VARIOUS FACINGS OF GEOGRID REINFORCED SOIL RETAINING WALLS - CONSTRUCTIONS WITH MORE THAN 10M

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ABSTRACT: Geogrid reinforced retaining walls have increasingly been accepted as an alternative to conventional retention methods, such as reinforced concrete. This is due to their economical and ecological benefits and the availability of numerous suitable and attractive facing systems for all requirements. Due to these aspects, steep slopes and retaining walls can be easily adopted into the natural surrounding of the structure. Depending on the required angle of construction, the designer can choose between various types of facings available on the market. A practical, attractive and economical reinforced facing system has to include facing elements, geogrids, and their connection. The inclusion of these fundamental parts allows for a system to be erected simply and quickly with minimal training. Despite the facing of the structure being the only element that is visible post construction, not enough attention is paid in its choice.

This paper shows the flexibility, durability and cost-effectiveness of the systems available. In the first part of this paper, various facing systems using different materials dependant on the angle of repose are presented. Part two of the paper provides case studies of very ambitious projects with heights of more than 10 m which have been realised with geogrid reinforced retaining structures. Special attention is given to the reasons behind the selection of the final facing in each case.

1 INTRODUCTION

In the last few years a growing acceptance in the use of geosynthetics for the reinforcement of soil structures has been recognized. The reasons behind this acceptance are the economical benefits in terms of material cost and time saved when using geosynthetic reinforced structures compared to conventional retaining structures. In addition the systems offer durability and high flexibility allowing them to be integrated easily within varied environments.

In recent years as the market has grown, a large variety of facings have become available, allowing solutions for almost every situation to be found.

2 REINFORCEMENT SOIL

The relative cost benefits of geogrid reinforced structures as compared to conventional solutions such as reinforced concrete has been documented in a number of publications and studies. One typical comparison was made by Koerner et al at the end of the nineties in the USA. He investigated the costs of conventionally built concrete retaining walls, and compared them with the costs of walls reinforced with geosynthetics. It showed that significant cost-savings could be achieved using geosynthetic reinforced soil retaining walls with a facing of modular concrete blocks. Experience in Europe tells us that the same magnitude of savings (up to 50% of the costs) can be achieved at this side of the ocean and contractors are increasingly interested in making alternative proposals with this construction method.

The general term “geogrid reinforced soil structures” represents a wide range of construction forms and facings. In general, they consist of the following components:

- reinforced fill,
- retained fill,
- subsoil,
- geogrids and the connection to the facing,
- facing units and, if necessary, a foundation.

In principle, the necessary layers of geogrids are placed horizontally between the compacted layers of fill. The first layer of reinforcement is placed directly upon the prepared sub-soil. On this the first fill layer is placed and compacted. The thickness between the single geogrid layers has to be calculated and is dependant upon the soil conditions and type of the chosen geogrids. Slopes with a face angle greater than 45° (1:1) require surface protection using a facing system against erosion or top soil sliding for either the time taken for vegetation to establish or for the whole design life. The facing elements are all physically connected to the reinforcement. This connection needs to have a strength which is as strong as the geogrid itself or able to withstand the active earth pressure against the facing for the time of the design life.

Facing elements, geogrids and connection have to match perfectly. This can be achieved most simply with a complete system delivered from one manufacturer.

3 FACING TYPE

Much attention is paid to the design of the structure regarding type, length and vertical spacing of the geogrids, but often the designer has insufficient choice in the selection of the facing.

Every project has different parameters to design to, in terms of height, soils, foundation conditions, hydrostatic pressures etc. Also the aesthetic appearance needs careful consideration. Typically the structure needs to ‘fit in’ with the surrounding area. Other considerations are the need to construct a green facing, the orientation, and influences from outside (vandalism, UV-attack, etc). Each construction is a unique structure and needs a unique design, both in the aesthetical and technical sense. Architects and designers normally lack sufficient information and choice to compare the pros and cons of the systems available. Often a formerly used and for the planner therefore familiar system is adopted on a new project, neglecting the individual aspects of this special project. In this way errors can be made, reducing even the stability of the whole system. Additionally, the facing deserves to have most attention as it is the only part of the construction that remains visible permanently and leads either to an acceptance or disapproval of the construction by the public at large.

Apart from the aesthetical aspect, the following technical aspects have to be taken under consideration:

- possibility of a quick and easy construction with a proven system, comprising facing, geogrid and connection
- stability against static and dynamic loads
- stability against permanent loads which are caused by buildings, temporary loads by traffic, during construction or by maintenance
- durability for the time span of the design
- connection between geogrids and facing
- resistance against UV-rays
- resistance against chemicals
- durability regarding the pH-value of the fill material.
  If waste disposal, that can have extreme pH-values, is used as fill material, this point should get even more attention
- durability against chemicals in rainwater
- micro biological resistance
- macro biological resistance
- stability against vandalism
- heat resistance.
  If the construction is located next to a road where car-accidents could occur, the facing has to withstand the fire of a burning car. In this case also the resistance of the connection facing-geogrid has to withstand a fire.

3.1 *Choice of the facing*

A number of different facing units can be used in combination with reinforced soil retaining walls, bridge abutments and steep slopes The choice for a special type of facing is dependent on the angle of the construction. There are many different facings available which can be divided into the following groups:

- green facings (also known as “flexible facing”),
- rigid or hard facings,
- combinations of those two facings.

In figure 1 there are examples of these different facings, often combined with stiff geogrids.

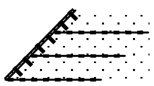
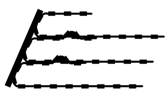
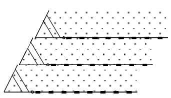
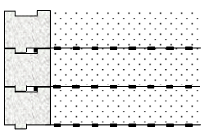
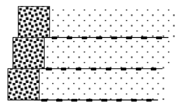
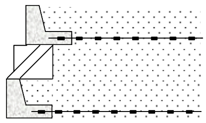
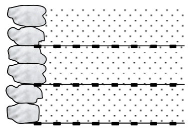
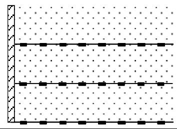
	Slopes up to 45°	
	Wrap around method	
	Steel mesh facing system, with vegetation	
	Modular concrete block facing units	
	Gabions	
	Crib wall facing, possible to be planted	
	Individual natural stone facing	
	Full height-panels method	

Figure 1: Different facing systems with geogrids

The best facing should be as flexible as possible in order to fit the requirements of each special case.

3.1.1 *Green facings*

Generally, a facing for slopes with angles up to 45° is not necessary.

The main problem in this case is stability of the construction until the vegetation has developed a sufficient and deep root system to protect the surface from erosion. A three-dimensional erosion control mat provides initial stabilisation of the soil surface while vegetation is becoming established. This method allows an economical and ecological solution and guarantees a green surface even during heavy rain periods.

For slopes with an angle of almost 45° and insufficient soil conditions it may be necessary to stabilize the construction by horizontal layers of uniaxial stiff geogrids and an additional erosion control mat on the surface.

For slopes with an angle of more than 45° a protection of the surface for the whole design life is necessary. The fill must be contained at the face to create a satisfactory and durable structure. In most cases, a green facing should be achieved to get optimal adaptation to the surrounding. The growing of the vegetation is dependant upon the amount of top soil, temperature and humidity and their variation and further on the geographical exposition of the slope.

On the market there are various facing systems for this application, comprising the wrap-around method and different steel mesh panel systems.

Apart from the general aspects (chapter 3), the following points are of importance for the construction of a green facing:

- stability against erosion
- sufficient stability and stiffness of the facing
- geographical exposure and slope angle of the construction with regard to the vegetation of the slope. Additionally, the surrounding vegetation has to be taken into account,
- amount and quality of top soil
- flexibility of the facing regarding angle, height and construction of curves
- (ground)water levels
- Differing water pressures or differing temperatures can cause horizontal forces which may damage the construction.
- amount of rain.

- If the climate is very dry, eventually an additional sprinkling of the green surface will be necessary
- resistance against corrosion.
- If the construction is situated next to a road, this effect may be increased by the use of melting salt used in frost periods
- Size of the apertures at the surface.
- The steeper the slope, the less rain it gets. In this case the importance of sufficient aperture sizes at the surface of the facings gets bigger. Eventually it is necessary to add constructive measures, e.g. berms or artificial irrigation.

It is of high importance that all single components together are seen as a whole system, because they should fit together perfectly and be certified. The static effective connection between geogrids and facing elements must be guaranteed. Beneficial to the builder is a quick and easy to handle system without demand for specialist installers.

When building a slope with the wrap around method, a temporary facing is needed. A prefabricated steel mesh system can undertake this demand either by leaving the steel mesh element as a “lost” facing in a wrap around construction or by connecting the geogrid to the bottom steel mesh with a proven connection, letting the wrap around out.

3.1.2 *Rigid or hard facings*

Angles steeper then 70° do normally not allow a green surface because of the lack of sunlight and rainwater. Surfaces for retaining walls or bridge abutments can be build with modular block facing units, full height or incremental block panels, crib wall facings that can be planted, or gabions.

The following additional aspects are of high importance:

- long-term stability using proven, independently certified products and systems
- easy-to-handle elements which allow a maximum flexibility
- frost resistance.
  facings made of concrete elements or by natural stone could be damaged by frost.
- Combination of facings.
  Higher constructions could be divided in a lower part with a high resistance against vandalism and a higher part which can hardly be reached and can therefore be build with a facing with lower requirements against vandalism. Additionally, a good visual appearance can be achieved.

Due to the critical nature and long design life of reinforced soil retaining walls and bridge abutments constructions using systems, concerns are often expressed during design approval regarding the components of the system. The quality and durability of the facing units as well as the geogrid soil reinforcement must be assessed and in particular the connection strength between the two components grid and facing.

All requirements listed above are fulfilled best with modular block facing units: they are flexible regarding the length, height and curves of the construction. Both convex and concave curves can be constructed. They are easy to handle because of their weight (handable by one man) and can be build by a normal building contractor, no specialist is needed. A polymer grid connector provides a high connection design strength.

The ease and speed of construction may lead to cost savings over conventional retaining wall designs whilst allowing a variety of surface finishes to be achieved.

4 CASE STUDIES WITH DIFFERENT FACINGS

4.1 *Landfill in southwest Germany; facing: prefabricated steel mesh and gabions*

In 2001 a household waste disposal in southwest Germany, in use from 1964 to 1992, had to be repaired. The cap was covered and measures were taken that seepage was prevented and waste gases were collected and drawn-off. Because of the drainage and gas collection the gradients of the cap were limited to 1:3 (18.4°) and massive quantities of waste were to be re-allocated to reshape the disposal. At one edge of the disposal a steep retaining slope was necessary to optimize the volume of the disposal. A retaining wall with a length of app. 330 m and a maximum height of 17 m had to be built in a very restricted place so that it was not possible to erect a standard slope with an angle of 1:1.5 (33.4°). As the retaining wall is situated next to a housing area both the aesthetical and vandalism aspects became important. For the facing of the bottom 3 meters of the retaining wall gabions with an almost vertical face were selected as protection against vandalism. The upper slope has an angle of up to 70° in the center of the construction. The spacing between the geogrid layers is 0.65 m. For the facing prefabricated steel-meshes were selected because of several reasons: the possibility to vegetate the surface so that a perfect assimilation to the green areas on both ends of the construction could be achieved. Furthermore, this system allows the variation of the height and the angle. As the construction reduces the height to both sides while the angle decreases, this very flexible system allowed a perfect and easy to install construction for these demands. Another very important aspect is the resistance of the system against the gases and fluids of the waste deposit. Last but not least the retaining wall could be built very quickly, which was an important aspect regarding the height.

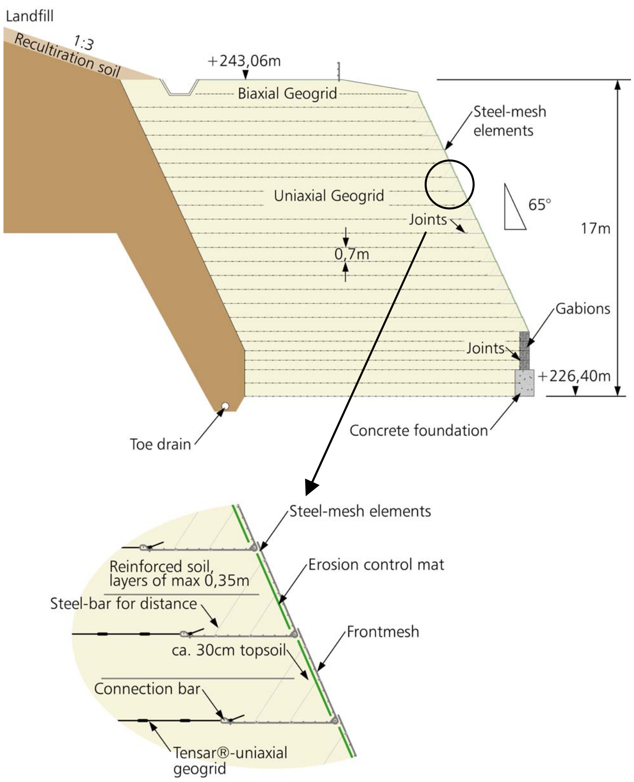


Figure 2: Cross section of the landfill

On the inside, the steel meshes were covered with a geotextile for the erosion control which allowed topsoil to be compacted at the spandrel; so a quick green surface could be achieved (see fig. 3). The connection between geogrid and steel-mesh is made by weaving a bar between the longitudinal geogrid ribs and threading through the eyes of the bottom steel mesh-element. By this method a full-strength connection can be obtained.

Figure 3: Photo of the landfill in southwest Germany

4.2 *Retaining wall in Taunus/Middle Germany; facing: gabions and reinforced slope*

In 2003, a trading estate in the middle of Germany with a total area of 78.000 m² was built. The hilly area fell from a height of 481 m NN in the southwest down to 459 m NN in the north respectively down to 445 m NN in the east and was used for agricultural purposes. In order to terrace the site, on the south side a slope with a height up to 9 m had to be constructed by cutting the rock as well as the sediments. The excavated material was used as fill material on the northern side for the construction of a geogrid-reinforced slope with a height up to 12 m. Partly, the lower 4 m had to be built with a gabion-facing because of the confined area.

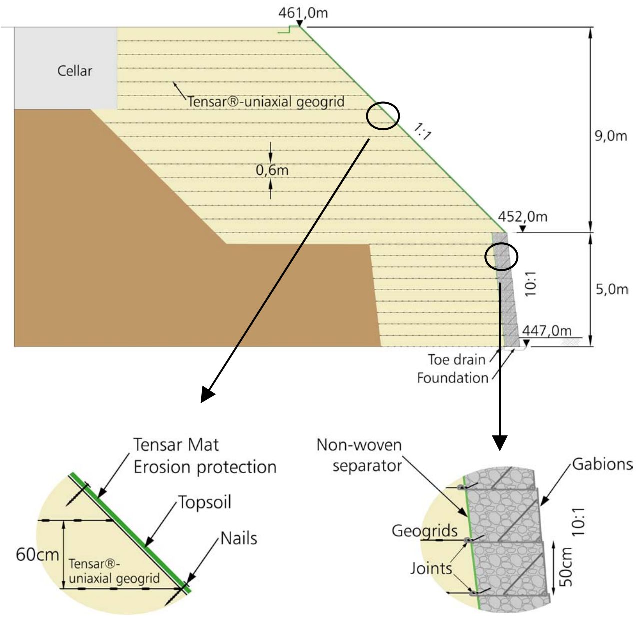


Figure 4: Cross section of the retaining wall

On top a berm was constructed as a depot for top soil. In the following upper part a slope with an angle of 45° was built making use of the excavated fill-material. This was reinforced with stiff, uniaxial geogrids and covered with an erosion control mat. The stiffness of the uniaxial geogrids allowed easy installation in horizontal layers. The erosion control mat allowed vegetation to establish quickly on the surface.

In the design, different loading conditions were checked.

The project will be supervised by long-time measurements.

Figure 5: Photo of the project in Taunus

4.3 *Retaining Wall in southwest Germany; facing: gabions and prefabricated steel mesh panels*

Between the states of Bavaria and Baden-Württemberg a route for very heavy and outsized traffic exists. In the city of Aalen this route crosses a railroad. In 2003, the existing bridge had to be rebuilt as the loads and the length of the trucks exceeded the curvature of the bridge approach; for example the new allowed maximum length is now 69 m. Bridge and road had to be connected by a ramp with a height up to 11,5 m and a length of app. 240 m. Because of the very restricted place it was decided that a geogrid reinforced retaining wall would provide the most appropriate solution.

The wall was divided in order to achieve an optical reduction of the height. The lower part up to a height of 5.5 m was constructed with a gabion facing with stones in different colours at the front both to get protection against vandalism and an interesting and varied texture to the surface. On the top a berm was constructed in order to achieve a reservoir for top soil for vegetation. The upper part with a height up to 7 m was constructed with prefabricated steel meshes with an angle of app. 63° which can easily be vegetated. This facing was chosen because the construction was built in the city of Aalen to achieve an aesthetic visual appearance. The steep slope should get easily green after the construction is finished.

The subsoil consists of loam and clay and is very weak. Therefore the construction was founded on vibro concrete columns to reduce the allowable settlement to a tolerable amount.

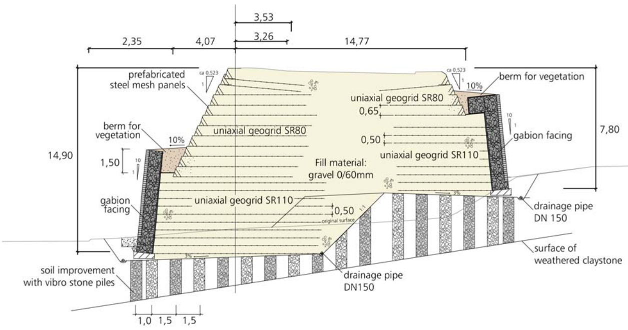


Figure 6: Cross section of the project in the city of Aalen

Figure 7: Photo of the project in the city of Aalen

4.4 *Dubai / Idhn Tawaian Dibba road; facing: modular block facing units*

In the summer of 2001 the building of the Idhn Tawaian Dibba road started. The project consists of a 29.5 km road built through a mountain range in the Emirate of Ras Alkhaima. The building of this road will save the local population a minimum of 1 hour in travelling time as it bypasses the coastal road. The terrain the wall has to be built through is very remote, rugged and dry with temperatures in excess of 50°C.

Key features of the topography of the area are the numerous gullies and wadi's (river's formed during heavy rainfall and storms). These features cut across the landscape forming steep sided valleys. As the road is 22 m wide, large amounts of construction was required to achieve the required grades, this include large infill and retaining structures. The cost of concreting and piling was not only costly but very difficult due access for the heavy plant required would be very limited.

Hence a dry laid modular block system was the only way to proceed, as the materials could be easily transported and built using readily available labour. The use of the block system was made even more attractive as locally cut fill material could be utilised. The design and drawings for each wall were provided by Tensar International's in house-design team, as and when required.

In total 18 individual retaining walls were required with an additional 6 wing walls for bridges. The walls varied in height from a minimum of 3 m to 18 m high, but averaged at 11 m. The longest wall was in excess of 400 m giving a total face area for the modular block walls of over 38,000 m².

The Tensar modular block system proved most versatile as culverts could easily be accommodated through the walls at various heights.

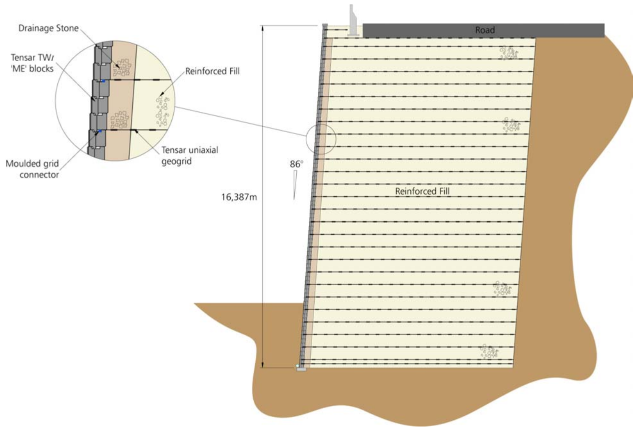


Figure 8: Cross section of the project in Dubai

Figure 9: Photo of the project in Dubai

4.5 *Lisbon/Portugal;facing: wrap around facing*

North of Lisbon (Portugal), a food distribution centre was constructed between 1996 and 1999. The area around Lisbon is hilly and undulating and under these conditions the site for the M.A.R.L. centre required an embankment to be constructed up to 21 m high. In order to create two terraces, enormous masses of soil were to be reallocated. A natural slope would have resulted in a relatively small area on which to build and the use of concrete retaining walls was viewed as too expensive. The cost-effective solution was a geogrid-reinforced soil slope because this could provide sufficient space for the distribution centre. The construction with an angle of 70° meant significantly reduced construction costs compared with a vertical concrete structure. Additionally, a wrap-around construction could provide the benefit of a green face making the construction even more acceptable by appearing to integrate with the environment. The constructed embankment has a length of 700 meters and a height of between 5 and 21 meters.

To achieve a rapid green surface, bags filled with soil and seeds were placed behind the geogrids, so that the retaining wall could be constructed without a formwork.

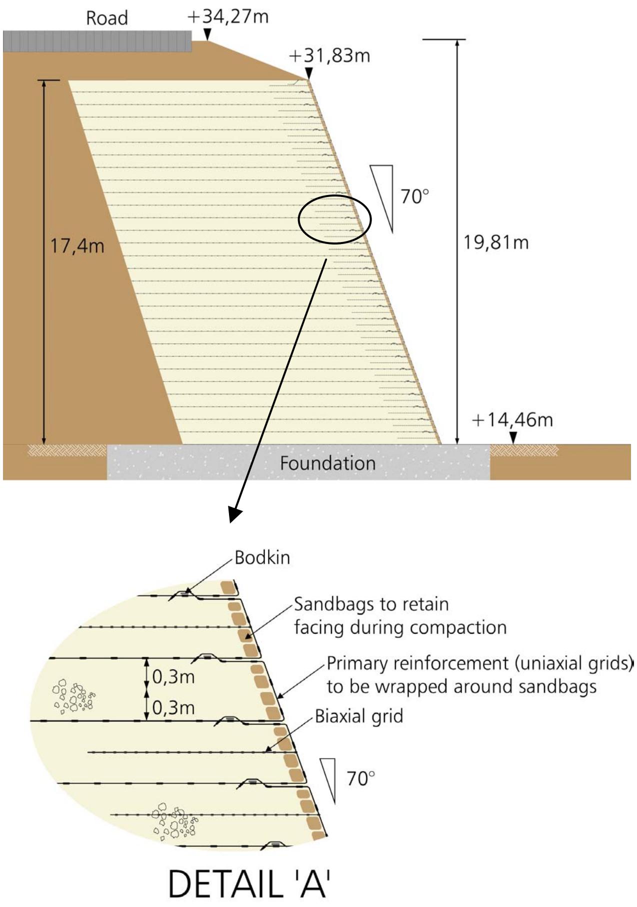


Figure 10: Cross section of the project in Marl/Portugal

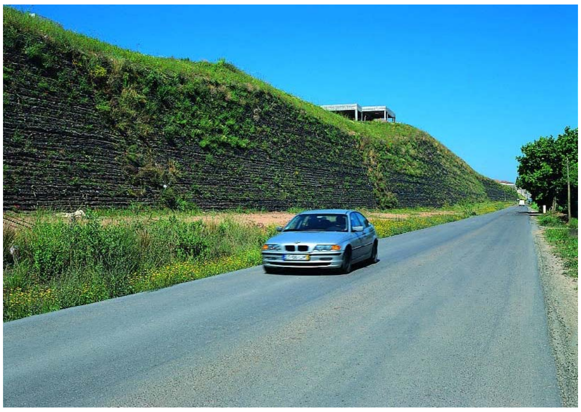


Figure 11: Photo of the project in Marl/Portugal

5 CONCLUSION

Consideration for the selection of the facing includes a combination of technical and durability aspects to be solved by the designing engineer. Important considerations are:

- Ease and speed of installation
- Optimal fit of the components: facing – connection – geogrid
- Guarantee of the connection strength between facing and geogrid
- Stability against loads (static and dynamic, temporary and permanent)
- Durability for the time span of the design
- Durability regarding the pH-value of the fill material
- Resistance against UV-rays and chemicals, micro and macro organisms
- Stability against vandalism
- Heat resistance

However, more importantly the selection of the facing needs to be acceptable to the public at large. Involvement of architects of the construction, politicians and representatives of the client are essential.

Durability of the vegetation, the concrete or other facing units need special attention, especially when used in the vicinity of roads.

The ease of construction will effect the risks of mistakes. In any case the supplier of the system should always be involved in the process of the facing selection and the actual construction of the structure.

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