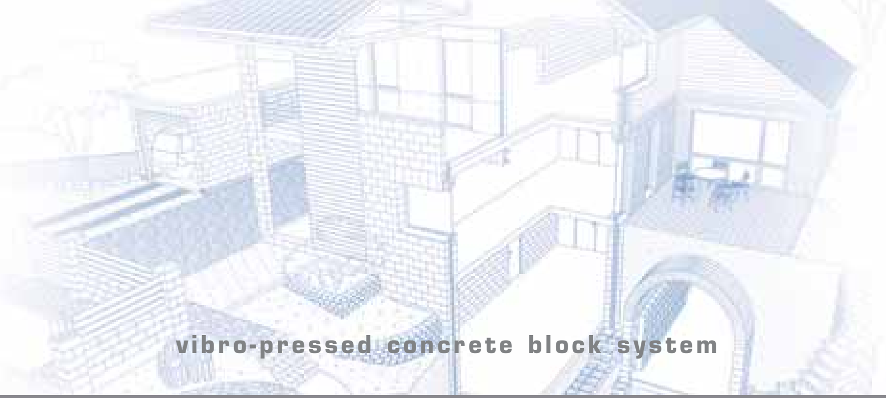
KB BLOK

PERFECT CONSTRUCTION SYSTEM

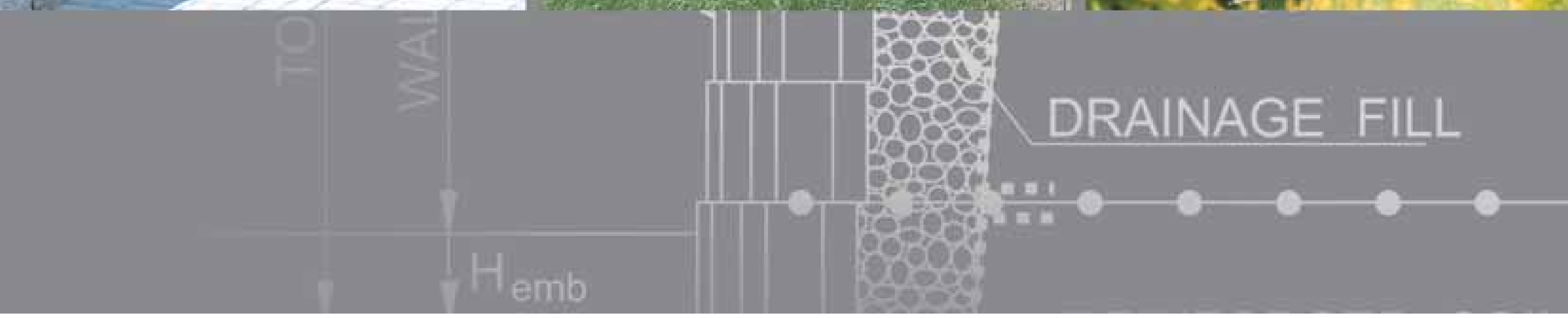


vibro-pressed concrete block system

TECHNICAL SECTION

REINFORCED SOIL SEGMENTAL RETAINING WALLS

practical handbook for investors engineers and contractors



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1. INTRODUCTION

Reinforced soil segmental retaining walls are a relatively new construction. They have been developed since 1960 with a rapid growth since the year 1985. However, the idea, i.e. retained soil, where reinforcing elements are inserted in the individual layers of soil and take the tension, is rather old. The constructions are based on the principle of retained soil that has been known for some 3,000 years. The development and growth of modern reinforced retaining constructions is closely linked with the development of plastic and the so-called geogrids used as reinforcing materials, and also with the vibro-pressed concrete technology used for production of modular concrete blocks.

Reinforced soil segmental retaining walls are basically formed by soil. Reinforcing elements inserted in the soil provide for retention of the desired inclination of soil. The reinforcing elements are subject to tension only. Retained soil thus means soil into which tension elements (e.g. geogrids) are inserted in order to improve stability and minimise deformations. The reinforcement must go through the potential failure plane in order to be effective. Deformations in the soil cause deformations and tension forces in the reinforcing elements. Tension forces in the reinforcing elements limit the deformation of soil and thus increase the shear strength of soil. Steel grids with anti-corrosive treatment were used in the beginning of modern retaining walls, while today we see almost exclusive use of plastic geogrids. Their resistance to corrosion is much higher than that of steel grids and they are usually resistant to other chemical and physical agents, while their disadvantage compared to steel grids is higher elongation. Facing of a retaining wall is made of modular concrete blocks connected to geogrids by plastic pins.

Reinforced soil segmental retaining walls may be used in many situations. Their utilisation requires adequate room for width, which is usually equal to seventy percent of the wall height at least. The width is necessary for the purpose of anchoring geogrids in the soil. Rather tall reinforced soil segmental retaining walls may be designed. Retaining walls may be designed for high load and also for dynamic load. Their advantages may be used in construction of roads and railways, fills, bridge supports, finishing of tunnel portals, etc. Reinforced soil segmental retaining constructions may be used not only for large scale construction works, but also in smaller contracts like terrain modifications including garden architecture. The reason for use in small constructions is good availability of the materials even for small builders, easy realisation and highly affordable price.

1.1 ADVANTAGE OF REINFORCED SEGMENTAL RETAINING WALLS

Aesthetics

Excellent aesthetic look is one of the main advantages of reinforced soil segmental retaining walls. This advantage is provided exclusively by modular concrete blocks. Construction of reinforced soil segmental retaining walls may currently benefit from the look of Gravity Stone concrete facing blocks as well as the new GEOSTONE® blocks designed specifically for use in reinforced soil segmental retaining walls. Engineers designing walls may choose from different colours and finishing options and decide between flat or plastic relief blocks. Modular concrete blocks are made in seven basic colour options in multi-color, in the range of colours for every year and two finishing options, the latter being smooth surface of split blocks. Different combinations of the range of blocks may bring interesting layouts of walls. Retaining walls may also include special vegetation blocks.

Versatility

Reinforced soil segmental retaining walls are highly versatile. Modular concrete blocks are designed so to make possible curved arrangement, both convex and concave. Curves of different radiuses and curvatures may be designed. Walls can also be returned in plan in both internal and external angles.
A wide range of modular concrete blocks may be used for construction of reinforced soil segmental retaining walls. Their combinations make almost any angle of the retaining wall possible.

In addition to that, vegetation concrete blocks may be included in the system to liven up the look of the wall, create terraces in the retaining wall and increase the angle of inclination of the retaining wall from vertical.
Minor constructions as foundations for fence columns, lighting poles, etc. may be built in the reinforced soil or into the blocks. Any plants may be planted in the area above reinforced soil.

High load capacity

Reinforced soil segmental retaining walls have very high load capacity. They may be designed for great heights and great loads. Walls may be designed for dynamic load caused especially by transport.

Reinforced soil segmental retaining walls may be used for bridge supports, wing-walls and reinforced road and railway embankments.

Price

Along with highly aesthetic look, reinforced soil segmental retaining walls are so popular also thanks to their very low price. The price of reinforced soil segmental walls is deep below the price of other retaining constructions. This is mainly due to a relatively low material consumption, low price of the materials and easy assembly. Studies of financial benefit of reinforced soil segmental retaining walls have been carried out in many countries. Provided below are results of the study by Prof. Koerner of the United States. The study clearly proves the economic benefit brought by reinforced soil segmental retaining walls.

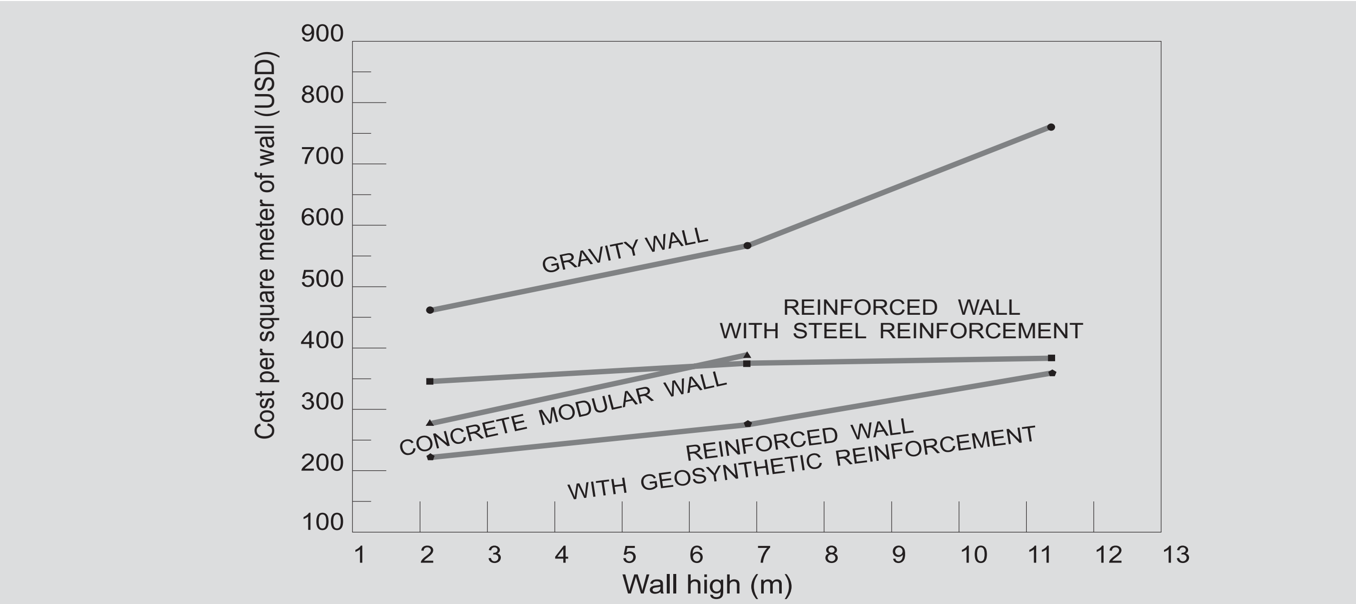


Fig. 1.1: Economic comparison of retaining walls in the USA

Assembly

Reinforced soil segmental retaining walls are very easy to build. Their construction does not require a special qualification and it may be carried out by personnel with just basic training. However, a well constructed retaining wall requires good work discipline and morale as any construction. The construction process does not require special mechanisms and machines except compacting machines and ground moving machines excavating and transporting soil. Manipulation with modular concrete blocks is very easy and it is done by one or two persons depending on the type of block. Manipulation with geogrids is also very easy as they are rather light.

A great advantage of reinforced soil segmental retaining walls is that the construction does not require the wet process, so it may be done even in not too good climatic conditions and in places without access for transport and laying of concrete.

Implementation

Reinforced soil segmental retaining walls use dry technology, which brings many advantages. Dry, mortar free joints provide for relatively small shift and deformation between blocks without deformation of walls or unsightly cracks. It is recommended to found columns of concrete blocks on a gravel base, which is soft and can adapt itself to minor deformations of the subsoil.

Service life

Reinforced soil segmental retaining walls are expected to last approximately 100 years. This is naturally given by the service life of modular concrete blocks and geogrids.

Modular concrete blocks are produced by vibro-pressed technology using a concrete mix with very low water content. This gives concrete blocks with high compressive strength and expected service life of 100 years. Concrete blocks with high resistance against CHRL are produced for the specific environment of roads, where there is an increased demand for resistance against chemical de-icing agents.

Geogrids are made of polymers, where manufacturers guarantee the service life of 100 years at least.

2. MATERIALS

Reinforced soil segmental retaining walls consist of modular concrete blocks, plastic pins, reinforcing geogrids, drainage material, reinforced soil, geotextiles and drainage pipe. The following paragraph provides a description of the materials.

2.1 MODULAR CONCRETE BLOCKS AND PLASTIC PINS

Modular concrete blocks for reinforced soil segmental walls are made by KB-BLOK system by vibro-pressed technology on US made production technology. The Gravity Stone modular block is manufactured under licence, while the other GEOSTONE® blocks are proprietary products of KB-BLOK system. Modular concrete blocks are made of a mix with very low water content, which together with other agents results in high compression strength of the concrete. Modular concrete blocks are specifically designed to be aesthetic, to have good drainage characteristics and to firmly anchor geogrids. Gravity Stone or GEOSTONE® blocks may be used for reinforced soil segmental retaining walls with geogrids.

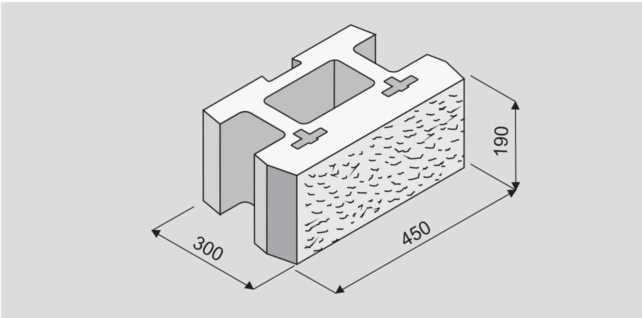
2.1.1 Gravity Stone concrete blocks

Facing blocks are used most frequently for reinforced soil segmental retaining walls of the entire Gravity Stone product range. However, this does not represent the only option. If the wall carries a high load or if it is very high and the geogrid must be anchored to concrete blocks more firmly, a segmental mini anchoring or single anchoring construction may be used instead of the facing block.

The Gravity Stone system that may be used in reinforced soil segmental retaining wall applications includes the following range of products.

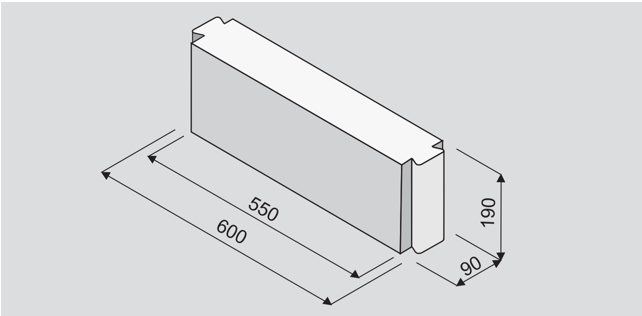
2.1.1.1 Facing block

The facing block may be produced in as many as seven basic colours, in the range of colours for every year and in two finishing options – smooth surface or split block. It is used as the facing block for segmental retaining walls. If it is used separately, its rear wall may be smooth. If it is used in combination with an anchoring dowel or an anchoring element, its rear wall features a socket for insertion of the anchoring dowel or anchoring element. Block weight is approximately 33 kilograms.



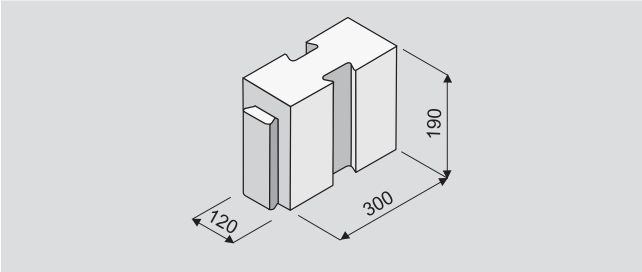
2.1.1.2 Anchoring dowel

The anchoring dowel connects the facing block and the anchoring element, thus creating the necessary construction depth of one anchor. This configuration is used in situations, where geogrid must be anchored to concrete blocks more firmly. The dowel is produced in natural concrete colour only. Dowel weight is approximately 24.5 kilograms.



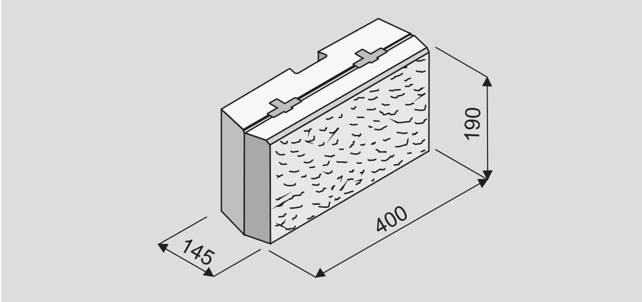
2.1.1.3 Anchoring element

The anchoring element is used for creation of one anchoring (for rear perpendicular section) or for a mini anchoring (for central and rear sections). One anchoring and mini anchoring fix the geogrid more firmly than a separate facing block. The block is produced in natural concrete colour only. Block weight is approximately 13 kilograms.



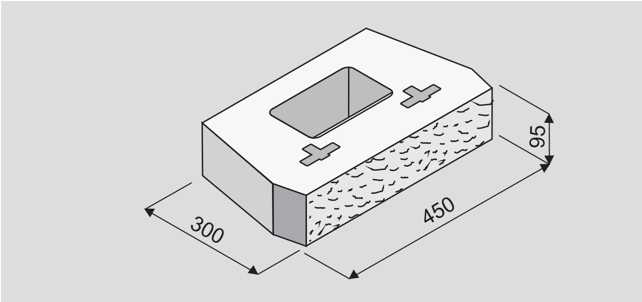
2.1.1.4 Special facing block 400

The block is used instead of the standard facing block in situations, where a fence adjoins to the retaining wall. Length of the block is 400 mm, identical with modular fence block. The block is made in seven basic colours, in the range of colours for every year and in two finishing options – smooth surface or split block. Block weight is approximately 21 kilograms.



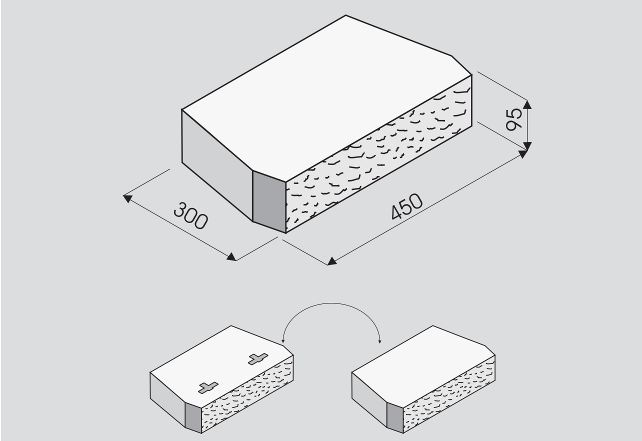
2.1.1.5 Facing block 95

The block is made in seven basic colours, in the range of colours for every year and in two finishing options – smooth surface or split block. It is used for artistic applications in the form of horizontal stripes in different colours. Block weight is approximately 21.5 kilograms.



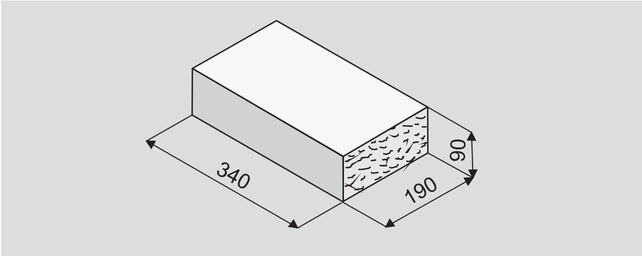
2.1.1.6 Cap block

The cap block is used for all wall configurations and is available in seven basic colours, in the range of colours for every year and in two finishing options – smooth surface and split block. The block is used to align the last row of facing blocks. Bock weight is approximately 25.5 kilograms.



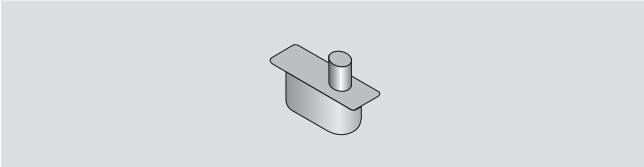
2.1.1.7 Cap block straight

The cap block is used for all wall configurations and is available in seven basic colours, in the range of colours for every year and in two finishing options – smooth surface and split block. The block is used to align the last row of facing blocks. Block weight is approximately 13.5 kilograms.



2.1.1.8 Gravity Stone connecting pins

The Gravity Stone system uses connecting pins the shape of which is illustrated by the attached picture. Pins are used to facilitate assembly and they increase the sliding resistance of dry bed joints.

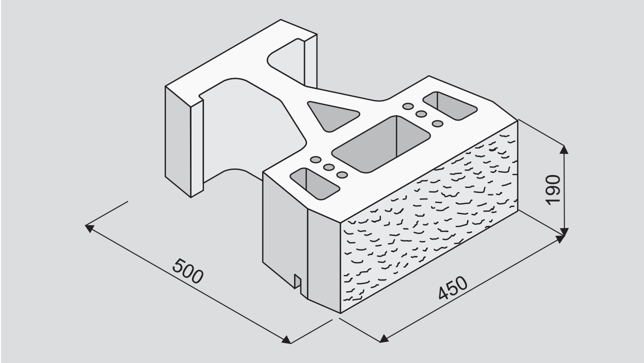


2.1.2 GEOSTONE® concrete blocks

KB-BLOK system developed modular concrete blocks that are successfully used in reinforced soil segmental retaining walls. The GEOSTONE® blocks can be combined to create a large range of retaining wall variants. The GEOSTONE® system includes the following blocks:

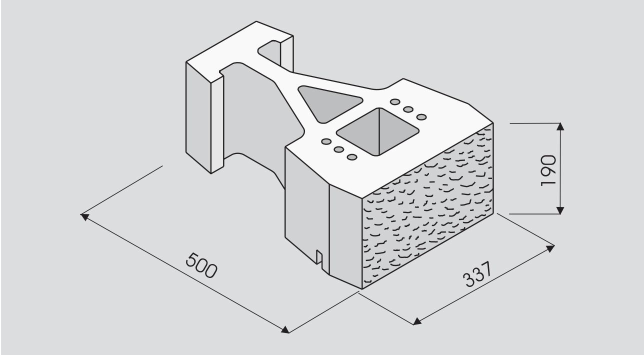
2.1.2.1 GEOSTONE® – FLAT

The block has a flat front wall identical with the front wall of the Gravity Stone facing block. FLAT block can be produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface or split block. The block is designed exclusively for reinforced soil segmental retaining walls. Block weight is approximately 42.5 kilograms.



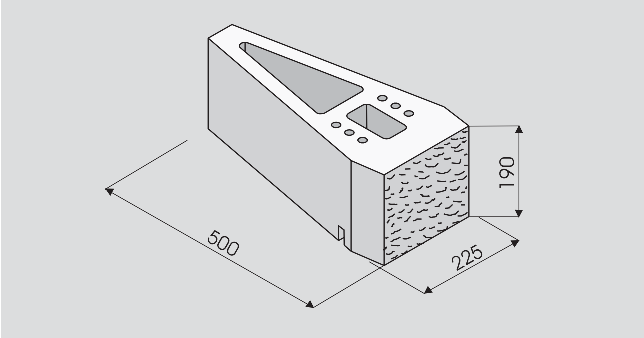
2.1.2.1.a GEOSTONE® – FLAT*threequarter*

GEOSTONE® – FLAT*threequarter* has a flat front face. Its length makes only three quarters of the basic length of FLAT block. GEOSTONE® – FLAT*threequarter* may be combined with all other GEOSTONE® blocks or be used separately. GEOSTONE® – FLAT*threequarter* can be produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface or split block. Its advantages include lower weight, only 33 kilograms.



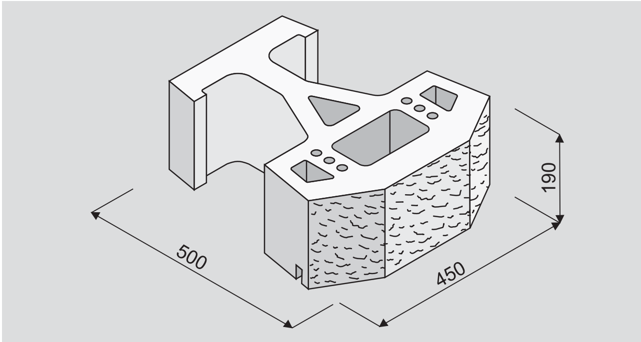
2.1.2.1.b GEOSTONE® – FLAT*half*

GEOSTONE® – FLAT*half* has a flat front face like all other FLAT blocks. Its length is a half of the length of the basic FLAT block. The block may be used separately or combined with all other GEOSTONE® blocks. GEOSTONE® – FLAT*half* may be combined with all other GEOSTONE® blocks or be used separately. GEOSTONE® – FLAT*half* can be produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface or split block. Its advantages include a relatively low weight, only 23 kilograms.



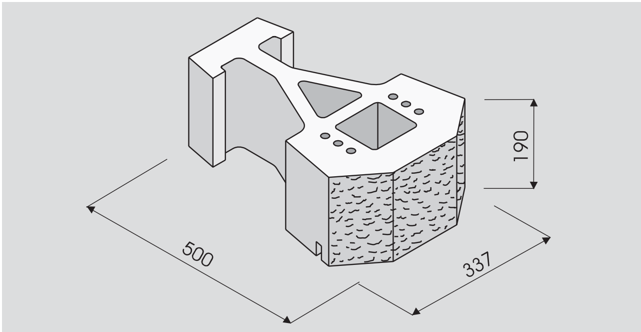
2.1.2.2 Prvek GEOSTONE® – BENT

The block has a bent front face with a highly plastic appearance. BENT block can be produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface or split block. The block is designed exclusively for reinforced soil segmental retaining walls. Block weight is approximately 40.5 kilograms.



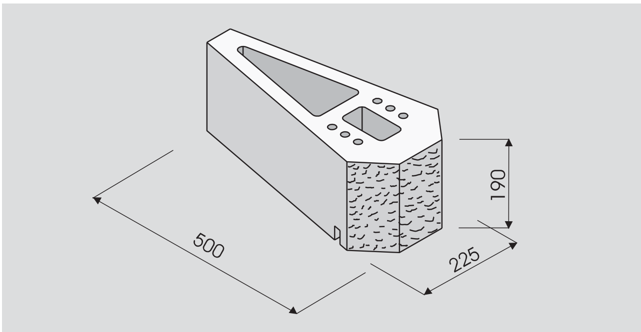
2.1.2.2.a GEOSTONE® – BENT*threequarter*

GEOSTONE® – BENT*threequarter* has a plastic front face similar to that of the basic BENT block. Its length makes only three quarters of the length of the basic BENT block. The block can be combined with all other blocks of the basic GEOSTONE® range or used separately. GEOSTONE® – BENT*threequarter* can be produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface or split block. Block weight is approximately 31 kilograms.



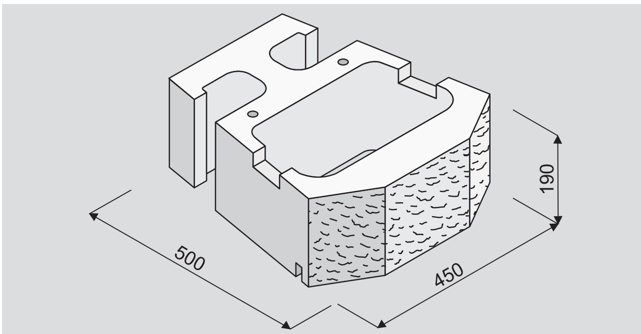
2.1.2.2.b GEOSTONE® – BENT*half*

GEOSTONE® – BENT*half* has a plastic front face similar to that of all BENT range blocks. Its length is approximately a half of the length of the basic BENT block. The block can be combined with all other blocks of the basic GEOSTONE® range or used separately. GEOSTONE® – BENT*half* can be produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface or split block. Block weight is approximately 21 kilograms.



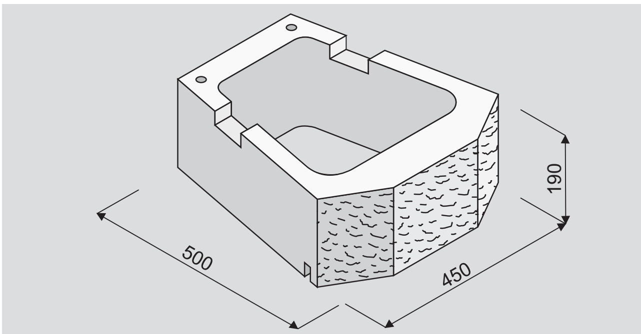
2.1.2.3 GEOSTONE® – POT

POT is primarily designed for planting flowers and other plants, but it may be used to liven up retaining walls made of FLAT and BENT blocks as well. The face of the block is identical to that of the BENT and SHELF blocks. POT can be produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface or split block. Block weight is approximately 40 kilograms.



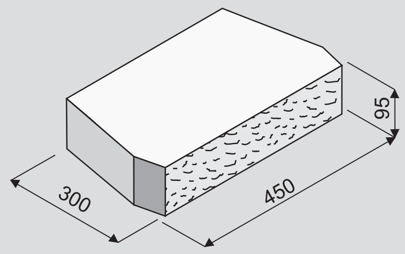
2.1.2.4 GEOSTONE® – SHELF

SHELF is primarily designed for planting flowers and other plants as well as creating small terraces in the construction of retaining walls. The shape of the front face is identical to that of BENT and POT blocks. SHELF can be produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface or split block. Block weight is approximately 34.5 kilograms.



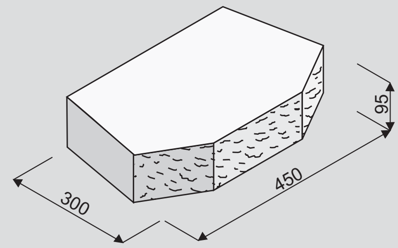
2.1.2.5 FLAT cap block

FLAT cap block is used for aligning walls made of FLAT or BENT blocks. The block is available in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface and split blocks. Block weight is approximately 25.5 kilograms.



2.1.2.6 BENT cap block

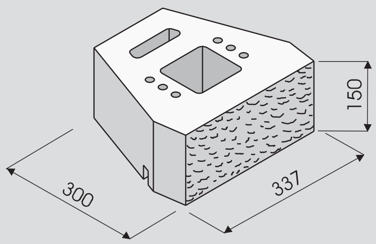
BENT cap block is used for aligning walls made of FLAT or BENT blocks. The block is available in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface and split blocks. Block weight is approximately 22.3 kilograms.



The GEOSTONE® – mini range of products was developed together with the standard product range. It is also to be used in retaining walls reinforced by geogrids. The products are 300 mm deep unlike the basic range with the depth of 500 mm. This main construction feature destines GEOSTONE® – mini blocks for many retaining wall applications, where the wall height and load are not extreme. This differentiates them from the basic GEOSTONE® range suitable for such extreme cases of great wall height exposed to high levels of load. The height of all GEOSTONE® – mini blocks is 150 mm.

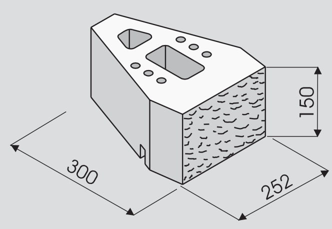
2.1.2.7 GEOSTONE® – miniFLAT

GEOSTONE® – miniFLAT has a flat front face. It is a basic GEOSTONE® – mini block with block length 337 mm longitudinally to the wall. The block may be used individually in retaining wall applications or combined with other GEOSTONE® – mini blocks. GEOSTONE® – miniFLAT can be produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface or split block. Block weight is approximately 22 kilograms.



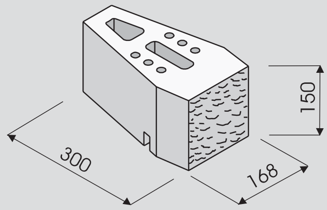
2.1.2.7a GEOSTONE® – miniFLAT*quarter*

Similarly to the GEOSTONE® – miniFLAT basic block, GEOSTONE® – miniFLAT*quarter* has a flat front face. The block dimension longitudinally to the wall is three quarters of the dimension of the basic GEOSTONE® – miniFLAT block. The block may be combined with all other GEOSTONE® – mini blocks or used independently. GEOSTONE® – miniFLAT*quarter* can be produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface or split block. Block weight is approximately 13 kilograms.



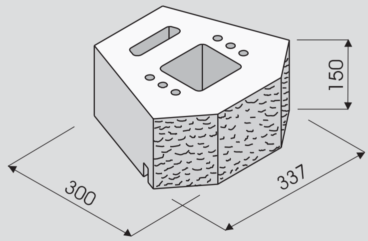
2.1.2.7b GEOSTONE® – miniFLAT*sixth*

Similarly to all other blocks of the FLAT group, GEOSTONE® – miniFLAT*sixth* has a flat front face. The block dimension longitudinally to the wall is a half of the dimension of the basic GEOSTONE® – miniFLAT block. The block may be combined with all other GEOSTONE® – mini blocks or used independently. GEOSTONE® – miniFLAT*sixth* can be produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface or split block. Block weight is approximately 11 kilograms.



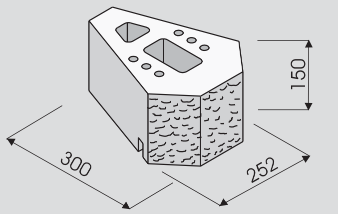
2.1.2.8 GEOSTONE® – miniBENT

GEOSTONE® – miniBENT has a plastic front face bent into three planes. External dimensions of the block are identical to those of the GEOSTONE® – miniFLAT. The block may be combined with all other GEOSTONE® – mini blocks or used independently. GEOSTONE® – miniBENT can be produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface or split block. Block weight is approximately 20 kilograms.



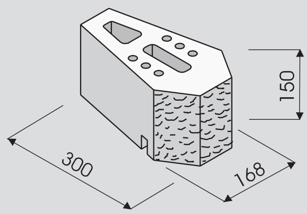
2.1.2.8a GEOSTONE® – miniBENT*quarter*

As all other BENT range blocks, GEOSTONE® – miniBENT*quarter* has a plastic front face. The dimension of the block longitudinally to the wall is three quarters of the basic dimension of the GEOSTONE® – miniBENT. The block is designed for independent usage as well as combination with other GEOSTONE® – mini products. GEOSTONE® – miniBENT*quarter* can be produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface or split block. Block weight is approximately 12 kilograms.



2.1.2.8b GEOSTONE® – miniBENT*sixth*

As all its related blocks, GEOSTONE® – miniBENT*sixth* has a plastic front face. The dimension of the block longitudinally to the wall is a half of the basic dimension of the GEOSTONE® – miniBENT. The block may be used independently or combined with other GEOSTONE® – mini products. GEOSTONE® – miniBENT*sixth* can be produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface or split block. Block weight is approximately 10 kilograms.



2.1.2.9 GEOSTONE® - connecting pins

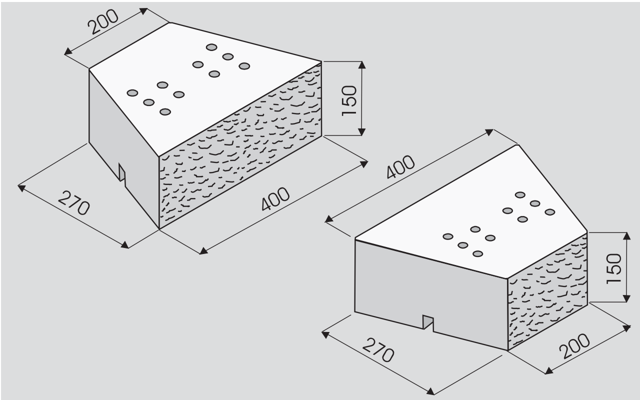
The shape of the connecting pins is illustrated by the attached picture. Pins are used to facilitate assembly of the wall and they increase the sliding resistance of dry bed joints.

2.1.3 Small concrete products

Small concrete products include two blocks – GEOZIQZAQ BLOK and GEOGARDEN STONE. These small blocks have been designed for smaller reinforced soil segmental retaining walls with maximum height of 3 metres. Compared to other blocks, these have the total of five rows of connecting pin openings. The purpose of this is to enable off-set of the blocks behind the front face of the retaining wall, but also their protruding. This makes several layouts of retaining walls possible – vertical, receding and plastic. Small concrete products do not have lightening holes and may be produced in GRIND variant. Retaining walls with plastic relief, where the individual blocks recede or protrude from the face of the retaining wall are highly aesthetic and attractive with GRIND blocks.

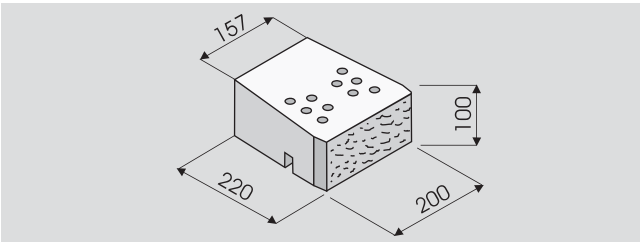
2.1.3.1 GEOZIQZAQ BLOK

GEOZIQZAQ BLOK is a 150 mm tall block specific by its highly tapered plan view. The taper makes curved sections of walls possible with a very small radius. Both the short and the long side walls of GEOZIQZAQ BLOK have a face, thus further expanding the possible range of retaining wall variants. GEOZIQZAQ BLOK is produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface and split block and also in GRIND variant. Weight of the product is approximately 26.6 kilograms.



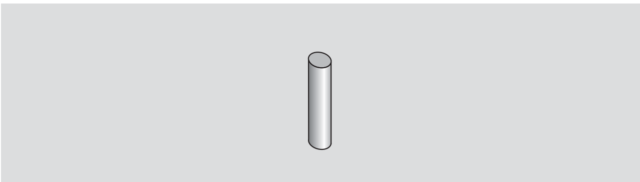
2.1.3.2 GEOGARDEN STONE

GEOGARDEN STONE is the tiniest block for retaining walls in the product range. It is only 100 mm tall and has a single face of 200 mm length. The product is only 220 mm deep, which limits its use for lower retaining walls and lower load level. GEOGARDEN STONE is produced in seven basic colours, in multi-color, in the range of colours for every year and in two finishing options – smooth surface and split block and also in GRIND variant. Weight of the product is approximately 8.7 kilograms.



2.1.3.3 Connecting pins for small blocks

The shape of the connecting pins is illustrated by the attached picture. Pins are used to facilitate assembly of the wall and they increase the sliding resistance of dry bed joints. Connecting pins identical with those of the GEOSTONE® system are used for small blocks.



2.1.4 Quality of concrete block production

Modular concrete blocks for reinforced soil segmental retaining walls are made by KB-BLOK system on production facilities by a world famous US brand, while maintaining the toughest technology standards. This brings high quality, top class products. Production quality is regularly tested by construction laboratories. Written records of test results are maintained.

Offer of colours and finishing options

Facing and capping products are available in the following basic seven colours, in multi-color, in the range of colours for every year and finishing options:

Basic colours: natural, red, brown, black, yellow, white, cinnamon
Finishing options: smooth surface, split block, GRIND

Required characteristics of the products:	
• compressive strength of a facing product	
- average value of 3 samples	min. 35 MPa
- individual value of a sample	min. 30 MPa
• compressive strength of an anchoring dowel and an anchoring element	
- average value of 3 samples	min. 25 MPa
- individual value of a sample	min. 20 MPa
• T50 frost resistance coefficient	min. 0,75
• absorption rate	max. 5 %
Production tolerance - length	600 ± 8 mm
- width	450 ± 5 mm
- height	190 ± 3 mm

2.2 GEOGRIDS

Geogrids are two-dimensional plastic constructions made of two mutually perpendicular rods, threads or rod clusters. In principle, they represent a reinforcing mesh that may be found analogical to a similar steel reinforcing mesh. Geogrids are made of various polymers. Polyester, high density polypropylene and polyethylene are most commonly used for production of geogrids. Different geogrids may have differently shaped rods and ribs. Longitudinal and perpendicular rods of different geogrids are also joined differently. As regards rigidity of geogrids, i.e. rigidity of their rods and rod joints, we distinguish between hard and soft geogrids.

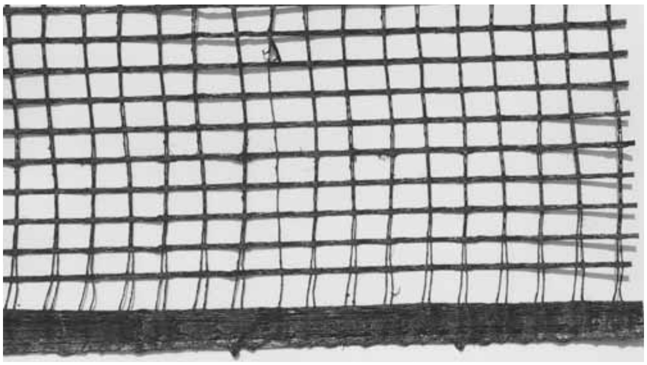
The main function of a geogrid in reinforced soil of a retaining wall is to take tension. Geogrid is exclusively tensioned – similarly to a steel reinforcing element in concrete. In order to satisfactorily perform its function, geogrid must be adequately anchored behind the potential failure plane. A design of a reinforced soil segmental retaining wall must include an analysis to identify the length and type of geogrids as well as their distance.

Lifetime of high-strength geosynthetics

Lifetime is the principle issue of all polymers required to perform their function over a long term. Geosynthetics as well as other construction materials degrade in time. The pace of degradation depends on molecular structure of the geosynthetic polymer and the environment, in which the geosynthetic material is located. Geogrids degrade very slowly due to their installation in soil. Measurable degradation takes place only in extreme conditions. Degradation of polymers usually causes a degradation of their strength. Calculations of reinforced soil segmental retaining walls require inclusion of the degradation impact. In practice, the design of a wall works with a long-term design strength of a geogrid that includes different degradation influences and factors. Calculation of a long-term design strength of a geogrid works with a reduction factor of durability of geogrids $\mathbf{RF_d}$. The reduction factor has been derived from experimental tests.

2.2.1 Miragrid geogrids

Miragrid geogrids are high strength polyester geogrids with high molecular weight. They are produced in high range of tension strengths meeting the requirements of reinforcing retaining walls.



Miragrid geogrids are woven and subsequently coated with a polymer coating for dimensional stability. They are capable of resisting the highest possible load that may arise with reinforced soil segmental retaining walls. The high molecular weight of polymer and high tension strength of polyester fibres used in Miragrid geogrids have excellent characteristics as regards long-term behaviour and resistance against long-term deformation. The high molecular weight of polyester fibres also guarantees resistance against the potential degradation influence of hydrolysis and chemical impacts within the pH range that may appear in the soil environment under normal circumstances.

Advantages and benefits of Miragrid geogrids:

- **No rolling back.**
  Miragrid geogrid is soft, which is why it stays flat having been placed in the retaining wall on the site and does not tend to roll back.
- **It is flexible and strong.**
  Tension is transferred from Miragrid geogrids into soil with minimum deformation of the ground construction.
- **It has low weight.**
  Miragrid geogrid is at least 33% lighter than most rigid geogrids.
- **Affordable price.**
  Polyester fibres of Miragrid geogrid have high tension strength and high long-term tension strength. This results in low need for the number of geogrids necessary to reinforce the wall.
- **It has high long-term design strength.**
  The long-term design strength of Miragrid geogrids has been defined based on long-term tests of more than 70,000 hours. Tests have been carried out by independent laboratories.
- **Easy manipulation.**
  Miragrid geogrid does not have sharp edges that might potentially cause personnel injury.
- **Supplied in wide rolls.**
  Miragrid geogrids are supplied in 3.6 meter wide rolls, which is more than other geogrids. Wider rolls significantly reduce the necessary deployment time, thus reducing the cost.

Miragrid geogrids have a high strength range. They currently have the highest tension strength of all geogrids available on the market. The table 2.2.1 provides a list of most frequently utilised Miragrid geogrids with strength specifications.

		2XT	3XT	5XT	7XT	8XT	10XT
Other designation		35/30-25	55/25-30	65/25-30	85/25-30	110/25-30	150/25-30
Longitudinal:							
Tension strength	kNm^{-1}	35	55	65	85	110	150
Strength in case of 5% strain limit	kNm^{-1}	16	20	29	33	40	50
Strain with maximum strength	%	11	11	9	11	12	12
Cross:							
Tension strength	kNm^{-1}	30	25	25	25	25	25
Mesh size	mm	25 x 25	25 x 30	22 x 30	22 x 30	22 x 30	22 x 30
Surface weight	gm^{-2}	255	277	305	346	387	485

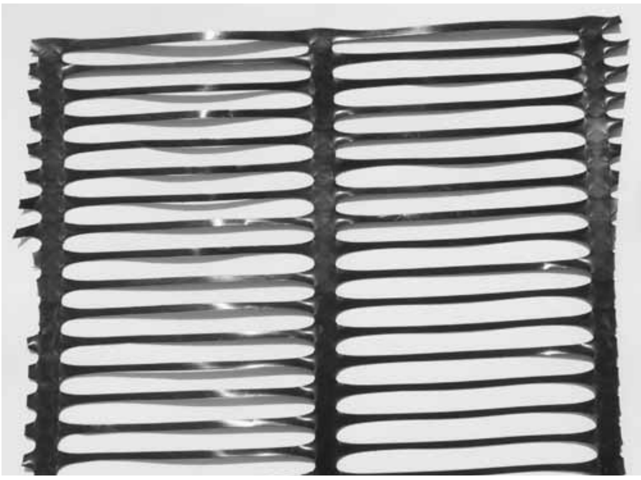
Table 2.2.1: Overview of most frequently used Miragrid geogrids

Principles of locating geogrids

The surface of modular concrete blocks, on which a geogrid is to be placed, should be clean and free of debris from drainage fill or soil. The soil the geogrid is laid on must be compacted to the defined level. Geogrid is rolled out from a roll and cut to the desired length. It is not allowed to connect geogrids in the direction of their stress, i.e. wall depth. Geogrids with different tension strength in the two directions are usually used to reinforce retaining walls and therefore proper directional orientation of geogrids is crucial. The main tension direction of a geogrid is identical with that of the rolling and it is also marked by a reinforced stripe on the edge. The main direction of a geogrid is identical with the stress direction, i.e. the wall depth direction. After geogrid has been installed, it must be stretched in order to lay level and unwrapped. Geogrid is stretched and levelled manually by slight stretching and then best by driving a pin into the bottom compacted layer. Geogrids are connected side-to-side in the longitudinal direction. It is not allowed to put one geogrid over another. A razor tool, a sharp knife or scissors may be used for cutting geogrids.

2.2.2 Tensar geogrids

Tensar geogrids are made of high density polyethylene. They are made by a special technology, where a continuous strip of high density polyethylene is perforated by openings of a certain shape in a regular pattern. Then the strip is heated and stretched, at the same time. This results in a geogrid with rigid joints of longitudinal and cross ribs and characteristic oval openings. Tensar geogrids are made in a range of tension strengths. They are supplied in 1 and 1.3 meter wide rolls. The table 2.2.2 provides a list of most frequently utilised geogrids including their strength specifications.



		40RE	55RE	80RE	120RE	160RE
Longitudinal:						
Tension strength	kNm^{-1}	52,5	64,5	88	136	173
Strength in case of 5% strain limit	kNm^{-1}	24,7	30,9	45,2	75,5	103
Strain with maximum strength	%	11,5	11,5	11,5	11,5	11,5
Mesh size	mm	16 x 235	16 x 235	16 x 235	16 x 235	16 x 230
Surface weight	gm^{-2}	290	400	600	940	1 240

Table 2.2.2: Overview of most frequently used uniaxial Tensar geogrids

Advantages and benefits of Tensar geogrids:

- **Unique technology and rib shape.**
  The above production technology guarantees a unique rib shape of Tensar geogrids.
- **Tension strength.**
  Tensar geogrids are made in a wide range of tension strengths.
- **Hydrolysis resistance.**
  Tensar geogrids are resistant to water solutions of acids, alkalises and salts as well as petrol and oil under normal temperatures.
- **Resistance against mechanical damage.**
  Tensar geogrids are rigid geogrids with relatively strong ribs less prone to mechanical damage.
- **UV resistance.**
  Tensar geogrids have good UV resistance that even increases with the addition of carbon.

Tensar has an advanced laboratory that carries out extensive long-term tests of their geogrids. Tests have been carried out since the beginning of the 80's. The results of long-term tests are used for determination of long-term design tension strength, which is design strength of a geogrid at the end of the projected lifetime. The long-term designed strength of Tensar geogrids has been set under the EN ISO 13 431 standard based on experimental tests.

Tensar geogrids show positive long-term behaviour of uniaxial geogrids. The most significant part of deformation takes place in the short initial period. Deformation relevant for the design actually takes place during the period of construction. The reinforcement is not deformed after the construction has been completed.

2.2.3 KB-grid geogrids

KB-grid geogrids are a part of the KB BLOK system. They are made of high density polyethylene. The geogrids are made in China on state-of-the-art production facilities and distributed throughout the world. The shape of the geogrids is very similar to that of Tensar and the same applies to the production – a stripe of polyethylene is punched in a regular pattern and subsequently stretched in one direction, by which typical longitudinal meshes are created. KB-grid geogrids are typical representatives of rigid geogrids with rigid joints of longitudinal and cross ribs. The stretching during production improves the mechanical and physical properties of polymer and thus also the tension strength of geogrids.

		50R	65R	90R	110R	130R	170R
Longitudinal:							
Tension strength	kNm^{-1}	52,5	65,0	90,0	118,8	136,0	176,0
Strength in case of 5% strain limit	kNm^{-1}	24,7	30,9	45,2	56,5	75,5	103,0
Strain with maximum strength	%	11,5	11,5	11,5	11,5	11,5	11,5
Mesh size	mm	16x225	16x230	16x240	16x240	16x245	16x245
Surface weight	gm^{-2}	300	400	550	700	800	1100

Table 2.2.3: Overview of most frequently used uniaxial KB-grid geogrids

Advantages and benefits of KB-grid geogrids:

- **Geogrid rigidity.**
  Joints of cross and longitudinal ribs of KB-grid geogrids are stiff, which improves interaction of the geogrid and soil.
- **Tension strength.**
  KB-grid geogrids are made in a wide range of tension strengths necessary for construction of reinforced soil segmental retaining walls.
- **Low deformation index.**
  KB-grid geogrids show rather low levels of deformation. The long-term deformation value is also low, which is a great advantage for long-term acting constructions.
- **Hydrolysis resistance.**
  KB-grid geogrids show excellent resistance against water solutions of acids, alkalises and salts.
- **UV resistance.**
  KB-grid geogrids have good UV resistance that even increases with the addition of carbon.
- **Resistance against mechanical damage.**
  KB-grid geogrids are rigid geogrids with relatively strong ribs less prone to mechanical damage.

Geogrids are highly resistant against ultraviolet radiation achieved by addition of the minimum of 2% of carbon to the basic polymer. The carbon is well spread in the original polymer.
Long-term deformation of a geogrid is highly relevant for supporting constructions like reinforced soil segmental retaining walls, where load acts permanently and in long-term. The manufacturer of KB-grid geogrids in China has a proprietary laboratory carrying out long-term tests of geogrids at room temperature as well as higher temperatures. The increased temperature virtually substitutes time. The effort is focused on behaviour of geogrids for very long time intervals.
KB-grid geogrids are made of high density polyethylene inert to chemicals including acids, alkalises and salts normally found in soils. The geogrids do not have nutrition values and therefore are not attacked by micro organisms.

2.3 DRAINAGE MATERIAL AND SOILS FOR FILLING MODULAR CONCRETE BLOCKS

The space between modular concrete blocks and the space of 200 mm width behind the blocks is filled with drainage material. The purpose of the material is to drain water that penetrates to the space behind the wall from the surrounding terrain as well as surface water soaking behind the wall. The purpose of drainage material is to drain such water as quickly as possible to the drainage collector pipe and then outside the retaining wall area. Drainage material removes the hydrostatic pressure that could otherwise act on the modular concrete blocks.

Retaining walls are usually founded on an aggregate pad. The material of the pad may be identical with that used for filling cavities between modular concrete blocks.
Aggregate, crushed stone or gravel is used as drainage material. There are several recommendations regarding aggregate gradation of the drainage material.

2.3.1 Drainage material as recommended by NCMA

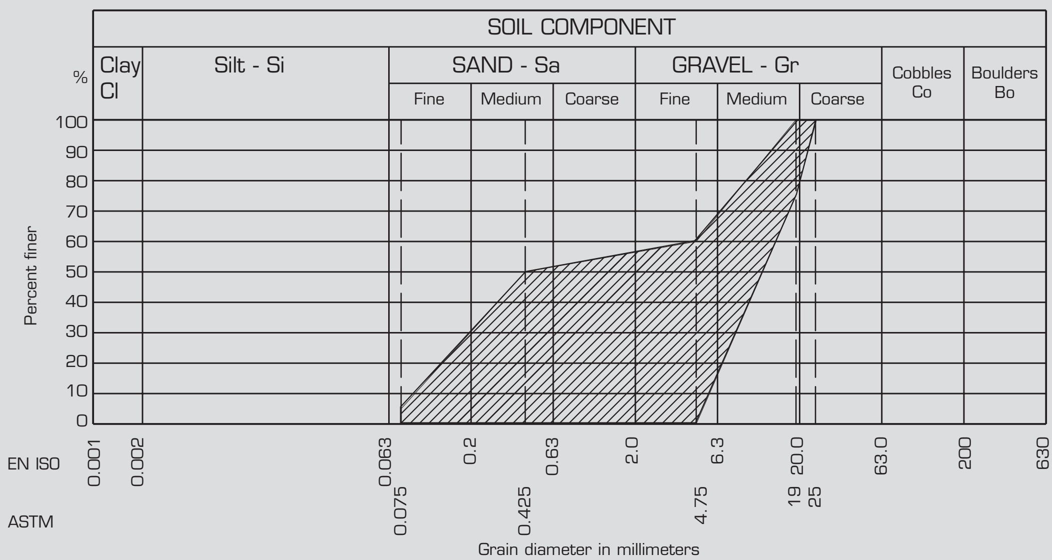
NCMA (National Concrete Masonry Association) recommends the gradation of draining material. The gradation is provided in Table 2.3.1 and Figure 2.3.1 provides the grain-size distribution curve of the material.

Coarse aggregate with good drainage characteristic is generally used as drainage material. It is used to absorb and drain water, thus relieving hydrostatic pressure. A soil with good drainage characteristics is represented by soil with less than 5% of grains smaller than 0.075 mm and less than 7% of grains smaller than 0.15 mm.

Sieve size (mm)	Percent passing
25	100
19	75÷100
4.75	0÷60
0.425	0÷50
0.075	0÷5

Table 2.3.1: Drainage material as recommended by NCMA

Fig. 2.3.1: Drainage material grain-size distribution curve by NCMA



2.3.2 Material for filling modular concrete blocks as recommended by AASHTO

AASHTO (American Association of State Highway and Transportation Officials) recommends the filling for concrete blocks in retaining walls. The gradation of the material is provided in Table 2.3.2 and by the grain-size distribution curve in Figure 2.3.2.
The recommendation considers different sizes of concrete blocks including concrete cabins and containers. The upper limit of grain size suitable for filling blocks must be set to 32 mm with regard to the size of cavities of concrete blocks produced by KB-BLOK system.

Sieve size (mm)	Percent passing
75	100
4.75	25÷70
0.6	5÷20
0.075	0÷5

Table 2.3.2: Drainage material as recommended by AASHTO

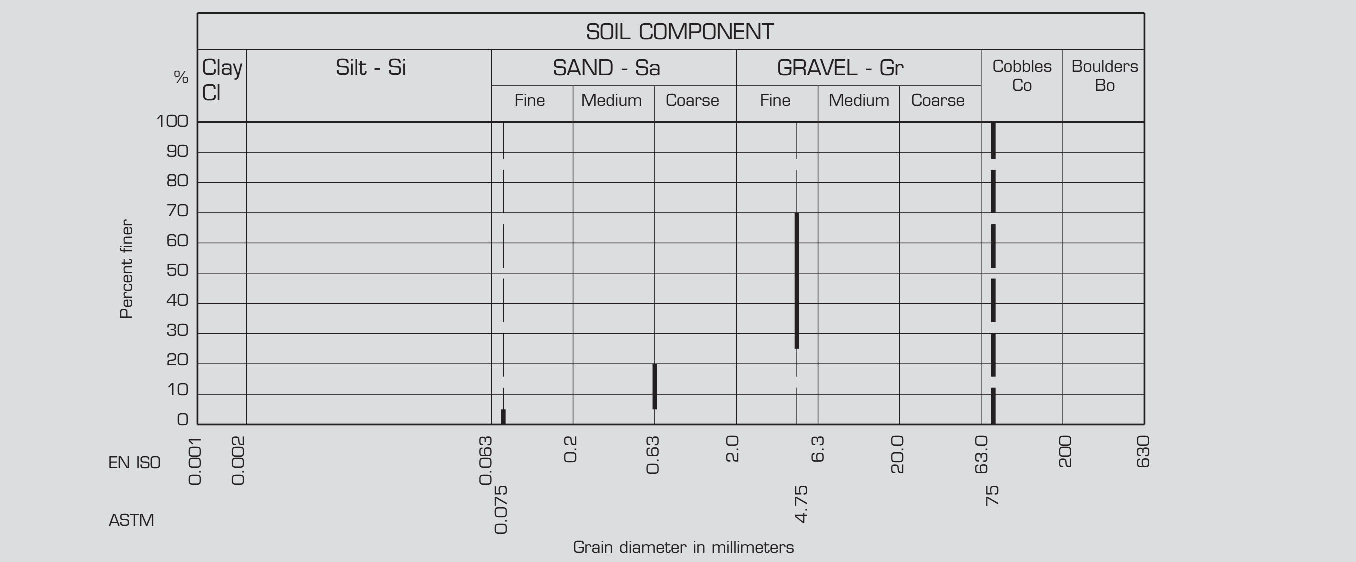


Fig. 2.3.2: Drainage material grain-size distribution curve by AASHTO

2.4 SOILS FOR FILLING BETWEEN GEOGRIDS – REINFORCED SOIL

The space between geogrids is filled with soil called "reinforced soil" for the purpose of simplification. The soil forms the structure of the wall. Reinforced soil is an important element of reinforced soil segmental retaining walls as it influences especially the stability of the structure, progress of the construction works and price.
Sand and gravel type soils are recommended as reinforced soils. As they are laid and compacted more easily than fine grain soils, have higher permeability than fine grain soils, which supports drainage, and are generally less prone to long-term deformation. Fine grain soils with lower plasticity (i.e. SC, ML, CL with PI <20) may be used for construction of a retaining wall under special circumstances. However, it must be taken into account that unacceptable time-dependent deformation may appear. When fine grain soil is used for a retaining wall, special attention must be paid to internal and surface drainage as they are crucial components in such a case. Pt, OH, OL, CH, MH type soils are not suitable.
An economic benefit of reinforced soil segmental retaining walls is the fact that soil available on the construction site may be used as reinforced soil in some cases. It may be advisable to minimise the cost of transport of material to the site, where excess excavated material must be transported from and such material has suitable grain-size gradation. If the quantity of material on the site is insufficient, it is economical bring soil with good drainage characteristics.

2.4.1 Reinforced soil as recommended by NCMA

NCMA (National Concrete Masonry Association) recommends the gradation of reinforced soil. The gradation is provided in Table 2.4.1 and the Figure 2.4.1 shows the grain-size distribution curve of the material.
Recommended grain sizes are characterised as gravels and sands. The material has up to 35% of grains smaller than 0.075 mm, so clay sands, silt sands, clay gravel and silt gravel types are also acceptable. It implies from the recommended grain sizes that soils with more than 35% of fine grains, i.e. thin clay (CL), silt (ML), thick clay (CH) and elastic silt (MH) should not be considered.

Maximum grain size of reinforced soil is set to 19 mm. If soil with larger grain size is used, tests are necessary to define the coefficient of geogrid damage during installation. The plasticity index of a fine grain size should not exceed 20.

Sieve size (mm)	Percent passing
100	75÷100
4.75	20÷100
0.425	0÷60
0.075	0÷35

Table 2.4.1: Reinforced soil as recommended by NCMA

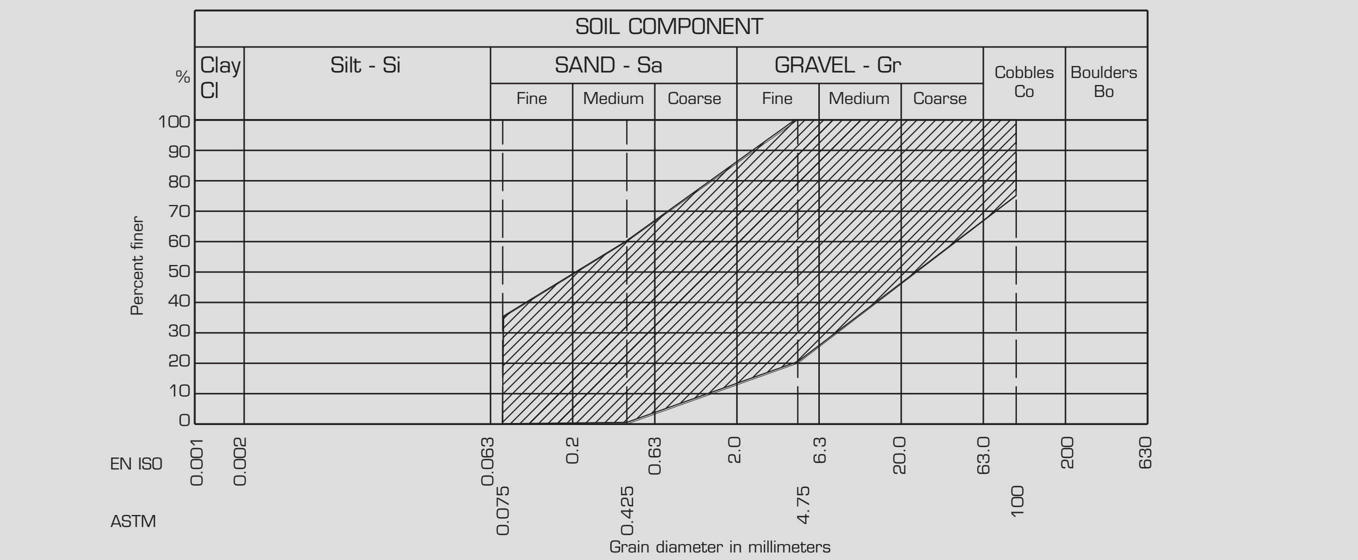


Fig. 2.4.1: Reinforced soil grain-size distribution curve by NCMA

2.4.2 Reinforced soil as recommended by AASHTO

AASHTO (American Association of State Highway and Transportation Officials) issued a recommendation on gradation of reinforced soil provided in Table 2.4.2 and the grain-size distribution curve in the Figure 2.4.2.

The materials for filling a reinforced soil segmental retaining wall may not include organic and other unsuitable components. The grain size should not exceed 19 mm. If larger size grains are used in reinforced soil, geogrid must be tested against damage during installation. Plasticity index should not exceed 6. The internal friction angle of the soil should be at least 34°.

Sieve size (mm)	Percent passing
100	100
0.425	0÷60
0.075	0÷15

Table 2.4.2: Reinforced soil as recommended by AASHTO

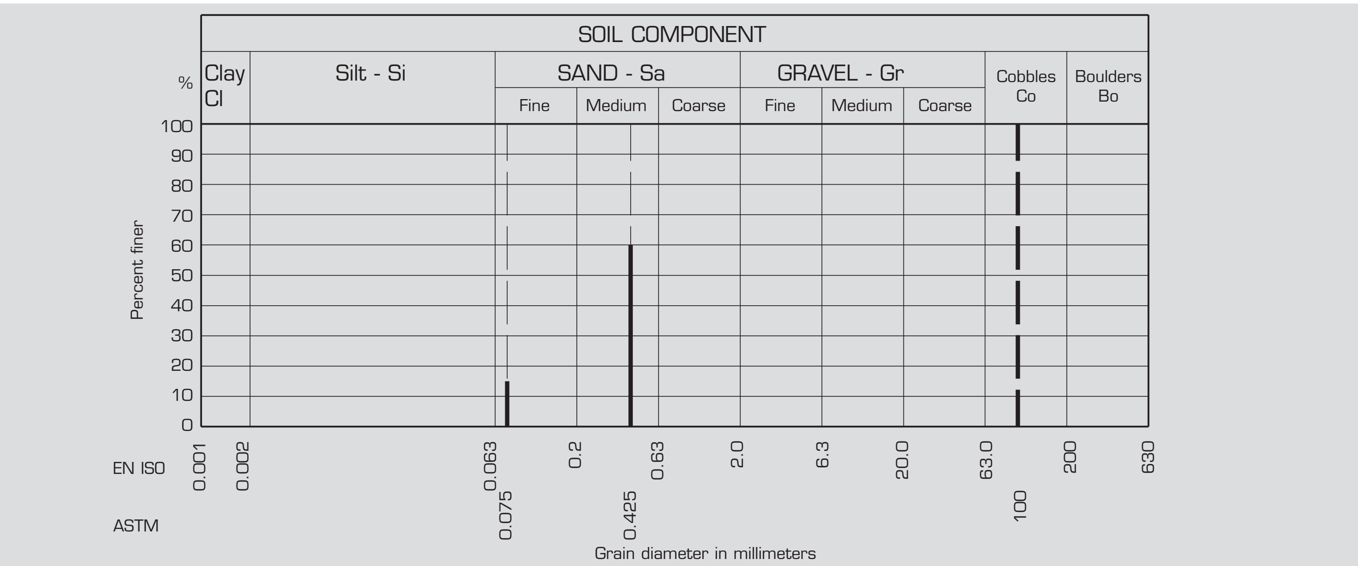


Fig. 2.4.2: Reinforced soil grain-size distribution curve by AASHTO

2.4.3 Reinforced soil by research results

Prof. Koerner and his colleagues in the US carried out a retaining wall research for different types of reinforced soil. The research was concluded by a recommendation of granular gradation of reinforced soil provided in Table 2.4.3 and Figure 2.4.3. The recommendation excludes the use of fine grain size and limits the use of larger size grains. The purpose of this is to provide for good drainage function of the wall while excluding excessive damage to the geogrid at installation. The research report does not exclude the use of finer grains than stated in Table 2.4.3, but internal drainage behind the retaining wall (chimney drainage) and under the retaining wall (blanket drainage) is recommended in such a case. The purpose of internal drainage systems is to relieve hydrostatic pressure of water in the retaining wall and behind the wall.

Sieve size (mm)	Percent passing
4.75	100
2.0	90÷100
0.425	0÷60
0.15	0÷5
0.075	0

Table 2.4.3: Reinforced soil as recommended by research results

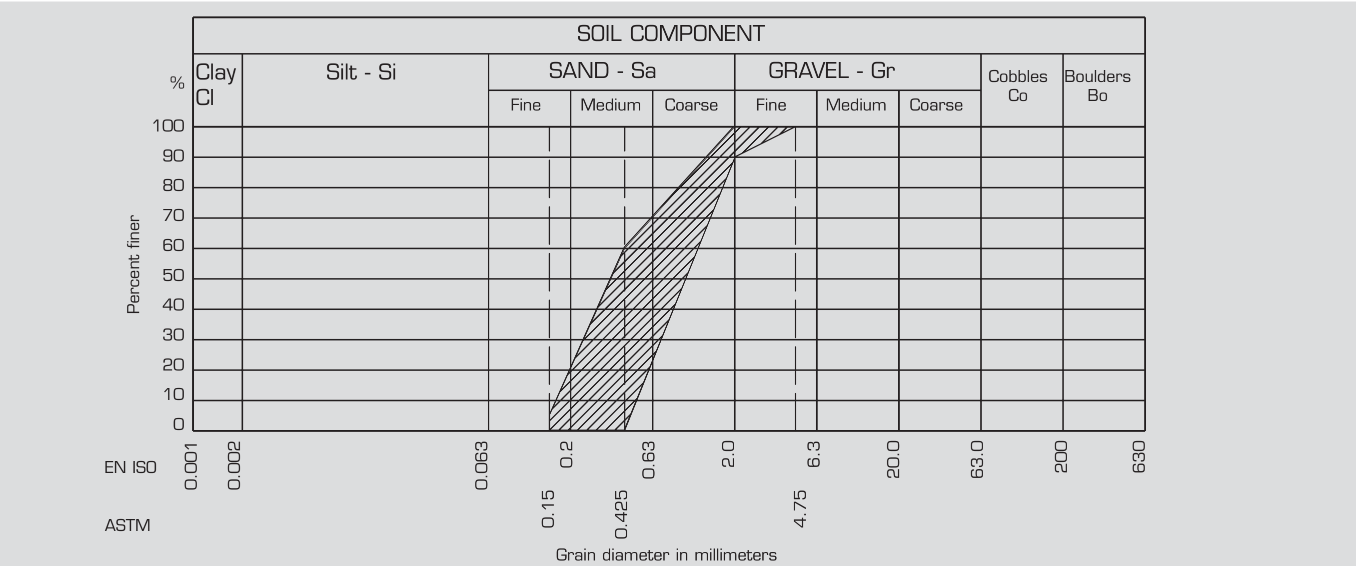


Fig. 2.4.3: Reinforced soil grain-size distribution curve by research results

It implies from the above regulations and recommendations that the NCMA requirements are the least strict, while the AASHTO recommendations are somewhat stricter with the research results being the strictest.

2.5 GEOTEXTILES

Geotextiles are permeable technical fabrics used especially as filters in the segmental retaining wall construction. Their task is to let water through, but filter fine particles. They are used to protect the drainage system of retaining walls against clogging by fine particles from soil, thus preventing deterioration of the drainage function of the wall.

Geotextiles may be woven or non-woven. Figure 2.5 shows examples of both woven and non-woven geotextiles.

Filtering characteristics of geotextiles are defined especially by the characteristic size of the openings, permeability of the geotextile and its permittivity.

- **Characteristic size of openings** is determined experimentally by washing a sample of grain material with graded grain size through a layer of geotextile without load. The geotextile layer is used as a sieve in the test. Characteristic size of openings is equal to a certain size of particles of the grain material let through. The capacity of the geotextile to filter soil particles directly depends on the characteristic opening.
- **Geotextile permeability** normal to the plane is also determined experimentally and it is expressed in $mm.s^{-1}$.
- **Geotextile permittivity** is the geotextile permeability divided by its thickness. It is expressed in sec^{-1}. Permittivity often defines the flow through the material especially due to compressibility of the geotextile.

Non-woven geotextile

Woven geotextile

Fig. 2.5: Examples of woven and non-woven geotextiles

2.6 DRAINAGE PIPE DRAINAGE TROUGH

Drainage pipe is the key element of the entire drainage system of a wall. Its task is to collect water that ran through the drainage fill between the modular concrete blocks and the drainage chimney behind the blocks, and to drain the water outside the retaining wall construction as quickly as possible. Perforated plastic pipes made of PVC or high density polyethylene of the diameter 75 to 150 mm are mostly used as drainage pipes.

Drainage trough is usually located in the wall crest just behind the cap units. The significance of the drainage trough increases if the terrain above the retaining wall is highly sloped. The function of the drainage trough is to collect water running down the slope and discharge it outside the wall construction. The drainage trough thus prevents the water from running over the retaining wall and covering it with dirt. Drainage trough may be open or closed. Open drainage trough is a standard concrete gutter. More demanding constructions may utilise a closed drainage trough, many of which are currently offered by the market. Closed drainage troughs are made of fibreglass filled polymer concrete or high quality, recycled high density polyethylene or other types of plastic with grids of steel, cast iron, zinced or stainless.

3. WALL CONSTRUCTION

The construction of a reinforced soil segmental retaining wall is virtually formed by soil secured against sliding by reinforcing elements. The reinforcing elements take the tension stresses that soil is not capable of resisting. It is an analogy of reinforced concrete, where the tension stresses in the concrete is transferred by steel reinforcement. Polymer geogrids are mostly used for reinforcement of retaining walls. Modular concrete blocks at the face of the wall are used to anchor geogrids, to protect geogrids against weather impacts (especially UV radiation) and to enhance the aesthetic quality of the retaining construction.

The soil laid between the individual geogrids is called reinforced soil. It is a great economic advantage that soil located directly on site may often be used as reinforced soil. There are regulations providing what types of soil are suitable for use as reinforced soil. Detailed information is provided in chapter 2.4 Soils for filling between geogrids. Incoherent materials like gravels and sands are highly suitable and they are even acceptable with certain content of fine grain soils. Fine grain soils with low plasticity are less suitable, while fine grain soils with high plasticity are totally unsuitable.

Correct function of a retaining wall requires a good drainage system. The space between modular concrete blocks is filled with drainage material, gravel with adequate grain size – see chapter 2.3 Drainage material for detail. Also the space of 200 mm width behind the concrete blocks is filled with the drainage material. The purpose of this is to discharge water, which leaked into the wall, downwards via the space behind concrete blocks and prevent it from leaking through joints between concrete blocks while causing dampening of the wall and covering it with dirt. Water from the space behind the concrete blocks is discharged to the gravel pad under the concrete blocks. Main drainage pipe is located in the bottom point of the gravel pad. The role of the drainage pipe is to discharge water away from the retaining wall construction. In case groundwater level may reach the level of the wall footing, the so-called blanket drainage is laid down, i.e. a gravel pad extended under the entire reinforced zone. In case the groundwater level may rise above the footing level, blanket drainage is accompanied by chimney drainage, i.e. a vertical column of drainage material between reinforced soil and soil behind the back side of the wall.
External drainage system is as important for the wall as the above internal system. In other words, water must be discharged from the construction earlier, it is not to be let soak into the construction. Water that has soaked into the construction will be discharged by the internal drainage system. External drainage system means to install a non-permeable or little permeable layer in the upper layers of reinforced soil, e.g. asphalt, concrete or clay in the case of green areas. A trough must be installed in the wall crest just behind cap blocks. There are several potential version of the trough. A simple gutter may be used as well as prefabricated drainage elements. The trough is important especially in case of walls where the terrain above the retaining wall is sloped up. It is important that the water running down the slope does not fall over the wall or is soaked into the wall construction, but is captured by the trough and discharged away from the retaining wall construction.
Figure 3 shows the basic type of reinforced soil segmental retaining wall with the description of basic elements.

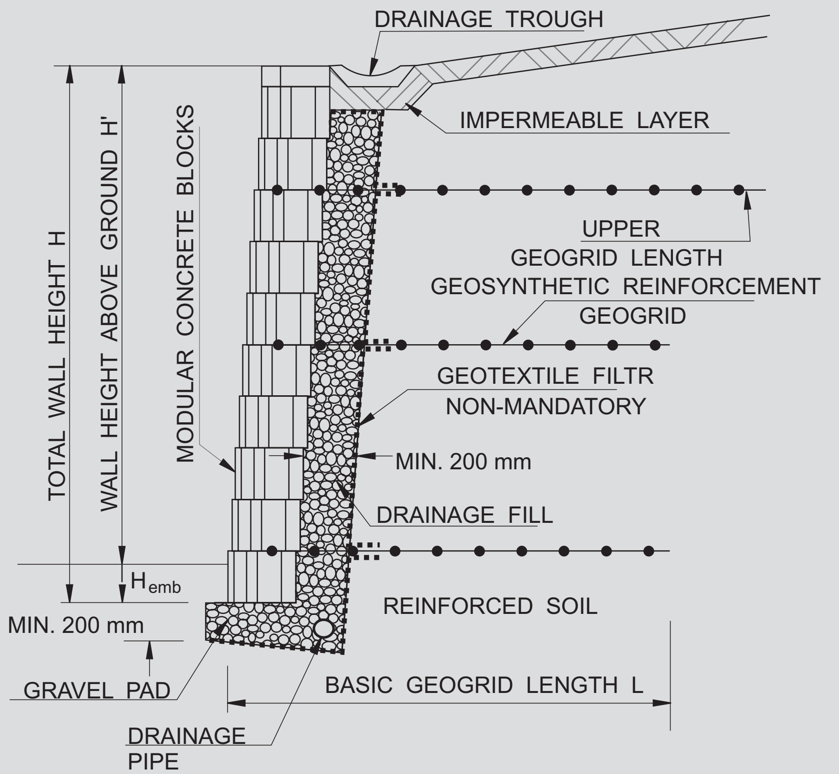


Fig. 3: Basic type of reinforced soil segmental retaining wall

3.1 WALL HEIGHT AND WALL FOOTING

Wall height **H** is understood as total wall height measured vertically from the wall foundation to the wall crest. The total wall height is the sum of wall height above ground **H'** and the depth of wall embedment below ground $\mathbf{H_{emb}}$. The individual marks are explained in Fig. 3.

3.1.1 Wall embedment below grade

The minimum depth of embedment of the wall below grade is measured vertically and it depends on wall height and the angle of terrain in front of the wall. Table 3.1 provides the minimum values of wall embedment below grade as recommended by NCMA.

The minimum embedment depth below grade should increase in the following cases:

- Major wall settlement is expected due to less carrying capacity subsoil
- There is a threat of soil erosion at the wall foot
- The wall makes a bank of a water course
- Soils prone to freezing are located below gravel pad
- There is a steep slope close to the wall foot

Slope angle in front of wall	Minimum wall embedment depth H_{emb}
Level terrain – retaining wall	H'/20
Level terrain – support (bridge, side)	H'/10
Sloped terrain, angle 18°	H'/10
Sloped terrain, angle 26°	H'/7
Minimum requirement	0.15 m

Table 3.1: Minimum depth of wall embedment below ground

It is generally applied that steep slope in front of the wall may have an adverse influence on the global stability of the retaining wall, which is to be assessed in such cases.

The depth of embedment $\mathbf{H_{emb}}$ needn't necessarily go as deep as frostline. Reinforced soil segmental retaining walls are founded on a gravel pad that is capable of interrupting capillary ascension of water from subsoil and of levelling deformations from their volume changes. Dry masonry of modular concrete blocks can shift slightly towards one another. If soil prone to freezing is under the gravel pad, it is recommended to increase the depth of the gravel pad so that the joint between the foundation soil and the gravel pad is below frostline. This will effectively found the wall below frostline without increasing its height **H**. The procedure is identical if soils prone to shrinking or expansion are located under the gravel pad. The gravel pad of at least 200 mm thickness is always required even in case the wall is founded on bedrock, the reason being provision for a level plane for laying down the first course of modular concrete blocks.

3.1.2 Gravel pad

It is recommended to found retaining walls on gravel pads of 200 mm height at least. The gravel pad distributes the load from the column of modular concrete blocks to greater width, thus minimising overload of the foundation soil. The width of the gravel pad should be the width of the block plus at least 200+200 mm (200 mm in front of block, 200 mm behind block). The gravel pad must be properly compacted. It provides a solid, but flexible foundation helping in re-distribution of stress and alleviating different settlement due to non-homogenous foundation subsoil or unequal wall heights. Such different settlement can cause the concrete blocks to crack in some cases.

The gravel pad also has a drainage function. A drainage pipe for discharge of water is usually installed in the bottom point of the gravel pad. The gravel pad is made of material described in chapter 2.3.

Drainage pipe cannot be installed in the gravel pad in some cases. It is then installed higher, usually above the ground in front of the wall and most often it is lead out to the face of the wall via modular concrete blocks. This procedure is used in cases, where there is no space for outlet of a drainage pipe under the wall or in cases where the wall regulates a water source. The gradation of the material of the gravel pad under the drainage pipe must be different, then. Along with coarse grains, the soil must contain finer grains as well, i.e. be of the uninterrupted grain type. The soil must be non-permeable in order to push water above its surface, i.e. to the drainage pipe. It is erroneous to put permeable filling under the drainage pipe in this case as water will leak through the fill to the footing bottom of the wall and not be drained by the pipe. Figure 3.1.2 shows the detail of installation of the drainage pipe above the terrain.

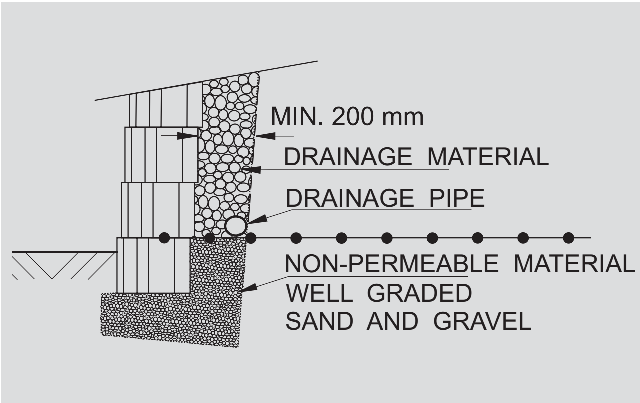


Fig. 3.1.2: Drainage pipe installation detail above surrounding terrain

3.2 WALL FACE INCLINATION FROM VERTICAL

Reinforced soil segmental retaining walls may be built as vertical or with a slight inclination from the vertical. The inclination is achieved by the concrete blocks setback in the individual course. Setback is provided for by a special position of connecting plastic pins. Connecting pins are used for connecting two blocks above each other, easy and exact setting of blocks and levelling the wall in all systems. Connecting plastic pins also increase the sliding resistance of dry bed joints.

The system of connecting pins is different for various systems:

Gravity Stone system

Every facing block of the Gravity Stone system, facing block 400 and facing block 95 has two T-shaped openings on the top side. Gravity Stone plastic pins are inserted in the stem of the letter T. The pin is not symmetrical and it may be inserted with the plug facing forward or backward. If the pin is inserted with the plug forward, the blocks are set precisely above each other and the wall is vertical. If the pins are installed with the plug backward, blocks in each course are setback by 15 mm, which results in the wall inclination from the vertical by 4.3°. Altering the positions in the individual courses enables you to achieve the inclination of 2.25°. Positions of connecting pins are depicted in Figure 3.2a.

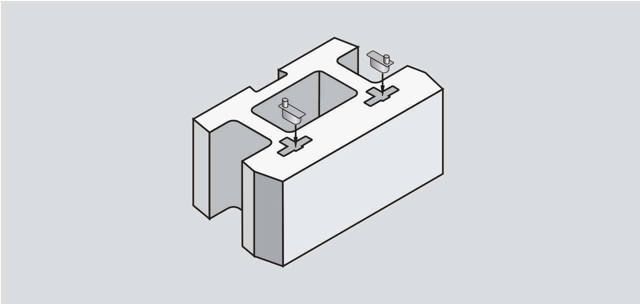


Fig. 3.2a: Positions of connecting pins in Gravity Stone system

GEOSTONE® system

The modular concrete blocks of the GEOSTONE® system designed for reinforced soil segmental retaining walls (Flat and Bent) have three rows of circular openings for connecting pins on top. Pins of this system are short plastic plugs inserted in the above openings. Blocks have grooves on the bottom used for setting the blocks onto the plastic pins. The groove is located on the level of the first opening (seen from block face).

If the pins are inserted in the first openings, the blocks sit flush above each other with no setback and with vertical wall.

If the pins are inserted in the second openings, the blocks in the individual courses are setback by 32 mm, which results in wall inclination of 9.5° from vertical. Altering of the first and second position in the individual courses provides for wall inclination of 4.8°.

If the pins are inserted in the third positions, the blocks are setback by 64 mm, which results in wall inclination of 18.6°. Alternation of the second and the third position results in wall inclination of 14.2°. Figure 3.2b shows the basic positions of connecting pins.

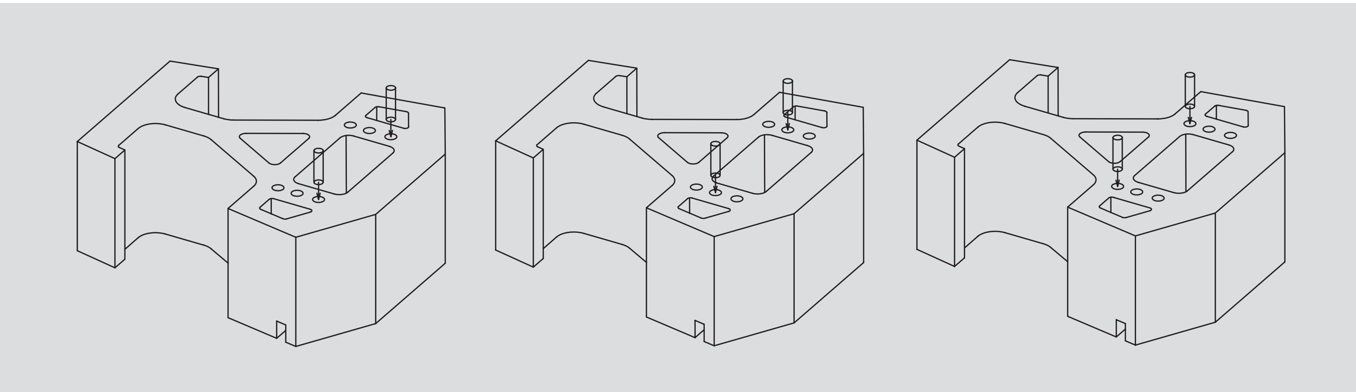


Fig. 3.2b: Positions of GEOSTONE® connecting pins

3.3 TERRACED WALLS

Reinforced soil segmental retaining walls are sometimes constructed as terraced. A lower set wall is usually higher than a higher set wall. If the horizontal distance between the faces of the two walls is greater than double the height of the lower set wall, both walls can be analyzed independently as two separate walls. However, if the horizontal distance between the two is shorter, the lower wall must be loaded by the effect of the higher wall. This is usually done by uniform loading. The procedure is analogical if a wall is made of several retaining walls situated behind one another. The stability of the entire slope formed by all terraced walls must be analyzed.

4. WALL DRAINAGE SYSTEMS

Wall drainage systems must be paid great attention as water may have highly negative influence on the structure of a reinforced soil segmental retaining wall. On the other hand, a suitably designed drainage system relieves the hydrostatic pressure, making the structure safer and helping keep concrete blocks dry and clean, thus increasing the aesthetic value of walls.
The supreme principle of designing a reinforced soil segmental retaining wall structure is to keep water away from the structure. Surface water and rain water must be lead away from the structure. A drainage system taking care of this is called **external drainage system**. However, there are many situations where water penetration in the reinforced soil segmental retaining wall structure cannot be absolutely prevented. Therefore, movement of water inside the structure is managed by the so-called **internal drainage system**. Both systems have their own specifics and principles.

4.1 EXTERNAL DRAINAGE SYSTEM

The role of the external drainage system is not to let water penetrate to the retaining wall structure, but to capture it and discharge it away from the retaining wall. The key elements if an external drainage system include the drainage trough in the wall crest and the use of non-permeable material in the upper layer above reinforced soil.

Drainage trough

The drainage trough is installed in the wall crest. Its role is to manage water flowing in from the slope above the retaining wall, capture it and discharge it outside the wall. Such captured water is not allowed to flow over the wall crest and thus make the wall damp and dirty. The significance of a drainage trough increases in situations, where there is a sloped terrain above the wall. The steeper the slope, the higher is the significance of a drainage trough. The drainage trough above the wall must have a gradient towards the end or both ends of the wall. Variant of the drainage trough depends on the type of surface above the wall. The most frequently seen troughs include:

- **Swale** – used main in the situations, where the terrain above the wall is covered with grass. The principle of the swale is that the terrain forms up in the profile.
- **Concrete or asphalt trough** – is mostly used in situations, where the surface above the wall is of concrete or asphalt or paved.
- **Concrete prefabricated trough** – may be used almost in all situations. Its advantages include easy and quick installation.
- **Drain channel** – is used in more demanding applications. The drain channel is protected by a grating, facilitating walking or driving over the drain channel.

Non-permeable material in the upper layer of the wall

The surface above the retaining wall in the reinforced area should be non-permeable to the maximum possible extent so that surface water could not penetrate from the terrain to the reinforced mass of the retaining wall. The worst situation regarding penetration is in the period of long rains or thaw. A suitable layer for grass terrain is a layer of clay beneath the arable land. In case of concrete or asphalt roads, the layer of concrete or asphalt may be considered non-permeable or low permeable. It is sometimes advisable to employ ditches, gutters, dams, etc. around the retaining wall in addition to the external drainage system so that flow of water is regulated to the desired areas. The system of the above structures depends on the topographic configuration of the terrain.

4.2 INTERNAL DRAINAGE SYSTEM

The role of the internal drainage system is to discharge water that penetrated into the structure of the retaining wall. This may be surface water, rain water, water that penetrated to the back side of the structure as well as underground water that rose to the wall foundation or even to the level of the wall structure.

The main elements of the internal drainage system include:
- drainage material in the cavities of concrete blocks
- drainage chimney behind concrete blocks
- gravel pad
- drainage pipe
- blanket and chimney drainage

Drainage material in the cavities of concrete blocks

Cavities of modular concrete blocks are filled with drainage material the gradation of which is described in chapter 2.3. The drainage material causes the water that penetrates to the area between the blocks to freely flow through the blocks down to the gravel pad. Water thus cannot accumulate in the cavities of the blocks and cause their dampening. Also important is the fact that drainage material between blocks increases sliding resistance of dry bed joints.

Drainage chimney behind concrete blocks

Drainage material is filled not only in the cavities of modular concrete blocks, but also in the space of minimum width of 200 mm behind concrete blocks. The material forms a kind of a chimney preventing water from flowing between concrete blocks, but leads it down to the gravel pad. The water that gets into the drainage chimney comes mostly from reinforced soil or it is soaked in from the terrain.

Gravel pad and drainage pipe

The role of the gravel pad is to act as a flexible foundation for dry stacked blocks and as a collecting drainage system for water that flowed down the wall. There is usually the main collecting drainage pipe on the bottom of the gravel pad, which should collect all the water running down the wall. The drainage pipe discharges water outside the structure of the retaining wall. Perforated plastic drainage pipe is usually utilised. It is laid down with longitudinal gradient of 2% to 3%. The common diameter of the drainage pipe is 75 mm to 150 mm. The drainage pipe must be discharged to the sewerage system, a reservoir or freely to the terrain.

Blanket drainage

In fact, blanket drainage comprises of drainage material spread under the entire width of the wall. The basic type of the retaining wall under Figure 3 is recommended only if the level of groundwater in the depth is greater than 2/3H under the foundation bottom of the wall. If the groundwater level may rise as high as the distance shorter than 2/3H, but not higher than the wall foundation bottom, than the so-called blanket drainage is to be laid. Blanket drainage is recommended in cases, where it is expected that the groundwater level will rise during the lifetime of the structure or if it will reside just under the gravel pad level.

Blanket drainage may be made of drainage material wrapped in geotextile or of prefabricated drainage geocomposite. In most cases, drainage material is enclosed in specially selected geotextile filter in order to prevent its contamination with fine particles that could later clog the coarse grains of the drainage material. If drainage geocomposite is used as blanket drainage, it must be taken into account that the geocomposite must be capable of bearing the pressure of the weight of reinforced soil.

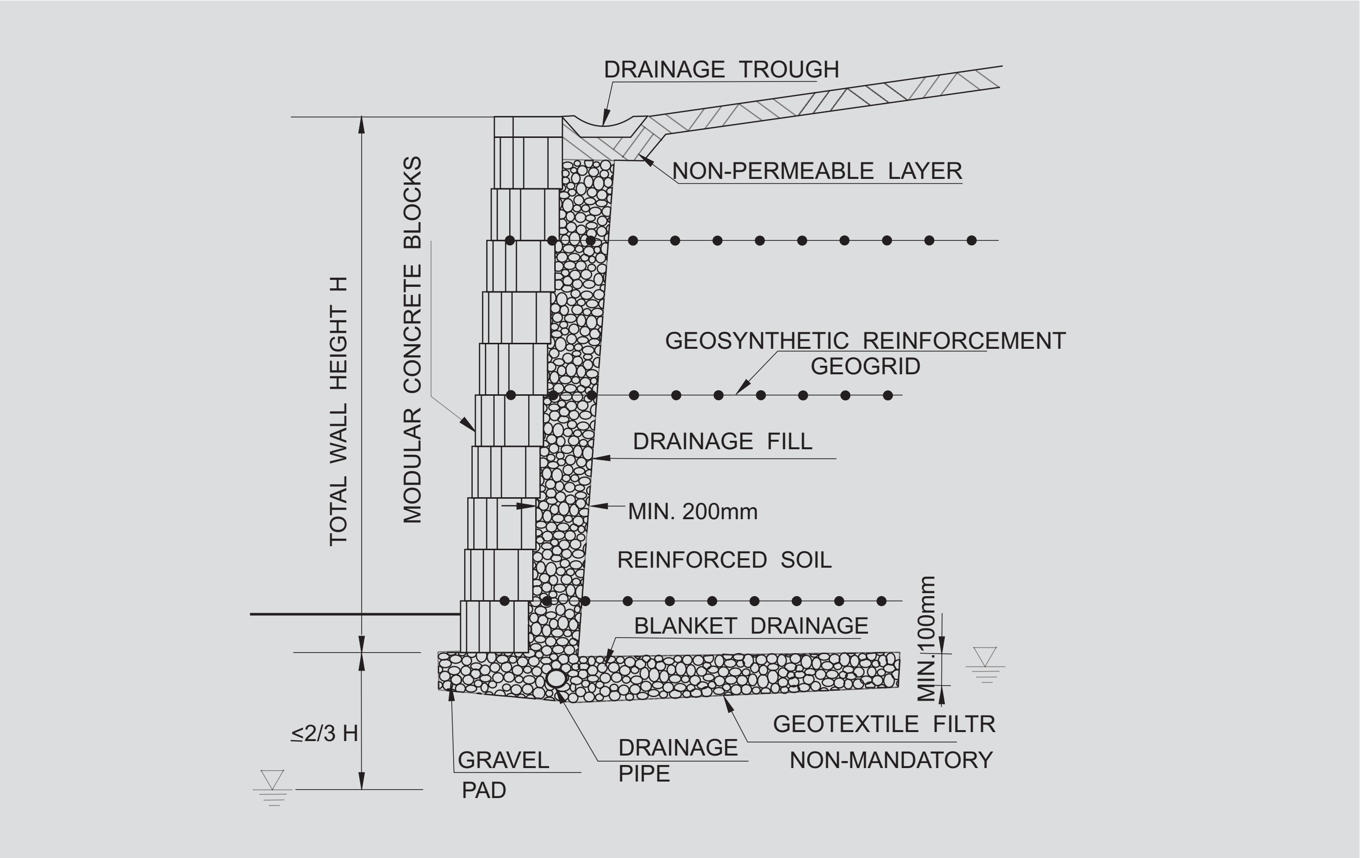


Fig. 4.2a: Typical section view of a retaining wall with blanket drainage

Chimney drainage

Chimney drainage is understood as drainage material located vertically between reinforced soil and soil behind the back side of the wall. Chimney drainage should be included in the drainage system of the wall in case it is expected that the groundwater level will rise above the bottom face of the gravel pad during the lifetime of the wall. Chimney drainage should reach at least to the height of the maximum expected level of groundwater behind the retaining wall structure, but at least to the height of 0.7H. Drainage material or prefabricated drainage geocomposite may be used for chimney drainage. The disadvantage of drainage material in this case is that it is rather difficult to place. Therefore, drainage geocomposite is more suitable for chimney drainage.

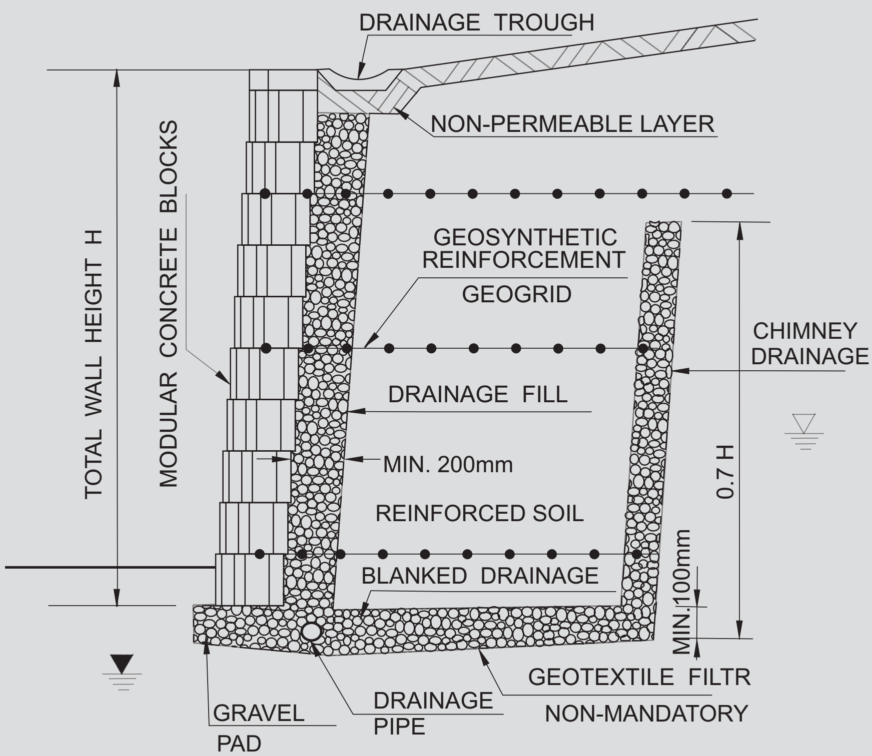


Fig. 4.2b: Typical section view of a retaining wall with blanket drainage and chimney drainage

Drainage geocomposite is formed by a core covered by geotextile or geomembrane. The core of the geocomposite may have different forms. Most often, it is a grid of a certain thickness, but it may also be in the form of a stiffer geomembrane with studs. The common feature of all cores is that they must have a certain thickness and must enable water flow in their plane. The core of the geocomposite is covered by geotextile retaining fine particles and letting water through to the core. The core then leads water to the blanket drainage.

5. STATIC PRINCIPLES

Reinforced soil segmental retaining walls statically act as gravitation structure the weight of which acts against the destabilising forces from the earth pressure and wall surcharge. The principle of gravitation walls is apparent from Figure 5a. The structure of a gravitation wall must be stable, which means they have to form compact mass of adequate width to resist sliding in the foundation as well as overturning of the wall. The wider and heavier wall 2 in Figure 5a is much more stable than the more subtle wall 1.

The necessary weight may be somewhat reduced in case of walls with some inclination of the face from the vertical. The basic task of analysis of reinforced soil segmental retaining walls is to define minimum wall width necessary to secure resistance against sliding at the foundation and overturning. The analysis principles of reinforced soil segmental retaining walls are very similar to those for standard gravitation walls. Specifics of reinforced soil segmental retaining walls must be taken into account.

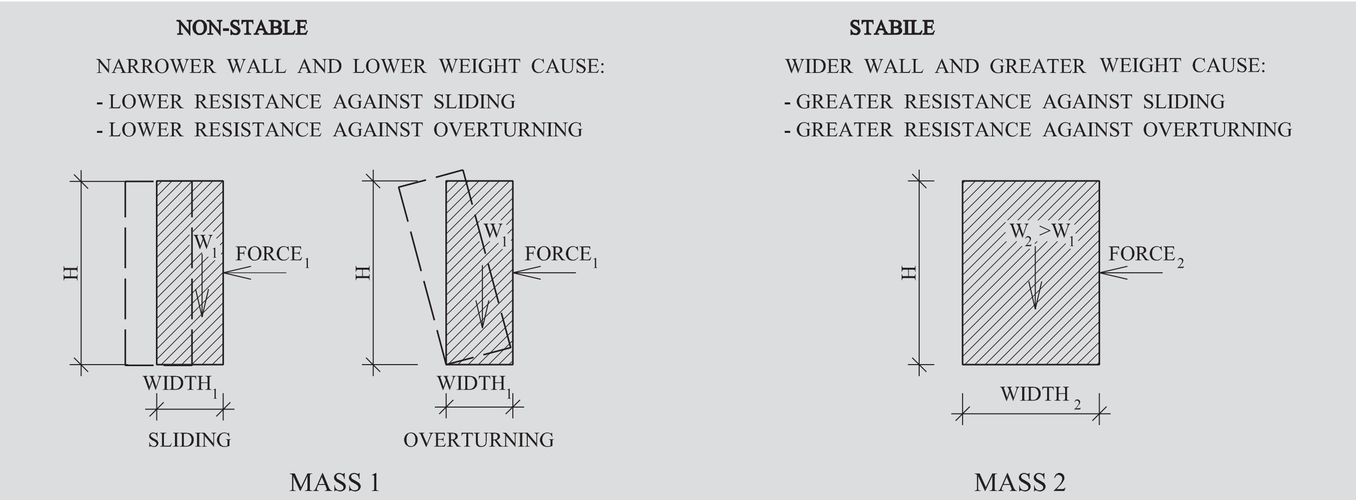


Fig. 5a: Principle of gravitation walls

Stability analysis taking into account the external forces acting on the retaining structure is external stability calculation. It is also necessary to carry out a series of calculations of internal stability to prove that reinforced soil together with modular concrete blocks form monolithic gravitation mass of adequate strength and width. Local stability of dry stacked blocks is also verified. Another step consists of assessment of global stability that is to be considered especially in cases of terraced configuration of walls. In some cases (e.g. banks under roads and railways, bridge supports, etc.) the last step consists of an assessment of settlement of the retaining wall.

The static principles provided herein provide only a general view of the static behaviour of reinforced soil segmental retaining walls. If you are interested in detailed information and calculation procedures, please consult the calculation manual published by KB-BLOK system.

Analysis background

KB-BLOK recommends analysis of reinforced soil segmental retaining walls under the NCMA (National Concrete Masonry Association, Virginia, US) standards. As regards reliability calculations, the methodology is combined in principle. The calculations include characteristic values of load (i.e. standard, not multiplied by partial safety coefficient), characteristic values of soils, but strength characteristics of geogrids are lowered by partial safety coefficients as damage coefficients in installation, long-term behaviour coefficient, durability coefficient, etc. The total safety coefficient, the value of which must be higher then required, is calculated at the end of each step of the calculation.

Earth pressure force calculation

Earth pressure acting on reinforced segmental retaining wall with external stability as well as internal stability is calculated based on Coulomb's earth pressure theory that enables inclusion of sloped terrain above the wall as well as friction impact in the calculation. The impact of friction between reinforced soil and soil behind the wall is applied in external stability, while the impact of friction between modular concrete blocks and reinforced soil is used for internal stability. Forces from earth pressure have horizontal and vertical components due to the impact of friction. Wall calculation utilises only the horizontal components, while vertical components are conservatively neglected.

5.1 EXTERNAL STABILITY

External stability includes verification of stability of the mass made of modular concrete blocks and reinforced soil body for actions of active earth pressure by the weight of the soil and wall surcharge. Analysis of external stability results in determination of the minimum length of geosynthetic reinforcement **L**.

Preliminary determination of the minimum length of geosynthetic reinforcement L

The minimum length of geosynthetic reinforcement **L** is equal to **0.6H**, where **H** is the total wall height. The length of the geogrid **L** is measured including the length anchored in modular concrete blocks – see marking in Figure 3. It must be noted that the minimum length should be found adequate only in highly positive examples, e.g. without wall surcharge, level terrain above the wall, reinforcing soil is of sand or gravel sand character, etc. In less positive cases, the minimum length of geosynthetic reinforcement **Lmin=0.7H** must be considered. In the situation, where the terrain above the wall is sloped, the minimum recommended length of geosynthetic reinforcement should be at **Lmin=0.8H**. Of course, the angle of the terrain slope must be considered.

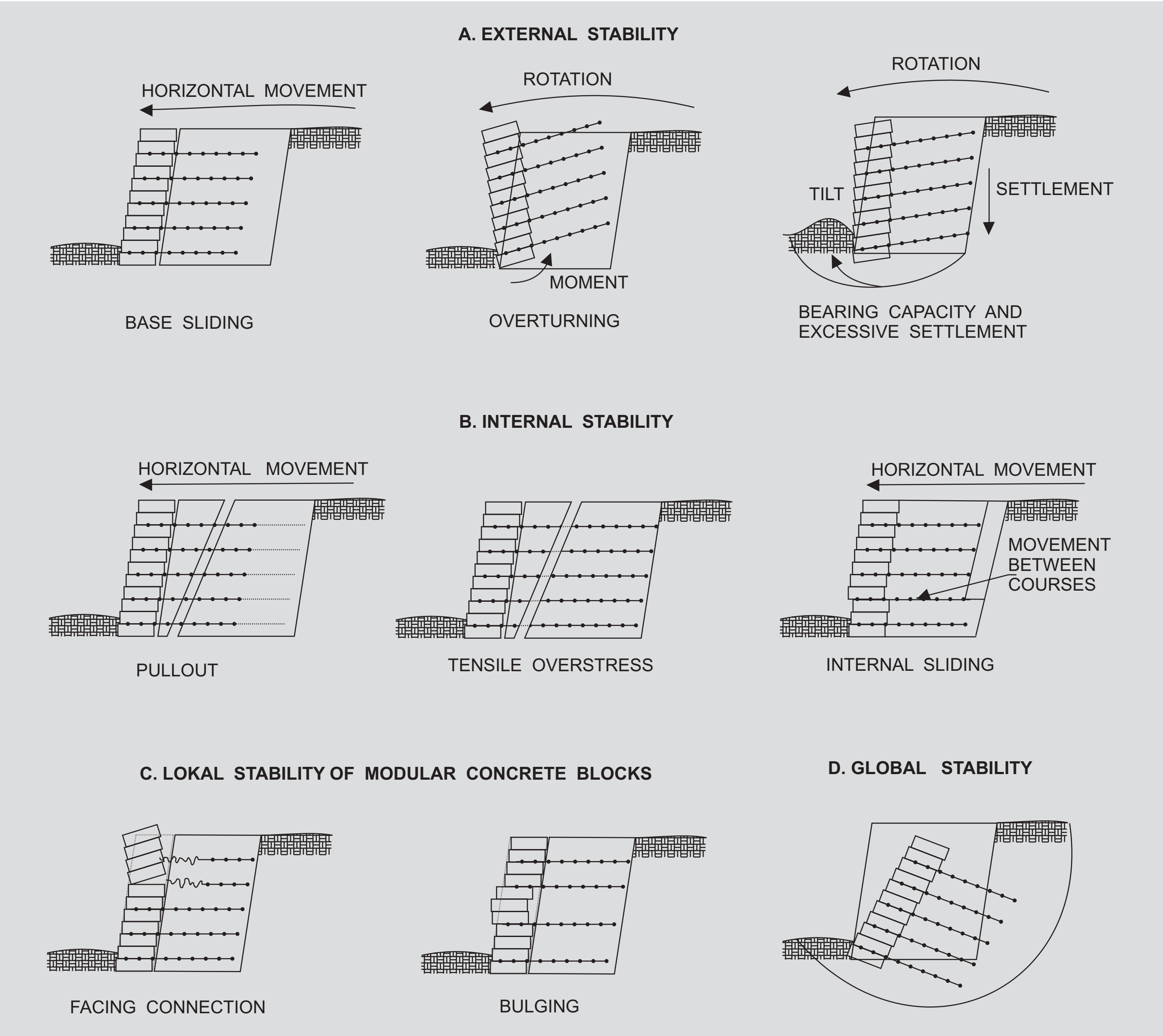


Fig. 5b: Basic modes of failure of reinforced soil segmental retaining walls

The following modes of failure must be considered within external stability:

- **base sliding** – external sliding of the entire reinforced soil mass along the foundation surface is analyzed
- **wall overturning** – potential of overturning of the entire reinforced soil mass is analyzed
- **bearing capacity and excessive settlement** – potential of failure by sliding or unacceptable deformations in the foundation soil due to increased pressure from the retaining wall weight is analyzed

Base sliding

The calculation of base sliding is usually crucial for calculation of external stability of the retaining wall. The possibility of movement in the reinforced soil layer as well the foundation soil is considered. In case of foundation soil, it is allowed to consider cohesion, which is not the case of reinforced soil as cohesion may not be considered in the case of filled in soils, notwithstanding the fact that non-coherent soils are more suitable for reinforced soil. If a geotextile is installed in the foundation bottom, the load capacity of the surface is reduced by direct sliding coefficient, which is determined experimentally for the individual types of geotextile and soil. Passive resistance of soil in front of the retaining wall is not considered as it is not guaranteed that soil will not be excavated during the lifetime of the structure (e.g. during improvement of areas in front of the retaining wall). The factor of safety for base sliding is 1.5. If the factor is not sufficient for the analyzed wall, extension of the length of the geogrids is the solution.

Overturning

In case of external stability, the potential of rotation of the entire reinforced mass about the toe is also evaluated. This failure mode is usually not critical for design of a retaining wall. It is rather difficult to imagine that heavy and flexible mass could actually rotate. However, the calculation must be carried out and adherence with the factor of safety for overturning must guarantee that the wall will not tilt and deform unacceptably. The wall factor of safety for overturning is equal to 2.0.

Bearing capacity

The last step in calculation of external stability is verification of the bearing capacity of the foundation soil. This failure mode usually is not critical as reinforced soil segmental retaining wall is rather wide at its base. As the stress from the retaining wall is distributed on a relatively large width, reinforced soil segmental retaining walls are suitable also for foundation conditions with less bearing capacity. With soils with less bearing capacity, this is often economically a more suitable solution than a structure of another retaining wall that would have to be founded on deep foundations or on improved soil.

Bearing capacity of the foundation soil is assessed based on the classic Mayerhof's criteria, where eccentricity of acting forces is calculated and the width of the foundation is reduced by double the eccentricity. The bearing capacity factor of safety is equal to 2.0.

5.2 INTERNAL STABILITY

Internal stability is analyzed in order to verify the integrity of reinforced soil mass and to prove that the soil mass together with the geogrids and modular concrete blocks acts as monolithic composite body.

Assessment of internal stability includes verification of use of geosynthetic reinforcement in the soil body on condition the geosynthetic layers of the reinforcement and the soil interact. Investigation of internal stability determines the required strength of the geogrid, number of geogrids and their vertical distances.

The following failure modes must be analyzed within internal stability:

- **tensile overstress of reinforced layers** – it is assessed whether tension stress in the geogrid does not exceed the acceptable tension stress for the geogrid
- **pullout of reinforcement** – it is investigated, whether geogrid may be pulled out from the soil mass without rupture
- **internal sliding** – it is checking, whether a part of the wall may slide along geosynthetic reinforcement surface

Tensile overstress of reinforced layers

Tensile stress of the individual geogrids is evaluated from the geogrid contributory areas and overburden pressures of the individual geogrids. The tensile stress is compared with the long-term strength of the geogrid, which means the strength of the geogrid divided by the reduction factors of durability, long-term load and resistance against damage at installation. Strength of geogrids is determined by their manufacturers experimentally as well as the values of the reduction factors. The factor of safety for this failure mode is 1.5.

Pullout of reinforcement

The internal plane of failure is determined in the reinforced soil (from the bottom rear face of the modular concrete block column) based on characteristics of reinforced soil. Geogrid must be adequately anchored behind that plane. The anchoring force of geogrid is calculated based on the overburden pressure of the geogrid, length of geogrid behind the failure plane and coefficient of interaction for pullout. The anchoring force is compared with the tensile force of the geogrid. Geogrid manufacturers determine the coefficient of interaction for pullout experimentally. As the highest situated geogrid has the shortest anchoring length and is exposed to the smallest overburden pressure, it may happen that it is found inadequate as regards anchoring and it has to be locally extended. The geogrid pullout factor of safety is equal to 1.5.

Internal sliding

The individual layers of geogrids determine the layers in which parts of the wall may slide as friction between the geogrid and soil is usually smaller than friction within the soil mass. The destabilising force is the force from the earth pressure on the level of the respective geogrid and the stabilising force is the sliding resistance of the layer. The sliding resistance of the layer is equal to the sum of the sliding resistance of the contact of the geogrid and the soil and the sliding resistance of the modular concrete blocks with the geogrid layer. Calculation of the sliding resistance of the contact of the geogrid with the soil requires experimental determination of the coefficient of direct sliding, which is determined by the geogrid manufacturer. Experimental tests carried out usually by the modular concrete block manufacturer are also necessary for determination of sliding resistance of the courser of modular concrete blocks with inserted geogrid. The factor of safety for internal sliding on the geogrid is equal to 1.5.

5.3 LOCAL STABILITY

The methods of dry connected modular concrete blocks and their connection to the reinforcing geogrid require a stability analysis to verify that the vertical column of facing blocks remains undamaged and that it will not bulge or tilt excessively. Assessment of local stability limits vertical distances between geogrids and determines their maximum distances.

The following failure modes must be analyzed within local stability:

- **facing connection strength** – it is determined whether geogrid may be pullout from the dry bed joint between modular concrete blocks
- **resistance of concrete blocks column against bulging** – it is determined, whether columns of modular concrete blocks may bulge between the individual geogrids due to active earth pressure
- **failure of the upper part of wall due to too much non-reinforced height** – it is determined whether the upper part of the wall from the top of the terrain to the first geogrid may fail by overturning or sliding in the bed joint

Facing connection strength

It is determined whether geogrid may be pullout from the dry bed joint between the modular concrete blocks. The tensile force acting in the geogrid is compared with the connection capacity of the geogrid. The connection capacity is determined experimentally for the geogrid and for the modular concrete blocks. This is usually carried out by the modular concrete block manufacturer. As regards serviceability criteria, deformation of the facing connection is limited to 20 mm. The factor of safety against facing connection strength is equal to 1.5.

Resistance of concrete blocks column against bulging

The column of dry laid concrete blocks is verified with regard to their bulging by the earth pressure of reinforced soil. A column of concrete blocks between the individual geogrids is verified. The force acting from the earth pressure on the respective reinforcement level is compared with sliding resistance of dry bed joints of modular concrete blocks with geogrid. The resistance is experimentally determined by the manufacturer of modular concrete blocks. The bulging analysis results in determination of maximum vertical distance of geogrids. The factor of safety against bulging is 1.5.

Failure of the upper part of wall due to too much non-reinforced height

The upper column of concrete blocks must be analysed with regard to sliding on the first geogrid and overturning of the column itself. The analysis method is similar to that of the calculation of internal stability of Gravity Stone conventional modular segmental retaining walls. The factor of safety against sliding is equal to 1.5 and the factor of safety against overturning is equal to 1.5.

5.4 GLOBAL STABILITY

Failure of global stability means a movement of the entire wall and the surrounding soil. It is anticipated that the reinforced soil body acts in total moving mass as complex, undisrupted structure. Failure of global stability means a general movement of the reinforced soil segmental retaining structure including the surrounding soil and it may be caused by changes of the terrain, layers of non-bearing soil, rising level of underground water and gravity forces acting on soil due to the weight of the retaining wall. It is also necessary to analyse global stability of terraced walls. Analysis of stability of the soil mass including the gravity wall and the surrounding soil is necessary as a part of the design.

6. CONSTRUCTION OF THE WALL

This chapter should help contractors decide on how to construct a reinforced soil segmental retaining wall. It describes the basic steps of construction of the wall as well as the most important rules that must be complied with.

Reinforced soil segmental retaining walls are flexible structures, so they needn't have their foundation bottom below frostline. However, this requires sufficient bearing capacity of the foundation soil.

6.1 COMPACTION OF SOILS

Adequate compaction of all types of soil in the retaining wall, i.e. reinforced soil, filling, drainage materials, gravel pad and also the foundation soil is essential for correct function of a retaining wall. Soils must be compacted during construction of a retaining wall in order to achieve maximum shear strength and stiffness. The compaction level is usually specified in the project documentation. If it is not the case, the common compaction level is considered to 95% of the standard Proctor test or 90% of the modified Proctor test. The difference between the standard and modified Proctor test is apparent from Figure 6.1.1a. The selection of the compaction machine and method depends on the type of soil.

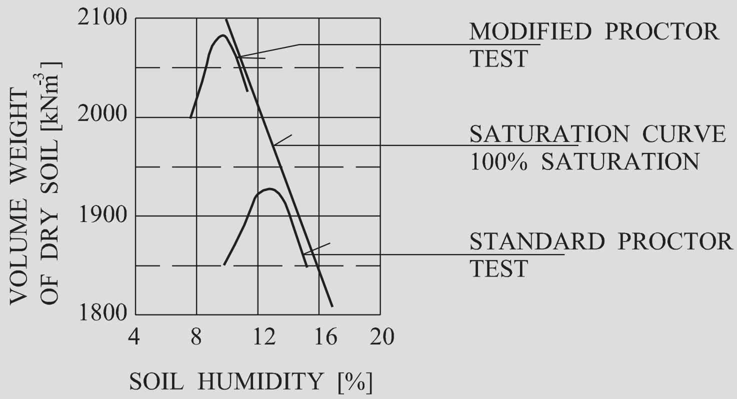


Fig. 6.1.1a: Comparison of standard and modified Proctor tests

6.1.1 Compaction tests

Soils may be successfully compacted only if they have adequate humidity. The relation of volume weight of soil, humidity content and result of compacting for different types of soil is given by standardised testing methodology. Different compacting energy is used for determination of optimum humidity content necessary to achieve the maximum volume weight with standard Proctor test and modified Proctor test.

The humidity content is defined as percentage of the weight of water per the weight of dry soil. The relationship between possible compaction and humidity content of soil is provided in Figure 6.1.1b for different soils. Figure 6.1.1a shows that if soil is compacted with higher than optimum humidity, it tends to approach 100% saturation. All air pores are filled with water. If the water content in soil is higher than 100% saturation at the time of compaction, than compaction cannot be successful no matter how much compaction energy is used. This is due to the pumping effect. If soil is to be compacted, it must have adequate humidity. It is generally applied that humidity of a compact soil should be within the interval of +1% to -3% of optimum humidity in the time of filling. The volume weight of the soil to be compacted should be as close as possible to the maximum volume weight determined by one of the above methods. If it is not so, the required shear strength of soils may not be achieved and this applies to reinforced soil as well as the fill. The design of reinforced soil segmental retaining walls is based on the assumption of an internal friction angle, the value of which is obtained in a laboratory. Insufficient compaction may lead to a lower angle of internal friction of soil and as a result of that, the structure of the retaining wall may not be safe. Insufficiently compacted soil also deforms and settles with the course of the time due to infiltration and it may even deform excessively. Maximum compacting height is equal to the height of the concrete block, which is 190 mm (possibly 150 mm).

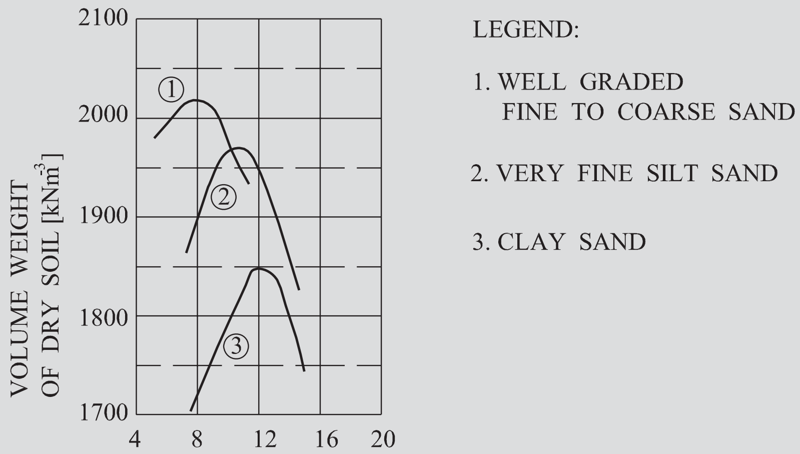


Fig. 6.1.1b: Relationship of humidity and volume weight of some soils

6.1.2 Compaction equipments

It is generally applied that vibration is the most suitable compacting method for non-cohesive soils like gravels and sands. Vibration compacting machines consist of drum rollers and steel plates passing over soils with high vibration frequency. Maximum volume weight of a compacted material to be achieved by compacting depends on the grain-size distribution curve and shape of grains of the compacted material.

Kneading type compacting machines are the most effective for compacting cohesive soils like silt and clay types. Machines with pneumatic-tired, sheepsfoot or hedgehog rollers are utilised. It is crucial for compacting to check soil humidity at filling. Special attention must be paid to avoid damage of geosynthetic materials, both geogrids and geotextiles, during the process of compacting.

6.2 SITE PREPARATION

It is necessary for the contractor to carefully prepare the site prior to starting construction.

Successful construction of a reinforced soil segmental retaining wall requires complete and exact information about the construction site and geologic composition as well as careful preparation and the construction programme.

The contractor must study the project documentation of the wall sufficiently ahead of the beginning of the construction. Preparation of the construction must include the decision about the soil to be used for reinforced soil. Tests must be carried out for such soil in order to provide for maximum volume weight according to the standard Proctor test. The tests should result in determination of optimum humidity of soil for filling and compaction. The analysis will bring a requirement for modification of humidity directly on site. Reinforced soil should also be tested for grain-size distribution curves and plasticity index. The values must be within the required range.

Prior to the beginning of the construction, it is necessary for the contractor to check, whether the original terrain and the modified terrain after the wall construction are in accordance with the project. It is very important to check the position of underground utilities to avoid their damage by excavation works.

After delivery of the materials, the contractor should check all the materials to make sure the required materials were delivered. Modular concrete blocks must be checked for appropriate colour of the material, shape and texture with regard to the project. The contractor should store the supplied material in a safe place and protect it from impairment. The material should also be protected against damage as damaged material may not be installed in the retaining wall structure.

6.3 PROCEDURE OF WALL CONSTRUCTION

The individual steps of construction of a retaining wall include the excavation work, filling in the gravel pad and installation of drainage pipe, laying down the first course and the following courses of modular concrete blocks, filling and compaction the soil in layers of block height, laying down the geogrid and finishing works.

6.3.1 Stake-out of the wall location

The first step of construction of a retaining wall is the stake-out of its horizontal location. The setting-out must be precise and it is best done using a theodolite.

6.3.2 Excavation for retaining wall

The contractor should carry out the excavation work as designed in the project. The excavation should be as small as possible, but safe.

Topographically, there are basically two basic cases of setting a retaining wall in the terrain. They are the **fill wall** and the **cut wall**. The difference between the two types is apparent from the Figure 6.3.2. The principal difference is in the volume of excavation.

Fill walls require minimum excavation, often just an excavation for the gravel pad and an excavation for the wall foundation. These walls may be used e.g. as bordering constructions of banks, wing-walls, etc. On the other side, **cut walls** require maximum excavation, i.e. the excavation for the entire reinforced mass and sloping of the cutting. These retaining walls are often used in situations, where it is necessary to expand the room in front of the retaining wall. Retaining walls found in practice usually range between the two extremes. The contractor should familiarise itself with the type of the wall and consider the amount of excavation work based on the type. It is important in case of cut walls not to undermine foundations of the structures and buildings located above the retaining wall.

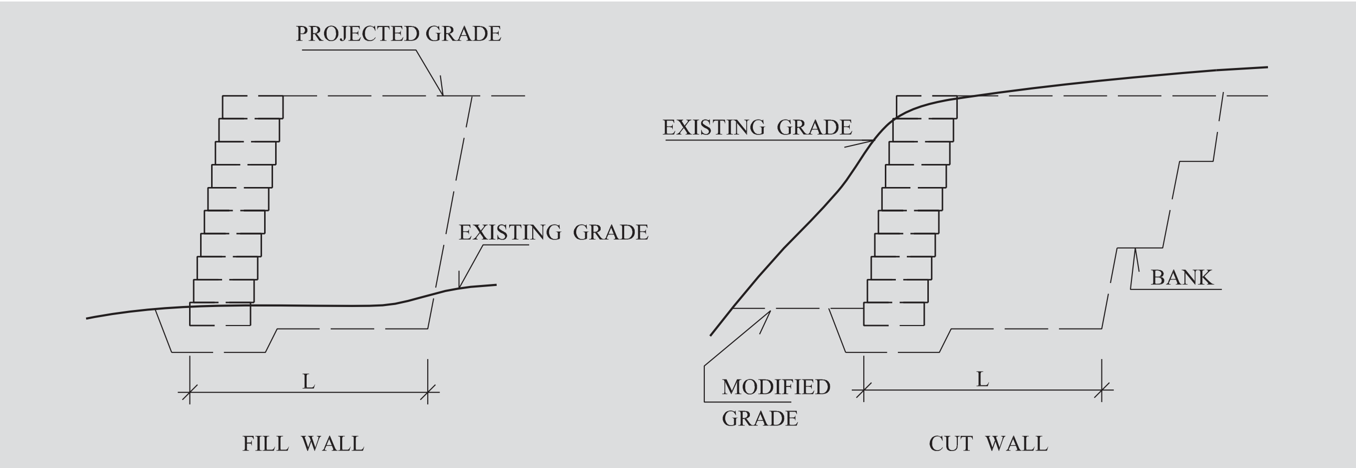


Fig. 6.3.2: Excavation for cut wall and fill wall

Main excavation

The main excavation usually represents the largest volume of excavation works. If possible, it is done all at once for a longer section of the retaining wall. If the wall is founded in multiple height levels, the main excavation is also excavated in multiple levels. The upper face of the main excavation should be identical with the border between the reinforced soil and the foundation soil. The main excavation should be as small as possible, but safe. The cutting must be sloped, with the main slope ratio being 2:1. Precautions against floodwater must be taken before work on the main excavation starts. Floodwater must be discharged by drains, water conduits, dams, etc. outside the main excavation.

Gravel pad excavation

Gravel pad excavation follows after the main excavation. The depth of the gravel pad excavation must equal the thickness of the gravel pad defined in the project. The minimum thickness is 200 mm. If a drainage pipe is installed on the bottom of the gravel pad, it must be taken into account that the thickness of the gravel pad will be increasing with the descending drainage pipe. If the wall is founded in uneven height, or step-wise, a separate sloping groove must be prepared for the drainage pipe, which may be deeper than the anticipated bottom of the gravel pad in this case.

The width of the gravel pad excavation may be identical as the width of the pad with regard to its relatively low height. In case the wall does not utilise blanket drainage, the width of the gravel pad is equal to the modular concrete block plus 200 mm in front of the block and min. 200 mm behind the block. In case the wall utilises blanket drainage, the excavation for blanket drainage is dug together with the gravel pad excavation. The width of the gravel pad is then equal to the width of the modular concrete block plus 200 mm in front of the block plus the entire reinforced zone. The bottom of the gravel pad excavation as well as the bottom of the blanket drainage excavation should be graded towards the drainage pipe in the minimum grade of 1:12, i.e. 5° or approximately 8%. The reason of this is better water discharge to the main drainage pipe.

After the excavation of the cutting, soil under the foundation must be examined whether it corresponds with the project preconditions. If yes, the bottom of the cutting must be modified before the gravel pad is filled. The bottom of the cutting is usually compacted by rolling. If the soil on the bottom is slacking, it must be replaced by other soil. The new soil must be compacted to 95% of the standard Proctor test.

If the soil does not correspond with the project preconditions, it must be replaced by more suitable soil. The type of new soil shall be proposed by the project engineer. The new soil shall be compacted to 95% of the standard Proctor test. Adaptation of the project documentation to the actual conditions is another solution. The adaptation would mean extension of the width of the reinforced wall.

6.3.3 Filling in the gravel pad

Gravel pad is filled as foundation under modular concrete blocks. The gravel pad also has the drainage function in the situations, where a collector drainage pipe is installed on the bottom.
Thickness of the pad is 200 mm at least. If a drainage pipe is installed on the bottom of the gravel pad, the thickness is increased according to grading of the drainage pipe. The width of the gravel pad is to be 200 mm in front of the concrete blocks and min. 200 mm behind the blocks. In cases, where blanket drainage is utilised, the gravel pad fluently transforms into blanket drainage and it should be 200 mm in front of the concrete blocks and under the entire reinforced part of the wall. Widths of gravel pads are illustrated by Fig. 6.3.3.

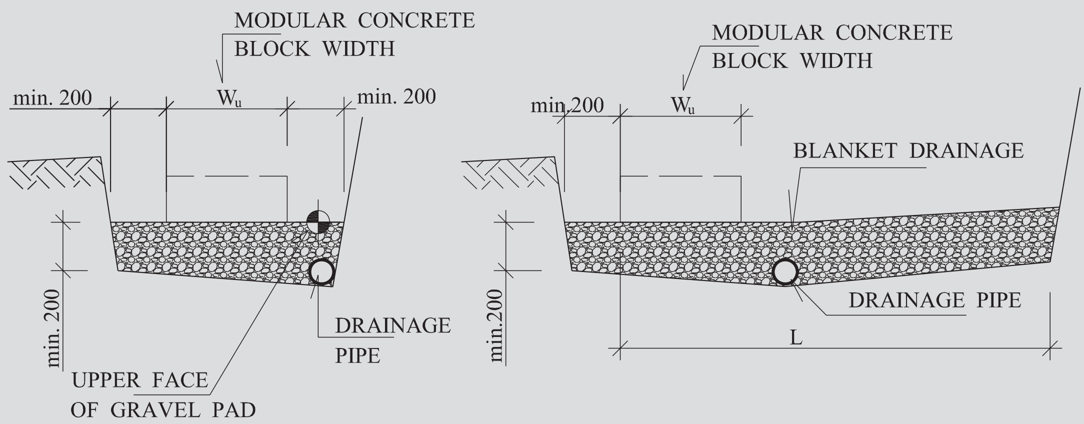


Fig. 6.3.3: Widths of gravel pads for retaining walls with and without blanket drainage

Geotextile filter must be installed on the bottom of the gravel pad or blanket drainage in some situations. These are the situations, when underground water level may rise as high as the level of blanket drainage. Geotextile filter is to prevent clogging of the drainage material by fine particles from the foundation soil. The geotextile filter must be laid on the bottom of the blanket drainage or gravel pad before drainage material is filled.
Drainage material the gradation of which is described in chapter 2.3 is to be used for the gravel pad and the potential blanket drainage. The drainage pad must be properly compacted in order to provide solid support for the first course of modular concrete blocks. Compacting should be done by light compacting equipment, e.g. vibration plate or ramming plate. The required compacting level is 95% of the standard Proctor test. The upper face of the gravel pad must be carefully levelled so that the entire bottom surface of the blocks in the first course is supported and the blocks are levelled. If blanket drainage is designed under the wall, the conditions of compacting are identical as in the case of the gravel pad.

Installation of the drainage pipe

A collector drainage pipe is installed on the bottom of the gravel pad, on the minimum compacted layer of the drainage fill. The material and diameter of the pipe should be defined by the project documentation. The drainage pipe is a perforated pipe, the task of which is to discharge water soaked through the retaining wall outside the wall structure. The drainage pipe should be discharged into sewerage or drain or freely to the terrain. The diameter of the main drainage pipe located in the gravel pad should be at least 75 mm. The minimum grading of the drainage pipe is 2%. If the wall has an auxiliary drainage pipe, e.g. under the chimney drainage, the connection between the discharge of the auxiliary pipe into the main collector pipe should be per 15 meters at maximum.

In some situations, the main drainage pipe may not be installed in the gravel pad, but it is installed higher, in the drainage chimney just above the terrain. These are the situations, where the drainage pipe must be discharge directly through modular concrete blocks, e.g. if there is not discharge for a low positioned pipe, in case of regulation of water courses, etc. In these situations, the drainage material under the drainage pipe must be of a somewhat different gradation. It must be non-permeable well graded material with fluent grain-size distribution curve, which does not let through water, but keeps it on its upper face, i.e. on the level of the collector drainage pipe.

6.3.4 Laying of the first course of modular concrete blocks

The first course of modular concrete blocks should be set in the right vertical and horizontal position as designed by the project.
The first course of concrete blocks should be laid on the gravel pad. It must be guaranteed during the laying of the first layer that the blocks are in full contact with the gravel bed. Therefore, the level of the upper face of the gravel pad must be guaranteed prior to laying down the blocks.
Laying down the first course of modular concrete blocks is the most time consuming phase of the process of the wall construction requiring maximum care and preciseness. Correctly laid first course of modular concrete blocks is the precondition of correct construction of the entire retaining wall. Correctly laid first course of modular concrete blocks will subsequently speed-up the construction of the following courses, where levelling of the blocks is minimum. Incorrectly and negligently laid first course brings problems with levelling the blocks in the following courses.
The position of modular concrete blocks is set-out by stakes and string. Special attention must be paid to setting out the first course of modular concrete blocks in curves, corners or vertical and horizontal steps. The string must be lead along the smooth back side of concrete blocks, not along the front face of blocks that may be split and thus uneven. Setting out the first course of modular concrete blocks is illustrated by Fig. 6.3.4.

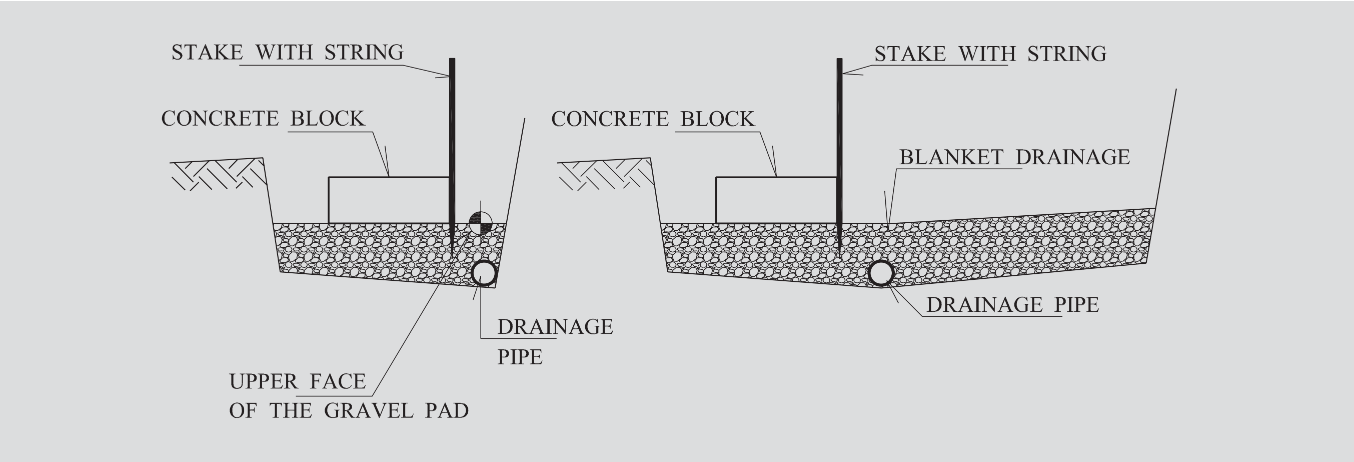


Fig. 6.3.4: Setting out the first course of modular concrete blocks

The first course of modular concrete blocks is laid flush with the string. Vertical position of blocks is verified by bubble. Higher positioned blocks will be levelled by rubber mallet, lower positioned ones must be levelled by added drainage fill. Damaged, broken or spotted modular concrete blocks should not be used for the wall.
Acceptable tolerance of the concrete face of the wall from the projected plane is 30 mm per wall length or height of 3 meters, but 75 mm in maximum. The acceptable tolerance applies vertically as well as horizontally.

Installation of plastic connecting pins follows correct installation of the first course of modular concrete blocks. The pins must be installed before the block cavities are filled so that they are not plugged by drainage material. Connecting pins must be installed in the correct position depending on the required wall inclination.
After the pins have been installed, block cavities are filled with drainage material specified in chapter 2.3. Drainage material fills not only block cavities, but also the 200 mm wide space behind the modular concrete blocks. After the wall has been completed, the drainage material behind the blocks will create a drainage chimney facilitating discharge of water to the drainage pipe and preventing water flow through concrete blocks and their non-aesthetic dampening and staining. If the project requires protection of the drainage material by geotextile filter, install the filter on the border between the drainage material and reinforced soil. Reinforced soil of 190 mm (aptly 150 mm) thickness is filled behind drainage material. The space between reinforced soil and the excavation cutting is filled with suitable soil. Soils are compacted after filling.

If the project specifies chimney drainage on the back side of the retaining wall, whether of geocomposite or gravel, the drainage is filled together with soils.

Founding a wall in different height levels

Some cases require founding a wall in different height levels. This is usually done in steps, where height of one step is equal to the height of the modular concrete block. Stepping must start already with the gravel pad. Laying of concrete blocks starts at the lowest point. Only a wall section in one height level is laid. After blocks have been filled and all soils filled and compacted, another course of concrete blocks is laid, fluently continuing to form the first layer of the higher level.

6.3.5 Filling reinforced soil

Reinforced soil is filled and compacted in layers equal to the height of modular concrete blocks, i.e. 190 mm (aptly 150 mm). Reinforced soil is filled identically for all layers.

Reinforced soil should be filled as defined by the project. The maximum height of a layer of filled soil is equal to the height of the block, i.e. 190 mm (aptly 150 mm). Each layer must be compacted to at least 95% of the standard Proctor test. Humidity of the filled soil must be equal to optimum humidity of the respective soil with 2% tolerance. Reinforced soil must be spread and levelled to avoid corrugation and sliding of geogrid and sliding of modular concrete blocks. It is allowed to use only light compacting equipment like vibration plate or jumping rammer in the stripe of 1.5 meter off the wall face. This stripe is compacted by a triple pass of such light compacting equipment. The level of compacting in this stripe must be at least 90% of the standard Proctor test. It is not allowed to pass over the geogrid, but geogrid must be protected by a soil layer of min.150 mm thickness. Turning of vehicles on the layer of soil above the geogrid should be limited to minimum, while sharp turning and braking on such layer should be prohibited. This precaution prevents undesired slide of the geogrid below the soil layer and the potential damage. In some cases, it is possible to pass right over the geogrid with rubber tires at very low speeds below 10 m/h. Fast braking and sharp turning must be absolutely prohibited in such cases. Direct passing over geogrids with rubber tires must be approved by the geogrid manufacturer.

After every working day, the contractor should provide for grading of the top surface of reinforced soil away from the wall front so that water is discharged away from the wall front in case of heavy rains and does not stain the wall. It must also be ensured that water from the surrounding areas does not flow in the wall structure.

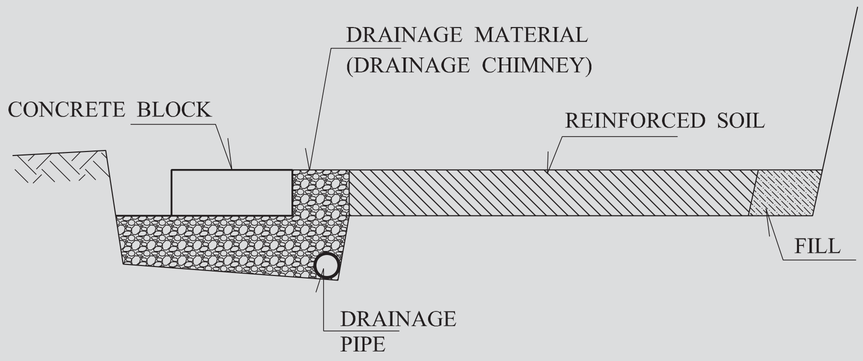


Fig. 6.3.5: Filling of reinforced soil and drainage material

6.3.6 Setting successive courses of modular concrete blocks

Upper surface of the previous course must be thoroughly cleaned before the next course is installed. The surface is best cleaned with a broom. There may be no residue of drainage fill or other soil on the top surface of the modular concrete blocks. Such residue would cause imprecise setting of the next course. In addition to that, when the wall is under load, the residue significantly reduces the shear capacity of bed joints and they may also locally damage the blocks. Concrete blocks of the next course are set on the connecting pins in running bond. Check, whether the plastic pins are correctly installed and whether the concrete blocks of the next course are setback from the bottom layer by the required distance. After the next course of concrete blocks has been installed, it is necessary to check whether the concrete blocks are in plane and potentially make the necessary adjustments. Plane of the blocks must be checked in all courses.

After blocks have been laid, plastic pins are installed in their openings. Cavities in concrete blocks and the area of 200 mm behind the concrete blocks will be filled with drainage material. If a geotextile filter is projected on the border between the drainage material and reinforced soil, separate the two soils with the filter. Spread reinforced soil to the height of a concrete block, i.e. 190 mm (aptly 150 mm). Fill the specific soil in the area behind the retaining wall and the excavation cutting. Compact all soils.

Continue setting the blocks until you have reached the planned wall crest. Geosynthetic reinforcement must be installed in some bed joints.

6.3.7 Instalation of geosynthetic reinforcement

Geosynthetic reinforcement or geogrids are installed in bed joints per project documentation. Geogrids must be installed at the height defined by the project. Geosynthetic reinforcement should be installed per manufacturer recommendation.

Geogrids must be installed in the correct direction. Personnel must be instructed about the main direction of the geogrid and how to install it in the wall. It is not allowed to extend the geogrid in the bearing direction, i.e. the cross direction. The main bearing direction of the geogrid is the direction perpendicular to the front of the retaining wall and it must be made of a single uninterrupted piece of the geogrid. Neighbouring geogrid stripes in the longitudinal direction are installed right next to each other in order to provide for 100% coverage. Stripes of geogrid may not longitudinally overlap each other, but be laid right next to each other.

First, geogrids are cut to the required length and then laid on the bottom, already compacted layer. Geogrids are laid so that the first row of cross ribs is behind plastic pins. Lay the geosynthetic reinforcement so that its bearing ribs are perpendicular to the wall front. Install the blocks of the next layer after geosynthetic reinforcement has been laid down.

Geosynthetic reinforcement must be straightened after it has been laid down. It is not possible to install corrugated geogrid. The reason is that it takes tensile forces and if it was corrugated, it would just straighten first by the action of the tensile forces and only then it could take tensile stress. But, such straightening of geogrid in the already finished structure may lead to unacceptable deformations. Geogrids are usually straightened manually and after straightening, the position of the geogrid is secured by a peg or a hook driven in the compacted soil. Straightening of geogrid is illustrated by Fig. 6.3.7.

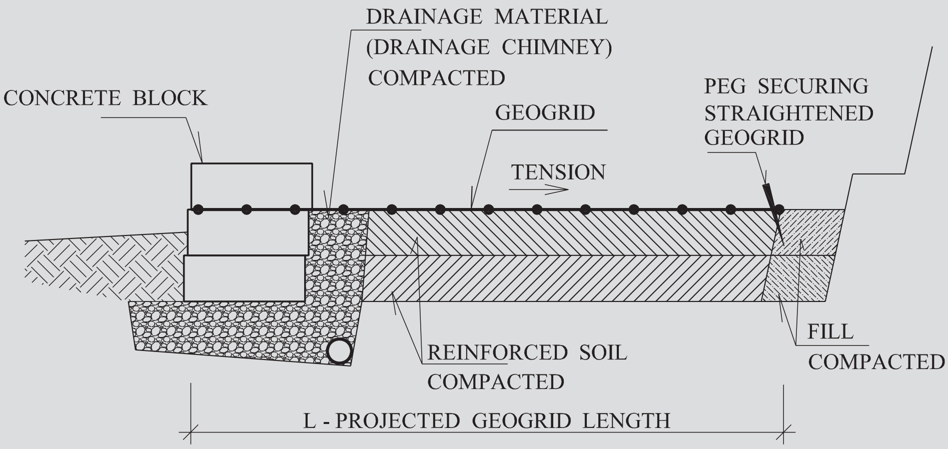


Fig. 6.3.7: Straightening the geogrid

6.3.8 Finalising the wall

After all the masonry courses have been laid as projected, the wall is finalised. There are several finalisation methods.

If there are blocks for vegetation in the last layer of the masonry (GEOSTONE® POT or GEOSTONE® SHELF), the wall is not capped by concrete blocks, but vegetation.

If there are other blocks not enabling vegetation to grow in the last layer, it is common to cap the wall with cap blocks. The surface of the last course of concrete blocks must be cleaned from residue of soils like in the previous courses. Cap blocks may be installed on the last course of modular concrete blocks on running bond or on stacked bond. There may also be various setbacks. Cap blocks may be installed on the concrete blocks of the last course so that they are off-set to the front, flush with the bottom layer or off-set to the back. All variants have their aesthetic specifics. The texture and colour of the cap blocks may be identical with those of the wall blocks, but they may also be different and create a prominent border appearance.

In order to prevent vandalism, it is recommended to bond the cap blocks to the course below them with a suitable frost resistant adhesive. Contact surfaces of both blocks must be dry and clean of any soil residue before bonding. Adhesive is spread on the bottom surface of the cap blocks in two parallel stripes and after some light curing it is pressed hard against the last course of modular concrete blocks. It is important to let the adhesive cure adequately.

7. DETAILS AND SPECIAL CONSTRUCTIONS

The below recommendations must be followed when constructing outer and inner corners of reinforced walls as well as when creating curves. Compositions of modular concrete blocks for such cases are provided in separate manuals. The below section is limited to installing geogrids in such cases.

7.1 OUTER AND INNER CORNERS

Reinforcing of retaining walls follows the principle that only one geogrid may be installed in a bed joint. This means that if an outer corner is being reinforced, a section of geogrid in the corner where geogrids overlap must be installed in the previous or following bed joint. There is a variant solution, where geogrids on the entire perpendicular wall are installed in the previous or following layer. Figure 7.1a illustrates reinforcement of the right corner.

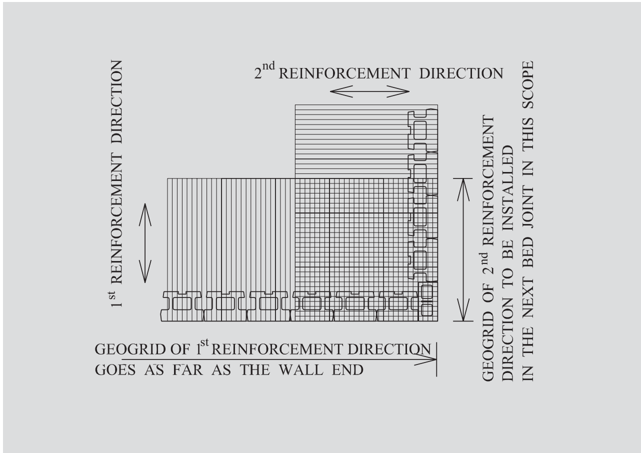


Fig. 7.1a: Reinforcement of an outer corner

An internal corner is reinforced so that geogrids of one direction are terminated at the corner location in the first reinforcement level. Geogrid of the second direction is pulled over round the corner by H/4, where H is the total wall height. It is altered in the next reinforcement layer, i.e. the geogrid terminated in the corner is pulled over round the corner by H/4 and the geogrid that was pulled over round the corner will be terminated in the corner. Figure 7.1b illustrates reinforcement of an internal corner.

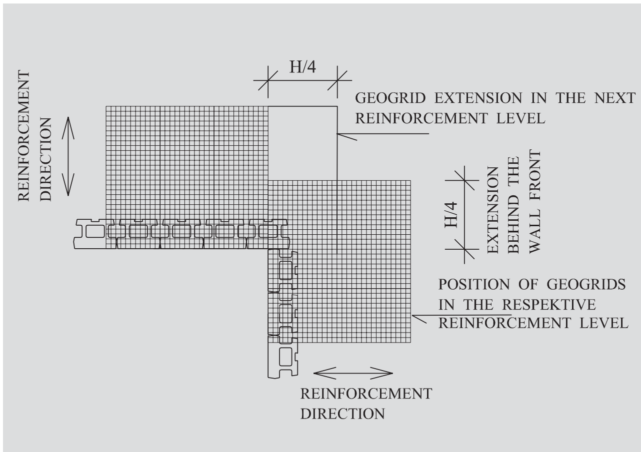


Fig. 7.1b: Reinforcement on an inner corner

7.2 OUTER AND INNER CURVES

The same rule must be adhered to in case of reinforcement of an outer curve, i.e. that there is only one geogrid in the bed joint between blocks. Reinforcement usually is the following: overlapping geogrids are conically cut at modular concrete blocks and installed so that there is a layer of soil of at least 80 mm between the overlapping geogrids. This means that one geogrid is installed with a slight grading downward, while the neighbouring geogrid is installed with a slight grading upward.

Another variant of reinforcing outer curves is to install overlapping geogrids in the previous or following bed joints. Figure 7.2a illustrates reinforcement of an outer curve.

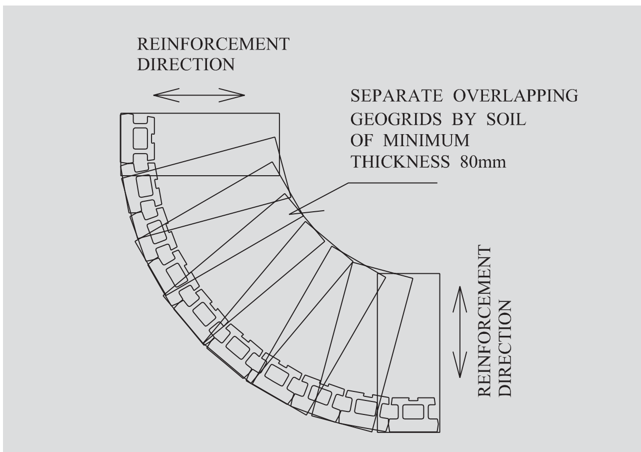


Fig. 7.2a: Reinforcement of an outer curve

Reinforcement of an inner curve brings the opposite problem – there are places behind the curve that are not covered by geogrid. As full coverage by geogrids is required, such uncovered places are covered in the previous bed joint or the next bed joint. Figure 7.2b illustrates reinforcement of an inner curve.

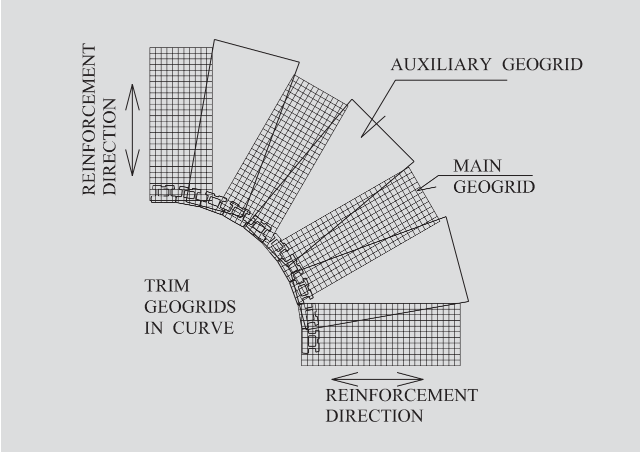


Fig. 7.2b: Reinforcement of an inner curve

APPENDIX A – DIMENSIONING TABLES

Dimensioning tables for reinforced soil segmental retaining walls should be used for preliminary and orientation design of a retaining wall. Tables have been prepared for angle of internal friction of the soil behind the wall $\varphi \geq 27°$, which may be considered a standard angle of internal friction of sandy-clay soil.

Tables are divided into three groups according to surcharge:

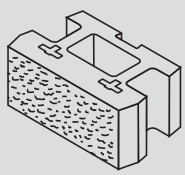
- **table in group one** – it is for cases, where the terrain above the wall is level or slightly sloped with maximum terrain slope 1:12, i.e. max. approximately 5°
- **table in group two** – it is for cases, where there is the surcharge of 12 kNm^{-2} above the wall at the distance of approximately 1 meter from the wall front
- **table in group three** – it is for cases, where the terrain above the wall is sloped with the angle of maximum 1:3, i.e. maximum of 18°

The first column in tables represents wall height above the terrain (terrain height difference). Wall height greater or identical with the height of the designed wall is selected. Third column provides total wall height including the embedment.

The fourth column gives the number of reinforcing geogrids, the fifth provides their basic length. The first geogrid under the terrain is usually somewhat longer than the other ones and its length is provided in sixth column. Height level of location of a geogrid is the upper face of numbered courses of concrete blocks. Height levels are provided in the seventh (last) column. Numbering starts at the bottom of the wall – see wall diagram.

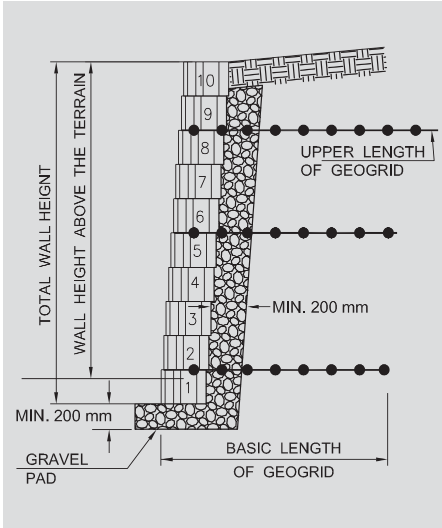
ORIENTATION DIMENSIONING TABLES FOR REINFORCED WALL WITH FACING ELEMENTS

These tables may be used if the angle of internal friction of soil behind the wall $\varphi \geq 27°$ and volume weight of soil naturally humid $\gamma \leq 19.5$ kNm^{-3}. These values are typical for clays with lower plasticity, silts and silts with added sand (CL, ML, SC, SM). Reinforced soil (soil in between geogrids) is expected to be gravel-sand. MIRAGRID 65/25-30 (5XT) is used.



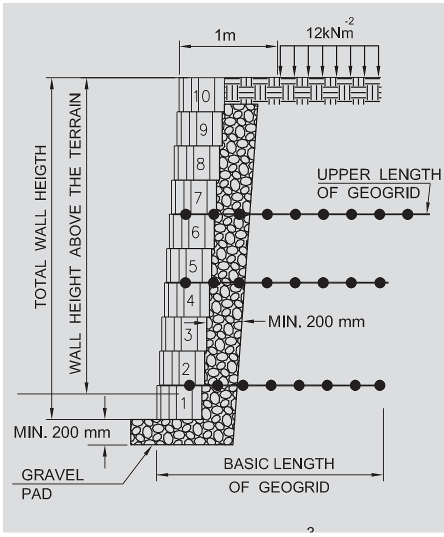
TERRAIN ABOVE WALL IS LEVEL OR SLIGHTLY SLOPED MAX SLOPE 1:12

HEIGHT ABOVE TERRAIN (m)	NUMBER OF BLOCK COURSES	TOTAL HEIGHT (m)	GEOGRID			INSTALATION OF GEOGRID ON UPPER FACE OF THE COURSE NUMBER
			NUMBER OF GEOGRIDS	BASIC LENGTH	UPPER LENGTH	
0,45	≤ 3	0,6	0	-	-	NONE
1,0	≤ 6	1,2	1	-	0,9	2
1,7	≤ 9	1,8	2	1,1	1,4	2, 5
2,3	≤ 12	2,4	3	1,5	1,9	1, 5, 8
2,9	≤ 15	3,0	4	1,8	2,3	1, 4, 7, 11
3,5	≤ 18	3,6	6	2,2	2,8	1, 3, 5, 7, 10, 14
4,0	≤ 21	4,2	7	2,6	3,2	1, 3, 5, 7, 10, 13, 17



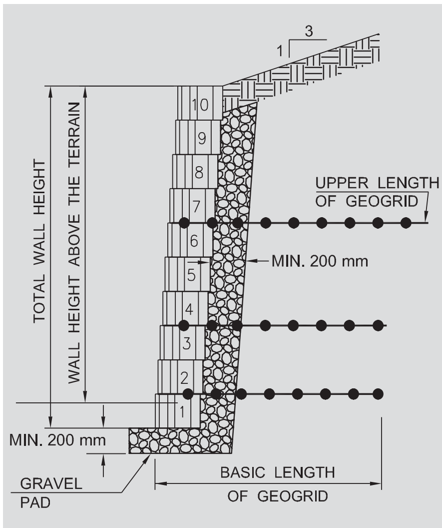
TERRAIN ABOVE WALL IS LEVEL, TERRAIN SURCHARGE 12 kNm^{-2}

HEIGHT ABOVE TERRAIN (m)	NUMBER OF BLOCK COURSES	TOTAL HEIGHT (m)	GEOGRID			INSTALATION OF GEOGRID ON UPPER FACE OF THE COURSE NUMBER
			NUMBER OF GEOGRIDS	BASIC LENGTH	UPPER LENGTH	
0,45	≤ 3	0,6	0	-	-	NONE
1,0	≤ 6	1,2	2	1,2	1,6	2, 4
1,7	≤ 9	1,8	3	1,3	1,8	1, 4, 6
2,3	≤ 12	2,4	4	1,6	2,4	1, 3, 6, 9
2,9	≤ 15	3,0	6	2,0	2,8	1, 3, 5, 7, 9, 12
3,5	≤ 18	3,6	7	2,5	3,3	1, 3, 5, 7, 9, 12, 15
4	≤ 21	4,2	9	2,8	3,7	1, 3, 5, 7, 9, 11, 13, 15, 18



TERRAIN ABOVE WALL IS SLOPED, MAXIMUM SLOPE 1:3

HEIGHT ABOVE TERRAIN (m)	NUMBER OF BLOCK COURSES	TOTAL HEIGHT (m)	GEOGRID			INSTALATION OF GEOGRID ON UPPER FACE OF THE COURSE NUMBER
			NUMBER OF GEOGRIDS	BASIC LENGTH	UPPER LENGTH	
0,25	≤ 2	0,4	0	-	-	NONE
0,45	≤ 3	0,6	1	-	0,8	1
1,0	≤ 6	1,2	2	1,1	1,4	2, 4
1,7	≤ 9	1,8	3	1,4	1,7	1, 3, 6
2,3	≤ 12	2,4	4	1,9	2,3	1, 3, 6, 9
2,9	≤ 15	3,0	6	2,4	2,9	1, 3, 5, 7, 9, 12
3,5	≤ 18	3,6	7	3,0	3,4	1, 3, 5, 7, 9, 12, 15
4,0	≤ 21	4,2	9	4,0	4,0	1, 2, 4, 6, 8, 10, 12, 15, 18



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