Ideas for improved geotechnical structures for natural disaster mitigation

Idées pour l'amélioration des ouvrages géotechniques pour l'atténuation des catastrophes naturelles

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ABSTRACT: Floods, earthquakes, tsunamis, landslides or avalanches / rock fall are current threats to human beings around the world. Geotechnical structures can be improved or developed with the use of geosynthetics to mitigate the impact of these kinds of natural disasters and to minimize damage and causalities. With erosion-resistant dykes the impact of flooding can be significantly reduced when the overtopping of a dyke cannot lead to a dyke failure with a big gap in the dyke with concentrated discharge. Embankment dams reinforced with geosynthetics are much more resistant to earthquake loading than conventional concrete structures. Artificial tsunami shelters as artificial hills are currently discussed to establish safe places near the coast. Finally new model studies are showing that the behaviour of embankments against dynamic rock fall impact can be significantly improved by reinforcing the structure with geogrids

RÉSUMÉ : Les inondations, tremblements de terre, tsunamis, glissements de terrain ou avalanches / chutes de pierres, sont des menaces courantes pour les êtres humains partout dans le Monde. Les ouvrages géotechniques peuvent être améliorés ou développés par l'utilisation de géosynthétiques pour atténuer l'impact de ces catastrophes naturelles et minimiser les dommages et causalités. L'impact des inondations peut être considérablement réduit avec des digues résistantes à l'érosion, car en cas de débordement, un déversement concentré n'entrainerait pas de rupture dans la digue. Les digues en remblai renforcé par géosynthétiques sont beaucoup plus résistantes aux contraintes sismiques que les ouvrages conventionnels en béton. Les abris artificiels contre les tsunamis, tels que des collines artificielles, sont actuellement considérés pour établir des lieux sûrs à proximité des côtes. Enfin, les études menées sur de nouveaux modèles montrent que le comportement des remblais de protection contre les chutes de blocs à impact dynamique peuvent être considérablement améliorés par le renforcement de la structure avec des géogrilles.

KEYWORDS: geosynthetics /geogrids, natural disasters mitigation, dykes/levees, embankments, tsunami shelter, rock fall protection.

1 INTRODUCTION

World´s population is growing further. Increasing numbers of people are living in mega cities close to flood plains of rivers and oceans endangered by floods or tsunamis, but also in areas endangered by earthquakes or landslides. Natural disasters have created and will create huge material damage and a high number of causalities. But already after a short time the experience is forgotten and the intention to spend money for improving the safety fades away. But it is the responsibility of governments and authorities to ensure that appropriate strategies and measures for risk mitigation are in place and applied. And it is our obligation as geotechnical engineers to communicate improved design and construction methods for geotechnical structures for natural disaster mitigation. Ideas for safer dykes of higher erosion resistance, for embankments with improved resistance to earthquake loading and/or higher protection against impacts from rockfall, avalanches or landslides and tsunami shelters are presented.

2 EROSION-RESISTANT DYKES / LEVEES

In the aftermath of past disastrous flood events in Germany and other European countries it became evident that levees are part of the society's infrastructure and need careful control and maintenance. Immediately after major flood events the willingness to improve flood protection structures is great and (tax) money is available. These programs to improve the flood protection should consider the present technical improvements e.g. for the construction of levees. The improvement of levee cross-sections by using different geosynthetics has developed to be state-of-the-art (Heerten 2010). The use of nonwoven filter materials to form a filter-stable, erosion-resistant transition between levee core and the air-side drain and ballast body or the arrangement of geosynthetic clay liners (bentonite mats) as a water-side surface seal have already been included as established alternatives in current regulations and guidelines. Beyond the three-zone levee the effects of geosynthetics integrated into levees as safety measures have been investigated and documented to have a high resistance capability during overflow load conditions. Erosion processes on the inner embankment and the risks of unexpected levee breaches can be minimized with geosynthetic construction techniques; geosynthetics can also be employed as support facilities for emergency reinforcing measures. Internal erosion in the embankments and sudden breaches to the surface of dykes can be prevented with knowledge and implementation of geosynthetics. Thus, these technologies provide not just structural defences but more time for evaluating risk and providing emergency response to populated areas that are threatened by rising water levels.

Geosynthetic clay liners (GCL) as needle-punched bentonite mats have gained widespread acceptance for levee improvement projects in a lot of countries because these products create a simple, effective, economical seal for a levee that simultaneously provides erosion protection for the levee body (Heerten and Horlacher 2002). Following the Elbe River floods that took place in Germany between 2002 and the end of 2005, about 150 levee reconstruction projects are known, being carried out in this period, in which about 2.2 million m² of needle-punched nonwovens, about 300 000 m² of geogrids and about 700 000 m² of needle-punched geosynthetic clay liners (bentonite mats) have been employed (Heerten and Werth 2006). One example is shown in Figure 1. In the meantime, needle-punched geosynthetic clay liners are considered as state-of-the-art construction materials in levee/dyke construction (DWA 2005) in Germany and show increasing acceptance and use also in other countries.

The installation of a GCL can be carried out in a simple manner with a minimum use of technical equipment. After construction of the profiled bedding the GCLs are unrolled and overlapped. Afterwards the GCL is covered with soil.

According to DWA (2005), a cover layer thickness of 80 cm is recommended for both types of mineral sealing (GCL and compacted clay liner (CCL)) in order to withstand climatic influences like wet-dry or freeze-thaw cycles considering German climate conditions. Bentonite mats offer the advantages of low sensitivity to settling without degradation to seal characteristics (deformation up to 25 % for needle-punched GCLs), consistent quality even after installation as well as good friction behaviour for steeper embankment slopes. However, the potential effects of root penetration and/or rodent infestation must be given attention just the same as with classic compacted clay liner made of cohesive soil. These effects can be counteracted by the design of the levee's project-oriented cross-section geometry, the use of non-cohesive cover layers which are unattractive to burrowing animals (Figure 2) or by additional engineering measures. Further information about planning and building with geosynthetic clay liners can be found in Heerten and Werth (2010).

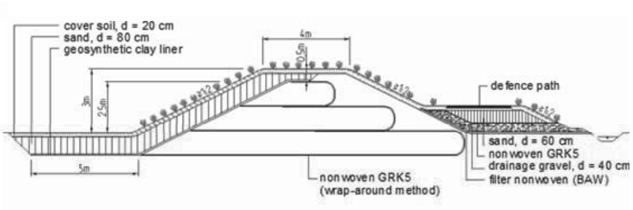

Figure 1. Cross-section of a levee after rehabilitation at Oder River, Poland (Heerten 1999).

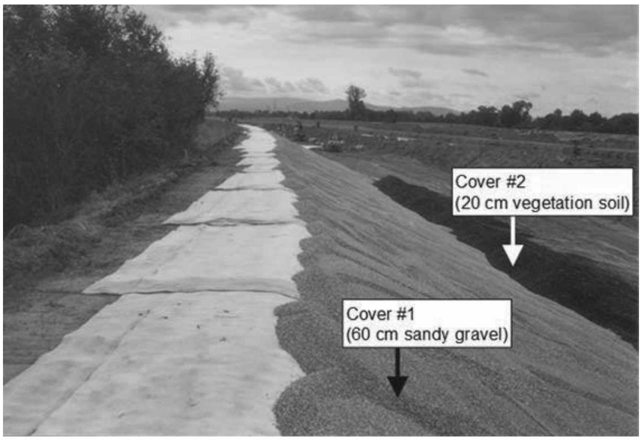

Figure 2. Dyke rehabilitation Kinzig 2000 / 2001 - Needle-punched GCL as water-side lining covered with locally available sandy gravel and top soil for gras vegetation.

3 IMPROVING SEISMIC STABILITY OF STRUCTURES

3.1 *Geosynthetic reinforced soil structures (GRS structures)*

In different regions of the world with potential high risks of earthquakes the advantages of geogrid reinforced embankments with reference to higher resistance to earthquake loading are well known and experienced. Based on the authors knowledge most know-how and experience with geogrid/geosynthetic reinforced soil structures (GRS structures) under earthquake loading have been generated in Japan, where even fast train tracks are constructed on embankments by using GRS structures.

This development is based on the very positive experience with geosynthetic reinforced soil structues under seismic loading in Japan e.g. during the Kobe earthquake. Figure 3 is showing a GRS structure before and after the Kobe earthquake (Tatsuoka 2008).

Figure 3. Geosynthetic reinforced soil structure (GRS structure) as railway embankment after completion 1992 and after the Kobe earthquake 1995 (Tatsuoka 2008).

The synthetic polymeric materials used for soil reinforcement applications (mainly geogrids) are thermoplastic materials with visco-elastic material properties. The partial safety factor for creep (A1) is often the most important reduction factor to calculate the (long-term) design strength (FBi,d) of a geosynthetic reinforcing element based on the characteristic (short-term) tensile strength (FBi,K0) estimated for a given reinforcing product by lab testing.

It has to be pointed out again and again that creep of a synthetic reinforcing product is a product-specific visco-elastic material response and not a deterioration or damage to the product like e.g. corrosion for metal products. Therefore the special product characteristics of polymeric geogrids for soil reinforcement show that after a period of sustained loading in a soil structure an additional spontaneous dynamic load can be met by the original short-term tensile strength of the product.

In a new seismic design code for Japanese railway structures this background is considered for the first time in geotechnical engineering. NO creep reduction factor is considered to obtain the design tensile strength of geosynthetic reinforcement under additional seismic loading.

The NO-creep-reduction-approach for seismic loading of geosynthetic reinforced structures (GRS) is part of the new concepts and procedures for the recent developed design code for Japanese railway structures reported by Tatsuoka (2009) with the following key elements:

a) very high design seismic loads (i.e. , level 2), as those experienced during the 1995 Kobe earthquake;
b) design against level 2 based on residual displacement;
c) the use of both peak and residual shear strengths with well-compacted backfill;
d) design based on the limit equilibrium stability analysis;
e) control to high backfill compaction and good drainage;
f) strong recommendation of GRS structures as highly earthquake-resistant soil structures;
and
g) no creep reduction to obtain the design tensile strength of geosynthetic reinforcement.

When following this design code, engineers naturally chose GRS structures.

3.2 *Geogrid reinforcement for masonry walls in houses*

It is also known that a lot of causalities during earthquakes are caused by falling bricks, when masonry walls in the houses e.g. between steel frames are collapsing. An important improvement of stability under seismic loading can be achieved by geogrid reinforcement of masonry walls (Figure 4) as investigated and developed in Germany at Bauhaus-University Weimar (Burkhardt et al 2005).

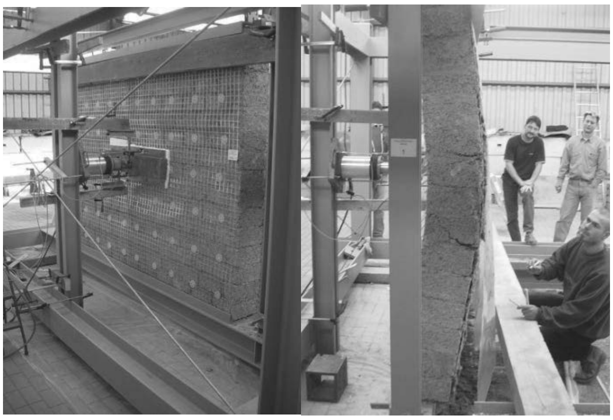

Figure 4. Strength test of geogrid reinforced masonry wall (Burkhardt et al 2005).

4 TSUNAMI SHELTER

When a tsunami warning is given people have to leave low coastal areas as quick as possible. After the devastating tsunami of 2004 in the Indian ocean in the meantime a "Tsunami Early Warning System" is in operation. But a big challenge still is the organization of an effective evacuation of the people living in the endangered big cities at the coast in the available very short time of about 30 minutes between "Tsunami Warning" and the arrival of the tsunami wave. In Indonesia for instance "raised earth parks" as cost effective tsunami shelter are discussed to establish safe places right at the coast. These artificial hills have to be high enough, stable against earthquake loading and erosion-resistant to the wash of the tsunami wave. It should also be easy for all people to get up to the safe top of the hill. Structures of geosynthetic-reinforced soil (GRS structures) can fulfil these requirements. Figure 5 is showing the idea of "TEREP – Tsunami Evacuation Raised Earth Park" as proposed for the city of Padang, Indonesia. For Padang five evacuation parks are discussed, each park as refuge for 15.000 people out of a 1.5 km radius. As of the author´s actual knowledge the construction of TEREP is still delayed. Let´s hope that fading away of the rembemering of the last tsunami desaster is not the reason – the next tsunami will come!

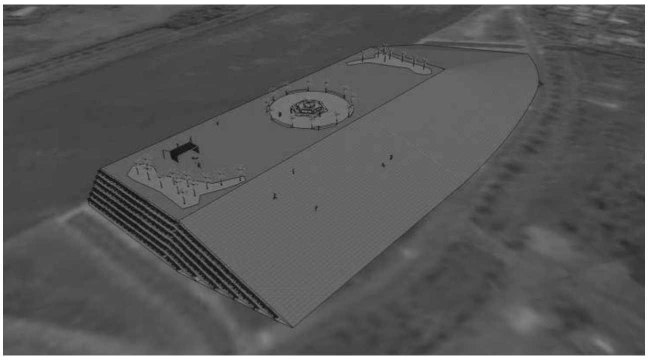

Figure 5. Idea of "Tsunami Evacuation Raised Earth Park" for the City of Pandang, Indonesia (Tucker, 2010).

Tsunami defense systems can be separated into different "defense lines" as shown in Figure 6 (Recio, J. and Oumeraci, H. 2007). The artifical hills or "raised earth parks" are subject of the 4th defense line.

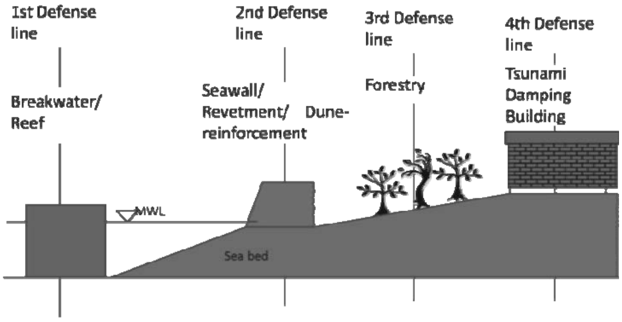

Figure 6. Different four defense lines for tsunami protection structures at endangered coast lines (Recio and Oumeraci 2007).

In the first off-shore defense line geosynthetic sand container which can be filled and placed with up to appox. 500 tons of sand have to be considered as cost effizient and environmental friendly solutions. The very positive results from e.g. the design and construction of the Narrowneck-Reef at the Goldcoast of Queensland, Australia with mega-sandcontainer made of needle-punched nonwoven staple-fibre geotextiles can be considered (Heerten 2010). At Narrowneck Reef the mega-sandcontainers have been hydraulically filled and installed with a special split-bottom hopper dredger (Figure 7).

In Japan geosynthetic reinforced structures for tsunami protection seawalls (defense line 2, Figure 6) are considered to improve the protection of nuclear power plants after the Fukushima disaster.

5 ROCKFALL-PROTECTION EMBANKMENTS

Much infrastructure buildings and densely populated areas with increasing population are located in rock fall areas. As rock fall protection by net-fences is restricted by the energy adsorption capacity (approx. 8000 kJ), embankments are built for higher design energies. New model studies to improve the prediction of dynamic rock fall impact on embankments have shown that the behaviour of embankments can be improved by reinforcing the structure with geosynthetics (geogrids). The lessons learned from the tests with geosynthetics are (Hofmann, R., Vollmert, L. and Mölk, M. 2013):

- The model tests with the geosynthetics all showed a significantly larger lateral distribution (influence width) of the displacements. An influence width of at least 8 - 9 times the diameter of the sphere (the impact) can be estimated from the measurements and the pictures taken with the high-speed camera.

- Very slim constructions with uphill and downhill slope angles of 70° and 60° were also investigated. These exhibited a noticeably more elastic behaviour than pure soil embankments (Figure 8)
- However, they require a markedly greater freeboard than embankments with stacked-rock facing. For geogrid-reinforced structures, a freeboard of 1.5 times the sphere diameter can be considered as being on the safe side.

Figure 7. Hydraulic filling and placing of mega-sandcontainers with a split-bottom hopper dredger at Narrowneck Reef ,Queensland, Australia (Heerten, 2010).

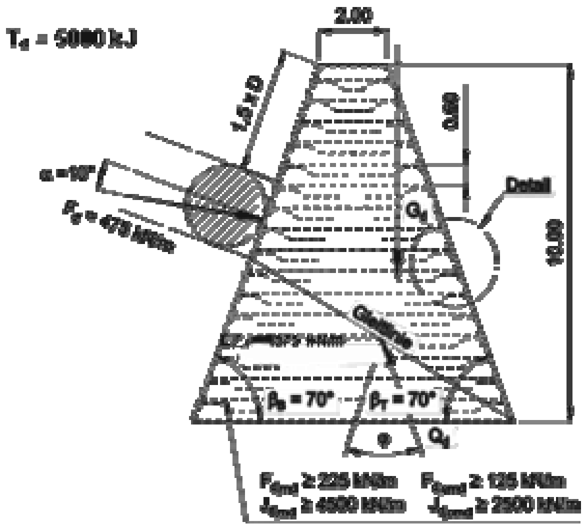

Figure 8. Possible slim and cost effective construction of rockfall embankments reinforced with geosynthetics. (Hofmann,R., Vollmert, L. and Mölk, M. 2013).

Corresponding structures can also been used for torrent-control and avalanche-protection structures.

6 CONCLUSIONS

Considering geosynthetics for design and construction of dykes/levees, embankments in earthquake endangered areas, tsunamia protection structures and rockfall protection embankments can considerably improve the function of the structures. An importend improvement of stability under seismic loading can also be achieved by geogrid reinforcement of masonry walls.

It is the task of the (geo)engineering community to inform the public about these improvments and the possible higher level of safety for material goods and people in case of natural disasters. Let´s hope that the last natural disaster experiences of earthquakes, tsunamis, floods and landslides and the need and intention to spend money for improving our safety does not fade away.

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