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Special design and construction features for a steep and very high plantable retaining and sound wall

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ABSTRACT: A very high cribwall combined with a geotextile reinforced fill sloping toward the airport side now protect the old village center of Steenokkerzel located directly next to the Brussels International airport. This task required to develop various design and construction features for this 16m high retaining and sound protection wall. These special features include (1) cribwall type retaining wall units, developed for excellent plant growth even on an overly steep wall face, now adapted for soil reinforcement, (2) connection of polyester fabric to wall facing without direct contact to concrete to eliminate effects of high pH-values (3) flexible connections between the relatively soft fill and the rigid concrete facing, and (4) manufacturing custom made geometry for prefabricated concrete units to exactly fit tight corners on the battered wall face. Whether predicted bulging at corners nor settlement deformations resulted due to these special precautions. The high structure resolves noise pollution by airplanes in a sensitive area and is considered as a state of the art solution for other airports.

1. WALL CONCEPT

1.1 Purpose

On Brussels International Airport ‘Zaventem’ a very high (16m) retaining wall was built, probably the highest sound wall ever built in Europe. This fully vegetated wall protects the picturesque village of Steenokkerzeel from noise disturbances. The wall stands up directly behind the backyards and is about twice as high as many of the private houses. After erection the steep and vegetated wall has turned the previously airport exposed area into a calm, concealed, and vegetated environment, now protected from the thundering discord of starting jets. This project required the development of special engineering technology and it opens new dimensions for protecting humans from airport noise pollution in densely populated areas.

1.2 Cribwall Gravity Type Retaining Wall

Originally a vegetated cribwall (cellular gravity wall) was designed with a large fill and gentle slopes toward the runways. After awarding the contractor challenged the designer to transform the gravity retaining wall into a much lighter facing retained by soil reinforcement using woven Polyester geofabric. This challenge was feasible, since the project required storage of otherwise unusable soil material and the engineer called for geotextile reinforcing of the fill to reduce differential settlement.

2. TECHNICAL SOLUTIONS

2.1 Plantable Precast Concrete Wall Facing

A vegetated wall face was imperative to ease the sight of such a high wall (similar to a building over five stories high). The wall follows the back yards of the houses closely and thus requires several turns with corner joints.

For saving space the front face was designed with a steep wall batter of 4:1 or 76° to the horizontal (no steps or resets). Such a steep wall facing is generally considered non plantable, because such a steep slope can hardly catch the rain needed to sustain plant growth. However the large Evergreen® cribwall units with very deep L-shape front trays (min. depth 0.28m) were specifically designed for voluminous pockets of top soil on each level to retain sufficient moisture for the plants to survive even dry summers.

Such deep topsoil pockets for moisture retention are impossible with traditional soil reinforcement facings, yet they are essential to grow shrubs, instead of grass, since small bushes are virtually maintenance free for several years. Grass requires one cut per year minimum maintenance, which is hardly possible and thus not acceptable for many owners. Thus deep L-profiles provide the key engineering design feature for vegetation, an important environmental aspect.

Vast experience in central Europe has shown that grass vegetated steep slopes, as widely used for the wrap-around or similar wall methods, require a minimum wall batter of 60° to 72° or 1.73:1 to 3:1. Nevertheless deep L-shape trays with the protected pocket of top soil retain moisture to support small brushes on a wall batter 76° to 79° or 4:1 to 5:1. Any steeper walls need irrigation, particularly if exposed to the South.

2.2 Avoid Chemical Degradation in Contact with Concrete

Polyester geofabrics are known to be efficient and reliable for soil reinforcement. However Polyester may deteriorate and loose much of the resistance if in contact with fresh concrete due hydrolysis in high pH-values environment.

Numerous tests have shown that Polyester fabrics in contact with lime stabilization deteriorate rather quickly; some 40% strength loss after 3 or 4 months are common. Thus the issue is of great practical importance: It is common engineering practice to avoid Polyester geosynthetics in conjunction with soil stabilizing, whether with cement or lime.

For a Geogreen® as developed and designed by the author for a retaining wall erected in Unterkaka, South of Leipzig, Germany, lime stabilized soil fill was required. Thus PVA Polyvinyl-Alcohol geogrids were selected, because this material is as strong and as stable as Polyester regarding creep, yet not susceptible to high pH.

A special survey was conducted in Europe and overseas to find clarification and investigate engineering practice regarding the weakening effect of Polyester in direct contact with several weeks old precast concrete units, possibly exposed to rain.

The BAM Federal Agency for Testing and Approving Building Materials in Berlin, is known for releasing very strict requirements in this regard. The German recommendation [2] clearly says: ‘Sensitivity of Polyester against high alkali environment must be considered.’ and: ‘...Stability of Polyester (internal and external hydrolysis) for permanent applications must be proven.' And: 'Products made of Polyester should not be used in lime or cement stabilized fill or in direct contact with concrete surfaces, unless permanently protected by applicable means.' However members of this code committee, revealed that protection of Polyester from high pH-values in direct contact with hardened concrete surfaces is no longer considered a big issue.

In Germany direct contact of concrete surfaces with Polyester geofabric is normally avoided by painting the concrete with black spread as used for concrete structures under soil cover anyway. A membrane fixed to the geotextile to avoid direct contact with concrete surfaces is another acceptable solution, yet both of them costly and reducing friction.

Before investing extra funds for Polyester protection, the engineer requested a proof with firm data. However in a survey it was impossible to collect laboratory or field test data to verify evidence and magnitude of potential damages of Polyester geofabric in direct contact with precast concrete elements. Possibly such test data do not exist or proved to be irrelevant. This might be the reason the subject is no issue in France or USA.

The geotextile manufacturers are fully aware of this pending question by responding accordingly: For projects in Germany usually PVC coated Polyester geogrids are shipped, whereas for similar projects in France no coating is required.

According to the survey, hydrolysis of Polyester is a complex question: As long as there is moisture and a concrete surface nearby, the potential loss of Polyester resistance is likely to occur. The practical solution selected for this project was:

Keep Polyester geofabric at a safe distance away from precast concrete surfaces by a sand cover of about 0.1m, since the high pH-values may exist with ample moisture and only within the immediate vicinity of concrete surfaces.

2.3 Flexible Geotextile Connection

Further technical development resulted in a positive, yet indirect connection of the large concrete units with the Polyester woven geofabric. The connection couples the lateral earth pressure forces from the reinforced soil to the front facing. It is essential to create a connection that is strong to transfer lateral forces, yet yields for local deformations within the backfill and for a unavoidable irregularity of fill material and compaction quality.

Rigid concrete retaining wall facings are definitely much stiffer than any backfill soil material. Thus differential settlement problems behind concrete facings are very common:

Even well compacted backfill may have a tendency to settle during the first few wet seasons, thus clearly showing a different behavior than the relatively rigid facing. Furthermore the concrete facing is heavier than the soil fill behind. Therefore on a soft sub-ground the facing is likely to settle more than the fill, sometimes even with a tendency to tilt the wall.

Under ideal circumstances these two effects may compensate each other, which is rarely the case. Consequently it is important to design and build retaining walls to accommodate such effects. This settlement and geogrid connection problem is not a big issue for short walls and for walls with clean sand or gravel backfill. Yet for high walls and soft sub-ground or second class backfill material connection problems from differential settlement may result in an important nuisance, resulting in cracking and uneven deformations and warranty claims hard to resolve.

For this very high wall a flexible connection was developed using the 'sandbag method' as shown in figure 1:

An additional connecting geofabric is placed all the way into the crib wall filling and then brought back all the way to the backfill, thus forming a 'sandbag' concealed in the cell up-front resisting the lateral earth pressures from behind. This method fulfills both requirements: It is very strong and it easily adjusts to local settlement or deformations, without creating overstress to the concrete members, by conceding for small deformations.

The use of the 'sandbag method' required a design change of the precast units: Instead of the L-shape cross sections at front and in the back, the cross section on the back had to be changed to a trapezoid section to space the anchoring geofabric on regular lifts and to make room for the required distance of geofabric from concrete surfaces.

After numerous discussions the following installation procedure was adopted as shown in figure 1:

1. Use high strength Polyester woven geofabric for anchoring at 0.36 rsp.0.73m vertical spacing. These main anchors are put all the way across the concrete units for developing maximum connection forces.
2. Place some sand and a connecting geofabric. Flip the connecting piece over the outside top of the wall temporarily and fill the second lift.
3. Flip back the connecting piece, add some sand to develop better friction in between and place the next anchoring geotextile. Note the small layer of about 0.10m over the top of the concrete units preventing direct contact to Polyester woven geofabric, thus eliminating potential weakening of Polyester.

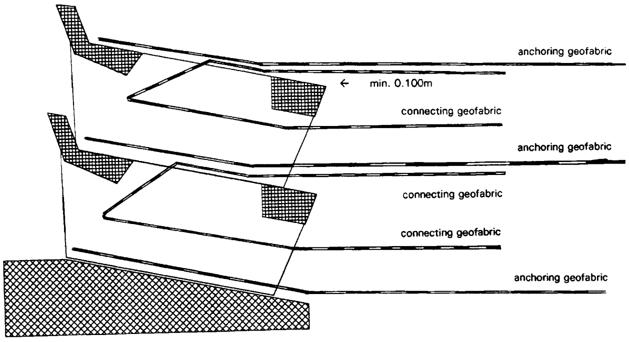

Figure 1 - Indirect Connection of Geofabric with Precast Concrete Cribbing - Special indirect connection between Polyester geofabric and precast Evergreen® units: The main anchoring geofabric reaches all the way across the cribwall, yet some 0.10m above the concrete members. An additional connecting geofabric wraps around the second layer in each concrete unit to ensure tight, yet indirect connection to the wall.

2.4 Custom Made Corner Units

The wall must follow the property lines as closely as possible, requiring two sharp corners in the battered wall. This causes an important geometrical issue: Any vertical wall is much easier to design than a wall with a batter. For this project precast concrete units for corners are custom made with shortened arms to match the geometry at each level: An outside corner requires longer units near the bottom and shorter units toward the top of the wall. In an inside corner the wall batter asks for short units near the bottom and long arms at the top.

Evergreen walls consist of very large units (5.40m long) in a frame like pattern with extending arms at both ends. The units are fabricated individually with shorter arms to meet in the corners. The geometry details are resolved using a special computer software that considers the wall batter, the wall height, the unit types and their relative setting (flush at front or flush at mountain side).

Obviously this imposes a very strict geometry for varied length of concrete units, so the units fit the three dimensional structure of the wall face depending on the angle of the individual corner and the height position within the wall.

Figure 2 illustrates the special layout for the outside corner on the first layer of units and figure 3 illustrates a similar solution for an inside corner. The individual precast concrete units are fabricated for each level and according to a shop drawing considering shortening in plan view, as well as the slight slant at the end of each 'arm' to fit the corner even in the third dimension. Several projects have shown, that such shortening must be well planned and factory made, since precise cutting of concrete units on site is not feasible; it is hard to imagine and measure the three dimensional position of each cut.

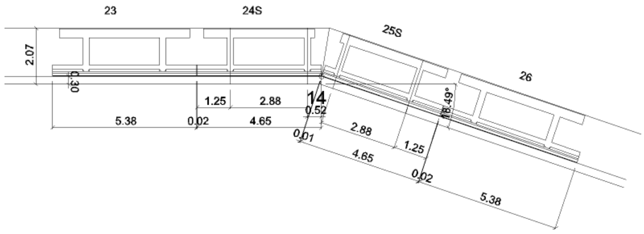

Figure 2 - Plan View of Typical Inside Corner - The frame-like Evergreen units are fabricated with shorter arm lengths to fit the turn. The figure shows the lowest layer of units only; higher level units are similar, yet slightly different length to account for the wall batter effect.

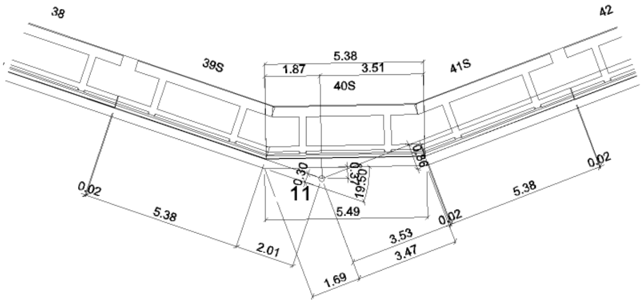

Figure 3 – Typical outside corner divided into two different turns to better fit the foundations that were placed beforehand. This demonstrates an additional flexibility to accommodate site restraints by shortening arms accordingly.

3. CONCLUSIONS

3.1 *Top Quality Standard is Essential*

With the height of 16m plus 2m high precast sound panels on top, this wall is about as high as a five or six story building and about two or three times the size of standard retaining walls for bridge abutments, sitting on medium soft subground. For these reasons a responsive attention is essential for both the designer and the contractor to perform with the utmost concern: Every little detail must be designed and built totally correct, considering the magnitude of size and potential for deformations and settlement. Actually this sound wall is the highest retaining wall in Belgium and probably the highest sound wall worldwide. The success bases on the use of new technologies to adapt for difficult soil conditions and construction during the worst possible (very wet) winter season.

3.2 *Dominant Position*

The sound wall totally commands the skyline together with the ancient church centered on the village square and is seen from miles away. Thus it is a question of professional responsibility to design engineering structures in a sensitive way so that they do not harm, but help to create a better quality of life. This high profile concept often seems to be neglected for sound walls by selecting the most economical material, irrelevant of the high visibility and impaired view.

In this case the wall achieves a pronounced sound reduction thereby providing a calm and relaxing environment in the village even at the toe of this very steep and totally vegetated wall providing a park like atmosphere.

Engineering monuments by mere size or appearance should not be felt like massive structures, which is another reason to care for quality of vegetation. It seems like a reasonable design attitude to develop technologies for erecting structures that enhance quality of life. This applies especially for locations, such as the International Airport of Europe's center, convenient to visit by professionals and specialists for using similar concepts for projects elsewhere. At last it is an important structure for the Airport Authorities to increase air traffic acceptance in neighboring villages.

Figure 4 - Front Face with Corners - Photograph along the front face of the wall under construction: Two angles of the battered wall are clearly visible.

3.3 *Deformation Effect*

The design engineers have made a deformation study [1] using the sophisticated finite element program Plaxis on the Zaventem sound wall. A first estimate envisioned substantial bulging of the wall structure of some 200mm. Even though there are numerous details to evaluate in any calculation, the experience did not show any bulging, nor tilting. Such deformations would be clearly visible in the sharp corners, and damages would result.

These reasons effectively prevent 'bulging':

1. The Evergreen wall units are large (5.40m long and 1.18 to 1.82m wide), weighing 2 to 3 tons each. Such heavy units with a relatively wide base erected one on top of the other form a rigid structure with a stability, preventing 'bulging' by inert stiffness, as long as the resultant contact force in the units remains within the core section.

Figure 5 - Close up of Corner Detail - A view of the inside corner from below to demonstrate the exact fabrication and erection of the wall even in this three dimensional environment of rough earthworks.

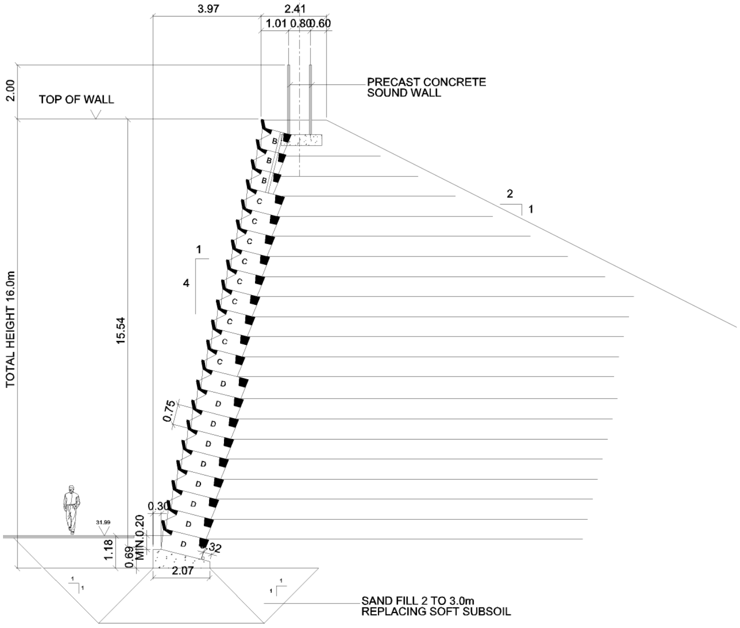

Figure 6 - Section of the retaining wall with reinforced fill that protects the village of Steenokkerzeel from intense noise of Brussels International Airport into a calm, concealed, and vegetated environment, protected from the thundering discord of starting jets.

2. Standard geosynthetics soil reinforcement design provides anchoring forces against lateral soil pressures and thus the tendency for bulging of the face is greatly reduced. Critical for perfect deformation behavior is proper fill compaction in a prescribed sequence, as well as fill material that remains similar in granulometry and water content throughout. These requirements are essential for the fill, at least within the zone a few meters from the face.

4. LITERATURE

[1] P. R. Rankilor, F. de Meerler, F. P. Jaecklin, F. van Bossuyt & S. Vandemeulenbroecke, M de Vos, W. Fransen: The reinforced design and construction of a noise barrier in reinforced soil at Brussels international airport, Proceedings of the second European Geosynthetic Conference, Bologna 2000, page 267

[2] 'Merkblatt für die Anwendung von Geotextilien und Geogittern im Erdbau und Strassenbau' (=Recommendations for the use of geotextiles and geogrids in earthworks and highway construction, Germany), Version 1994.