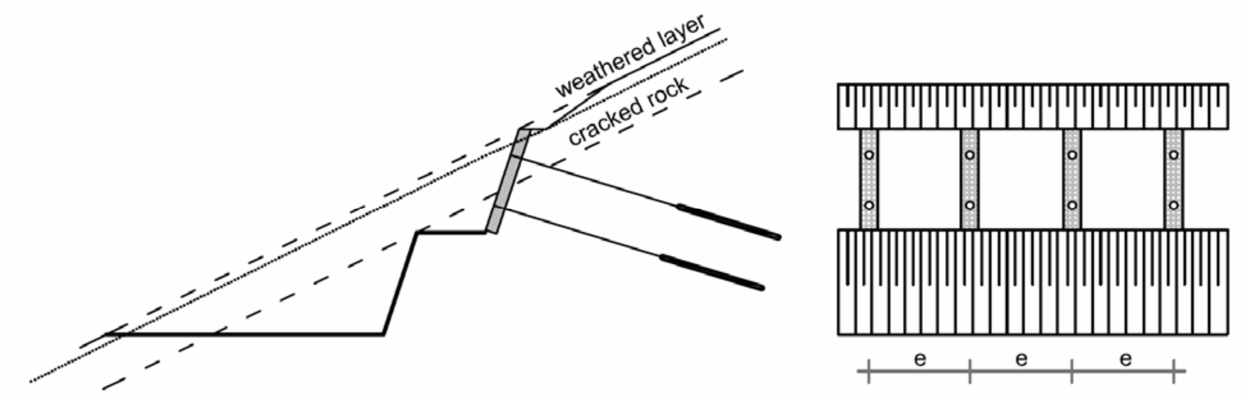


Fig. 4.2: Anchored columns

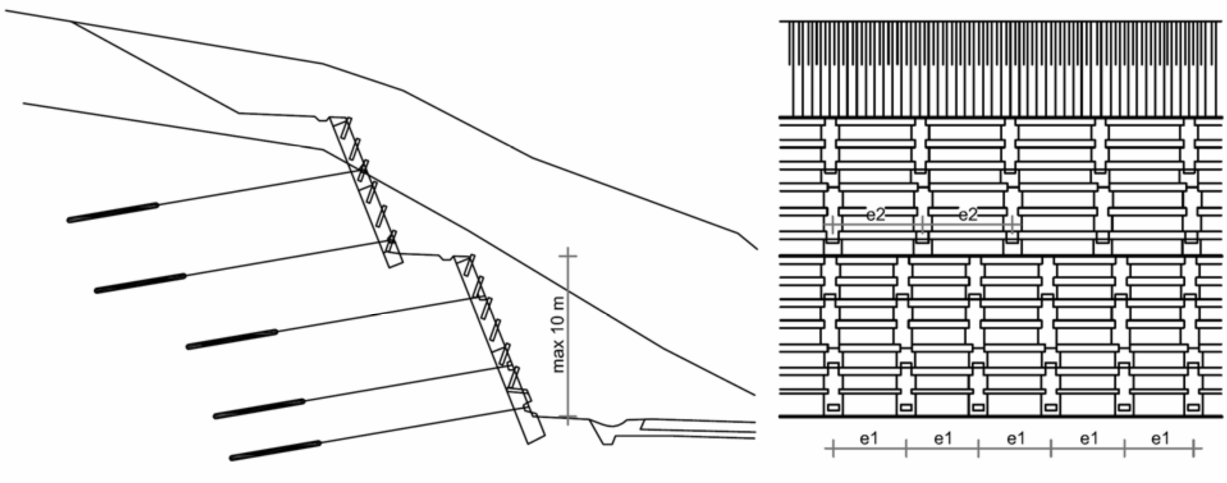


Fig. 4.3: Anchored columns with filling elements in-between

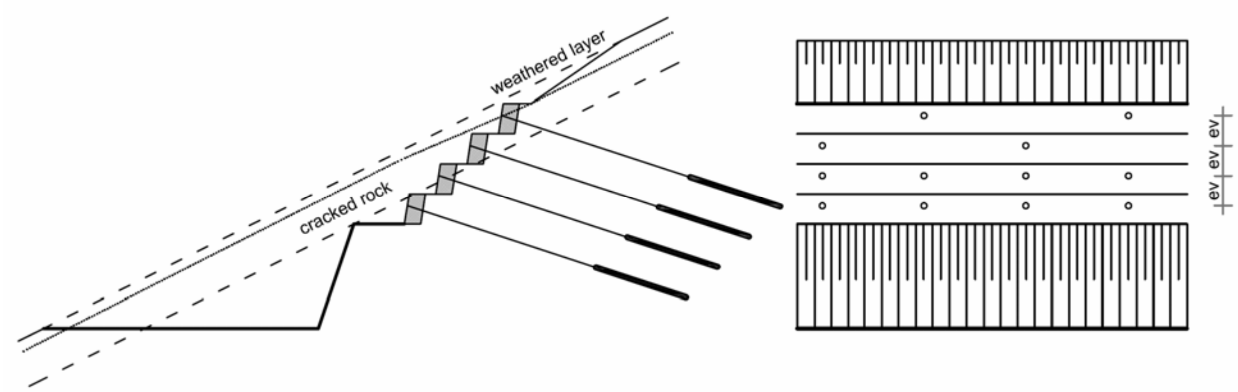


Fig. 4.4: Anchored beams

4.1 Anchored Blocks

Anchored reinforced concrete blocks of different shapes, over which the anchor force is transferred into the ground, are used in case of relatively solid rocks and semi-rocks. They are intended to reduce a natural slope angle and to ensure the slope overall stability.

The space between the blocks is protected by suitable vegetation.

4.2 Anchored Columns

Anchored reinforced concrete columns of different sections, placed onto the ground approximately vertically, enabling transfer of the anchor force into the ground, are used for cracked rocky slopes, where protective meshes do not provide sufficient safety.

An overall stability and safety are ensured by means of anchored columns. A local safety can be ensured either by protective meshes or shot cement concrete, depending on rock properties in view of erosion, and local stability.

4.3 Anchored Columns With Filling Elements In-Between

Anchored reinforced concrete columns of different sections, placed onto the ground approximately vertically, with reinforced concrete filling elements placed in-between, are used for cracked rocks, where protective meshes do not provide sufficient safety, and where it is intended to increase the natural angle of the slope.

Load bearing capacity, an overall stability, and safety are ensured by means of anchored columns, whilst the local safety and protection of the slope from erosion are attained by the help of pre-cast reinforced concrete horizontal filling elements or packed rock-fills placed between the columns.

The height of anchored columns shall be up to 10 m.

4.4 Anchored Beams

Anchored reinforced concrete beams of different sections, placed onto the ground approximately horizontally, enabling transfer of the anchor force into the ground, are used in cases of cracked rocky slopes, where protective meshes do not provide sufficient safety.

Anchored beams are used in cases, where anchored columns could become too dense and therefore ineffective. They are suitable to less solid rock, ensuring a continuous transfer of the anchor force.

In contract to anchored walls, anchored beams are 0.80 m to 1.50 m high and without any foundations. Their purpose is to protect either the entire slope or only the unstable part of the cut or slope (e.g. tunnel portals).

4.5 Anchored Columns And Beams – Grid Structure

Anchored reinforced concrete columns of different sections, placed onto the ground approximately vertically, and anchored reinforced concrete beams of different sections, placed onto the ground approximately horizontally, interconnected to a grid structure, are used in case of cracked rocks, where protective meshes do not provide sufficient safety, and where it is intended to reduce the natural angle of the slope.

An overall stability and safety are ensured by means of such an anchored grid structure, whereas the local safety is provided either by the help of protective meshes or by applying shot cement concrete to the entire surface, depending on rock properties in view of erosion, and local stability.

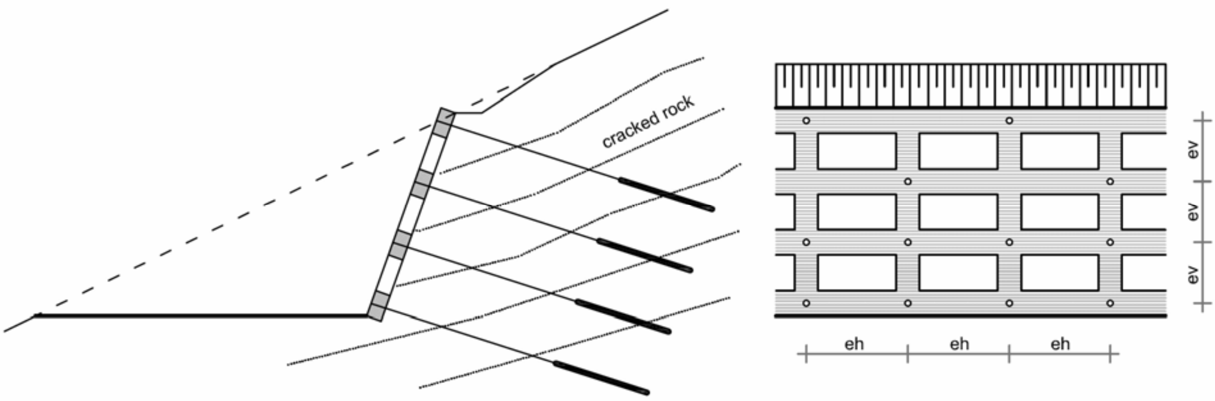


Fig. 4.5: Anchored columns and beams – grid structure

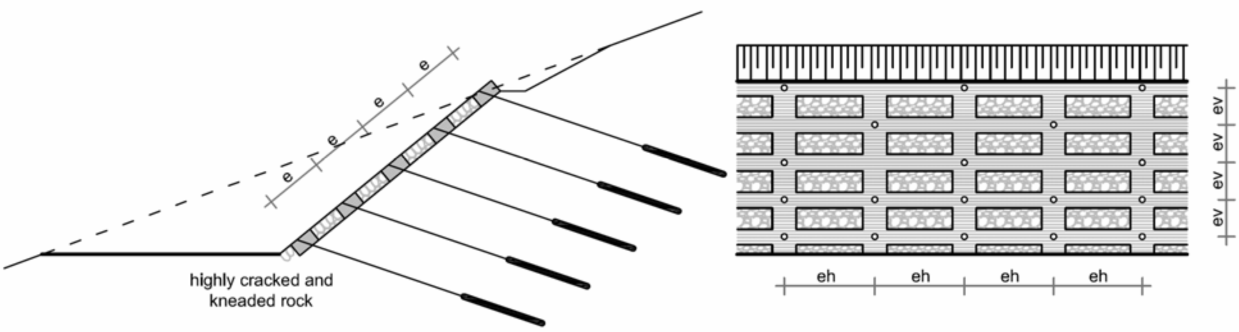


Fig. 4.6: Anchored columns and beams – grid structure with filling elements in-between

4.6 Anchored Columns And Beams – Grid Structure With Filling Elements In-Between

Reinforced concrete columns and beams interconnected to a grid structure containing filling elements in-between are used for soils relatively favourable in view of geology (weathered rock), highly cracked and kneaded rocks and semi-rocks (Permian-Carboniferous rock, flysch, marl), where a slope shall be protected locally.

These retaining wall types are used, where it is intended to increase the natural inclination of a cut. By such a grid structure, the overall stability is ensured.

By means of the filling elements between the columns and beams, slope erosion is prevented, local stability ensured, and drainage of the rear made feasible. The inclination of the entire structure depends on the soil or rock properties. When a weathered rock is in question, the inclination shall not exceed 45°. In case of cracked kneaded rock and semi-rocks, the inclination of the structure depends on the excavation inclination that can still be carried out within the required safety limits.

The selection of the type and method of placing the filling elements between the columns and beams also depend on the properties of the rear soil, as well as on the available material to be used as filler.
An extremely cracked and kneaded rock shall be protected my means of a stone retaining wall. In such a case, the rear is usually permeable thus it is not necessary to foresee any drainage.

Where a weathered rock is in question, a packed rock-fill on a drain cement concrete shall be used as filling element between columns and beams.

The columns and beam spacing depends on the properties of the rear soil and the wall height. However, the column spacing shall not exceed 6 m, whereas the beam spacing shall not be greater than 4 m.

An individual wall shall not be higher than 10 – 12 m, depending on its inclination. In case that a higher structure is required to protect a cut, it shall be executed in two parts with a berm in-between, in order to ensure proper drainage and maintenance of the wall. The berm width shall amount to at least 3 m.

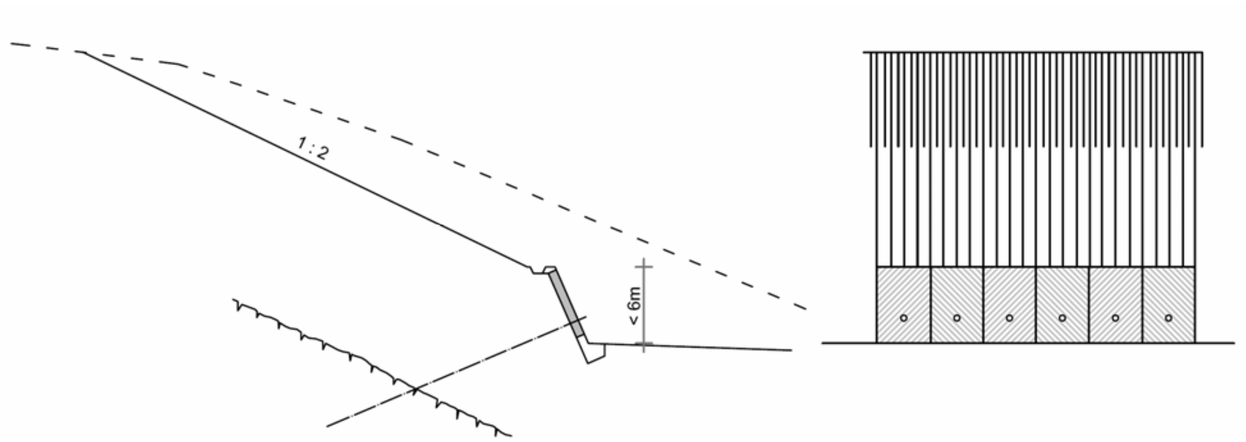


Fig. 4.7: Anchored wall

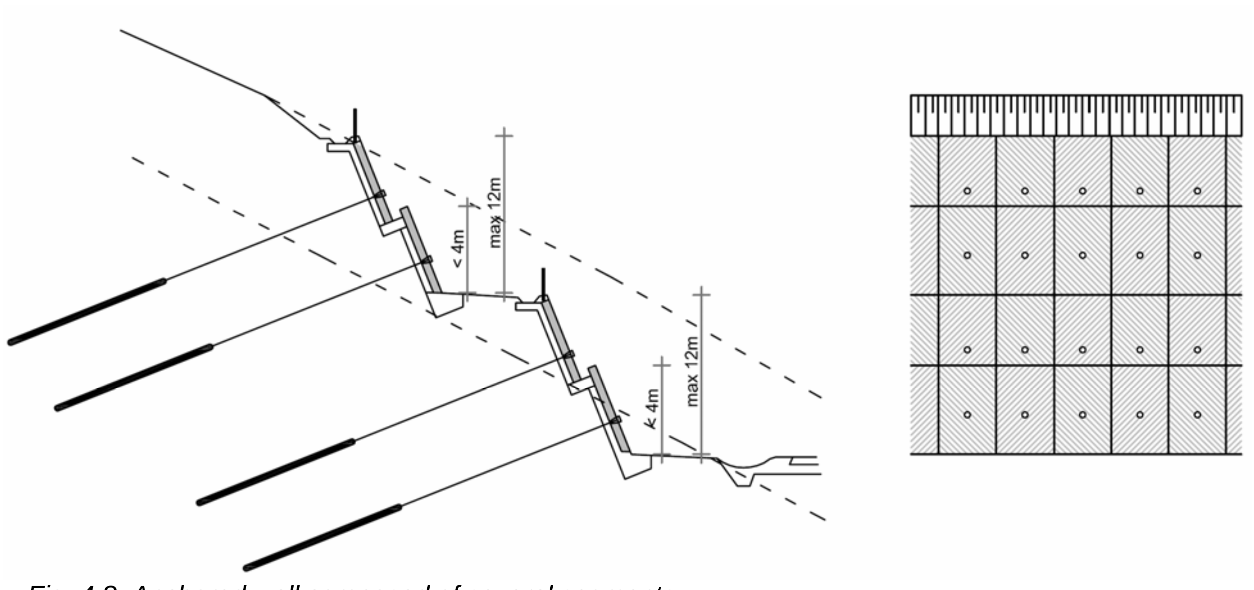


Fig. 4.8: Anchored wall composed of several segments

4.7 Anchored Walls

Anchored cast-in-situ and/or pre-cast/cast-in-situ reinforced concrete walls are used in case of non-cohesive and cohesive soils.

A wall can be composed of several longitudinal stages located one above another. If the wall height does not exceed 6 m, one level of longitudinal stages is sufficient.

Walls higher than 6 m are executed of two or three levels of longitudinal stages. Each individual horizontal segment level can be up to 4 m high, whilst the total height of the corresponding wall part can amount to 10 – 12 m maximum. The wall total height depends on the height of the required slope protection.

Between individual levels of horizontal segments up to 1 m wide stairs shall be foreseen, serving the construction, dewatering, and maintenance of the structure.

If the slope height exceeds 10 – 12 m, a berm of 3 m in width shall be designed between the individual wall parts. The berm serves the construction, dewatering, and maintenance of the structure.

The anchored wall thickness shall amount to 40 cm minimum (to allow transfer of the anchor force) and 60 cm maximum.

When anchored prefabricated slabs are foreseen, one shall take account of their weight, as they shall be brought to the site and erected. The slab dimensions are also limited for transport reasons.

In this type of anchored walls, the foundation is only required for the erection at the construction stage.

4.8 Special Anchored Walls Constructed From Above Downwards

This anchored wall group is used in case of protecting slopes of non-cohesive and cohesive soils of medium grade.

A basic feature of this wall type is a limitation of horizontal segments to 3 m maximum due to less favourable soil properties as in case of anchored walls.

The construction of such walls commences on the top of the wall and ends with the foundation, thus one can speak about a very complex execution method.

The walls are constructed of horizontal segments in several levels of a maximum height of 3 m, and in sections of a maximum length of 6 – 7 m. In an individual vertical segment the works can be carried out on several sections by skipping according to a chessboard system.

For aesthetical appearance and functionality the height of such walls is limited to approximately 10 m. Where a greater wall height is required to protect a cut, first an intermediate berm shall be foreseen, followed by execution of one of the aforementioned wall types.

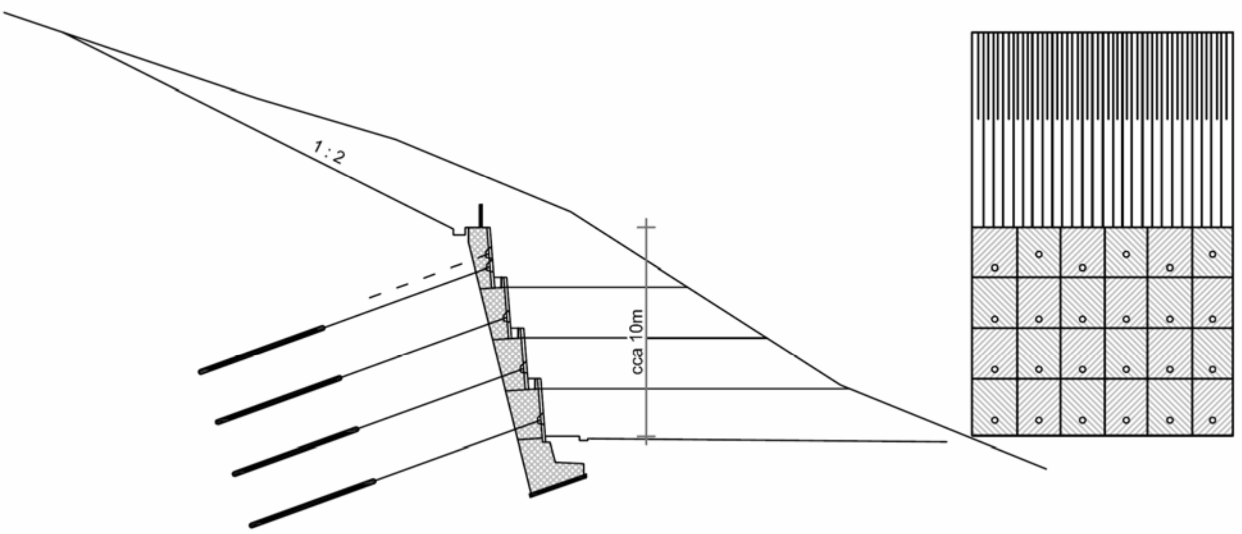


Fig. 4.9: Anchored wall constructed from above downwards

4.9 Pile Walls

Pile walls are flexural structures consisting of reinforced concrete circular piles of 80 – 150 cm in diameter. They are used to protect cut slopes, fill slopes, deep construction pits, and in cases where, due to a potential instability of the ground, it is necessary to build-in a supporting/retaining structure in the ground prior to carrying out the excavation. Pile walls are often anchored.

Pile walls are expensive structures, complex in execution, and demanding for maintenance due to limited ground anchor durability. Therefore, the decision, whether to foresee them or not for protection of a fill slope or a cut slope, shall be justified and made at an early stage of the road design.

Both selection and argumentation of introducing a pile wall shall be mutually made by road designer, expert in soil mechanics, and structural designer. To make an adequate decision, sufficient geomorphologic bases shall be available, and at least two alternative solutions shall be worked out.

In view of their position or in which way they take the load, pile walls can be divided in
- supporting walls protecting or supporting the fill or the slope below the road, and
- retaining walls protecting the cut slope above the road.

With regard to how they take horizontal forces, pile walls can be divided in the following types:

- **pile walls without anchors** are structures, which protect a cut slope or a fill slope only by their embedment in ground and flexural resistance – cantilever wall;

- **pile walls with anchors on top** are structures, which protect a cut slope or a fill slope by their embedment in ground, flexural resistance, and ground anchors located on the top of the pile wall;

- **multiple-anchored pile wall** is a structure, which protects a cut slope or a fill slope by its embedment in ground, flexural resistance, and ground anchors placed in several levels.

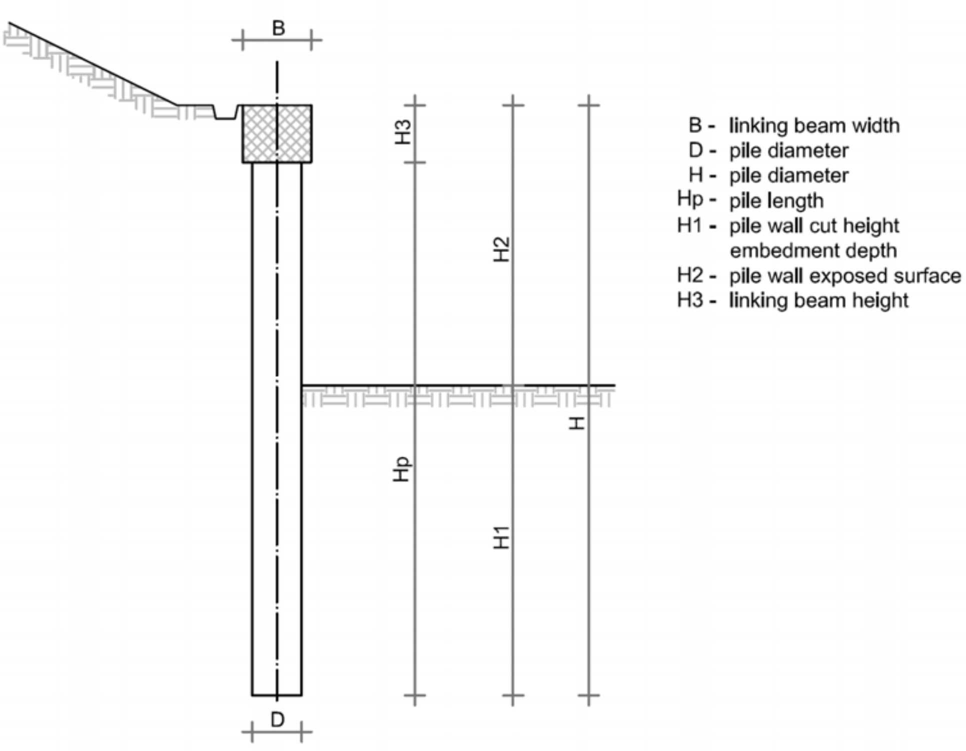


Fig. 4.10: Pile wall without anchors

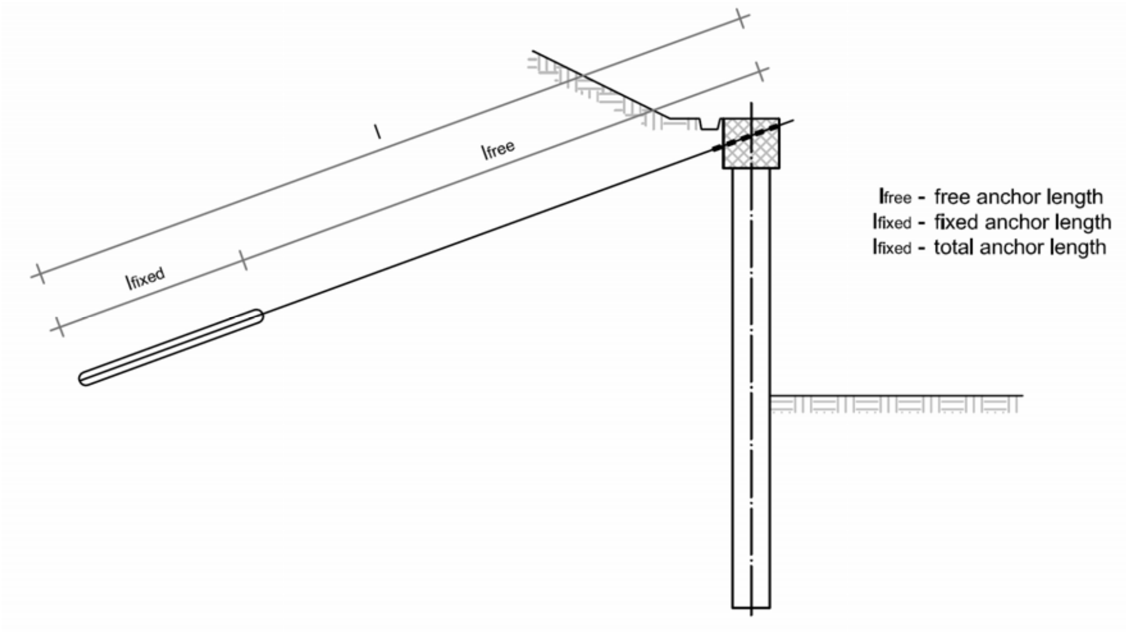


Fig. 4.11: Pile wall with anchors on top

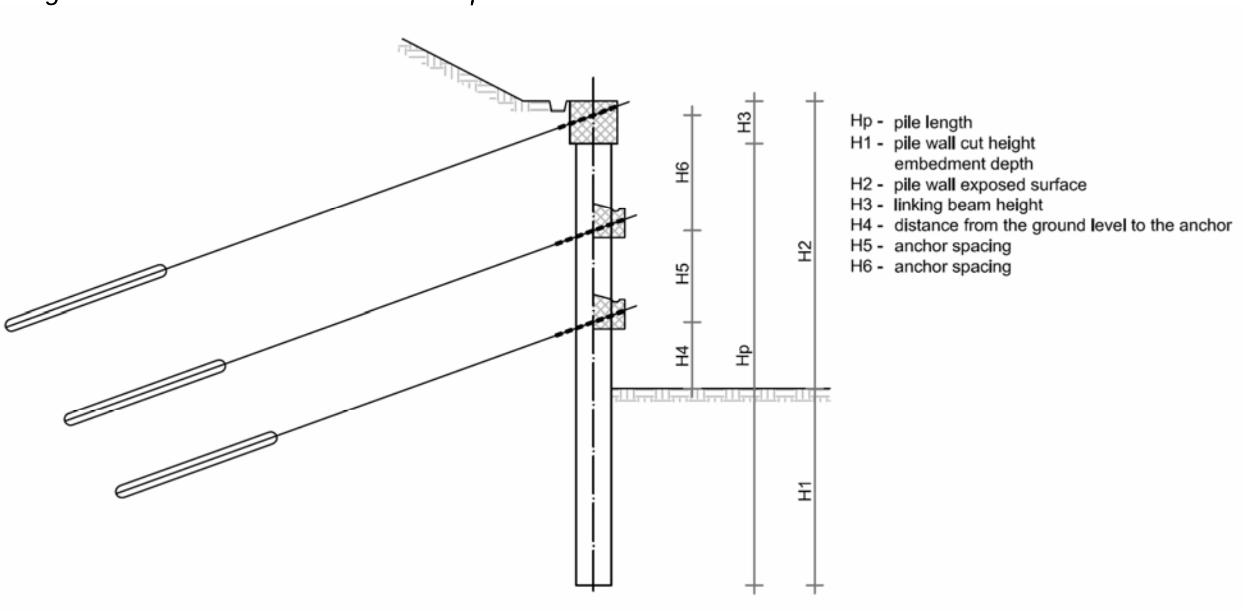


Fig. 4.12: Multiple-anchored pile wall

5 ANCHORED WALL DESIGN

5.1 General

The constructional conception of anchored walls results from the fact that ground anchors take the horizontal force, whilst the concrete structure is a base for realization of pressures and forces.

Typical feature of anchored walls is that they are constructed by contact concreting. Therefore it is impossible to carry through a usual drainage of filter layers behind the wall, as this is the case in gravity walls. For this purpose, drainage concrete made of single grain size aggregate, or drainage geo-textiles are placed behind the wall.

Drainage geo-textiles also prevent mixing of concrete and soil during contact concreting. In case that there is a great amount of water at the wall rear, horizontal drainages shall be executed into the slope and connected with the wall drainage system.

Slopes protected with anchored walls shall be adequately dewatered. For this purpose, channels or ditches shall be foreseen on the top of the wall and on the top of eventual vertical segments. The entire drainage shall be designed in compliance with the hydrological and hydrotechnical data.

Special attention shall be paid to how the gutters/channels and ditches are led on steep slopes at wall terminations. The ditches shall be made of such materials and be of such shapes as to ensure a normal and continuous water flow, and to dissipate the water energy as much as possible.

The number of ground anchors shall be as small as possible. The maximum anchor bearing capacity shall be such as it is admitted by the grade of the retained/supported ground behind the wall.

Concrete of at least C25/30 (MB30) grade and exposure class XC2 (OMO) shall be used for anchored walls. The concrete shall be waterproof. Steel reinforcement of at least S400 (RA 400/500) grade is required.

Where an anchored wall is located at the carriageway, the concrete exposure class shall be at least XF2 (OSMO). The wall surface shall be coated with an epoxy coating to increase the concrete resistance to frost and de-icing salt. The coating shall be applied from the lower exposed edge of the wall up to a height of at least 3.0 m.

There are many alternative solutions of anchored walls in view of their conception, purpose, and execution. The solutions indicated herein, i.e. from an anchor block to anchored walls, are the most frequent ones in Slovenia and neighbouring countries.

On the basis of principles and conceptions presented it is possible to design several types of anchored structures for high cuts of different geological – soil mechanical profiles and slopes.

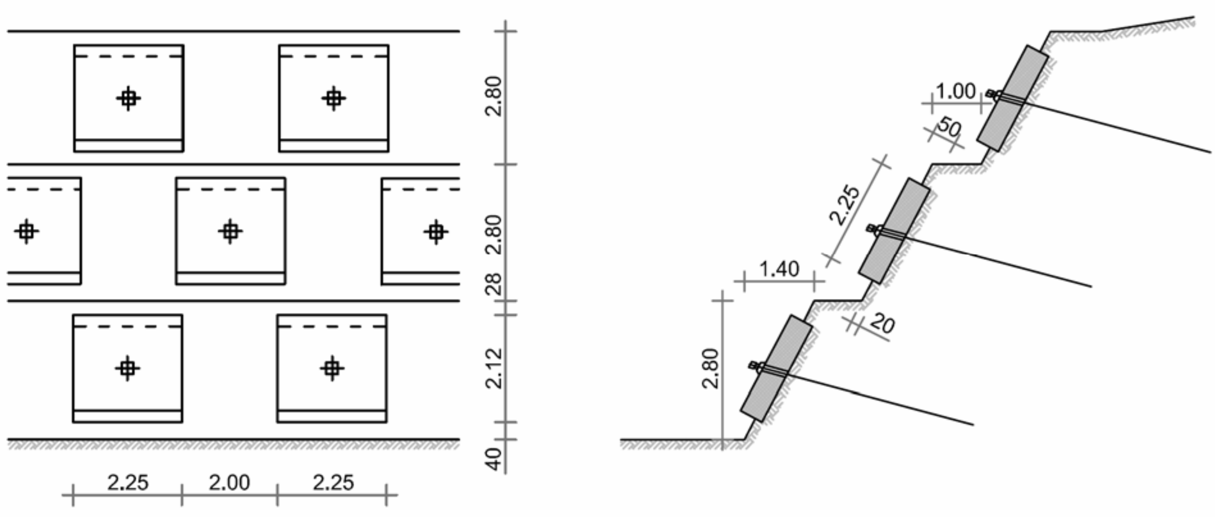


Fig. 5.1: Rectangular anchored block

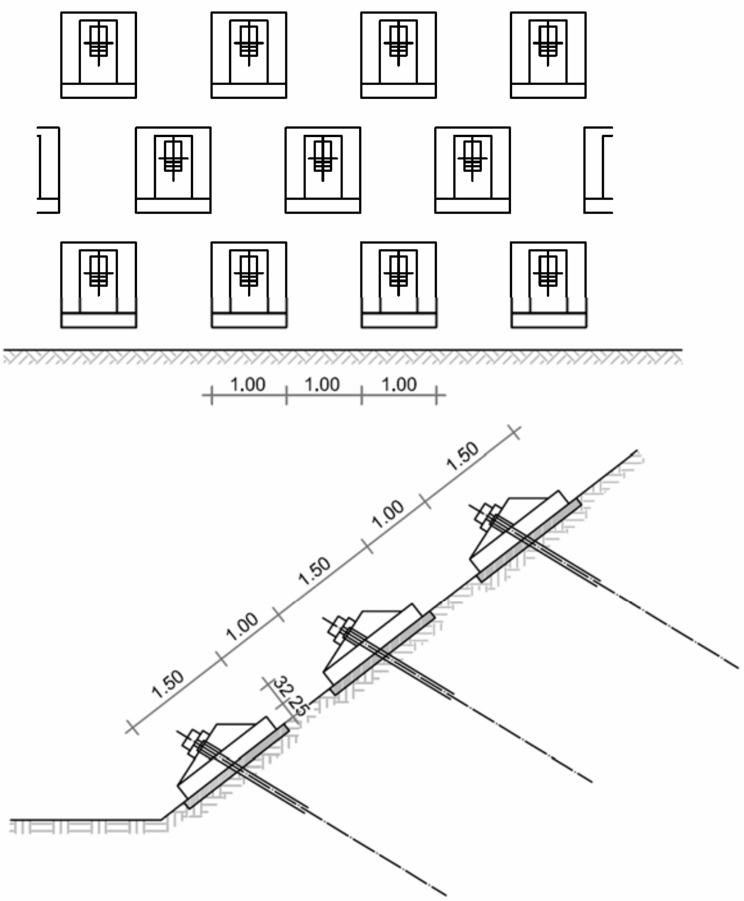


Fig. 5.2: Three-sided prismatic anchored block

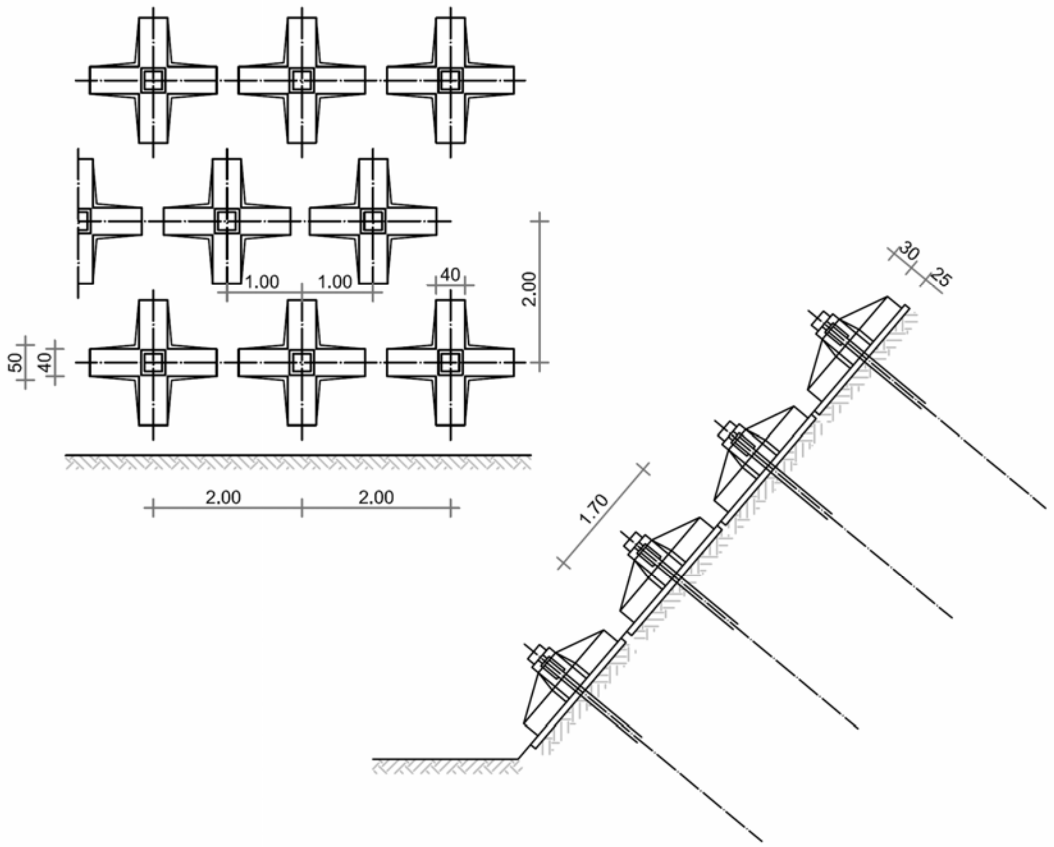


Fig. 5.3: Starry anchored block

5.2 Designing Anchored Blocks

Anchored blocks are reinforced concrete elements, which dimensions are determined by the admissible contact stresses in ground, the anchor force magnitude, and the required dimensions for the anchor installation.

The blocks are either prefabricated or cast-in-situ.

The design shall take account of a uniform transfer of the load into the load-bearing stratum. This means that the anchor force shall almost coincide with the centre of gravity of the contact surface.

The anchor head can be either “plunged” into the anchored block or “pulled out” to the block surface. The advantage a drawn out anchor is a simpler formwork erection and reinforcement placing, the concrete section is not weakened, and the transfer of the anchor force to the block is better.

Pre-cast blocks shall be placed to a surface levelled by means of an approx. 10 cm thick concrete underlay.

An anchored block can be of different shapes: square, rectangular, circular, elliptical, or starry (Figs. 5.1, 5.2, and 5.3).

5.3 Designing Anchored Columns

Anchored columns are reinforced concrete elements, which dimensions, arrangement, and inclination are determined by the slope geological – soil mechanical properties, contact stresses, anchor force magnitude, the required dimensions for the anchor installation, and the execution method.

Columns are mainly constructed in-situ. If allowed by the slope properties, access roads, and required mechanisation, they can also be prefabricated.

The column spacing depends of the slope properties and varies between 2 and 6 m.
The column cross sectional dimensions depend on the anchor head installation method. In case of a “plunged” anchor head, the dimension w/h = 80/80 cm. When an anchored head is “pulled out” to the surface, the dimension w/h shall amount to 40/40 cm. For in-situ columns it is necessary to place a column by 15 – 20 cm into the slope. Contact concreting shall be carried out onto an approx. 10 cm thick concrete underlay (Fig. 5.4).

For prefabricated columns the contact surface shall be so prepared as to enable a full contact over the entire contact surface. This is usually attained in such a way that a void between the ground and the column is left upon the slope erection, followed by filling up the void with lean concrete, which is also used to place the underlay.

In a less solid soil where shot cement concrete is used to protect the slope between blocks, the latter are placed or cast onto the shot cement concrete layer.

5.4 Designing Anchored Columns With Filling Elements In-Between

Dimensions, arrangement, inclination, anchor force magnitude and execution method of this anchored wall group depend on the same factors as indicated in 5.3 above. The only difference is that anchored columns with filling elements in-between can be used in slightly less favourable soil mechanical conditions, where the space between columns shall be protected. This can be achieved by shot cement concrete, with or without steel reinforcement (Fig. 5.5).

Where a weathered slope is in question and certain aesthetics is longed for, pre-cast reinforced concrete elements can be used as fillers, enabling placing topsoil and grassing of exposed areas. The dimensions of prefabricated elements depend on the column spacing and slope properties (Fig. 5.6).

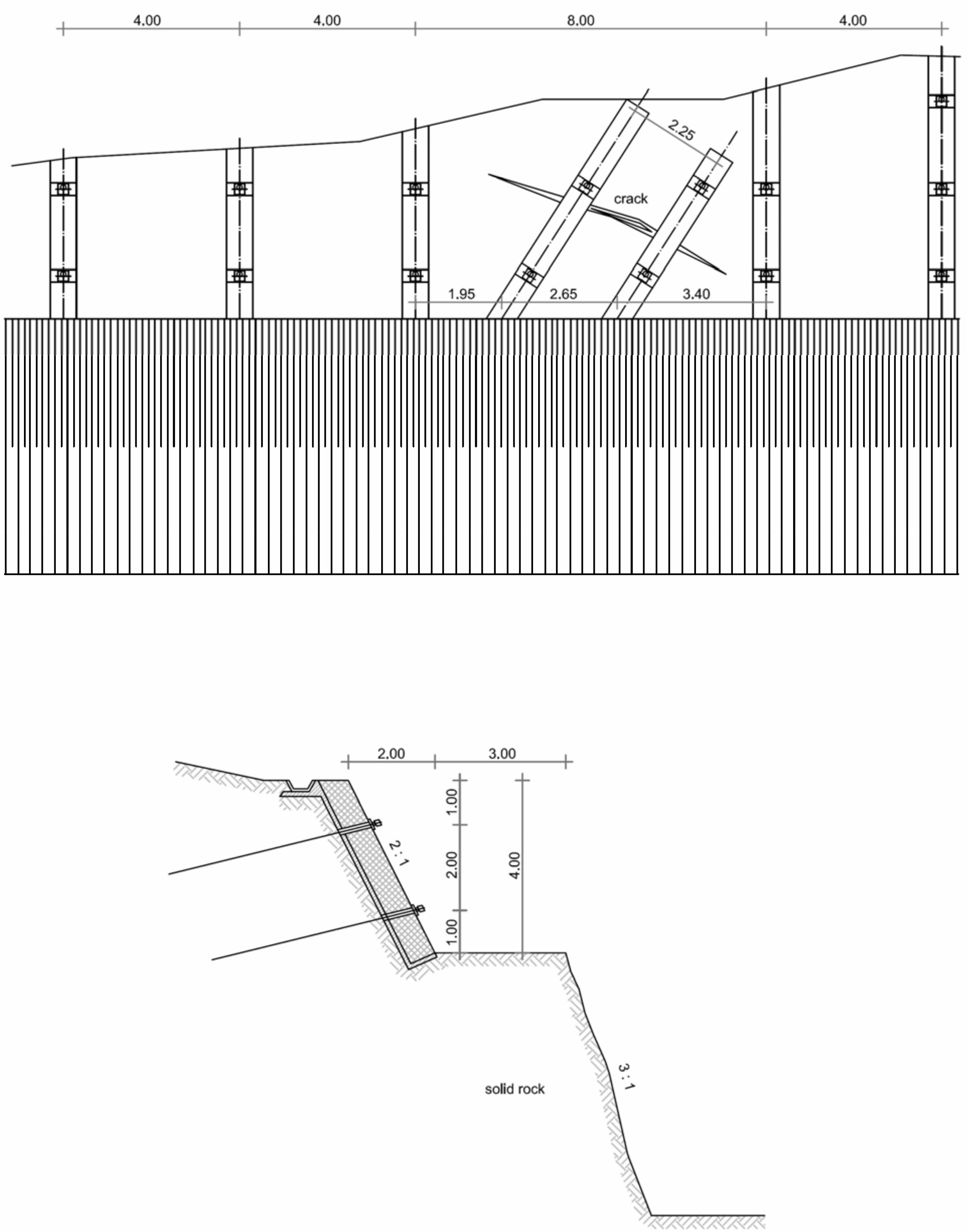


Fig. 5.4: Anchored columns

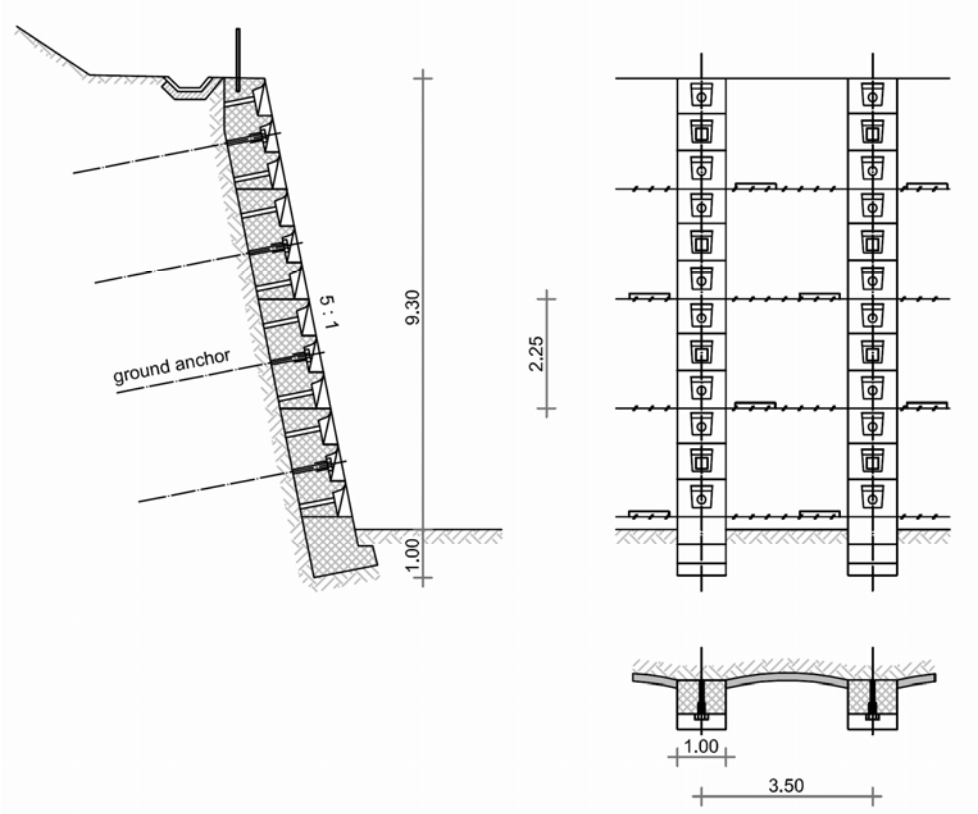


Fig. 5.5: Anchored columns with shot cement concrete in-between

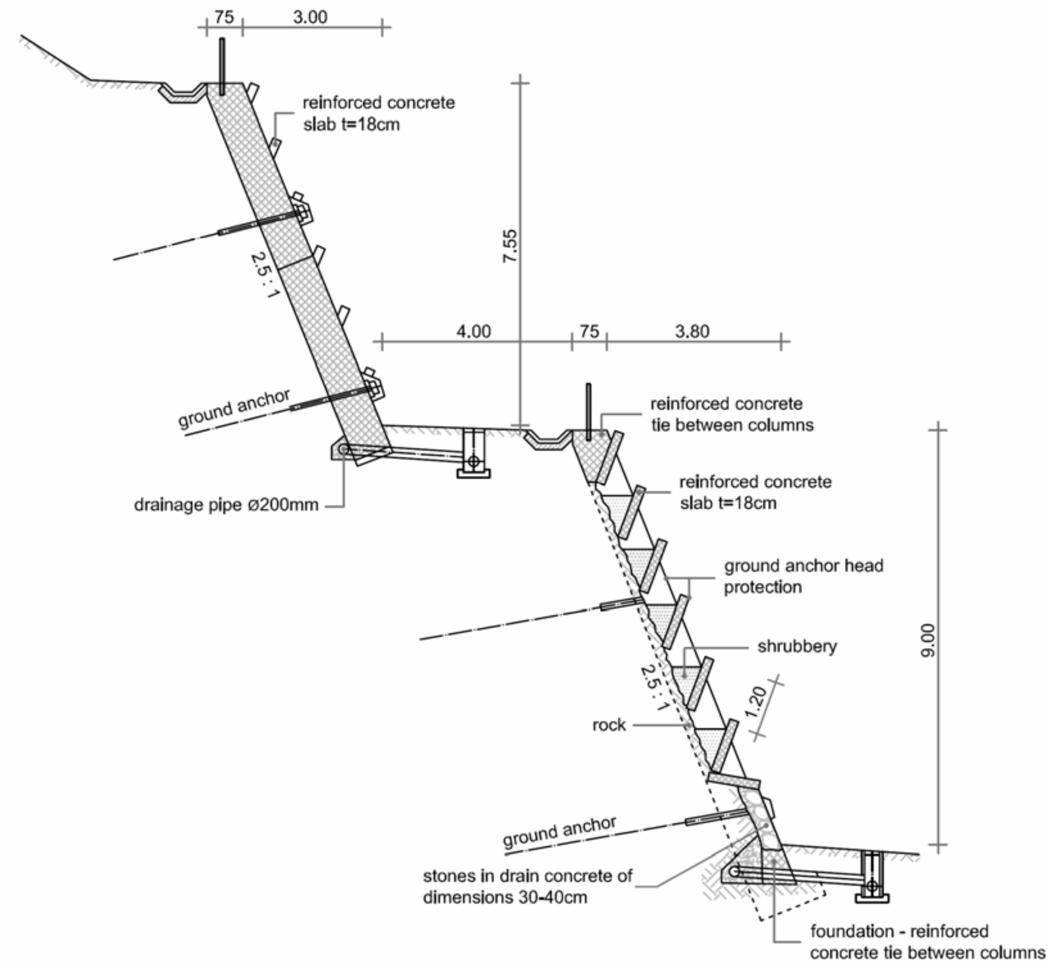


Fig. 5.6: Anchored columns with reinforced concrete slabs in-between

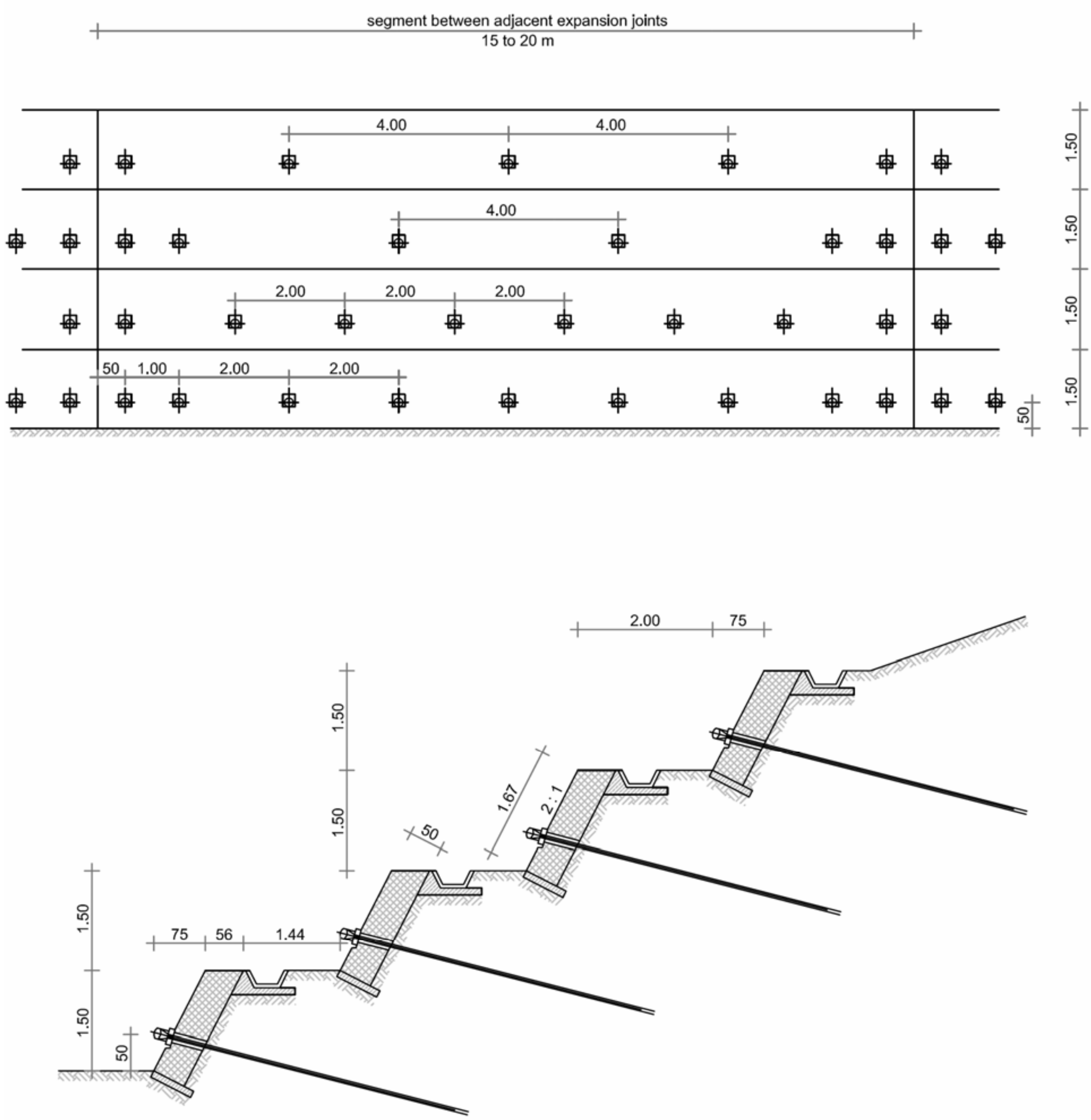


Fig. 5.7: Anchored beams

5.5 Designing Anchored Beams

Anchored beams are reinforced concrete elements, which dimensions, arrangement, and inclination are determined by the slope geological – soil mechanical properties, contact stresses, anchor force magnitude, necessary dimensions for the anchor head installation, and the execution method (Fig. 5.7).

Beams are mainly cast-in-situ, but can also be prefabricated. The length of cast-in-situ beams is theoretically unlimited; therefore, their efficiency is greater as well. On the contrary, pre-cast elements are limited both by dimensions and weight.

The beam height amounts to 0.80 – 1.50 m, whereas its thickness is 30 – 60 cm, depending of the anchor head type.

Cast-in-place anchored beams shall be laid by 15 – 20 cm into the slope. Contact concreting shall be carried out onto the base levelled by means of shot cement concrete.

Where the slope is locally so stable as not to require any protection with shot cement concrete, geo-textiles shall be stretched over the beam rear, thus preventing mixing of soil with concrete.

For an easier and less complex reinforcing, and to achieve continuous loading and stresses, it is recommended to foreseen anchor heads “pulled out” to the beam surface.

Such structure is usually used at such locations and in such conditions, where no ground water can be found behind the wall. Therefore, no drainage is required on the beam rear side.

On the top of each beam, a gutter of suitable dimensions shall be foreseen to drain away surface water above the wall.

5.6 Designing Anchored Columns And Beams – Grid Structure

Anchored columns and beams, i.e. a grid structure, are reinforced concrete elements, which dimensions, arrangement, and inclination are determined by slope geological – soil mechanical properties, contact stresses, anchor force magnitude, required dimensions for the anchor head installation, and the construction method (Fig. 5.8).

Grid structures can be executed easiest and best in-situ.
The column and beam cross sectional dimensions depend on the anchor head installation method. In case of a “plunged” anchor head, the dimension w/h = 80/80 cm. When an anchored head is “pulled out” to the surface, the dimension w/h shall amount to 40/40 cm.

The columns spacing shall amount to 3 – 6 m, whilst the beam spacing shall be 2 – 5 m.
Ground anchors shall be foreseen at intersections of columns and beams. The required additional anchors and holes for spare anchor shall be executed at interspaces.

Both columns and beams shall be constructed on a suitably prepared concrete underlay base.

Such structures are usually used at such locations and in such conditions, where no ground water can be found behind the wall. Therefore, no drainage is required on the column and beam rear side.

On the top of each beam and on the top of eventual berm, a gutter of suitable dimensions shall be foreseen to drain away surface water above the wall.

For an easier and less complex reinforcing, and to achieve continuous loading and stresses, it is recommended to foreseen anchor heads “pulled out” to the beam or column surface.

Where the slope is insufficiently stable, the space between columns and beams shall be protected by means of shot cement concrete.

5.7 Designing Anchored Columns And Beams – Grid Structure With Filling Elements In-Between

Dimensions, arrangement, column and beam spacing, anchor force magnitude, and execution method depend on the same factors as indicated in 5.6 above. The only difference is that anchored columns and beams with filling elements in-between can be used in slightly less favourable soil mechanical conditions, where the space between columns and beams shall be protected from slips and weathering. Here, the inclination of the structure is smaller than in structures without filling elements (Fig. 5.9).

As filling elements between beams and columns, packed rock-fills made of autochthonous stone placed to drain concrete shall be foreseen. The stone dimensions shall vary from 40 to 70 cm, whereas the drain concrete thickness shall amount to at least 80 cm. At a depth of 10 – 15 cm, surface joints between stone blocks shall be filled up with turf or cement mortar.

Vertical columns are cast onto the concrete underlay, whilst beams, same as packed rock-fill, are concreted onto the filter concrete enabling an optimum draining away the rear water. At the lowest point of the wall, i.e. at the wall toe, a drainage pipe shall be led throughout the entire wall length. At a minimum spacing of 30 m, the drainage shall be linked to the inspection shaft in front of the wall; these shafts are connected with the drainage of the entire wall.

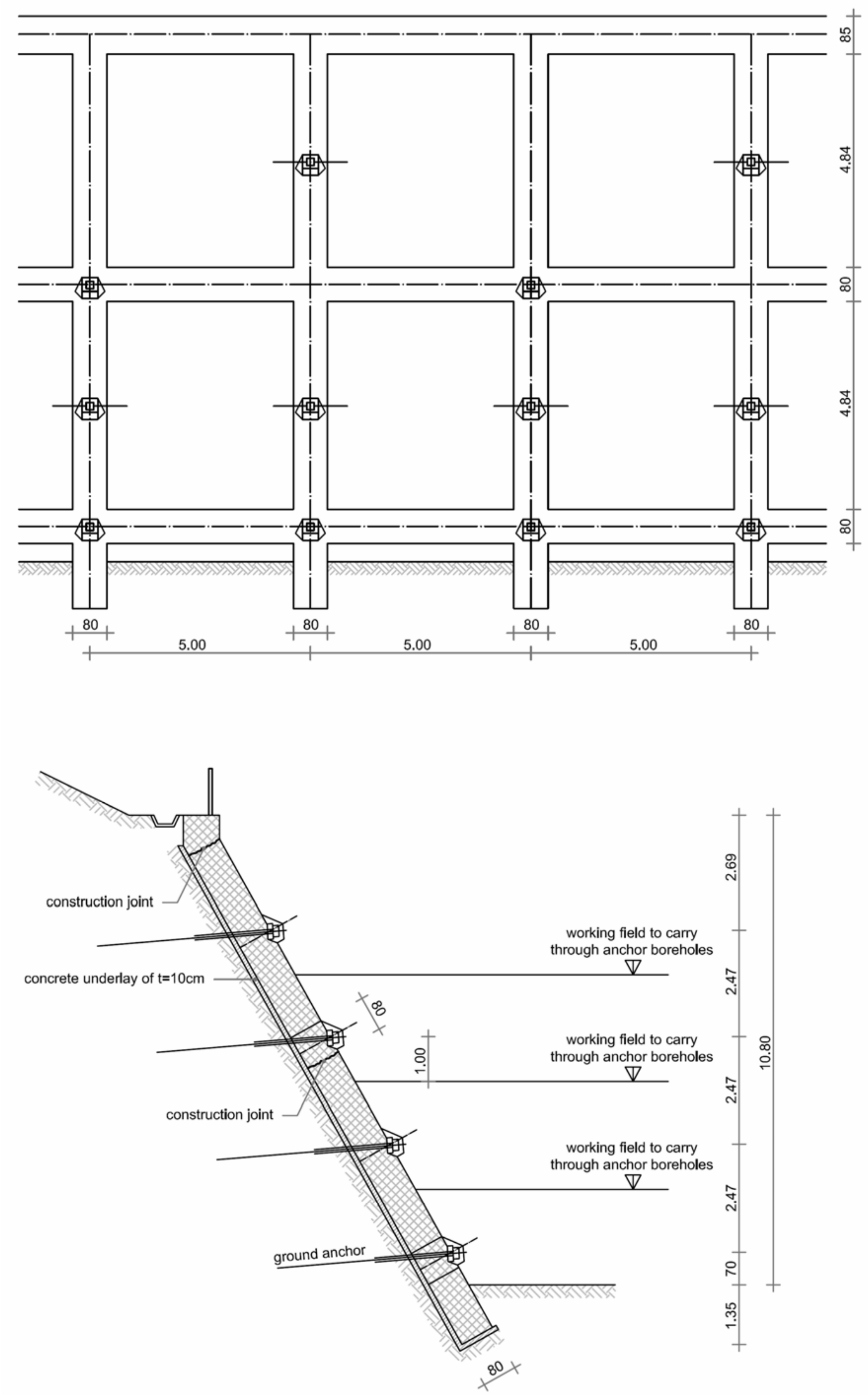


Fig. 5.8: Anchored columns and beams – grid structure

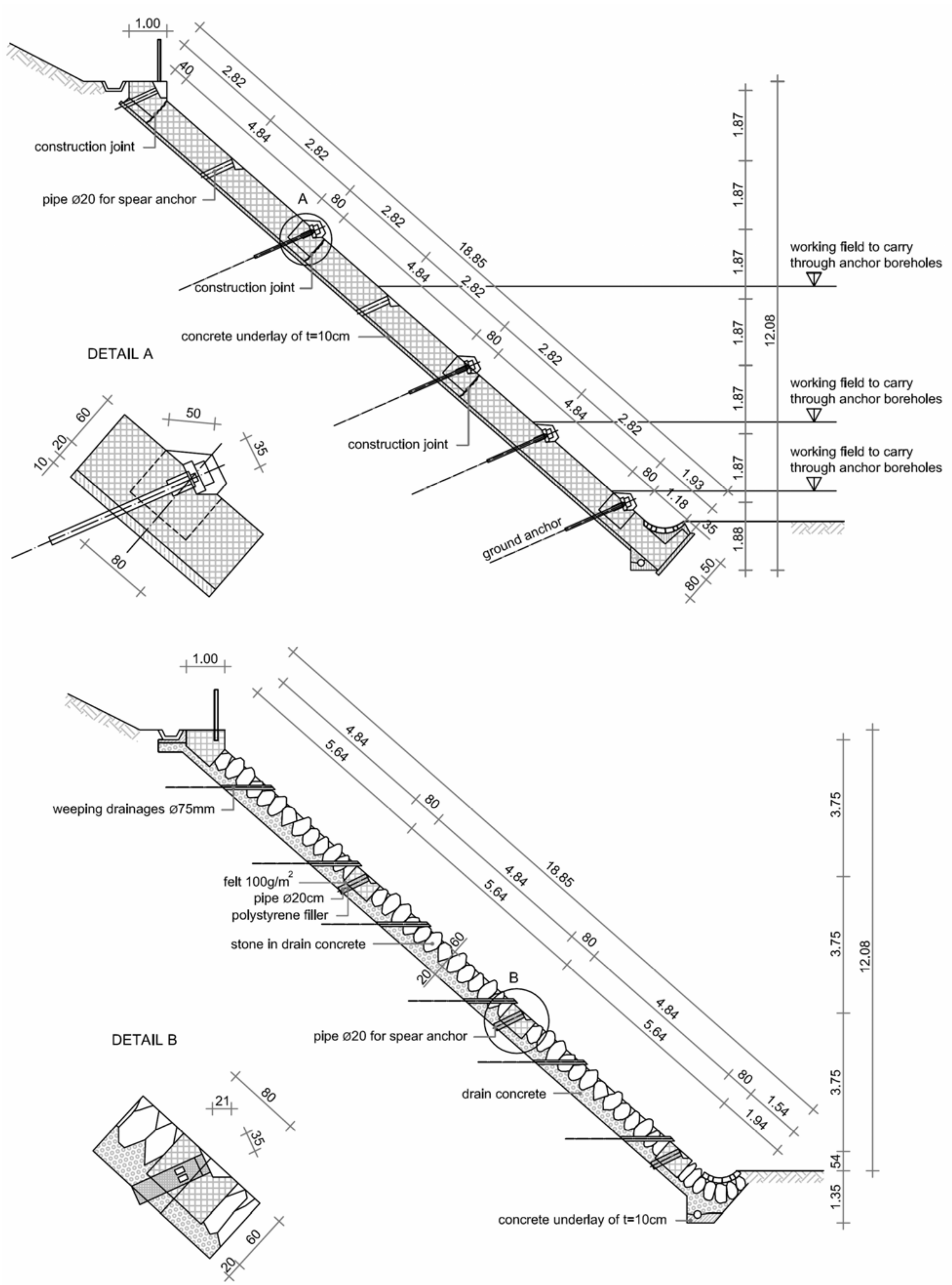


Fig. 5.9: Anchor columns and beams – grid structure with filling elements in-between

5.8 Designing Anchored Walls

Anchored reinforced concrete walls can be entirely executed in-place, or they can be semi-prefabricated. Their dimensions and inclination are determined by the slope geological – soil mechanical properties, contact stresses, anchor force magnitude, required dimensions for the anchor head installation, and execution method.

Where the construction is carried out in-situ, a layer of drain concrete shall be applied or a drainage geo-textiles shall be stretched first, followed by construction of the wall, which thickness shall amount to 30 cm minimum, depending on dimensions of the trumpet of the ground anchor stressing system. The drain concrete layer thickness shall be at least 15 cm. The anchor head shall be “pulled out” from the wall plane (Fig. 5.10).

In case of a semi-prefabricated construction, at least two alternatives exist:

In the first alternative, drainage geo-textiles is stretched onto the excavated slope, whereas the wall formwork is carried out by means of a prefabricated reinforced concrete slab to which special wall reinforcement is fixed. The void between the geo-textiles and the slab shall be filled up concrete. The slab shall be equipped with suitable anchors or loops to ensure a composite action with the wall load bearing system. The minimum thickness of those slabs shall be 15 cm plus additional concrete of t = 30 cm minimum. The total thickness depends on the dimensions of the trumpet of the ground anchor stressing system. The slab size depends on transportation possibilities; a slab should not be wider than 220 cm, whereas its height should not exceed 350 cm (Fig. 5.11).

This alternative is advantageous due to reduced formwork costs, faster work progress, higher quality of wall exposed surface, and better appearance of the wall.

In the second alternative, a foundation is constructed. It contains holes to build in dowels, onto which pre-cast slabs are placed (Fig. 5.12). The thickness of those slabs shall amount to 30 cm, whilst their dimensions and weight shall be such as to allow erection and transportation by the help of lighter means. The void between the slope and the slab shall be filled up with filter drain concrete of a minimum thickness of 15 cm. To prevent eventual mixing of filter concrete with soil, geo-textiles shall be stretched over the slope prior to erecting the slabs.

For evacuating both drain and surface water, common rules apply.

5.9 Designing Special Anchored Walls Constructed From Above Downwards

Special anchored reinforced concrete walls constructed from above downwards can be entirely cast-in-place, or can be partly prefabricated. The wall dimensions and inclination are determined by slope geological – soil mechanical properties, contact stresses in ground, and available anchor force magnitudes (Fig. 5.13).

In contrast to the anchored walls indicated in 5.8 above, this wall type allows a steeper inclination of the slope excavation, usually 4 : 1. In this way, the intervention in the wall rear is reduced, and the danger of a slope local failure is nil.

The construction technology for this wall type leads to a partial illogicality in structural dimensions, as the wall thickness is the greater in the area of the highest quality of the slope.

A typical feature of these walls is that their cross section is inconstant by height, which results from the construction technology. Each longitudinal stage of the wall is shifted by approx. 35 cm to enable casting of the lower longitudinal stage.
A further characteristic of these walls is a foundation and a contact casting. Therefore, drainage geo-textiles shall be stretched over the rear to be in contact with concrete.

The minimum thickness of the first longitudinal stage amounts to 40 cm, whereas the subsequent segments shall be thicker due to their shifting as mentioned above.

Usually, such walls are partly cast-in-situ and partly pre-cast. Prefabricated slabs of a minimum thickness of 15 cm shall be used serving as a formwork for the wall front side. Due to transport limitations, the slab width shall not exceed 2.20 m, whilst their height shall not be greater than 3.50 m. The weight of a slab of such maximum dimensions is such as to allow handling and placing by means of a usual mechanization at locations of difficult accessibility.

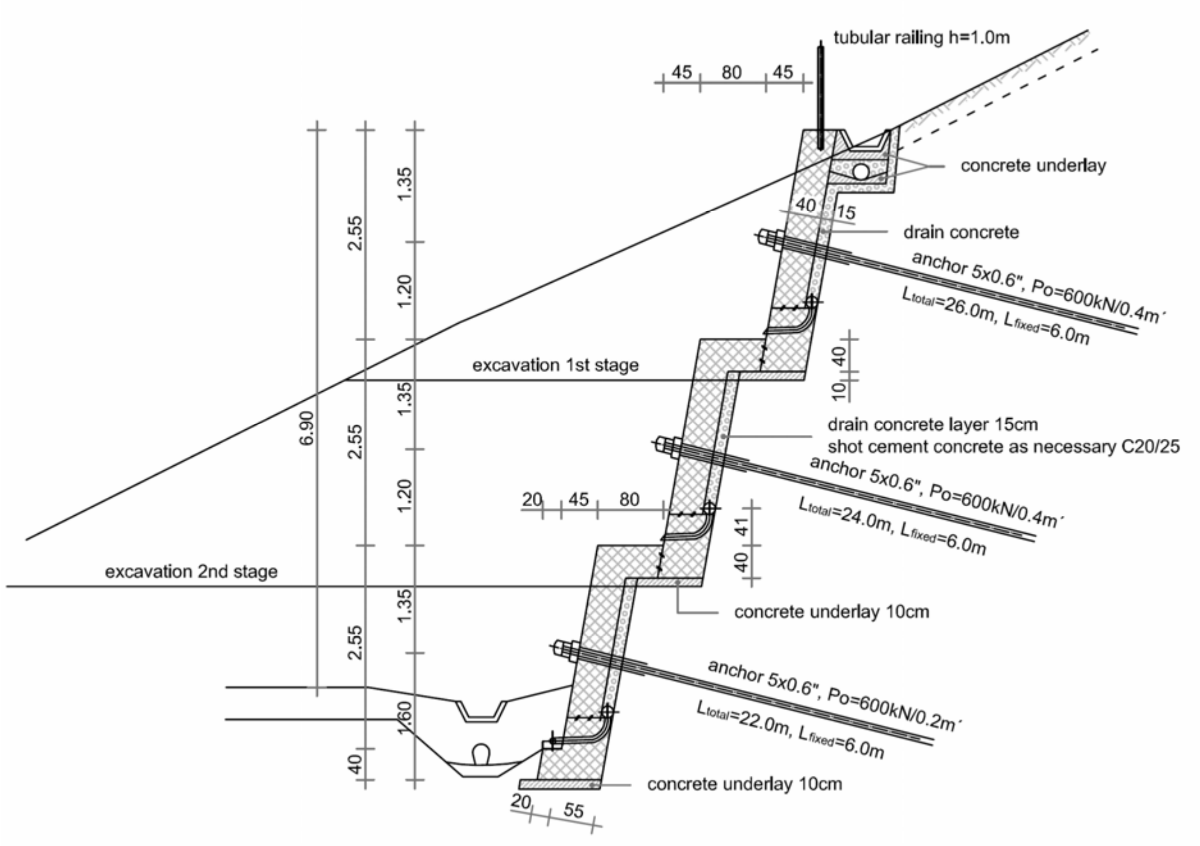


Fig. 5.10: Cast-in-situ anchored wall

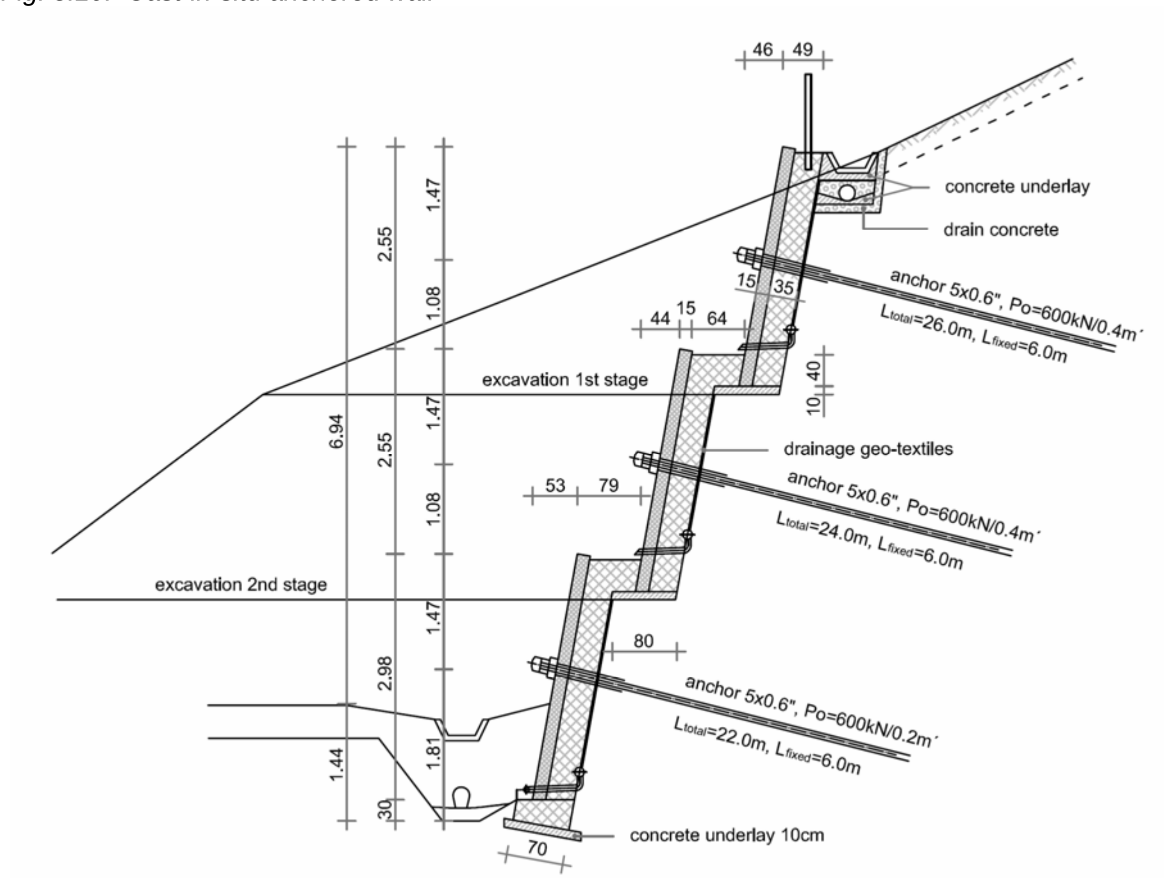


Fig. 5.11: Semi-prefabricated anchored wall

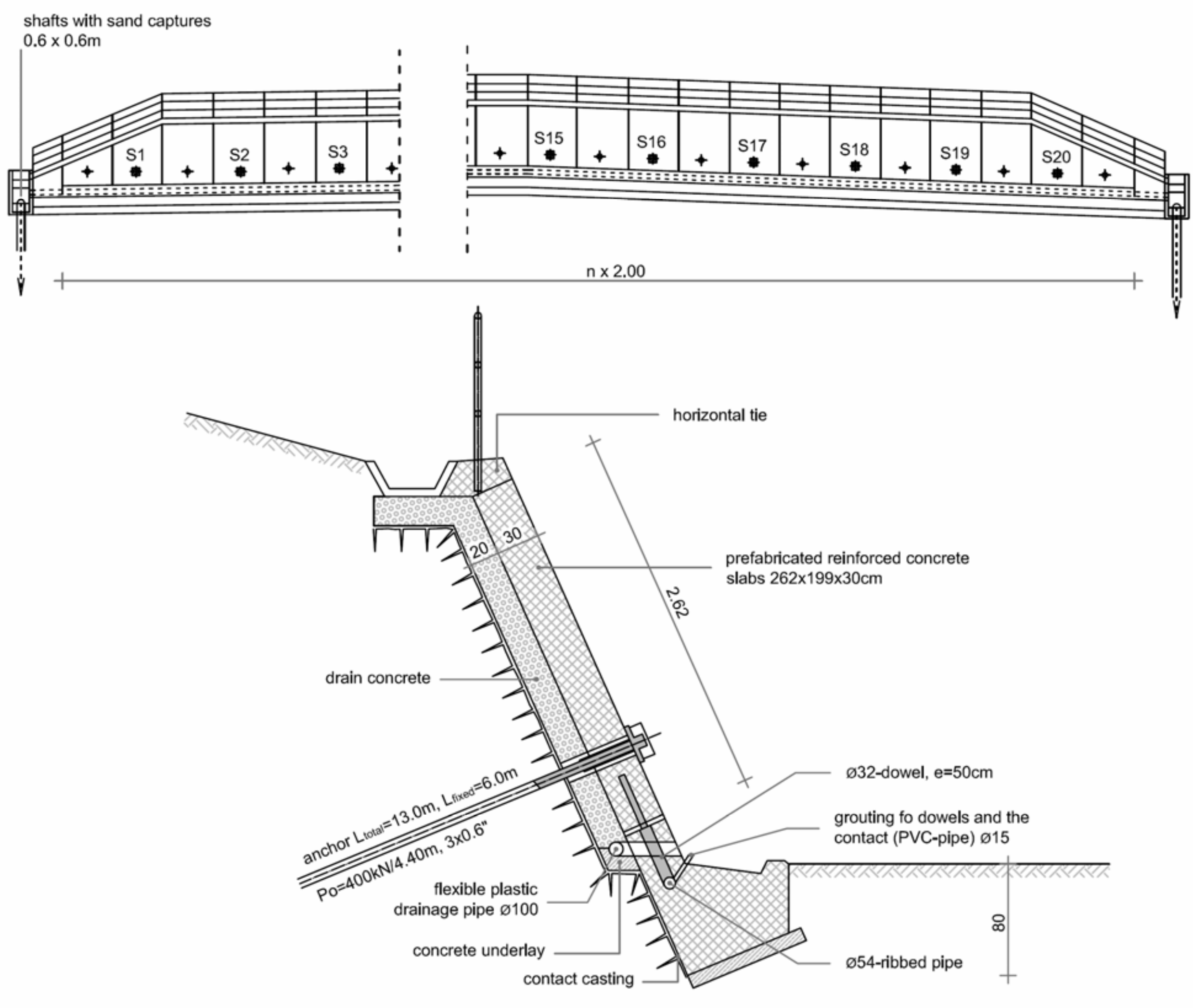


Fig. 5.12: Partly prefabricated anchored wall

The first longitudinal stage shall be constructed extremely carefully, as it is usually executed in the worst geological – soil mechanical conditions. In order to prevent wall rotation, anchor heads shall be installed at two different levels of the first longitudinal stage.

Each individual constructed longitudinal stage shall be anchored prior to any continuation of the works. Only after all the sections of a vertical segment have been anchored, the works can continue by excavating below the completed longitudinal stages. The subsequent longitudinal stages shall be carried out of vertical segments by skipping according to a chessboard system.

At the bottom of each vertical segment, anchor reinforcement ϕ 32/33 or ϕ 28/25 shall be placed to ensure connection between the vertical segments.

Prior to concreting the wall, over the slope surface to be in contact with concrete, drainage geo-textiles shall be stretched. The latter is connected with a drainage pipe running longitudinally behind the wall at each vertical segment. At each end, these drainage pipes are led into gutters running on the wall termination.

A drainage pipe shall also be laid onto the wall lowest point, i.e. foundation toe. At each end of the wall this drainage pipe is linked to the road drainage or led into the open.

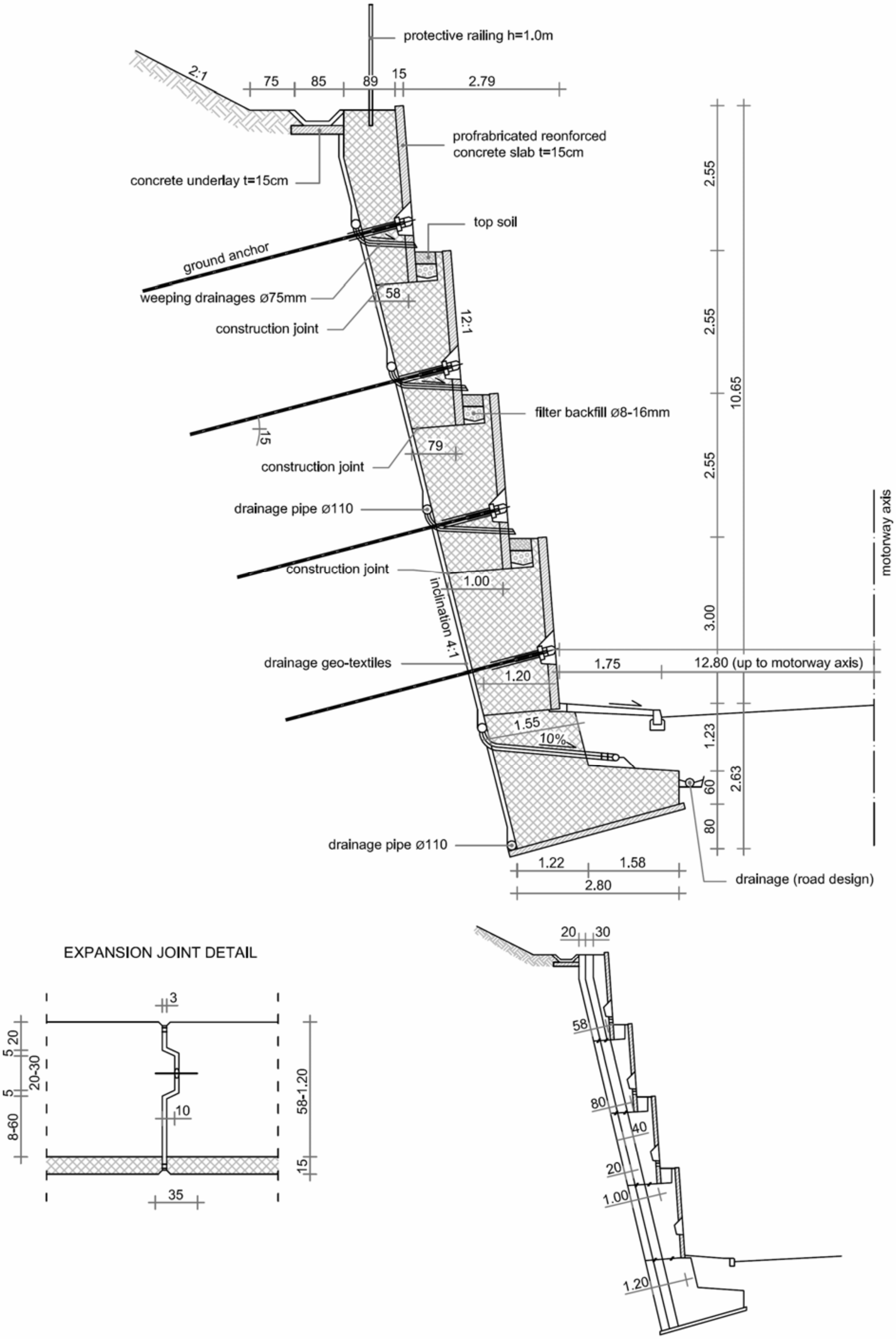


Fig. 5.13: Characteristic cross section of an anchored wall constructed from above downwards

5.10 Designing Pile Walls

Both stability and safety of pile walls shall be ensured by earth resistance, ground anchors if anchored, and flexural stiffness, which plays the most important role in ensuring reliability of such a structure.
To incorporate all the pile wall elements into the structure properly and to ensure their adequate use, it is necessary to devote to structural elements and geological – soil mechanical conditions all the available past experience and knowledge.
One shall be aware of the fact that such constituent structural elements are in question, which are mathematically not entirely controllable thus certain experience is required to work out an appropriate design.

Pile walls are structures, which, by their size and shape, represent a foreign body in the environment. As they are independent supporting or retaining structures, some architectural design elements shall be involved in addition to the emphasized static importance.
The terminations as well as the shape of the top of a pile wall best indicate whether a pile wall is properly incorporated into the environment. The linking beam line shall conform to the slope morphology to the greatest extent possible. Excessive angle breaks of the linking beam are not wished for. Both ends of a pile wall, i.e. the contacts between the pile wall and the slope, shall be suitably shaped in order to avoid an unusual beginning of the structure. The contact between the pile wall and the slope shall be carried out unobtrusively, and shall be adjusted to the shape of the ground. In this way, an adequate evacuation of the surface water from the channel to the inspection shaft is ensured.
The type of surroundings where a pile wall is planned shall be taken into consideration. In case that a pile wall is foreseen in a sensitive and culturally/historically protected environment, a “rough” pile wall bearing structure shall be suitable treated in the aesthetical sense. A pile wall facing as a façade is particularly important.
Elements serving to fix the facing to the load bearing structure (piles, beams) shall be so fastened as to provide sufficient ventilation of the facing, and the evacuation of the rear water. In particular, the details of fixing shall be such as not to represent a weak point in the structure.
Pile wall facings fixed to piles or beams make the inspection of and the access to the load bearing structure impossible. Such facings are particularly unsuitable, where an anchored pile wall is in question, as control and maintenance of anchor heads, as well as the access to the measuring and control anchors are made unfeasible or at least difficult.
Usually it is recommended to foresee an exposed surface of a vivid shape of semicircles at different spacing as such a solution offers an aesthetically interesting and serious structure, which, by its robustness, shows off its purpose.
Pile walls without facing shall be washed with water jet of such a pressure as to prevent damage to the exposed concrete surface.

An aesthetical improvement of a pile wall can be achieved by natural vegetation. For this purpose, a 60 – 80 cm wide space in front of the wall shall be foreseen, where fertile soil shall be filled in and climbers planted. A mesh fixed to piles allows those plants to climb and partly hide the view of the pile wall. The selected climbers shall fit the width of the road clearance gauge and be resistant to de-icing salt.
When the appearance of the piles and fillers in-between is not sufficiently uniform, the entire exposed surface of the pile wall, with the exception of the linking and anchor tie, shall be sprayed with cement concrete containing micro-fibres.
In case that a pile wall is located next to the carriageway (retaining wall), an epoxy coating shall be applied from the road level up to a height of 3.0 m. By means of such a coating, resistance of concrete to frost and de-icing salt is increased. The coating shall be colourless and transparent, as the natural appearance of the concrete should remain visible.
Pile design, reinforcement, and construction method are described in detail in the Design Guidelines 1.3.1 Deep foundation on bored piles and wells.

For pile walls, either cantilevered or anchored, it is recommended to foresee piles of ϕ 100 – 150 cm.
In view of static considerations, a circular cross section of piles is not the most suitable to flexure, as the reinforcement is exploited to a relatively small extent in the cross section. Symmetrical pile reinforcing is recommended for a simpler execution and subsequent additional anchors.
The pile diameter mainly depends on the soil geological – soil mechanical properties, hydrological conditions, and wall height. It is also dependent on pile length and applied loading.

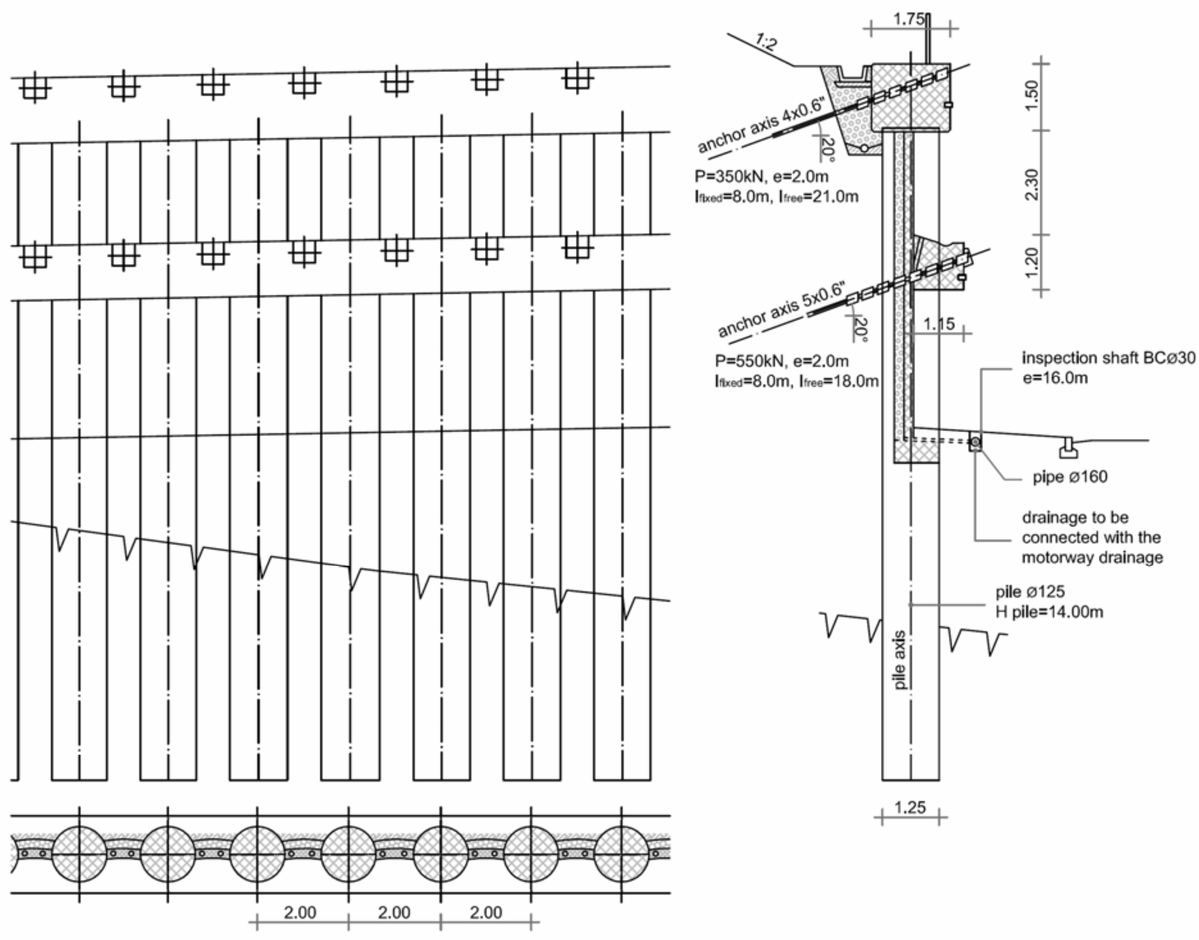


Fig. 5.14: A portion of a pile wall anchored at two levels

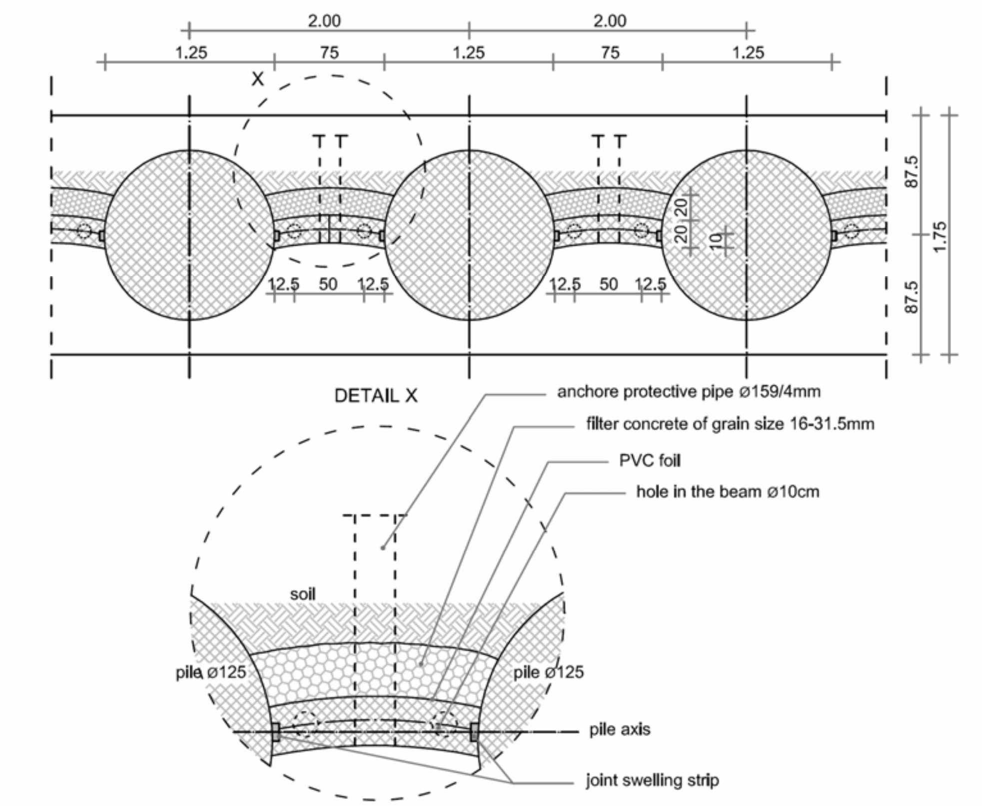


Fig. 5.15: Fillers between piles

Depending on applied loading, piles of large diameters, usually of ϕ 150 cm, shall be used for cantilevered pile walls.
For pile walls anchored at either one or multiple levels, piles of ϕ 100 cm shall be foreseen. For higher loading, piles of ϕ 125 cm shall be designed. By their stiffness in the structure – soil interaction, such piles co-act with the anchors better than the piles of larger diameters.
The pile diameter can also depend on the pile length. When a pile is longer than the available reinforcing bar of the principal reinforcement, thus the pile reinforcement cage shall be extended, a problem in keeping the specified minimum spacing of reinforcing bars in the overlapping zone can occur. The bar spacing shall amount to at least 3 cm to ensure a proper concrete cover to the reinforcement.
Where piles of ϕ 125 cm are longer than 12 m, and reinforced by more than 2.5%, their cross section shall urgently be increased to make a correct overlapping of reinforcement cages feasible.
In case that a pile is shorter than 12 m, the percentage of reinforcement can also be higher.
The pile spacing depends on loading acting on the wall, and on the properties of the soil behind the wall, as the intermediate spaces between the piles must be temporarily "opened", and then the voids in-between shall be filled up with a suitable facing.
For each selected pile diameter, adequate pile spacing shall be defined. The minimum spacing is theoretically equal to the pile diameter; however, it is recommended that the spacing amounts to at least 10 cm, as accuracy problems in connection with boring works can be avoided in this way. The maximum pile spacing depends on the pile diameter, i.e.:

- for ϕ 100 cm: e = 2.00 m
- for ϕ 125 cm: e = 2.50 m
- for ϕ 150 cm: e = 3.00 m

A linking beam connects the pile tops and represents a termination as well as an extremely exposed structural element. As it is visible, it shall be suitable shaped (no sharp edges, suitable concrete grade, good formwork).
Special attention shall be paid to placing anchor heads onto the linking beam, if the pile wall is anchored. In this case, control and/or measuring anchors shall be foreseen at certain locations. An appropriate maintenance of those anchors is obligatory.

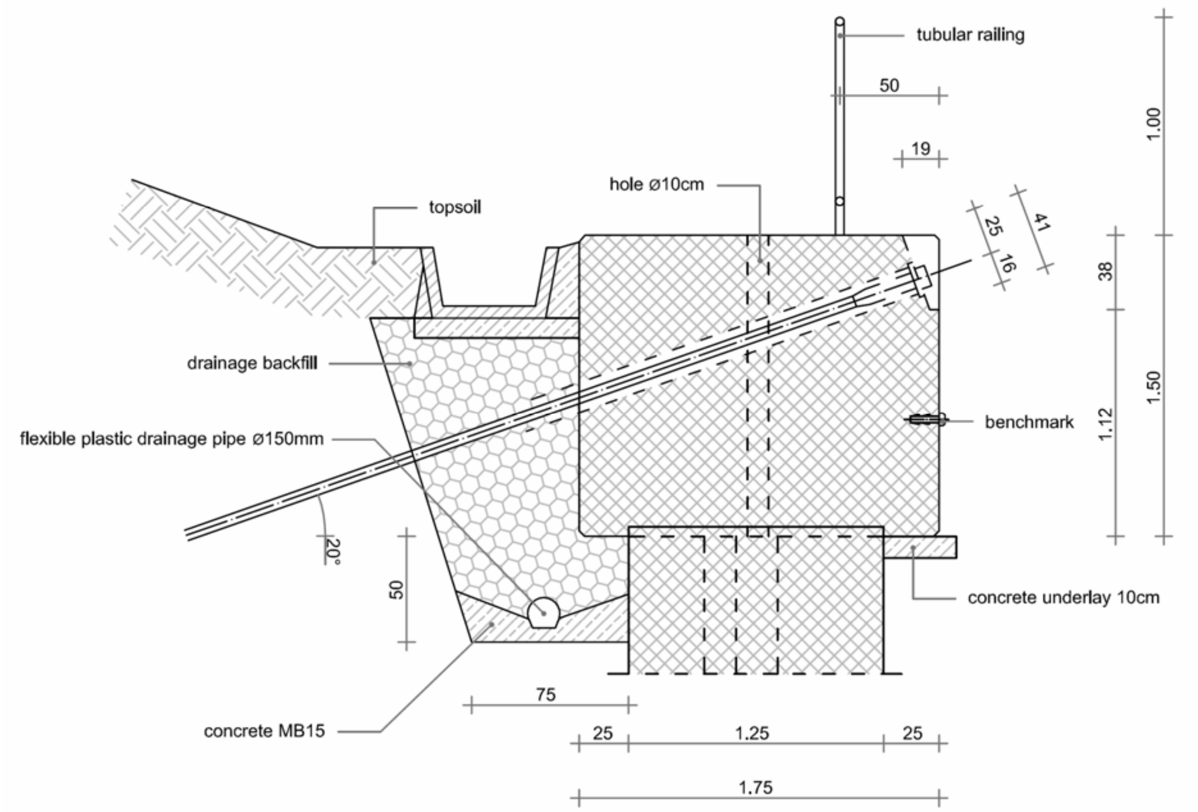


Fig. 5.16: Cross section of linking beam

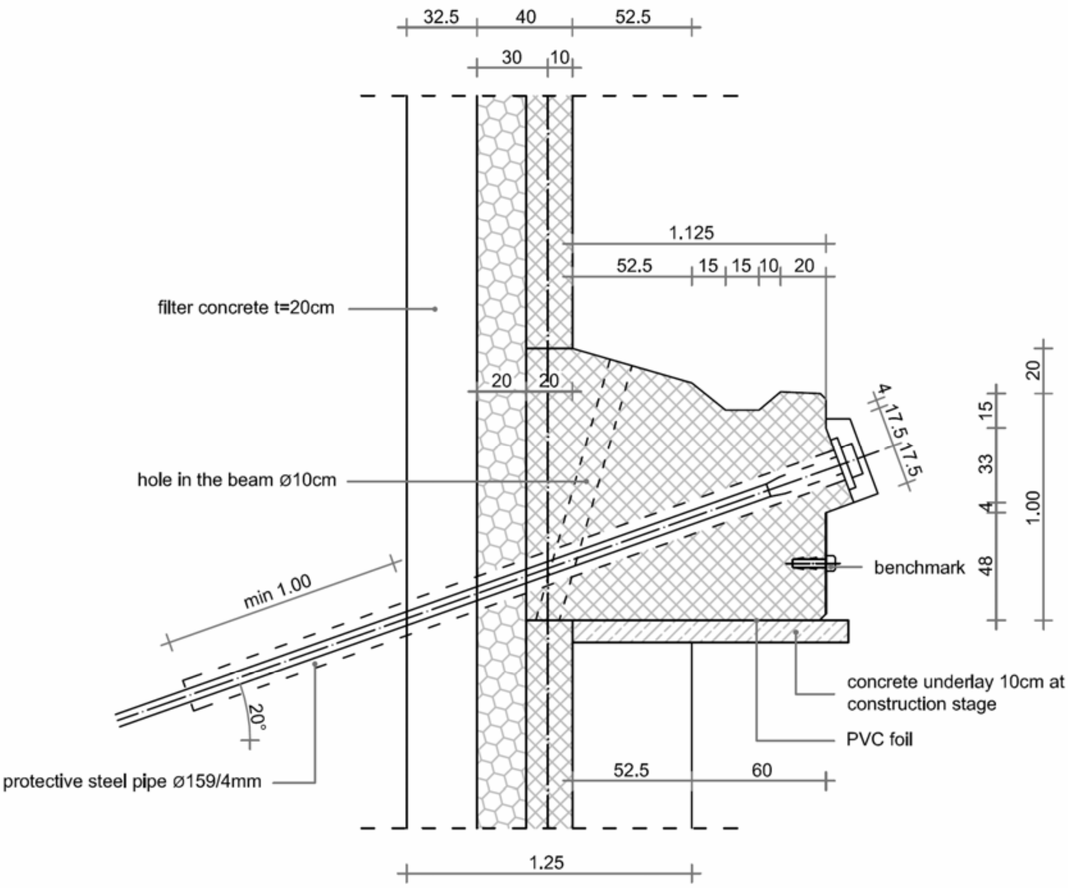


Fig. 5.17: Cross section of intermediate anchor beam

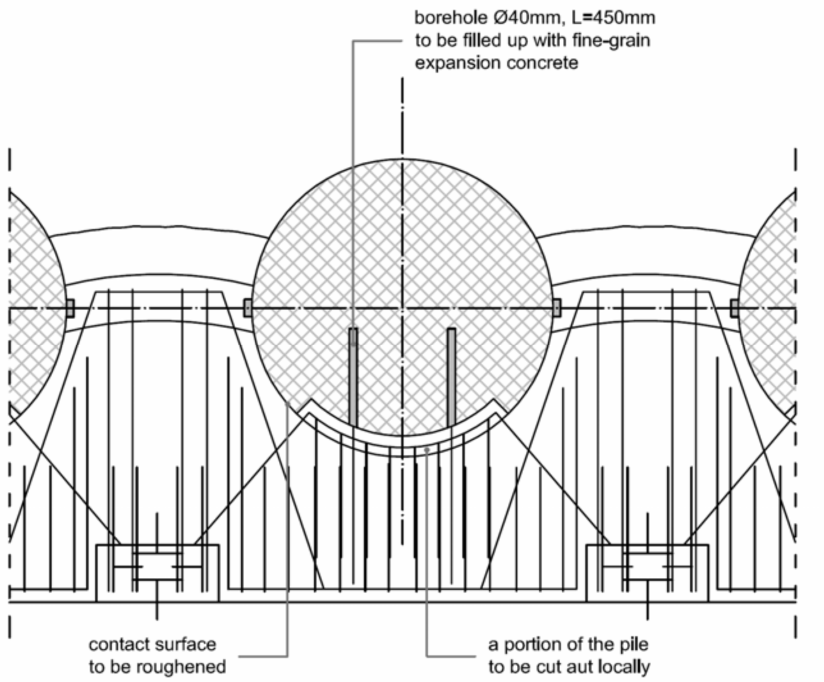


Fig. 5.18: Connection of intermediate anchor beam with piles

Where a road runs immediately above a pile wall, the linking beam becomes a part of the carriageway; therefore it shall be adequately designed and equipped with a railing and a walkway.

A linking beam shall be of such dimensions and stiffness, that it can take consequences of eventual damage to pile wall structural elements (a higher earth pressure locally, drop of anchor force, ...) and to transfer the load to adjoining piles or anchors.

The width of a linking beam shall be on both sides by 15 – 25 cm greater than the pile diameter in order to accommodate eventual inaccuracies of pile execution and to place the beam reinforcement properly. Namely, the vertical reinforcement of a pile does not enable a uniform arrangement of the reinforcement over the beam lower side. Such widening enables a more adequate distribution of the beam horizontal reinforcing bars.

The linking beam height shall be greater than the length of anchoring the reinforcement from a pile plus 10 cm. If a pile wall is anchored, the linking beam height shall amount to at least 120 cm to allow a correct treatment of ground anchor heads.

In the longitudinal direction, the linking beam shall receive expansion joints spaced at 15 – 20 m. In case that the linking beam line fits the ground morphology on top, thus it is repeatedly broken, the distance between adjacent expansion joints shall be reduced and adjusted to the inconstant beam line.

Expansion joints shall be carried out as "tongue-and-groove" joints.
Intermediate anchor beams only occur, when a pile wall is anchored at two or more levels. Such anchor beam connects piles into an entirety, and it is particularly a structural element, to which ground anchor heads are installed. The anchors are usually placed in-between the piles.

The contact between a pile and a linking beam shall be carried through perfectly. At such contact two holes of ϕ 40 mm and 45 mm in length shall be bored in each pile, and anchor reinforcement shall be inserted into those holes. The reinforcement shall be filled up with expansion mortar. In this area, as shown in Fig. 5.18, the pile shall be cut away from the reinforcement, whereas on the remaining surface, which is contact with the linking beam, the pile shall be washed and roughened.

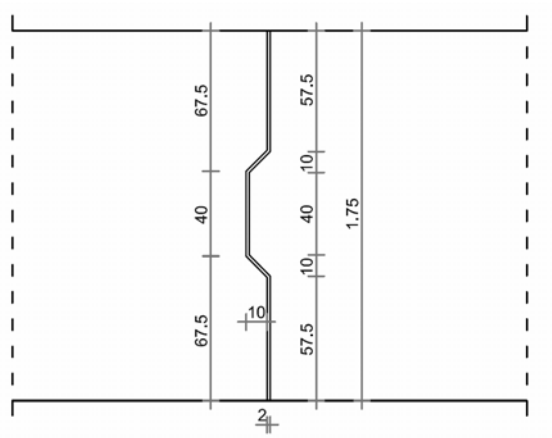


Fig. 5.19: Linking beam expansion joint in plan

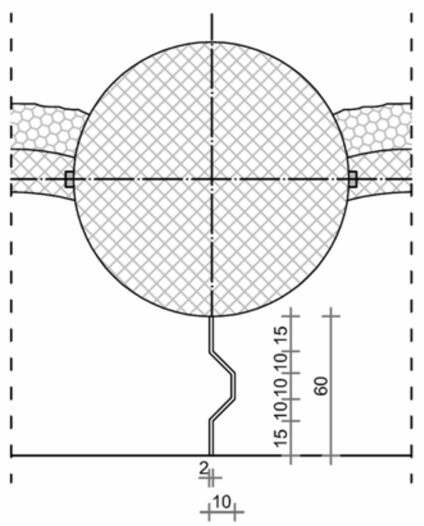


Fig. 5.20: Intermediate anchor beam expansion joint in plan

The anchor spacing depends on the anchor load bearing capacity and the loading that a pile wall has to withstand. As the number of anchors shall be as small as possible, anchors of maximum load bearing capacities shall be foreseen. This means that anchors of usual external resistance, i.e. a resistance, which can be taken by rock or soil, shall be used.

The anchor spacing on the linking beam shall not be less than 50 cm in the same plane. When the anchor spacing is less than 1.5 m, two different anchor lengths shall be foreseen. These anchors shall be installed alternately, and the angle of anchor inclination shall also be alternating. The difference in length shall be equal to the fixed anchor length plus 2 m, whereas the difference in the angle of inclination shall amount to at least 10°.

Where anchoring is carried out in a solid rock, the abovementioned conditions apply to the anchor spacing of less than 1 m.

If possible, the anchors on the linking beam shall be located between the piles. Otherwise two or three pile reinforcing bars shall be partially cut off, as they might get in the way of an anchor head.
On the linking beam test anchors are usually installed as well. They are a basis for an assessment test and to determine the anchor external resistance.

On the linking beam, anchors shall be obligatorily placed between the piles. As necessary, the anchors can be arranged in two rows.

Draining of the pile wall rear is important as to prevent hydrostatic pressures on the pile wall. However, in an extreme case this can lead to some structural damage.
Pile wall drainage is divided in two parts: pile wall rear drainage and surface water drainage.
To drain the rear water adequate drainage shall be executed along the upper linking beam (Fig. 5.16), and the space in-between the piles shall be dewatered.

Behind the linking beam, approx. 50 cm below the horizontal beam lower edge, a horizontal drainage shall be carried through. A drainage backfill shall extend over the entire beam height.

Backfilling shall be performed after completion of anchor installation. It shall be carried out very carefully to prevent damage to anchors.

The space between the piles can be drained in two ways:

- By means of filter concrete between the piles and of a reinforced concrete on the exposed side. Such a method provides a high quality, yet more working stages are required.
- By foreseeing vertical drainage pipes in the space between the piles, which is simpler to execute, but less effective.

All the accumulated drain water shall be monitored via inspection shafts and linked to the dewatering system, or, where the water in not polluted, it can be released to nature at an adequate location.

It is of an extreme importance to solve the surface water evacuation punctually and effectively. The surface water shall be canalized out of the pile wall area on the shortest way possible. For this purpose, gutter and ditch cross section shall be suitably dimensioned as to prevent spilling over during heavy rain. The bottoms of drainage channels running on a steep rear of the pile wall shall be so designed as to reduce the speed of the water flow and to dissipate the water energy before entering the inspection shaft (linings of quarry-stone, sills).

The pile concrete grade shall be at least C25/30 (MB30) for the exposure class XC2. Steel reinforcement grade S400 (RA 400/500) shall be used.

Where a pile wall is located at the carriageway, the concrete exposure class shall be at least XF2 (OSMO). The wall surface shall be coated with an epoxy coating to increase the concrete resistance to frost and de-icing salt. The coating shall be applied from the lower exposed edge of the wall up to a height of at least 3.0 m.

Drainage cement concrete

Concrete type	**Special properties in accordance with the design and technical conditions**	**Additional requirements in accordance with technical conditions**	**Cement, water, and aggregate content**
Drainage concrete – coarse, “A”	f_{cc} = 5 N/mm^2 permeability to water the same as to gravel, *k* by Darcy	single-grained, 8 – 32 mm	170 kg-C, 58 I-V, 8-16 mm … 40% 16-32 mm … 60%
Drainage concrete – fine, “B”	f_{cc} = 5 N/mm^2 permeability to water the same as to gravel, *k* by Darcy	single-grained, 8 – 16 mm	170 kg-C, 56 I-V, 8-16 mm … 100%

Placing the drainage coarse concrete

Coarse drainage concrete is spread onto the ground directly from a dumper truck or by means of a digging machine with a loading shovel. In plan, the concrete is laid in transverse stripes – continuously longitudinally in one or more stages, while in a single layer of 35 cm thickness in height. The compaction of the layer is carried out by means of a manual vibratory roller (e.g. BW 70), passing twice, i.e. transversally and longitudinally.

A PE foil or felt is used for concrete after-treatment. It shall be laid onto free surfaces. Running water is not admitted for the after-treatment, as the drainage system might get clayed.

Shot cement concrete (“Shotcrete”)

Shot cement concrete (of D_{max} = 8 mm or D_{max} = 16 mm) is used to prevent loosening of the rock, and as s supporting element. A lining of shot cement concrete closes cracks in the rock, and prevents crumbling of rock and falling-out of rocky pieces. The maintenance of the initial rock strength is essential to enable formation of an arch in the rock, e.g. directly around the excavated profile of a tunnel.

The sprayed and anchored reinforced or micro-reinforced (with mesh reinforcement or micro-fibres) lining can be 5 – 25 cm thick. Spray application is carried out by stages of construction progress and by layers to achieve the specified thickness.

The primary lining is anchored by means of anchors of types Swellex, SN or IBO. The number of anchors per unit of area depends on the rock category (e.g. A2, B1, B2, and PC in the portal area).

To the filling of the spraying machine with the dry concrete mixture, as well as to the application of the shot cement concrete, similar requirements shall apply as to the normal concrete cast into formwork. Suitable steel mesh reinforcement and steel anchors, which ensure the adhesion to the rock and the transfer of forces, shall be fixed to the rock. The latter shall be cleaned by means of compressed air or by high-pressure water jet. The spraying machine shall be equipped with a dosing device for the accelerating agent. The distance between the nozzle and the surface shall amount to 1.0 – 1.3 m and shall not exceed 2 m.

6 ANCHORED WALL GEOSTATIC ANALYSIS

The reliability verification of an anchored wall is a constituent part of both the preliminary design and the building permit design.

It shall be conceived on the basis of the results of geological - soil mechanical investigations, assessment of soil mechanical ground properties as well as spatial and town planning, traffic, surveying, road, hydrological/hydro-technical, meteorological-climatic, and seismic data.

The term reliability comprehends safety, serviceability, and durability of retaining/supporting structures. The reliability verification is a mandatory constituent part of an anchored wall design, which can, in dependence on the geotechnical complexity, include verifications at ultimate limit states, serviceability limit states, and durability limit states.
The required reliability of anchored walls shall be verified for transient, persistent, and accidental design situations occurring during construction, service, maintenance, and in exceptional conditions in the entire service life of a retaining/supporting structure.

The geotechnical design cannot take account of all the actual design cases, which might often be accidental, but possible in the anchored wall service life. Therefore, for each construction and service stage critical design cases shall be determined, considering the most critical states in the anchored wall service life.

Each geostatic analysis of an anchored wall shall take account of at least the following design situations:

- Design situation of the initial condition of the slope, existing structures, and infrastructure in the influence area prior to commencing construction works;
- Technological design situations, which can include construction of access roads and working fields, pit excavations, and working stages during the anchored wall execution;
- Design situations of a permanent exploitation of the structure in its design service life;
- Seismic and accidental design situations.

By analysing individual design situations it shall be verified that no ultimate limit state, serviceability limit state, and durability limit state will be exceeded in the entire service life of the anchored wall considered.

When more sophisticated mechanical models of the ground and retaining/supporting structures are introduced, several design situations can be gradually analysed by simulating individual construction stages at simultaneous verification of all the ultimate limit states and serviceability limit states.

Less complicated mechanical models of retaining/supporting structures and the ground enable analyses of individual ultimate limit states and serviceability limit states, yet the results are less reliable, thus experiences are more important for the interpretation.

Only such models may be used that sufficiently demonstrate the mechanical properties of the ground and of the individual elements of retaining/supporting structures at the limit state.

6.1 Ultimate Limit States (ULS)

In accordance with the European geotechnical standard prEN 1997-1:2001 the following limit states are distinguished:

- Loss of overall stability of the foundation ground mass including retaining/supporting structures, which causes excessive ground movements due to shear deformations, settlements, vibrations or uplifts, damages or reduction of serviceability of adjacent existing structures, of roads and other infrastructure due to ground movement. To verify the considered case the most important factors are the ground strength and the stiffness or bearing capacity of individual structural elements;
- Internal failure or excessive deformations of structures or structural elements including foundations, piles, walls, anchors, etc., where the strength of structural materials is of essential importance to establish the required resistances (STR);
- Failure or excessive deformations of the ground where the strength of soils or rocks is the most important factor to establish the required resistances (GEO);
- Loss of equilibrium of geotechnical structures or ground due to uplift caused by water pressures (UPL);
- Hydraulic heave of the ground, internal erosion of soils, and local failures in the ground due to the loading applied to the ground by hydraulic gradient (HYD);
- Loss of equilibrium of structures or ground as rigid bodies where the strength of structural materials and the strength of ground have an insignificant influence on ensuring the required resistances (EQU). For retaining structures this limit state is less important.

The overall stability limit state deals with the soil mechanical conditions of loss of overall stability or of excessive ground deformations where the strength of soils and rocks is the most important factor to ensure the required resistances.

In the anchored wall design and construction the overall stability of the influence area shall be verified including the pile wall and existing structures in all the analysed design situations.

The overall stability of the anchored wall, earth slopes above and below the anchored wall, access roads, excavations and working fields conditioned by the construction method shall be verified.

To select suitable methods for the verification of the overall stability limit states the following shall be taken into consideration: stratification of slopes, phenomena and directions of discontinuities, seeping of ground water and pore pressures, conditions of short-term and long-term stability, deformations due to shear stresses, and adequateness of the mode of the analysed potential failure.

The GEO limit state deals with the danger of failure or excessive deformation of the ground where the strength of soils and rocks is important to ensure the resistances.

In retaining/supporting structures the GEO limit state considers, as a rule, the following: ground bearing capacity, determination of earth pressures and activated resistances, external resistance of ground anchors, etc.

The STR limit state deals with the internal failure or with the excessive deformation of a structural element including foundations, piles, walls, and anchors where the material strength prevails in the bearing resistance verification.

In retaining/supporting structures with the STR limit state, sufficient bearing resistance of cross sections of structural elements shall be considered and verified with regard to tensile, compressive, flexural and torsional loading, as well as to combinations of these actions.

The UPL limit state considers failure of the ground and/or retaining/supporting structure due to the loss of the vertical equilibrium where the ground stiffness is of a minor importance only.

The HYD limit state considers the state of ground failure in the retaining/supporting structure influence area due to exceeded hydraulic gradients where the soil or rock strength is of major importance. The analysis of the HYD limit state is always required where the ground water is filtered upwards in front of the retaining/supporting structure, as well as in all cases where the ground water levels in front of and behind the structure are different.

In anchored walls or in all the cases where the structural stability depends on the passive resistance in front of the structure, it is necessary, when verifying ultimate limit states, to reduce the design ground level by a value Δa, which shall, for anchored or supported anchored walls, amount to 10% of the distance between the lowest support and the ground, or the lowest anchor and the ground, however not more than 50 cm, provided that an average control of reliability and a moderate site supervision are in question.

6.2 Serviceability Limit States (SLS)

In anchored walls, the serviceability limit states shall be considered in both transient and persistent design situations.

The serviceability limit states particularly refer to deformations of retaining/supporting structure and ground, as well as of other structures and infrastructure in the retaining/supporting structure influence area.

When selecting design values of limit displacements it is necessary to take account of risks in determining acceptable values, of the phenomenon and intensity of ground movements, the type of structure and structural material, foundation method, deformation type, dilatation, and connections with other structures.

For more complex concrete structural elements, limit states of cracks shall be verified, including a special argumentation of expected events at inaccessible places as well as in the area of construction joints foreseen.

For the serviceability limit state verification of structural elements provisions of the European standards prEN 1992 shall be taken into consideration.

6.3 Modelling Of Ground And Anchored Walls

Soil mechanical analyses of anchored walls shall be performed on mechanical ground models and mechanical retaining/supporting structure models. In general, results of analyses carried through on any models being scientifically justified, acceptable and approved in the geotechnical practice.

In order to execute a safe and economical retaining/supporting structure to the greatest extent possible, design engineers employ different software. The term “different” refers to theoretical bases and not to the origin (authorship). All the software allows simple preparation of input data for numerical analyses, and the results of those analyses enable dimensioning of a retaining/supporting structure.

As a rule, the following information is sufficient to design an anchored wall: the required wall foundation depth, the required anchor force, and the data on bending moments and forces along the wall. If practicable, the designer should also be familiar with the displacements and deflections of the particular retaining/supporting wall.

In practice, a planar deformation state is assumed in the anchored wall analysis, which means that a wall behaves as a slab. Usually, anchored wall are calculated as 1D-elements of 1 m width.

In the static sense, anchored wall are simple 1D (lineal) beams, elastically supported in one or more points (anchor locations), and by a continuous elastic support in the foundation ground.

The loads acting on those 1D beams are rear earth pressures and ground water pressures behind the retaining/supporting structures, whereas the reactions are ground anchors and ground resistance on the front side of the retaining/supporting structure.

Notwithstanding that the anchored wall static analysis seems to be quite simple, this is not the fact. An essential difficulty is the lack of information on the deformations of both retaining/supporting structure and surrounding ground. The effect of the structure – ground interaction significantly influences both the load magnitude and reactions in the retaining/supporting structure.

6.3.1 Stiff-plastic model of ground and anchored walls

In this simplest modelling, the ground properties are represented by a stiff-plastic model of selected design shear strength (with parameters c' and φ'), whereas for retaining/supporting structures the model of a stiff or elastic body can be introduced. Ground anchors are considered by design values of anchor forces. In the mechanical model, the ground water as well as the surface loads and additional seismic loads are taken into consideration as surface or volume forces, thus being substituted by a load model.

A basis for these design models is the kinematics of a retaining/supporting structure, specified in advance, and the limit or design stress state in the ground in front of and behind the retaining/supporting structure.
Actual displacements of a retaining/supporting structure cannot be calculated by introducing a stiff-plastic model of both ground and the anchored wall. Therefore, earth pressures at slip shall be calculated applying adequate safety factors, which are greater for active earth pressures and smaller for passive earth pressures.

As soon as the course of both active and passive earth pressures along an anchored wall is known, the determination of internal forces and moments, as well as of ground stresses and required anchor forces, is relatively simple.
In such modelling structure-ground interface friction angle δ is essential. Its activated portion shall be determined with regard to the conditions of activation of relative displacements in the structure-ground interface.

Verification and assessment of reliability of the foreseen design solutions are enabled by means of such a simplified model of both ground and retaining/supporting structures, as well as by introducing individual simple models of limit states.

These models of retaining/supporting structures enable relatively accurate determination of limiting values of actions and resistances (active and passive earth pressures, load bearing capacity of the ground), whilst the activated portions of these values shall be assessed in terms of expected or admissible deformations of both retaining/supporting structure and ground in the influence area.

Analyses, which take account of the prescribed kinematics as well as active and passive earth pressures at slip, are simple and therefore very usable, providing safe and relatively economical structures, on condition that mobilized strength parameters of the surrounding ground are considered properly. This method, however, cannot take account of the influence of the retaining/supporting structure deformability on the earth pressure redistribution, thus its application is limited to an analysis of rigid walls. On the basis of the results obtained it is only possible to calculate the relative displacements, yet no absolute displacements of an anchored wall.

In the calculation using earth pressures at slip, two extreme cases shall be discussed:
- limit state of passive resistance to determine internal forces and moments, and
- considering of mobilized passive resistance to determine the foundation depth.

A bad point of the described model is that fact that it is not possible to calculate structural displacements; therefore it also not possible to verify the magnitude of the resulting active and passive earth pressures, and to justify by calculation the selection of safety factors. Taking into account of the most frequently used safety factors for design earth pressures (usually, for active earth pressures, the cohesive strength c and the quotient of the shear angle tanφ are reduced by the factor F_a = 1.3 – 1.5, whilst the passive resistance is reduced by the factor F_p = 1.5 – 2.0), the hazard of failure of an anchored wall verified in this way is quite insignificant.

6.3.2 Elasto-plastic mechanical model

Elasto-plastic modelling of both retaining/supporting structures and ground enables to perform analyses of design situations taking into consideration the entire influence area including structures located in the considered influence area. In such a model, ground properties are considered by means of elasto-plastic constitutive models, whereas elements of retaining/supporting structures, struts, and anchors are modelled by elastic or elasto-plastic beam elements.

To analyse the actual condition within individual design situations, the finite element method (FEM) is appropriate.

The calculations shall allow for additional design loading, imposed displacements, and ground water effects in accordance with the effective stress state theory.

The advantages of such analyses are reflected particularly in the ensured comparativeness of deformations of the ground and individual retaining/supporting structure elements, as well as in the fact that the actual actions on the retaining/supporting structure elements and the deformations in the entire influence area are assessed.

A numerical analysis of anchored wall according to the FEM based on elasto-plastic models and enabling modelling of the foundation ground, retaining/supporting structure, anchors, and conditions at the contact of different media using an appropriate collection of finite elements, offers the best possible insight into the stress-strain state of the particular wall, anchor, and surrounding ground. A consideration of the soil – structure interaction leads to a realistic distribution of earth pressures in view of wall and ground deformations.

Such an approach to the analyses requires extremely accurate data on the ground properties (shear strength, deformability for both burdening and relieving states, influence area stratigraphy, information on structures in the influence area, etc.) thus relatively extensive investigation work is indispensable.

6.3.3 Model based on ground reaction modulus

The lack of information on the actual displacements of a retaining/supporting structure affecting the distribution and magnitude of both active and passive earth pressures of the surrounding soil on the pile wall is the main reason of introducing the modulus of reaction of the ground into the pile wall analysis.

In practice, pile walls are modelled as beams, which are, on the front side of the pile wall below the ground surface (Fig. 6.1a and 6.1c) or below the zero-point (where a nil-difference between the active and passive earth pressures is foreseen – Fig. 6.1b), supported by a system of elastic supports (springs). When a pile wall is anchored at one level only, an elastic support is usually foreseen at the location of fastening the anchor as well.

Active rear pressures at slip are taken into consideration as the load acting on the pile wall. With regard to the method of supporting the pile wall by the system of springs on the front side of the retaining/supporting structure (instead of the earth passive resistance), the load considered either over the entire beam length (Fig. 6.1a), or up to the zero-point (Fig. 6.1b), or to the bottom of excavation on the wall front side only (Fig. 6.1c).

Usually, the ground reaction modulus k [kN/m^3] is an estimated value. It is defined as a proportionality factor between the normal stress in a certain point of the retaining/supporting structure and the displacement of that point ($\sigma = k * w$). This simple expression shows that the final result (particularly the passive earth pressure) of a pile wall analysis using the ground reaction modulus is much dependent on the estimated value of that modulus, as well as on the decision whether the modulus is taken as a constant value over the entire depth, or its value increases by depth in dependence on the geological soil composition.

The results obtained are also largely dependent on the assumed system of elastic supports at the bottom of the retaining/supporting structure, as well as on the stiffness ratio of individual design elements (wall, anchor, elastic supports).

From the aforementioned considerations it can be derived that the results of the static analysis of a retaining/supporting structure using the ground reaction modulus can sometimes be pretty questionable. Particularly dangerous is the use of different computer programs enabling introduction of elastic supports of defined elasticity (pliability), however of undefined bearing capacity. In such cases, depths of the pile wall embedment can be underestimated (the equilibrium conditions are fulfilled, but the resulting reactive pressures in the elastic supports exceed the limit states).

These models are useless, if, in addition to the elasticity (pliability) of elastic supports, the load bearing capacity of the latter is not taken into consideration to determine the depth of embedment of a pile wall. This shall be determined either by the stability analysis or from the equilibrium of the earth pressures at slip.

By the method using the modulus of reaction of the ground, displacements of a retaining/supporting structure can be assessed, on condition that both elasticity (pliability) and bearing capacity are taken into consideration for elastic ties. However, the influence of the assumed value for the modulus of reaction of the ground is still present.

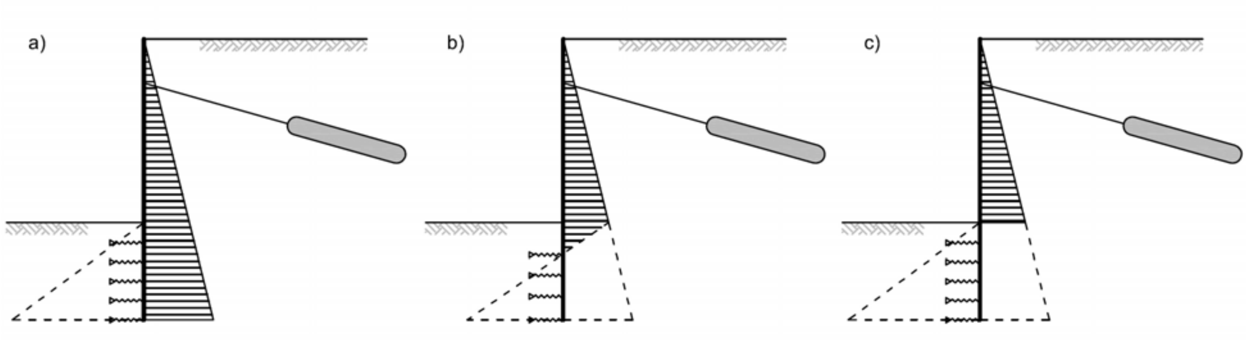


Fig. 6.1: Possible calculation methods in the static analysis of a pile wall, anchored at one level, using the modulus of reaction of the ground

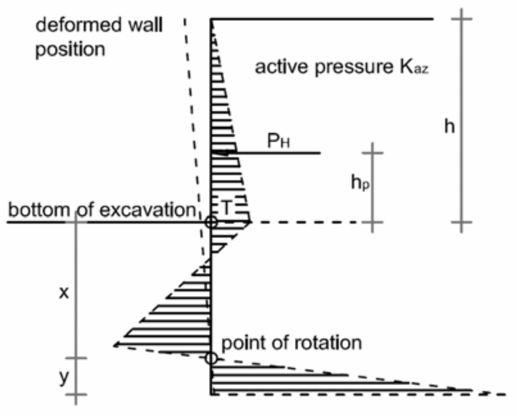


Fig. 6.2: Pressure distribution and displacements for a cantilevered pile wall

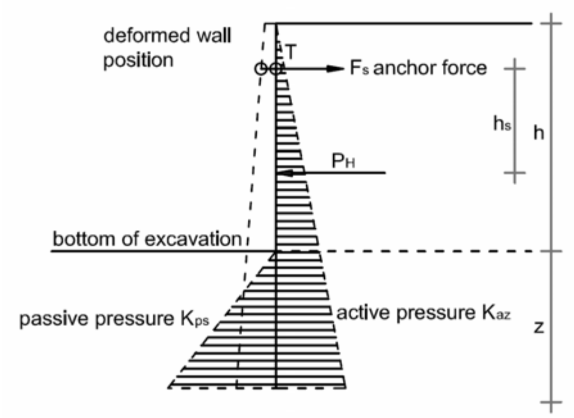


Fig. 6.3: Pressure distribution and displacements for a pile wall, anchored at one level

7 ANCHORED WALL CONSTRUCTION

7.1 Anchored Wall Construction in General

The present chapter deals with procedures to be considered in the anchored wall construction in order to ensure safety, adequate quality, appearance, and serviceability of the structure executed.

Both structural designer and soil mechanics expert shall indicate the particularities, which might occur during the wall construction (landslide locations, ground water inflows, maximum local inclinations of provisional cuts).

An anchored wall construction is composed of several stages, which are interdependent and shall be executed in a correct sequence. The construction stages shall also be harmonized with the works related to eventual other structures in the vicinity. The design shall take account of the individual safety of anchored wall and adjacent structures, as well as the safety and stability of the entire area in connection with a possibility of execution of each individual stage.

The contractor shall prepare a construction method statement, which shall ensure the design shape, quality, and durability of the structure, taking account of all the requirements related to health and safety at work.

The general organization and sequence of construction works shall be emphasized, and the construction shall comply with the static analysis of the design situations.

For each wall a method statement shall be worked out, which shall deal with access roads, working fields, evacuation of surface and rear water, wall construction stages and segments, including temporary protection as well as construction programme and individual time schedules.

A wall construction shall be harmonized with the entire construction sequence foreseen on the complete road section. The construction of an individual wall is relatively simple, whereas the execution of different wall systems is a rather complicated job, which shall be worked out in several alternative solutions. A wall construction must not endanger the safety of another, already completed wall or wall part (Fig. 7.1).

Any deviation from the design shall be approved by both the client and structural engineer.

Access roads to working fields shall ensure a reliable and safe transportation of both labour and materials. The access road shall be suitably consolidated, and its use must not affect adversely the stability of cut and fill slopes of the road. The access road width shall be adjusted to the field conditions and types of transportation means and mechanization. However, it shall not amount to less than 3.0 m. For the pile wall construction, the road shall be at least 5.0 m wide.

The working field shall be sufficiently wide as to enable a correct and safe construction. The working field design shall take account of the required width to erect formwork elements, to support and secure those elements, to erect working scaffolds, and to employ the required mechanization.

Drainage of both access roads and working fields shall be carried out immediately as to prevent instabilities at the site and damage to access roads and working fields.
The excavation for anchored walls or individual wall segments (vertical segments, longitudinal stages) shall take account of the design solutions. A construction pit may be opened at a length of one vertical segment maximum, or to an extent admitted by the design.

The excavation on the rear side shall be executed to such an extent as to ensure a suitable stability of the cut slope. In case that a cut slope of a greater inclination angle than foreseen by the design is required for objective reasons, a suitable protection shall be provided, ensuring at least an equivalent stability. The structural designer shall approve such a modification.

Design instructions dealing with the anchored wall formwork shall be taken into consideration. The formwork element quality depends on the side of the wall (front, rear) and on eventual additional finishing of exposed surfaces.

Reinforcement shall be placed in compliance with the wall reinforcement drawings. Attention shall be paid to the concrete cover, which shall amount to 5 cm for surfaces in contact with soil, and 4.5 cm for all the remaining surfaces respectively. To ensure the concrete cover design thickness, suitable spacers made of concrete or fibre concrete shall be used.

Concreting of anchored wall may only start after the reinforcement has been taken over by the responsible supervisor. The number of construction joints shall be as small as possible. If such joints cannot be avoided due to technological reasons or the wall height, they shall be made waterproof, same as it applies to the entire retaining/supporting structure.

Contact joints between vertical segments shall be carried through in accordance with the Design Guidelines 1.2.9. Special attention shall be paid to cases of a non-uniform ground bearing capacity. In such cases, the walls shall be urgently executed with a shear groove (tooth) to prevent displacements between individual vertical sections. At such joints, the density of anchors usually becomes greater as well.

Basic elements to compose an anchored wall structure are reinforced concrete and ground anchors. The execution of reinforced concrete elements is commonly known, whereas the ground anchor execution is specially discussed in chapter 9 of this Design Guidelines.

7.2 Particularities Of Construction Of Individual Anchored Wall Types

All the construction stages are shown in Fig. 7.1 in detail.

Special attention shall be paid to anchored wall constructed from above downwards. As such walls are foreseen in relatively severe geological – soil mechanical conditions, they are usually executed from vertical segments with skips of at least 5 m in-between (chessboard system). In dependence on the geological – soil mechanical properties and hydrological conditions, vertical segments are up to 7 m long, whilst the longitudinal stages are up to 3.5 m high.

For walls longer than 30 m expansion joints shall be foreseen. Each expansion joint shall be equipped with a shear groove (tooth) through which a strip runs. The length of individual units between adjoining expansion joints shall amount to approx. 20 m.

Along expansion joints, anchors shall be foreseen on both sides and in each longitudinal stage, although they are not required from the geostatic point of view. By means of a shear groove (tooth) and anchors at the expansion joint, eventual non-uniform wall deformations are prevented.

7.3 Pile Wall Construction

A pile wall construction is composed of several stages, which are interdependent and shall be executed in a correct sequence. The construction stages shall also be carefully planned and harmonized with the works related to other structures in the vicinity.

All the methods for construction as well as for a safe and correct work shall be described in the pile wall method statement and the site organization plan to be prepared by both designer and contractor.

Both structural designer and soil mechanics expert shall indicate the particularities, which might occur during the wall construction (landslide locations, ground water inflows, maximum local inclinations of provisional cuts).

The working field shall be sufficiently wide as to allow a proper and safe work of the machine for the pile execution, a removal of excavated material arising from pile boring works, as well as placing the reinforcement cage and casting concrete.

The minimum working field thickness shall amount to 5 m. The working field shall be adequately consolidated and drained.

The working field drainage shall be so executed as to prevent any ground instabilities at the construction site.

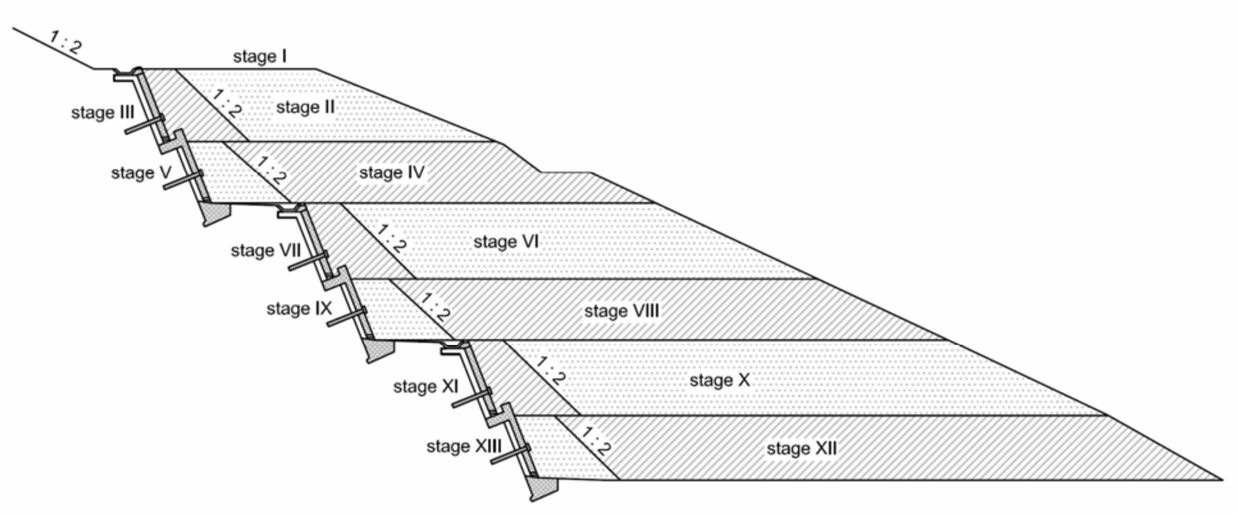
For the pile execution the working field level is also important. It shall be at least by 10 cm higher than the future upper level of the linking beam. In this way the reinforcement, jutting out from the already constructed piles, cannot be damaged/bent by machinery caterpillars.

On the working field, pile staking out is also executed. The building permit design shall include the pile wall staking out in characteristic profiles (usually every 20 m), whereas the project execution design shall provide the staking out for each individual pile separately. The staking out shall be in Gauss coordinates.

When boring for a pile is carried out, special attention shall be paid to the accuracy in view of the pile verticality and the location. Eventual deficiencies can be very disturbing after the soil has been excavated; during the construction, inconstant dimensions can cause additional problems.

Boring works shall be supervised by an expert in the field of geology, who has to make simultaneous records of the ground composition. Both geologist and contractor's site manager are responsible that the piles are carried out on the specified level sufficiently embedded (fixed) into the load bearing ground. In case that the load bearing ground differs from the design assumptions, both geologist and site contractor's site manager shall inform the structural designer immediately, and suitable action shall be taken in terms of additional instructions.

After the required boring depth is reached, pile reinforcement shall be inserted into the borehole as soon as possible. If a pile is longer than reinforcing bars, two reinforcement cages shall be coupled in place. Attention shall be paid to the increased concentration of spiral reinforcement in that area.



Stage I: Wide excavation by the road contractor up to linking beam

Stage II: Wide excavation by the road contractor up to the lower edge of the first longitudinal stage at inclination 1:2

Stage III: 1.Excavation by the wall contractor at the wall inclination for the first longitudinal stage of individual vertical segment
2.Execution of temporary concrete underlay of t = 15 cm
3.Placing longitudinal drainage pipe
4.Execution of concrete at drainage openings
5.Slab erection
6.Execution of filter concrete
7.Ground anchor stressing
8.Placing channel (gutter)
9.Casting slab linking beam

Stage IV: Wide excavation by the road contractor up to the lower edge of the second longitudinal stage at inclination 1:2

Stage V: 1.Excavation by the wall contractor at wall inclination for the second longitudinal stage of individual vertical segment
2.Removal of concrete underlay
3.Placing drainage geo-textiles and longitudinal drainage pipe behind foundation
4.Execution of foundation
5.Slab erection
6.Execution of filter concrete
7.Casting the joint between slabs
8.Ground anchor stressing
9.Execution of berm

Stage VI: as stage II
Stage VII: as stage III
Stage VIII: as stage IV
Stage IX: as stage V
Stage X: as stage II
Stage XI: as stage III
Stage XII: as stage II
Stage XIII: as stage III

Fig. 7.1: Schematic presentation of anchored wall construction stages

After the reinforcement is placed, casting of the pile shall commence. It shall be carried out via contraction hose, which must be at any time immersed into the concrete mixture by at least 1 m, thus concreting shall be carried out without any beaks and stops.

Simultaneously with the casting progress, the borehole protective pipe is pulled out. This shall be carried out carefully to prevent pulling out of the reinforcement as well.

Casting shall be executed by approx. 30 – 50 cm above the foreseen level of the pile upper edge. Concrete mixture with admixed earth is driven out to the top. Therefore it is recommended to break off the pile excessive length already next day, when the concrete strength is still relatively low.

The linking beam is carried out on an underlay. As the beam is usually visible, formwork for exposed concrete shall be used, and sharp edges shall be made round at corners.

When anchor heads are located in the linking beam, attention shall be paid to placing the formwork to ensure that the anchor heads are perpendicular to anchors.

Immediately after completion of a linking beam, a benchmark shall be built-in into the latter, and its accurate position shall be surveyed.

Where anchors are foreseen, they shall be installed and stressed after the linking beam construction is completed.

After the anchors are stressed, the earth on the front side shall be excavated up to the level of the next linking beam or to the bottom of the wall. The procedures of linking beam construction, of anchor installation and anchor stressing are the same as indicated above.

After the primary elements of a pile wall are completed, execution of drainages shall begin, i.e. horizontal drainages below the linking beam and vertical drainages between the piles. Simultaneously, exposed surfaces of the piles are finished, e.g. faced or washed with a high-pressure water jet.

At last, a final filling layer between the piles is carried through: over the drain concrete layer a PVC foil is stretched, a swelling strip is stuck onto the pile on the lateral side, and the space between the piles is concreted.

At the bottom of the wall exposed part, drained water shall be gathered from the spaces between the piles by means of a longitudinal drainage pipe, and shall be led to the surroundings at the wall end, or connected to the drainage system of the entire surroundings.

8 SUPERVISION OF CONSTRUCTION, QUALITY ASSURANCE, AND MAINTENANCE OF ANCHORED WALLS

8.1 Supervision And Quality Assurance Of Anchored Wall Construction

To ensure construction of a good and safe anchored wall, an adequate supervision of construction is required in addition to a professional and capable contractor.

The following shall be checked by the responsible supervisor:

- whether all the modifications and supplements occurring during construction are entered in the project execution design, and whether both the client and the designer have agreed with those modifications;
- conformity between the project execution design and current constructional regulations;
- quality of materials and products, installations, technological devices and equipment as well as the adopted methods;
- agreed construction programme/time schedule.

The responsible supervisor shall enter his findings in the construction diary daily.

On landslide slopes the ground shall already be examined prior to commencement of the construction with the goal to allow the structural engineer, soil mechanics expert and supervisor to decide, whether and where any inclinometers should be installed in the construction area. Immediately after the inclinometers are installed, zero-measurements shall be carried out and the frequency of the subsequent measurements determined. The measurement frequency is dependent on the measurement results.

During construction special attention shall be paid to measurements of benchmarks built-in in the structure. Benchmarks shall be placed onto linking and anchor beams at spacing of approx. 20 m, simultaneously with the construction progress.

However, if a retaining/supporting structure is located on a ground of extremely high landslide probability, the benchmarks shall be spaced at approx. 10 m.

For the benchmarks a zero-measurement shall be carried through as well. The subsequent measurements shall be performed at least after all major earth works (excavation on the wall front), which might cause additional pressures on the pile wall, as well as after each stressing of ground anchors.

When displacements in the inclinometers built-in in the wall area, and at the beginning of the structural monitoring are noticed, the benchmark measurements shall be carried out every 7 days.

When the displacements measured within the intervals of 7 days are greater than 5 mm, the time interval shall be reduced to three days. If the displacements continue to occur, the benchmark measurements shall be executed daily.

When the benchmark displacements are smaller than 5 mm, the next measurement shall be performed after 7 days, and then after 14 days. When even after 14 days no total displacements greater than 10 mm are recorded, the measurement interval can be extended 30 days, and subsequently to 90 days. During construction the monitoring interval shall not be less than 90 days.

When sudden displacements are recorded during intermediate measurements, the measurement frequency shall be as described above.
Benchmark displacement shall be measured with geodesic instruments of a guaranteed accuracy of $\pm$ 1 mm.

Simultaneously with the benchmark measurements it is also necessary to perform measurements on control anchors if any. Additional anchor and benchmark measurements shall be carried out in case of a drop or an increase of the anchor force by more than 10 kN.

Anchor forces shall be measured with attested and calibrated apparatus. The calibration shall be executed in compliance with the producer's instructions.
All the measurements performed on benchmarks, measuring anchors, and control anchors shall be submitted to both structural designer and supervising engineer.

8.2 Anchored Wall Maintenance

After the wall construction is completed, it is the turn of the next type of supervision (superintendence), which goal is to ensure safety, serviceability, and durability of the retaining/supporting structure.
For this purpose the legislator has prescribed the maintenance and operation plan, being a constituent part of the technical documents.

The maintenance and operation plan is a systematically organized document comprising photos, drawings, and texts in a form of guarantees, certificates, lists, schemes, instructions, and similar, determining rules for the use and operation of the constructed or re-constructed structure and installations built-in, on the basis of which the owner is able to maintain his structure properly.

Main characteristics or features of the structural maintenance, which one shall be familiar with for a better comprehension, maintenance, and inspection of a structure are the following:

- Permanent ground anchors: forces in measuring anchors shall be regularly read and recorded in a table, which shall be attached to the maintenance documents. When eventual force drops or increases are greater than 10 kN, measurements shall be carried out more frequently than foreseen.
- A regular reading and recording of benchmarks coordinates is obligatory. Both zero-survey and table shall be attached to the maintenance documents. If benchmark displacements are greater than 5 mm, measurements shall be performed more frequently.
- Rear water drainages shall be cleansed to enable an undisturbed rear water flow.
- The drainage in front of the wall shall be regularly inspected and cleaned.
- The drainage outflow and both inspection shafts behind the wall shall be regularly checked and cleaned.
- The gutter behind the retaining/supporting wall shall be regularly inspected and cleaned. Eventual damages shall be immediately made good to prevent any unnecessary water inflow to behind the retaining/supporting structure.
- Eventual crack formation on the wall shall be inspected visually.

By implementing the superintendence, a level of the regular maintenance can be determined, and deficiencies that might cause major damage can be established and made good.

The superintendence is composed of the following activities:
- carrying out inspections,
- preparation of reports,
- planning maintenance and repair works,
- controlling quality of maintenance and repair works.

The inspections are divided by time and function in the following ones:
- technical inspection (upon handing over of the structure),
- routine inspections (at least once a month),
- regular inspection carried out one year after the technical inspection
- regular inspections every 2 years,
- main inspections every 6 years and upon expiry of the guarantee period,
- extraordinary inspections (immediately after exceptional events),
- detailed inspections (with a special intention).

8.2.1 Technical Inspection (Zero-Inspection)

This is the initial technical inspection upon the project handing over, also called zero-inspection. It shall be carried out in accordance with the current Construction Law by the authority that has issued the building permit.

By the technical inspection it shall be particularly established:

- whether the wall has been constructed in compliance with the design as well as relevant current standards and regulations;
- to check the quality insurance documents for all the materials built-in (certificates, control measurements, super-control, ...);
- to verify the general safety of both structure and traffic.

Both zero levelling and protocol of the measurement of reference points, i.e. benchmarks, shall be attached to the maintenance documents.

8.2.2 Routine Inspection

Routine inspections are carried out by road inspectors at least once a month.

Intention:
To find out and make good particularly those deficiencies that might jeopardize the traffic safety.

Extent and method:
Visual establishing of deficiencies on the furniture (safety barrier, drainage, eventual corrosion) as well as making good minor defects, particularly in view of cleaning.

Documents:
A record of inspections performed shall be kept in the wall maintenance book. When a major defect is discovered, the inspector is obliged to inform the maintainer in writing.

The inspection shall be carried out by the road inspector being supplementary schooled in this domain.

8.2.3 Regular Inspection

The first regular inspection shall be carried out one year after the technical taking over. Other regular inspections are performed every two years, unless a main inspection coincides with the regular one.

Intention:
To check all the elements of the furniture and the load bearing system, which are accessible without any special devices. Beside phenomena, that threaten the traffic safety, damages and adverse features on the wall, which could jeopardize the structural safety, serviceability and durability, shall be found out.

Extent:
- on the entire structure, all the changes that have occurred from the last regular inspection shall be established;
- condition of the wall and its individual elements shall be assessed, as well as a deviation from the original quality shall be found out;
- eventual major deformations of the wall shall be measured;
- in case that benchmark displacements are smaller than 5 mm, the next measurement shall be performed upon the next regular inspection (two-years inspection);
- in case that displacements are greater than 5 mm, measurements shall be repeated after 6 months;
- upon the regular inspection, benchmark levelling shall be carried out, and the results shall be recorded in a suitable form prepared in advance;

- ground anchors shall be obligatorily inspected, both visually and by reading forces in measuring anchors; these inspection works shall be carried through by a specialist in inspecting and assessing ground anchor condition;
- when the anchor force increase is less than 10 kN, next measurements shall be carried out upon regular inspection (two-years inspection);
- when the anchor force increase is greater than 10 kN, the measurements shall be repeated after 6 months;
- eventual measures for additional investigations shall be proposed;
- maintenance provisions shall be suggested.

Method:
The inspection works shall be carried through visually or by means of simple investigations (percussion, sclerometry, levelling, reading anchor forces by means of a special device, etc.).

Measuring devices:
Measurement of anchor forces shall be carried through by means of attested and calibrated apparatus. The calibration shall be executed in compliance with the producer's instructions. Benchmarks displacements shall be measured with geodesic instruments ensuring an accuracy of $\pm$ 1 mm.

Documents:
It is mandatory to keep an inspection record. General data as well as the condition of the wall, its bearing elements, and its furniture shall be recorded, and appropriate measures shall be foreseen. A standard or some innovated record can be used.

Performer of the inspection:
A crew under the lead of an expert, i.e. civil engineer having passed a professional exam and being adequately experienced. In the guarantee period, a representative of the contractor, who is liable to the guarantee, shall attend the inspection.

8.2.4 Main Inspection

Main inspections are carried through every six years and upon expiration of the liability period.

Intention:
The goals and content of main inspections are the same as it applies for regular inspections. However, a main inspection shall also cover locations of an insufficient accessibility or covered places, such as lower side of the deck, piers, bearings, etc. Suitable devices (standing or suspended scaffold, special vehicle) enabling access shall be employed. Uncovering of backfilled surfaces shall only be carried out in case of suspicion of damages, which can be indicated by soaking, deformations, cracks or similar.

During each main inspection, measurements of benchmarks shall be performed, which must be entered into a suitable form.

Performer of the inspection:
A crew under the lead of an expert, i.e. civil engineer having passed a professional exam and being specially qualified for inspection of retaining/supporting walls and assessment of their condition. As circumstances require, a professional institution can be engaged to perform special measurements and investigations.

8.2.5 Extraordinary Inspection

Extraordinary inspections shall be carried out after exceptional events such as:
- earthquake, heavy rainfall, flood, landslide, exceptional temperatures, fire in close vicinity;
- heavy traffic accidents and impacts of vehicles on the retaining/supporting wall;
- exceeded loads or occurrence of sudden damages;
- regular or main inspection have shown an increase of the anchor force by more than 10 kN or a benchmark displacement greater than 5 mm; in such cases, measurements shall be performed every 6, 3, or even one month, depending on the magnitude of anchor force increase or benchmark displacements.

Both extent and goal of the inspection depend on the type and extent of damages or on the reason of the inspection.

8.2.6 Detailed Inspection

A detailed inspection serves as a base to assess the actual quality and safety of the entire structure or as a base to carry through a diagnosis and define the rehabilitation method. A detailed inspection shall be executed in the following cases:
- if the quality, bearing capacity or safety are doubtable;
- if the results of regular or main inspections impose certain rehabilitation measures;
- in case of disputes, litigations or similar.

The content and extent of a detailed inspection depend on the motives for such an inspection. Beside visual inspection, the structure shall be tested statically and dynamically. In addition, characteristic structural elements and their materials shall be investigated as well.

Detailed inspections are performed by professional institutions, having at disposal adequate equipment and experienced staff being able to execute the investigations required and to interpret the results obtained. The report shall include the results of all the measurements carried out, as well as appropriate decisions foreseen.

8.3 Maintenance Works

Due to their substantial loading with earth pressure, traffic action, erosion phenomena and road maintenance measures (de-icing salts), anchored walls are classified in the category of highly loaded structures. Therefore, proper maintenance is of an extreme importance to the anchored wall service life.

Beside cleansing of an anchored wall and its furniture as well as replacement of wearing parts, all other works not intervening in the structure also belong to the maintenance works.
The extent of the required maintenance works, except regular cleansing, is determined by the conclusions of the abovementioned inspections.

A maintenance book shall be kept where all the events that have happened on the anchored wall (such as maintenance works, inspections, exceptional heavy transports, etc.) are recorded. The maintenance book shall be accessible to the contractor until the liability period has expired.

Each anchored wall shall have its own record, which shall contain the following fundamental information:

- title of the structure,
- name and surname of the designer,
- design number,
- contractor’s name,
- year of construction,
- name of the owner/maintainer,
- annual plan of routine inspections including a column indicating dates of the inspections performed,
- name of the person responsible for routine inspections and routine maintenance works.

The anchored wall record shall be located at the premises of the anchored wall direct maintainer.

When some damage to the structure is ascertained, the maintenance service shall immediately notify the wall owner/manager, and, until the liability period has expired, the contractor as well.

8.3.1 Regular Cleansing of Anchored Walls

Regular cleansing of an anchored wall includes a general cleansing twice a year, i.e. in the spring and autumn, and an additional cleansing ordered by the road inspector, when his own capabilities are exceeded. Both the date and extent of regular cleansing shall be entered in the anchored wall record.

8.3.2 Spring Cleansing

Spring cleansing shall be carried out after the winter season of ploughing and strewing sand or de-icing salt. The extent of the spring cleansing is as follows:

- after the snow has melted, the anchored wall surfaces exposed to the de-icing salt shall be washed thoroughly,
- cleansing of drainages,
- cleansing of sewers behind and in front of the anchored wall,
- cleansing of drainage outlets behind the wall,
- cleansing of channels behind the wall.

8.3.3 Autumn Cleansing

Autumn cleansing shall be performed prior to the winter season, in particular comprehending removal of pollution due to traffic, and of vegetation. The following works are included:

- cleansing of drainages,
- cleansing of sewers behind and in front the anchored wall,
- cleansing of drainage outlets behind the wall,
- cleansing of channels behind the wall.

8.3.4 Winter Cleansing

Where an anchored wall is located at a road, the winter cleansing shall include a complete removal of snow from the structure lower part after ploughing. A daily thawing of non-removed snow can cause an adverse soaking of the structure, which, in combination with the de-icing salt water, increases the concentration of chloride ions.

8.3.5 Additional Cleansing

Additional cleansing is carried out when the road inspector orders so. The reasons such as traffic accidents, rigours of the weather, etc., that have led to such decision, shall be done away.

8.3.6 Maintenance of Measuring Instruments

Measuring instruments/devices located on an anchored wall shall be suitably and regularly maintained in the entire structural service life. The following maintenance works are required:
- maintenance of measuring instruments in compliance with the producers' instructions;
- touching-up or renewal of corrosion protection of anchors heads including anchor plates;
- sealing elements and protective coating on anchor head protective caps shall be renewed.

9 GROUND ANCHORS

9.1 Ground Anchor Types And Composition

A ground anchor is a constituent part of a geotechnical structure. It is a load-bearing element capable of transmitting an applied tensile load from a structure to a load-bearing stratum. In this way structural stability is enabled or increased. This is the basic task of a ground anchor.

The most important ground anchors are pre-stressed anchors having a clearly expressed free anchor length. Such an anchor represents a geo-static element being a constituent part of the structure – anchor – ground system where stress-strain states at the interface anchor cylinder – surrounding ground are always extremely complex.

In general, a ground anchor consists of a pre-stressed tendon. The use of pre-stressed ground anchors began 25 – 30 years ago.

Ground anchors can be classified in different ways. The most frequent classifications are as follows:

- by constituent parts: anchors can consist of one bar or several tendons;
- by the ground where they are anchored: soil anchors or rock anchors;
- by the character of load transfer: 1D-, 2D- or 3D-load transfer;
- by the character of functioning: passive or active (pre-stressed) anchors;
- by the application mode: permanent, temporary, or test anchors.

The service life of permanent anchors shall be the same as that of the anchored structure, whereas the service life of temporary anchors shall amount to at least two years. Test anchors are specially designed anchors installed in a common way serving to obtain sufficient information to select suitable anchors and to specify the fixed anchor length.

In compliance with the Eurocode 7, the design resistance of ground anchors is calculated by introducing the factor γ_m amounting to 1.25 for temporary, and 1.5 for permanent anchors.

A ground anchor consists of three principal elements (Fig. 9.1):

- fixed anchor length,
- free anchor length, and
- anchor head.

The fixed anchor length L_{fixed} serves to transmit the load from the anchor to the ground.

The free anchor length L_{free} is multiple. For pre-stressed ground anchors it is essential to analyse and select correctly the free anchor length.

The free anchor length depends on the following:

- soil-mechanical characteristics of the ground
- results of stability analyses,
- weight of the earth mass activated at anchor for a safe load transfer,
- rock strength,
- dimension of the anchored structure and the shape of the anchor head.

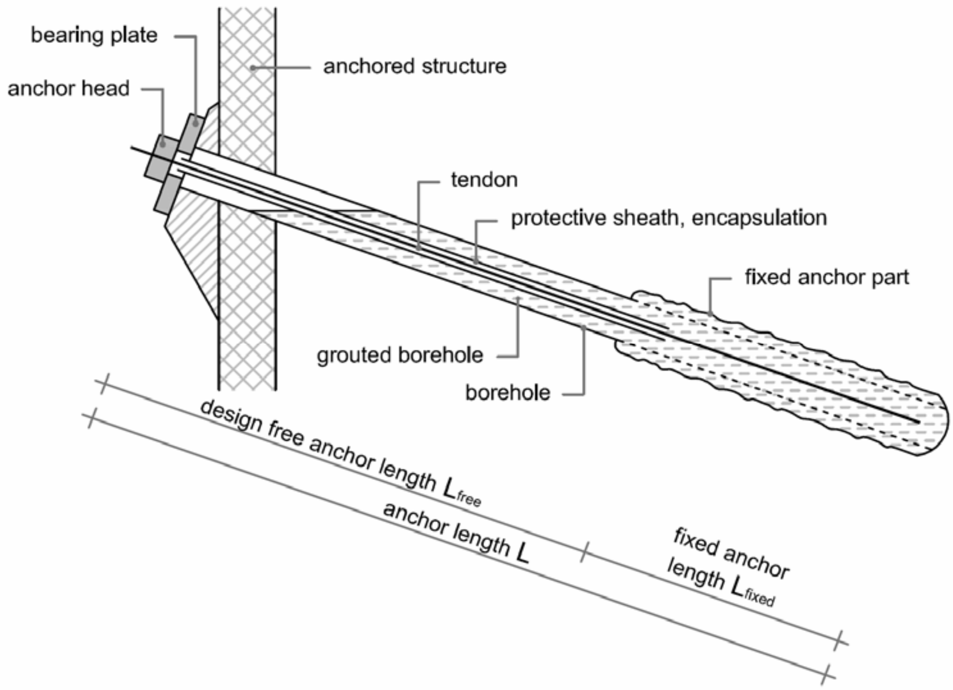


Fig. 9.1: Pre-stressed ground anchor with typical elements and symbols

9.2 Load And Material Partial Factors According To Eurocode 7

Eurocode 7 comprehends two types of partial safety factors:
- **for the load**, where the expected loads are multiplied by the load safety factors,
- **for the material**, where material properties are reduced by the material factors.

In the Eurocode 7 design situations to be verified in the design stage are exactly specified, and requirements in view of the durability of structures and materials are given. An essential newness is a sub-chapter that defines the calculation methods of the geotechnical design. Partial safety factors are introduced in the geotechnical practice. This is reflected in the design load model, load (forces or imposed displacements), material characteristics, and geometrical data, as well as in the limit values of deformations, cracks or vibrations. Three different cases shall be verified by calculation in accordance with the Eurocode 7:

- **Case A:** Loss of structural stability when the strength of the ground or structure is not relevant (e.g. loss of stability due to buoyancy);
- **Case B:** Failure of the structure or its elements (piles, sheet piles, anchors, etc.) depending on the material strength;
- **Case C:** Failure of foundation ground when the structural strength is not relevant and does not enter the calculation. The case C is relevant in stability analyses, when determining the size of a retaining wall, or to specify the required depth of fixing a pile wall in the foundation ground.

For each situation safety factors γ_m are specified to determine the design values of loads and the degree of mobilization of the shear resistance of soils (Table 9.1).

Table 9.1: Partial safety factors

Case	Load			Ground			
	Permanent		Intermittent	$\tan \phi$	c'	c_u	q_u
	Favourable action	Unfavourable action	Unfavourable action				
A	0.95	1.0	1.5	1.1	1.3	1.2	1.2
B	1.0	1.35	1.5	1.0	1.0	1.0	1.0
C	1.0	1.0	1.3	1.25	1.6	1.4	1.4

The design values of loads are obtained by multiplying the characteristic loads, whereas the design values of ground shear parameters by reducing the characteristic shear strength. To verify the serviceability limit state (displacements, deformations), all the values of the safety factors shall be taken equal to 1.0, whereas the limit values of rotations and differential displacements are prescribed.

When anchored retaining structures are designed in accordance with the Eurocode 7, two calculations shall be carried through:

a) to design structural elements of an anchored retaining structure (anchors as well) in accordance with the case B considering the load factors, whereas the material factors are taken equal to 1.0;
b) to verify the global stability of an anchored structure (foundation ground) according to the case C where the load safety factors amount to 1.0 (exceptionally to 1.3 when an intermittent load acts unfavourably), whereas the material factors for shear angle, cohesion or non-drained cohesion shall be taken as specified.

9.3 Assessment Tests Of Ground Anchor Resistance

To design anchored structures adequately, on-site assessment test is required.
Minimum three test anchors are required. They shall be executed in advance or at least at the beginning of the anchor works. Such testing of the ground anchor resistance ensures a safe, reliable and economical anchored structure.

The number of control anchors to monitor the anchored structure during its service life shall amount to minimum 5% of the total number of anchors, or at least three anchors per structural element.

By assessment testing in situ characteristic anchor resistance is determined. The number of test anchors shall amount to at least 1% of the foreseen temporary anchors and 2% of the foreseen permanent anchors or minimum two test anchors for the temporary anchors and three test anchors for the permanent anchors. The assessment test shall be carried through in such a way that cessation of deformations due to creep and pre-stressing is ensured.

The characteristic external anchor resistance R_{ak} is determined with regard to the number of assessment tests, the mean and minimum value of the resistance R_{am} at testing, and the value ξ given in the table 9.2.

$$R_{ak} = R_{am}/\xi$$

The design (permissible) value of the external anchor resistance R_a is obtained by dividing the characteristic value R_{ak} (the lower value is relevant) by the factor γ_m amounting to 1.25 for temporary and 1.5 for permanent anchors.

$$R_a = R_{ak} / \gamma_m$$

Table 9.2

Number of assessment tests	1	2	>2
(a) ξ for mean value of R_{am}	1.5	1.35	1.3
(b) ξ for minimum value of R_{am}	1.5	1.25	1.1

The number of test anchors (assessment tests) affects the magnitude of the permissible force and indirectly the costs of the anchor works.

9.4 Ground Anchor Functioning

The intention of pre-stressing of ground anchors basically differs from the intention of pre-stressing of concrete.

By a high degree of pre-stressing of a steel tendon, compression stresses are applied to a concrete element to cover tensile forces thus preventing a risk of formation of tensile cracks during the service life of a structure.

Ground anchors are predominantly pre-stressed in order to:
- enable that an anchor is instantly activated by self-stressing, if required (due to a change of the state of deformations in the system structure – anchor – ground for any reason);
- prevent eventual harmful (undesired) displacements of the anchored structure;
- verify the performance of an anchor (complete or simple stressing test of an anchor);
- provoke favourable effects of fixing between wall blocks and fragments or to increase the integrity of cracked rock masses.

The functioning of a pre-stressed ground anchor can be easily explained with an anchored concrete block on which vertical lifting force P acts (Fig. 9.2).

By pre-stressing an elastic elongation s_e of an anchor is attained being always substantially greater than the ground settlement s_b below the concrete block. If, for instance, due to creep and shrinkage reasons the ground under the block settled exactly by s_e in the course of time, this would mean that the pre-stressing force in the anchor has dropped to zero. Therefore all efforts shall be directed to the goal that the ratio s_e/s_b is as high as possible. Taking into consideration that at force N_p the settlement of the ground beneath the observed concrete block is a function of the ground type, only the value s_e can be influenced. It can be obtained by introducing the Hook's law:

$$S_e = N_p \cdot \frac{L_f}{E \cdot F}$$

At certain force N_p the value s_e will augment with the increase of the free anchor length as well as with the decrease of the modulus of elasticity E and the cross-section F of the steel. Taking into consideration that the value E is more or less equal for all types of steel, there is no other alternative but to increase the value L_{free} and to decrease the value F in order to augment s_e.

The steel cross-section can be additionally reduced introducing high-strength steel. From this is clear that the free anchor length is an essential anchor component having a great influence on the magnitude of s_e. Therefore free anchor lengths shall be as great as possible. In practice the free anchor length shall always be greater than the fixed anchor length, particularly when anchors are installed in rock.

Figure 9.2b shows the activation of normal bearing stresses below the concrete block due to the action of the force N_p applied to the anchor by pre-stressing. When an external force P of magnitude $P < N_p$ (Fig. 9.2c) acts on the block, the displacements of the system block – ground will be insignificant, however sufficient to establish a new equilibrium by a decrease of bearing stresses. In the meantime the anchor force remains practically unchanged. When the force continues to increase up to the value $P = N_p$ (Fig. 9.2d), the equilibrium is re-established by minimum displacements of the system, and the bearing stresses amount to zero. The anchor force still remains practically unchanged. By augmenting the force to the value $P > N_p$ (Fig. 9.2e), the equilibrium can only be established by an increase of the anchor force, which is, however, accompanied by significant displacement a between the block and the ground.

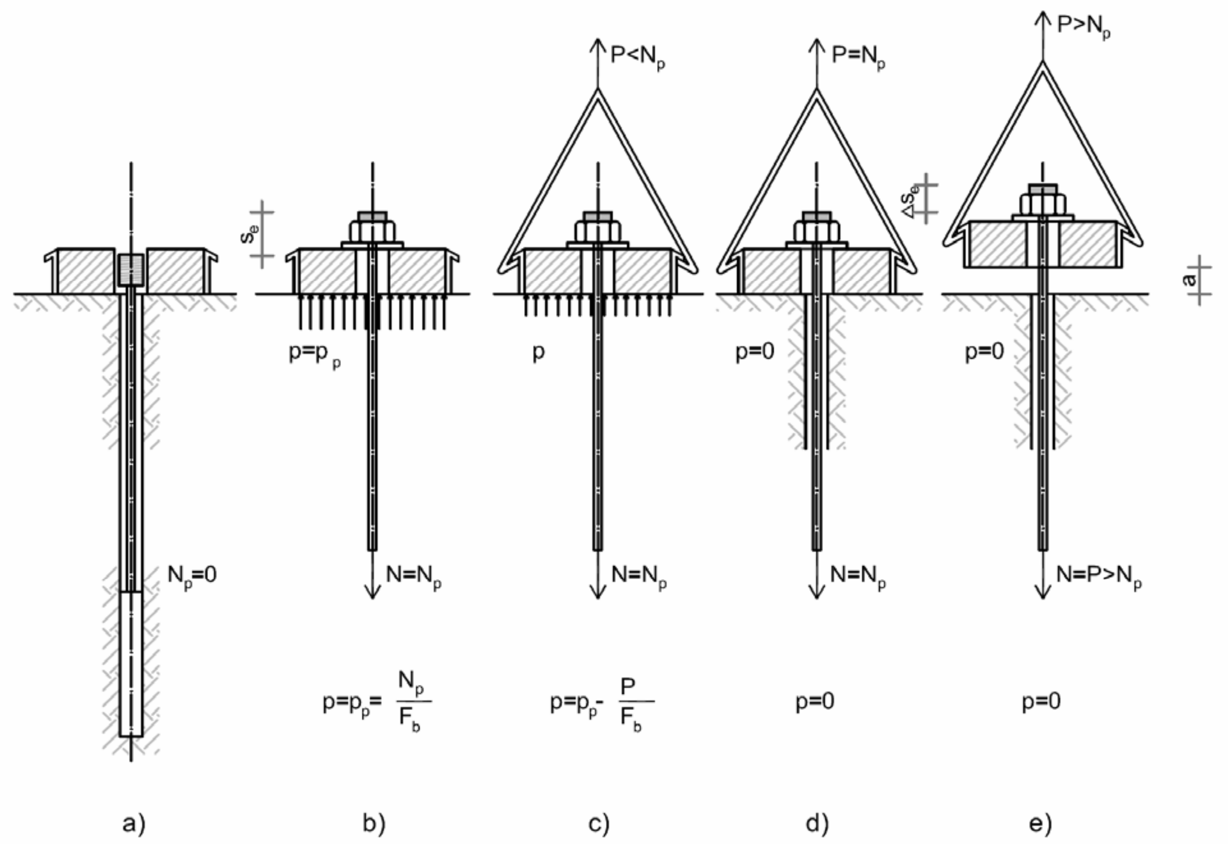


Fig. 9.2: Scheme of functioning of pre-stressed ground anchor

a) anchor prior to pre-stressing
b) pre-stressing of anchor activating bearing stresses below concrete block
c) external force $P < N_p$ acting on concrete block
d) magnitude of force equal to anchor pre-stressing force N_p
e) force P greater than force N_p – anchor force $N = P > N_p$ arising

9.5 Transfer Of Anchor Force To The Ground

The load capacity of an anchor mainly depends on an adequate transfer of the pre-stressing force to the ground. Beside a quality corrosion protection of an anchor this is a major problem appearing in this type of structural elements.

The load bearing ground where an anchor is installed can be either rock or soil.

Significant forces are transmitted from the fixed anchored length to the rock by means of cement-grouted anchors. Testing of such anchors indicates an adhesion of 5,000 kN/m^2 in the fixed anchor length. When the contact with the rock is fixed, significant forces can be transferred to the rock. For this purpose, water-tightness of the borehole shall be preliminarily tested. In case that the borehole is not watertight it shall be consolidated by means of grouting. Afterwards, drilling of the borehole is repeated and the anchor installed. In this way, sufficient safety of the load transfer is obtained. Several factors show different possibilities of transmitting the load to the rock. With regard to different characteristics of the rock and to the roughness a possible load transfer can only be established by test anchors indicating the actual loading the rock is able to withstand. For testing purposes the fixed anchor length is generally reduced by a third or by the ratio to the safety factor, whereas the anchor is loaded up to failure. The latter generally occurs either at the interface steel – cement grout or at the interface cement grout – rock.

The load capacity of anchors in soils mainly depends on the soil characteristics and the technology of installation of the fixed anchor length. The most important factor that affects the anchor load capacity is the fixed length, which is efficient under certain restrictions. By increasing the displacements of the fixed anchor length the friction on the anchor exterior decreases. The next factor influencing the anchor resistance is the borehole diameter.

By increasing the borehole diameter the friction force augments as well. However, such measure is limited by the drilling costs since the borehole has to be enlarged over its entire length.

The resistance of an anchor installed in soil is influenced by a correct execution of the borehole over the whole fixed anchor length. One of the most suitable provisions to obtain an adequate load capacity of such anchors is to measure the increase of the grouting pressure. Frequently a common simple grouting is sufficient even for cohesive soils. However, when the physical properties of the particular soil are poor, such simple grouting is not satisfactory. Therefore, an extra grouting is adopted is such cases. This means a repeated grouting of the fixed anchor length after a certain period. In cohesive soils, only cracks in the borehole or minor caverns are generally filled up during the first grouting. In this way transfer of relatively minor forces is enabled. By an extra grouting of the fixed anchor length under high pressure, radial stresses at the interface grout – soil are increased thus augmenting the friction forces acting on the anchor exterior. Moreover, an irregular anchor shape and surface is created ensuring a better adhesion of the anchor to the surrounding ground. By a multiple additional grouting the abovementioned effect is even amplified.

9.6 Ground Anchor Execution

The execution of a complete ground anchor consists of four principal operations:
- drilling of a borehole,
- assembling and inserting of an anchor,
- grouting, and
- stressing.

The borehole drilling method shall comply with the type of the ground and the required borehole diameter. During the drilling works it is obligatory to keep an adequate record. After completion of drilling the boreholes shall be protected from eventual entry of foreign materials. In soils containing clay as well as in soils and rocks subjected to rapid weathering the anchors shall be immediately inserted into boreholes and grouted. Water-tightness of boreholes in rock shall be verified. Eventual consolidation grouting or other suitable measures shall be foreseen.

In sandy-gravel materials where the boreholes are not stable drilling shall be carried through using protective pipes enabling the installation of anchors. These pipes are pulled out from the borehole simultaneously with grouting.
After drilling is completed, the position, inclination and length of the boreholes shall be checked.

Ground anchors shall be assembled in factory conditions. Transportation, storing and installation of anchors shall be organized in such a way that the function and efficiency of the corrosion protection are not jeopardized.

Anchors can be inserted manually as well as by means of different cranes or special devices.

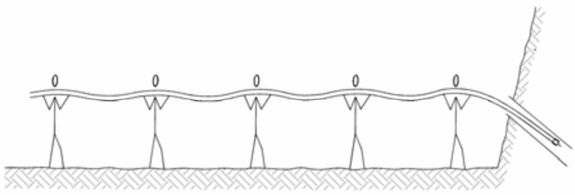


Fig. 9.3: Manual installation of anchors

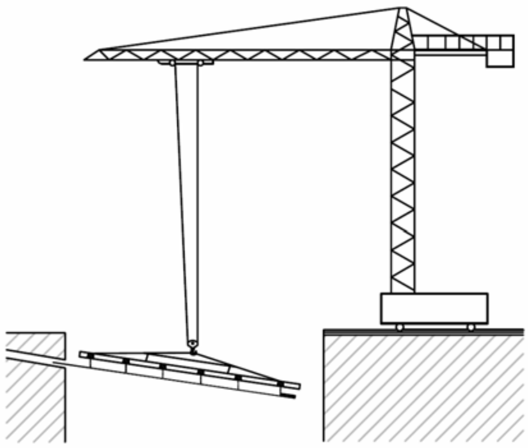


Fig. 9.4: Installation of anchors by means of cranes

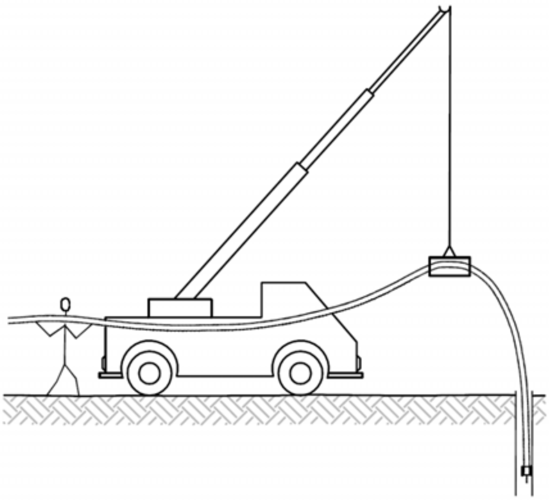


Fig. 9.5: Installation of anchors by means of a mobile crane

Grouting is an operation particularly ensuring the anchor load transfer from the fixed anchor length to the ground as well as the protection of anchors from corrosion.

Grouting pressures and quantities shall be adjusted or selected in compliance with the geometrical, geological and hydro-geological conditions as well as with the type and composition of an anchor. Grouting shall start at the lower end of the anchor whereas an air outlet and an outflow of eventual water from the borehole shall be ensured at the opposite end.

The grouting mixture mainly consists of pure Portland cement, admixtures and water. The water-cement ratio generally amounts to 0.36 – 0.44. For extra (additional) grouting that ratio shall come to 0.5.

To obtain a correct viscosity of the colloidal mixture highly turbulent mixers are used. The grouting mixture is preserved in special tanks where continuous stirring and pumping is granted. To achieve high pressures, piston pumps shall be employed.

The grouting mixture quality required to create the fixed anchor length shall be adjusted to the capability of the ground to grouting.

When instead of a cement suspension some other material is used for grouting, its suitability with regard to application, corrosion protection and durability as well as to mechanical properties shall be demonstrated.

In general, grouting is carried through in two stages. First the fixed anchor length is grouted; then, after completion of stressing, the free anchor length is grouted.

Grouting is one of the most important procedures of the anchor execution. Therefore a record of all the procedures adopted and the composition of grouting compound shall be kept.

By **stressing** the high-strength steel an anchor attains its intended function.

An anchor may be stressed when the grouting compound of the primary grouting has reached the prescribed strength. The period after which this can be performed is determined on the basis of tests or in accordance with the manufacturer of the grouting mixture.

Prior to commencement of the stressing, the site manager shall appoint a responsible person to manage the entire stressing procedure. Stressing shall be consistently carried out in compliance with the written procedure of stressing to be elaborated by the designing engineer.

Stressing shall be executed in the spirit of the anchor investigation and of the stressing test. The first serves for the anchor dimensioning whereas the second for the assessment of the anchor resistance and for the acceptance of anchors.

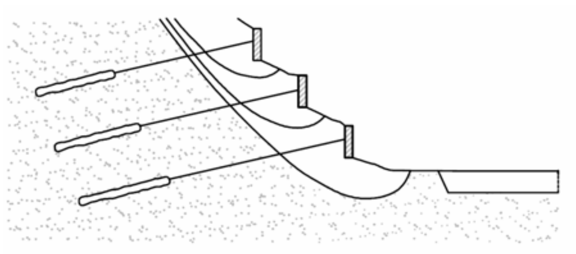


Fig. 9.6: Retaining structure anchors

In the fabrication, transportation, storing and installation stages local corrosion of stressed or non-stressed tendons that have still not been grouted must be prevented. Temporary protection such as wrapping up in oiled paper, transportation in ventilated wooden boxes, is quite understandable. Formation of condensed water shall be prevented as well; therefore the pre-stressing steel must not be exposed to temperature variations.

The residual water from concrete that is located in protective sheath and contains chlorides and sulphates is particularly hazardous to the pre-stressing steel. Therefore it shall be removed after concreting (e.g. by blowing out). Pre-stressing tendons in the protective sheaths shall not be left without grouting for a longer period in order to minimize the jeopardy due to condensed water.

9.7 Ground Anchor Application

Notwithstanding that the ground anchors are relatively new in the engineering practice their application is rather widespread. However, one shall realize that ground anchors may be foreseen only when all other options are essentially less suitable, e.g. when a structure to be saved is threatened to fail, in case of aesthetic demands or when certain works cannot be executed without anchors at all.

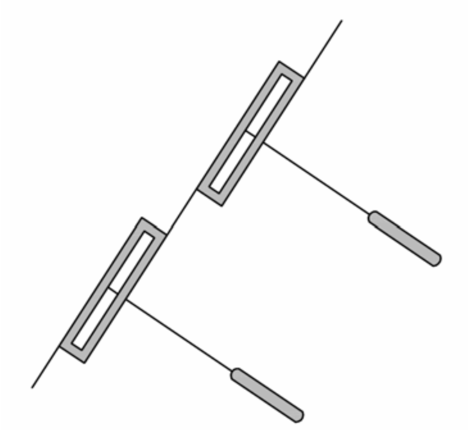


Fig. 9.7: Anchored blocks on rocky slope

However, one can hardly imagine some types of structures without anchors:

- In high barrages favourable stress states are formed in critical zones, i.e. where a safe interaction of ground and structures is required or to prevent unwished deformations.

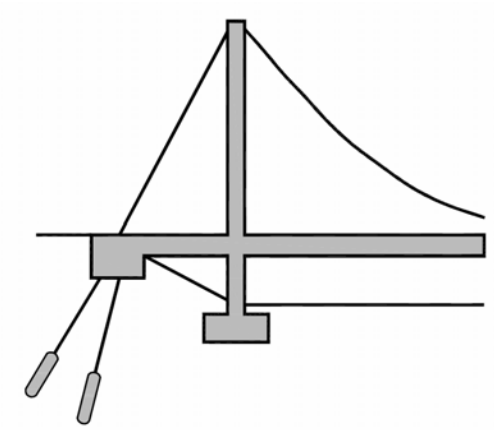


Fig. 9.8: Anchor block of cable-stayed bridge

- In hydro-technical structures a general stability is ensured (buoyancy, slip), eventual superstructure can be connected with the existing structure, loads acting to the water control equipment can be taken, and structural stability during seismic events is granted.

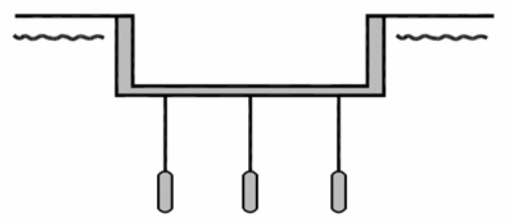


Fig. 9.9: Anchoring to take forces due to water buoyancy

- In deep construction pits the excavated walls can be secured.
- Unstable slopes and landslides can be improved, arches of tunnels or similar structures as well as bridge abutments can be anchored, etc.

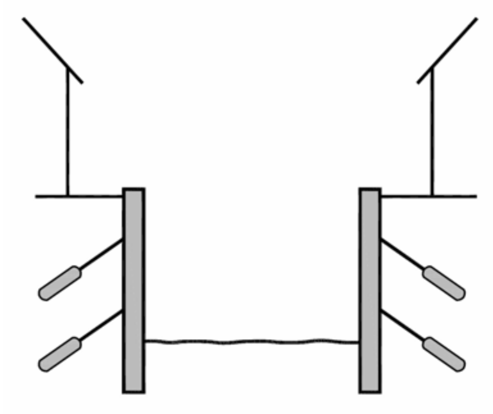


Fig. 9.10: Anchoring of construction pit protective walls

9.8 Ground Anchor Protection

Ground anchors shall be designed and executed in such a way that their function is not jeopardized during the entire service life of an anchored structure. Anchors are practically always of an existential importance for a particular structure. Therefore, permanent anchors shall be perfectly safe structural elements of long duration. The following requirements shall be fulfilled:

- service life of a ground anchor shall be at least equal to that of the anchored structure;
- condition of an anchor shall be examinable at any time;
- one must be able to perceive an eventual early failure of an anchor in due time; this means that the available time shall be sufficient not only to evacuate endangered persons but also to replace the anchors.

As long as ground anchors are made of high-strength steel, an anchor will be considered as a safe element of long duration only in case that it is perfectly and durably isolated from water as well as that its isolation and load capacity can be verified at any time.

According to metallurgists' findings the high-performance steels, which are the most suitable material for anchor tendons in view of mechanical properties, are jeopardized by each electrolytic process that takes place on the surface, irrespective of the fact whether an anchor plays a role of an anode or a cathode.

This difference between high-strength and common reinforcing steel leads to the result that galvanizing or cathodic protection as a measure of corrosion protection fails to be successful in case of ground anchors. The phenomenon of electrolytic processes can only be prevented by a sufficient and durably functioning isolation of the entire anchor from water. This demanding goal has still not been reached in the engineering practice; however the truth is that particularly in Switzerland a significant progress in this domain has been made in recent years.

It is well known that the steel is subjected to corrosion. Decomposition of steel is a consequence of different corrosion types. The more complex the steel composition, the more complicated is the corrosion mechanism.
Both common reinforcing steel and high-performance steel used for anchors are subjected to four corrosion types:

Surface corrosion takes place on an unprotected steel surface at sufficient air humidity.

Spot corrosion (pitting) is a result of different potentials on the steel surface; as a consequence of an anodic reaction, an accelerated formation of iron ions occurs. Free chloride ions are a very dangerous promoter of this corrosion type.

Stress corrosion is a phenomenon of high stress states in steel bars. It is conditioned by anodic reactions that create certain circumstances for the hydrogen brittle failure as well.

Hydrogen brittle failure is a corrosion type being a consequence of preliminary treatment of iron. The metal decomposition is not related to the abovementioned corrosion types being a subject of anodic corrosion.

For pre-stressing steel subjected to hydrogen brittle failure, reactions in acid media where hydrogen ions are reduced and in electrolytes without oxygen, or in extremely potentials where even water is decomposed, represent a direct jeopardy due to hydrogen atoms taking rise on the surface.

In ground anchors special attention shall be paid to the stress corrosion, which has been ignored so far. The following shall be considered:

Local corrosion attacks breaking out when alkaline protective cover around steel tendons is lost due to action of chlorides. The resulting crack either act as mechanical cracks or represent a source of stress corrosion induced by hydrogen.

Formation of macro-element, characterizing a local separation of anodic and cathodic partial reaction. In this particular case the subject in question is a macro-element created by structural reinforcement and the ground anchor. The reinforcement is embedded in concrete and is in a passive state, whereas the anchor is in an active state where it is insufficiently protected from corrosion. The difference in potential ΔU between the active and the passive steel in this macro-element causes an electric current I that leaves the metal on the anchor and enters it on the structural reinforcement. A reaction takes place at the exit from the anchor. This means that the load-bearing cross-section is reduced, and the originated notching effect may cause stress cracks. The electric current density of anodic dissolution can amount to more than 1 mA/cm^2 depending on the size of the damage. Even a so-called double corrosion protection that has become more or less common (inserting of pre-stressed tendons into cement mortar and a continuous protection by means of a PE sheeting), cannot completely prevent the hazard due to the considered macro-element. This is only possible by electric insulation from the anchored structure. Galvanizing often applied to common steel also represents such a macro-element. The less precious zinc layer plays the role of an anode whereas the steel is a cathode. The cathodic reaction, taking place on the steel at a lack of oxygen or at a too intensive cathodic polarization leads to a risk of formation of hydrogen atoms. Galvanizing as direct corrosion protection of protective caps and bearing plates must not be applied due to the hazard of hydrogen brittle failure. Therefore, such type of corrosion protection shall be superseded by a suitable painting system.

Stray currents usually appear next to railway tracks with direct current. A portion of recurrent electric current leaves the track, enters the surrounding ground and runs as a stray current through the ground back to the rectifier. When metallic structures (reinforcement) as electric conductors appear on this way, a portion of the stray current enters that structure, leaves it next to the rectifier, and finally enters the tracks again.

A hazard due to the stray currents arises particularly at the exit of the stray current where an anodic partial reaction takes place, whereas a cathodic partial reaction occurs particularly at the entry of the stray current. In case of the lack of oxygen or at high current densities the water is decomposed at well. The steel is highly polarized as cathode and hydrogen atoms take rise, which might lead to hydrogen brittle failure of a ground anchor. The electric current of 1A can "dissolve" approximately 9 kg of iron in one year. Measurements have shown that such stray currents can reach values over 100 A. Only an electric insulation in combination with the so-called double corrosion protection can prevent an anchor from the hazard of failure.

Cathodic protection is a type of corrosion protection where the potential is reduced and the metal decay prevented by means of a controlled electric current running between the anode and the steel element to be protected. This method frequently used for pipelines and tanks buried in ground can become problematic when high-strength steel need to be protected, since hydrogen brittleness and consequently stress corrosion of steel can appear (refer to stray currents above).

From the abovementioned facts one can derive that anchors and pre-stressing steel must be permanently protected from corrosion to ensure safety as the smallest scars may act as notches causing stress corrosion. Beside the fundamental knowledge of the jeopardy, the protection technology and a possibility to verify the foreseen measures are important as well.
Full attention shall be paid to the corrosion protection at any time, i.e. during transportation, installation, and service.

The basic corrosion protection of pre-stressing steel is ensured by alkaline grouting compound provided that the grouting has been executed perfectly, i.e. without any voids, and permanently controlled. The grouting mixture must not contain admixtures that might accelerate the process of corrosion. The second corrosion barrier is the protective sheath. Plastic sheaths are more appropriate than metallic ones. The most important corrosion barrier is the concrete cover that shall be sufficiently thick as it applies to ordinary reinforcing steel. Such protective concrete covers must not be executed by means of procedures used to prepare high-performance concrete.

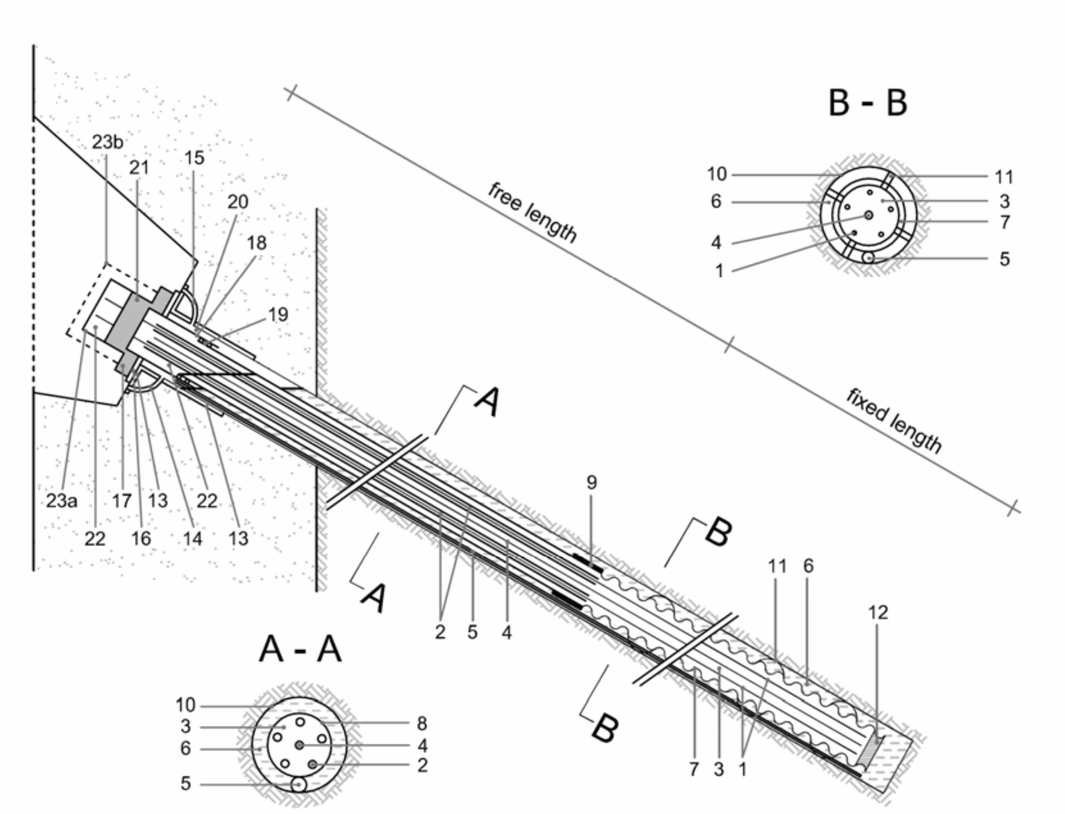
All up-to-date systems of permanent anchors are based on "double corrosion protection" generally consisting of the outer protection (PE sheath over the entire length) and the inner protection of individual strands with grouting compound (or with a suitable grease in the free anchor length). The most important requirement is a waterproof plastic (hard PE) protective sheath preventing water to enter the anchor. At the same time the waterproof protective sheath ensures protection from stray currents. Macro-elements can only be prevented, isolating the ground anchor from the structural reinforcement.

The principles of corrosion protection of ground anchors and pre-stressed tendons are as follows:
- **to prevent an entry of aggressive medium (water);**
- **to prevent an electric contact with the structure;**
- **to enable control.**

Several tests carried through on executed anchors by measuring electric resistance have shown that anchor system with so-called double corrosion protection have substantial constructive deficiencies. Beside frequent damage of PE protective sheath due to unscrupulous handling on site such sheath is often damaged due to excessive deformations of the fixed anchor length during stressing tests. It shall be noted that only a single damage of the plastic sheath may cause that an anchor becomes a macro-element with a certain electric current. The intensity of this electric current depends on the difference in potentials between the anchor head (which is electrically connected with the anchored structure) and the ground next to the damage. Eventual stray currents considerably increase the electric current running through the anchor. On the damaged place concentrated entry and exit of the electric current takes place causing material losses or hydrogen brittleness of anchor steel.

One can notice that there is a pretty large gap between the theory of double corrosion protection and the construction practice. Enormous work, numerous tests and measurements as well as verifications of procedures and critical points have been carried out to surmount this gap between the theory and the practice.

The results of the abovementioned endeavour can be noticed in the latest Swiss recommendations SIA 191 that leaves off the notion of double corrosion protection. Ground anchors shall have an outer protective sheath (of hard PE) over the entire length of the pre-stressed tendon. This protective sheath must not be damaged during transportation, installation and grouting. For a reliable isolation of the anchor head from the structural reinforcement, an isolating plate shall be installed between the anchor bearing plate and the anchored structure. In this way resistance of an anchor to the entry of electric current is increased and macro-element currents in the structural reinforcement running transversally through the anchor in the anchor head area are prevented. The connection between the anchor trumpet and the protective sheath shall be waterproof. The void between the anchored structure and the anchor trumpet shall be grouted. Anchor heads of control anchors shall be covered with protective caps that must not be galvanized but protected with paint coats being electrically neutral to the steel.



Legend:

1 = unprotected strand
2 = greased strand in PE sheath
3 = inner grouting
4 = injection pipe for inner grouting
5 = injection pipe for outer grouting
6 = outer grouting
7 = corrugated PE sheath
8 = smooth PE sheath
9 = joint between corrugated and smooth sheath
10 = borehole wall
11 = spacer
12 = plug for anchor foot protection
13 = outer anchor support with a flange steel plate, a spiral fixed by welding, injection pipes and air vent pipes
14 = injection pipe at outer anchor support
15 = air vent pipe
16 = isolation plate (“cevolit”)
17 = bearing plate (embedded in concrete or protected from corrosion)
18 = trumpet (welded to bearing plate)
19 = sealing ring (gasket)
20 = grouting compound of anchor outer circumference
21 = anchor head
22 = inner grouting of anchor head (grease or cement)
23a = protective cap (exposed or embedded in concrete)
23b = protective cap protected from corrosion by means of paint coats

Fig. 9.11: Permanent anchor in compliance with the latest corrosion protection requirements