Steep-sided temporary bunds reinforced with nonwovens and steel tubes

U. Köhler
Baugrundinstitut Dr. Köhler und Herold GmbH, Weimar, Germany

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ABSTRACT: The retaining bunds surrounding a slurry pond in a gravel plant in Thuringia had to be raised by 3 m in order to allow the continued pumping of slurry into the pond. Conventional soil bunds were not feasible because of space limitations. In addition, the solution chosen for the first stage had to be suitable for the construction of two additional 3 m high bunds to further heighten the structure. The system, originally developed for flood protection applications, was chosen for the bund construction. The cross section consists of 3 m high steel-tube space frames with an external skin of nonwoven geotextile. Additional reinforcement is provided by rigid steel sections bolted to the space-frame tubing. The main stresses on the geotextile are very high mechanical loads. The first stage of the structure, with a length of approx. 300 m, was constructed in August/ September 1999 in only 3 weeks and is currently under trial. Various construction sequences and different fill materials were experimented with. Samples of the weathered nonwoven outer skin were taken and tested. Reductions in tensile strength as a consequence of UV exposure, and at welded seams, can lead to failure modes even in temporary (short-term) applications. Therefore, trials were carried out to study how to repair failed sections of the bund and to evaluate various types of UV protection. The use of the system in the above configuration confirms that this type of steep embankment reinforced with nonwoven geotextiles is suitable as a temporary support structure, and that it can be recommended for other types of application.

Figure 1: Gravel plant in winter, showing the approximate location of the bund

1 INTRODUCTION

Slurry which occurs during gravel and rock processing in the mining industry is flushed into sedimentation basins created for this purpose or into exhausted extraction pits. Figure 1 shows such a basin in a gravel plant in Thuringia. Sedimentation basins need large areas in most cases. For this reason, top-up bunds have often been constructed by placing fill material on an existing bund to increase the volume of such basins. Three constraints had to be taken into account for the construction of the top-up bunds in the application described here:

- The top-up bunds had to be constructed in 3 stages of 3 m each until reaching the maximum height of 9 m.
- Only a relatively short construction time of approximately 1 month is available for every extension stage.
- Conventional earth-fill bunds were out of the question because of insufficient room.

Figure 1 shows a sketch of the top-up embankment's course, covering an overall length of about 300 m. The Quick-Damm® (quick fill dam) developed for flood control has been modified and tested in order to solve this problem. This article documents the most important results obtained in this process, and it gives indications for future applications.

2 DESIGN

The System consists of a framework structure made of welded steel tube sections which fix the external geometry of the bund segment. Nonwoven textiles are fixed to the steel tube sections to obtain an outer skin as a facing for the structure. This design allows the external profile of the bund to be established in an extremely short time, using the steel tube sections which may then be filled with any kind of fill material. Originally, this framework structure has been designed as an embankment allowing rapid construction for flood control. For this purpose, impervious sheets are used instead of nonwoven material to cover the steel structure, thus allowing it also to be filled with water instead of soil material. The weight of the soil material filled into the structure guarantees stability in the simple case of the 3 m high embankment segments even when the element is placed in a flat position on the ground surface. This means that the system's stability concept corresponds to the principle used in gravity dam walls. The distinctive feature of this embankment project was the need to place 3 levels of bund segments with a height of 3 m each one on top of the other in order to reach the maximum bund height of about 9 m. Figure 2 shows the cross section of the 3 bund levels. Reinforcing elements had to be included in all three levels of the structure to prevent the rupture of the bund during the third stage of construction as earth pressure builds up in the embankment's three-layer system and may lead to the displacement of the outer elements. The inclusion of these steel fasteners in the design of the entire bund structure made it possible to perform the earthwork's structural analyses for external stability as for the determination of the equilibrium in gravity walls. The steel structure shown in figure 2 includes the following elements:

1 trapezoidal frame made of steel tubes 108/3.6
2 channel sections (U80)
3 flat steel elements 60/8 to link 2 superimposed segments
4 horizontal tube connecting elements made of steel tubes 108/3.6 with a length of 4.15 m
5 horizontal reinforcement layers consisting of nonwoven material

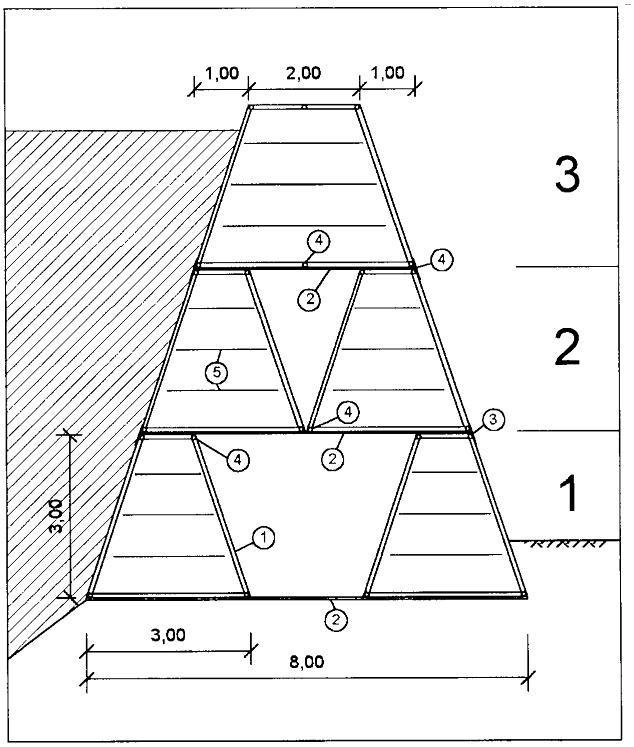

Figure 2: Cross section of the bund's steel framework

Figure 3: Bund elements during construction

The bund is placed segment by segment. One bund segment is arranged each on the inside and on the outside during the first stage. The space between the segments is filled with embankment fill material. The two outside segments meet at the centre on the second level. The triangular space left between them is also filled using embankment fill material. Trapezoidal tube sections of the same kind are used for the lower and intermediate embankment levels (height: 3 m; upper width: 1 m.) A single but bigger trapezoidal element with a lower width of 4 m and an upper width of 2 m must be used for geometrical reasons in the upper bund segment.

The geotextile skin which determines the external shape is fixed to the lower and upper steel tubes running lengthwise (with a length of 4,15 m each) as shown in figure 3 ,4 and 5.

The 3 intermediate geotextile layers placed each within the bund segments have an important function for embankment construction and for maintaining geometrical stability. Mechanically bonded continuous-filament nonwoven material (with a tensile strength of Fk ≥ 28 kN/m) is used for these intermediate layers. The horizontal intermediate geotextile layer absorbs part of the earth pressure which develops within the segments. This significantly reduces bulging in the external geotextile panels. It has been shown that a precision of ± 0.3 m in terms of height is sufficient when placing the horizontal intermediate geotextile layers. For additional stability, crash-barrier sections are bolted to the trapezoidal sections in the lower third. At the same time, these sections provide mechanical protection against damage by vehicles, figure 4.

The segment rows are placed along a straight line. An additional trapezoidal element is placed at each corner, and it is welded using custom-made fasteners to allow for changes in the direction of the embankment axis. Figure 4 shows a solution for a rectangular change of direction.

Figure 4: External bund segment with guard board; filled with cohesive soil

3 GEOTECHNICAL CONSTRAINTS

A soil investigation must be carried out to obtain sufficient geotechnical data on the subsoil prior to performing the analyses of external stability. Particular attention must be paid to the analysis of the slurry which will be impounded in the basin. The bunds on the impoundment side are gradually filled with slurry. . The silt and clay fraction in the slurry lead to the very quick formation of a slurry skin at the geotextile surface. For this reason, the geotextile skin below the slurry surface on the impoundment side may be compared to a bentonite mat.

The pond sediment in the case under consideration essentially consists of slurry with a grain size of $< 35\ \mu m$. Slurry density is $\gamma = 12$ kN/m³. Vane-shear measurements have shown that the slurry still has a liquid consistency at least up to a depth of > 4 m. The consolidation process is very slow because of the high clay content in the slurry.

The slurry consolidated on the geotextile surface leads to an impermeabilisation of the bund segments. In consequence, the drainage system installed at the embankment base has remained almost without effect. But this fact also has an influence on the design of the bund. The structural analyses were based on the assumption of a steady flow through the bund which does not occur in this way in reality. This situation requires particular checking in all other projects in which this system is applied. A comparable process will take place in most cases.

Fill material selection has an essential influence on the stability of the structure and on the extent of bulging in the outer geotextile skin. Initial considerations were based on the assumption that high permeability was the main criterion for the fill material to be used on the slurry side of the bund segments. Gravel with a grain size of 8/16 was used during the first trial. Figure 5 shows the impoundment side of such an embankment segment filled using non-cohesive gravel. The lack of cohesion exposes the external geotextile skin to very high stresses and elongations caused by the fill material.

But it has been shown in fact that the embankment body is not exposed to an extent of seepage which would require the use of highly pervious soils as fill material. Cohesive to highly cohesive gravel is the most suitable fill for the bund segments.

The lack of space allows only a moderate compaction of the fill material. For this reason, this material should have a water content with an order of magnitude which corresponds to the optimum Proctor water content at the time of filling. Trials have shown that gravel is most suitable when it has the following parameters:

Density	$\gamma = 20.5$ kN/m³
Angle of friction	$\varphi = 40°$
Cohesion	$c = 30$ kN/m²

The permeability of this gravel is in the order of magnitude of k_f = approx. $1 \bullet 10^{-7}$ m/s. This permeability is sufficient to divert the small amount of water which enters the embankment to the drains placed in the embankment base.

Figure 5: Bund segment filled with non-cohesive gravel

4 DRAINAGE

Seepage water must be intercepted within the embankment body, and it must be collected at the embankment base in order to be diverted below the bund to the downstream side. A drainage blanket with a collector that allows back flushing must be installed at the bund base in every case if this embankment design is used to contain slurry deposits. To a very large extent, the amount of seepage water depends on the composition of the slurry impounded in the basin, and on the amount of blocking or clogging caused by fine grained particles in the geotextile skin. Special seepage drains should be provided between the external bund segments to prevent flow across the entire bund only in applications in which a strong seepage flow is expected in the embankment body.

5 STRESSES AND STRAINS ON THE GEOSYNTHETICS

In this application, geosynthetics are used both as outer skin, and as internal reinforcement layers. The change in strength caused by UV exposure plays a particular part in this case because the geotextile is used as a facing for the bund segments used in this project. In this function, the entire surface of the geosynthetics is exposed to weathering for a long period of time.

The geotextiles must be wrapped around the steel frame structure. After wrapping, the geotextiles are welded to one another using gas burners. Changes in textile properties are inevitable at the weld seams. Welding must be done by experienced personnel as serious damage may occur in the nonwoven material otherwise.

Mechanically bonded nonwoven material with a short-term tensile strength of 28 kN/m lengthwise and crosswise (Polyfelt TS 80) has been used for the reinforcement layers and as outer skin during the testing of the first segment rows. Practical experience has shown that damage during installation islargely limited to the weld seams. The dramatic losses in strength associated with direct UV

radiation will start spontaneously unless the outer skin made of nonwoven material is protected against UV exposure immediately after placing.
Six samples of nonwoven material without UV protection were taken 3 months after placing during the construction period. Three of these samples were obtained from steel tube wrapping, while three further samples were taken from welded portions. The samples taken from the steel tube wrapping are exposed to a particularly high thermal stress of up to 40 ... 50 °C in addition to UV irradiation. The following residual strength values have been measured at the samples:

- Samples with damage caused by welding
  - 56...66 % length direction
  - 40...50 % cross direction
- Steel tube wrapping samples
  - 64...66 % length direction
  - 50...56 % cross direction

The results allow the derivation of the reduction factors A1 to A4 as required for determining the design strength F_d in accordance with EBGEO. The reduction factors are defined as follows:

A1: Chang in strength due to creep
A2: Reinforcement damage due to transportation, placing and compaction
A3: Processing (joints, connections to structural elements)
A4: Environmental influence (resistance to weathering, resistance to chemical agents, microor ganisms and animals)

In general, the factor A1 = 1.1 is applied for creep if no other boundary conditions have been defined. The results of the investigation may not be distributed to the factors A2, A3 and A4. For this reason, the reduction factor of

$$A2 \times A3 \times A4 = 1/40 \times 100 = 2.5$$

should be defined for the lowest residual strength obtained. In addition, EBGEO requires a partial safety factor of $\gamma = 1.75$, so that the design strength F_d is calculated as follows:

$$F_d = F_k / (A1 \times A2 \times A3 \times A4 \times \gamma) = F_k / (2.5 \times 1.1 \times 1.75)$$
$$= F_k / 4.81$$

The effects of processing and the damage caused by transportation stop at the end of construction operations. But environmental influence will continue to have an effect unless the geotextile is protected against exposure to UV radiation (factor A4.) For this reason, it is absolutely essential to protect the entire outer skin of the bund against UV radiation as partial ruptures must otherwise be expected in the outer textile skin both on the upstream and on the downstream faces.
Initially, the Quick-Damm® system was designed for flood control with a useful life of a few weeks. The nonwoven material is definitely suitable for such applications even without UV protection. But bunds of the type under consideration are supposed to last for a useful life of several years. The following alternatives lend themselves to UV protection:

- Cover the outer surfaces using a “sacrificial” nonwoven material or a plastic sheet;
- Cover the surface with slurry
- Shotcreting the surface

6 STABILITY CHECKS

6.1 *External stability*

The failure modes of overturning, sliding, shear failure, and slope failure have to be taken into account during the check of the structure's external stability. The bund will be considered as a gravity wall during all stages of construction. The case of bursting must be checked in every case as well. In this context, bursting is defined as the event in which earth pressure may push the internal and external bund segments apart. The following safety factors apply to bunds under operating conditions:

Location of resultant force acting on base: $e \leq b/6$
Sliding stability and bursting: $\eta \geq 1.3$
Safety against slope failure: $\eta \geq 1.4$

Slurry pressure acts on the bund as a load on one side. The bund is embedded into the ground up to a depth of > 1.0 m on the downstream side (see figure 2.) Minimum earth pressure is applied as a decisive criterion since the gravel used has a high cohesion. We apply $\delta_a = {}^2/_3 \bullet \varphi'$ as the angle of wall friction. A sufficient safety margin against sliding and overturning was proven for all stages of construction. The resultant force acting on the base remains within the 1st core area ($e \leq {}^b/_6$) in all cases.

Active earth pressure is applied to the downstream bund segments for the bursting check. The calculations showed that the position of the resultant force acting on the base of the lowest downstream bund segment is only in the 2nd core area ($e \leq {}^b/_3$) when the upper bund segment is being placed (in the 3rd stage of construction.) The required sliding stability cannot be guaranteed in this case either. For this reason, it is necessary to provide an effective connection between the trapezoidal steel frames of the internal and external segment rows with the channel sections shown in figure 2, thus allowing the entire structure to be considered as a monolith.

6.2 *Geotextile reinforcement*

During the analysis of the geotextile skin, a minimum earth pressure of $K_{ah} = 0.2$ must be applied to cover the condition during fill material placing, i.e., the most extreme condition in terms of the stresses and strains acting on the geotextile. Elongation by bulging is the main stress. Observations of the form of bulging in the geotextile skin have shown that the maximum earth pressure acts on the lower end of the geotextile skin in the bund segment. The following applies to the 3 m high segment:

$e_{ah} = 20.5 \text{ x } 3 \text{ x } 0.2 = 12.3 \text{ kN/m}^2$

Bulging up to a maximum of 0.7...0.9 m has been measured in the geotextile skin of the individual 3 m-high bund elements. During trial placing, maximum bulging effects have been observed in segments filled with filter gravel. The extent of bulging can be limited to 0.7 m for stability calculation based on these bund segment dimensions as the latter material will be replaced on future projects by cohesive fill material. This bulging corresponds to a geotextile elongation of 7.4 % lengthwise and 13.9 % vertically. These elongations do not give rise to any problems in the case of intact homogenous nonwoven materials. Problems will only occur in the areas in which the nonwoven material is exposed to changes by welding using open flames, figure 6.

The earth pressure is distributed evenly in a vertical direction from top to bottom, so that the geotextile is suspended at the upper steel tube under the full earth pressure.

Figure 6: Open flames are used for weldig nonwoven material on the upper steel tube

The tensile force in the nonwoven material in the lower third is calculated for the maximum earth pressure ordinate on a 1 m wide strip in horizontal direction. The maximum values of the tensile force in the geotextile are obtained as follows:

$Z_{horizontal} = q_h$ x 1.00 m x 4.15 m /2 = 25.5 kN

The corresponding characteristic short-term tensile strength F_k is determined by the following estimate in this case:

Required $F_k \geq$ 25.5 x 4.8 = 122.4 kN/m

The external geotextile skin must carry the required design strength alone if no additional geotextile layers are placed. But a strength of this order of magnitude not achievable by nonwoven materials. Composite materials consisting of a combination of nonwoven material and glass-fibre wovens with a high tensile strength should be used for the outer skin of the bund system in this case.
Another means of reducing the tensile load on the outer skin is to use additional intermediate layers consisting of geotextile sheets placed horizontally as shown in the cross section in figure 2. This reinforcement can reduce the earth pressure acting on the outer skin by the effect of friction. It has been shown that the frictional force which may be taken up by this additional horizontal geotextile layer is considerably greater than design strength F_d. For this reason, the design strength of the intermediate geotextile layer may be used to calculate the reduction of earth pressure. Only 3 layers of a nonwoven material with

F_k = approx. 25 kN/m or, F_d = 25 / 4.81 = approx. 5 kN/m will significantly reduce the tensile force in the geotextile skin. The following estimate is obtained for the decisive 1 m strip when only 1 reinforcement layer with $F_d = 5$ kN/m is placed in the lower third:

$$Z\text{ (reduced)}= Z_{horizontal} - F_d \times 4.15\text{m} = 25.5 - 20.75 = 4.8\text{ kN/m}$$

In contrast to figure 5, figure 4 shows that the additional reinforcement layers and the use of cohesive fill allow a considerable reduction in the load which acts on the outer skin.

7 REPAIRING A SEGMENT

The repair of a section of the dam has been tested in a field trial. To do this, the nonwoven material skin on the upper steel tube was cut through in one segment. The dam is separated into individual vertical plates by the trapezoid steel frames. This has the great advantage of always confining local failures to one single segment between 2 frames. To make a repair, the external skin is removed from the steel structure and the fill material is lifted out. After this, a new skin can be inserted which can be welded onto the adjacent non-woven material in the intact segments. Several layers of welding are recommended to be made in the transition to the adjacent segments. Subsequently, the fill material can be replaced. In the case tested here, the friable gravel was replaced by cohesive gravel when refilling. This enabled the failed segment to be significantly stabilised.

8 SUMMARY AND OUTLOOK

This bund system has proven itself for the purposes of the mining industry. The first bund level was constructed in a time of only 3 weeks, and was impounded with slurry up to a depth of approximately 2 m after a service period of 1 year. The system may also be recommended for other applications using the method described here. But the following important notices should be observed in every case:

The steel frames must be welded so as to a form a solid bond to the channel sections located in the bund base. The steel frames of the 2nd and 3rd bund rows must also be welded solidly to the lower bund frames so as to exclude any risk of failure by bursting. Gravel with a high cohesion is the most suitable fill material. Nonwoven material may only be used for the outer skin when additional horizontal reinforcement layers (made of nonwoven material) are placed at three levels in every bund segment at the same time. If this is omitted, the outer skin must be constructed using a geotextile with a high tensile strength. (The best solution is to use composite materials made of nonwoven and glass-fibre wovens.) The bund system must be placed on a base which incorporates a drainage system that can be inspected; it consists of a drainage blanket and a drainage pipe which allows back flushing. Measures to protect the entire structure against UV radiation must be carried out without delay during the construction phase.

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