Solving Landslide Problems by Combined and Geosynthetic Reinforced Systems

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ABSTRACT: Landslide stability, prevention, post-failure reconstruction etc. are some of the most complex problems in geotechnical engineering, as well as debris and rock-impact protection dams. Geogrid-reinforced oversteep slopes, walls and dams can be an efficient, flexible and environmental friendly solution. They can be combined with other "classic" stabilization systems e.g. doweling piles, drainage etc. Often the local slid soil can be re-used for the new stabilizing solutions as compacted in fill combination with appropriate geogrids. Construction is mostly weather independent and can be performed in complicated terrains. Three different projects are shortly described pointing out their most specific issues.

1 INTRODUCTION

Landslide stability, prevention, post-failure reconstruction etc. are some of the most complex problems in geotechnical engineering, as well as debris and rock-impact protection dams. Geogrid-reinforced oversteep slopes, walls and dams can be an efficient, flexible and environmental friendly solution. Additionally, geosynthetic reinforced soil structures (walls, slopes, dams) demonstrate a very ductile behavior, i.e. they can absorb and dissipate successfully dynamic energy remaining intact as a whole and experiencing only small movements and deformations. This ductility is a very advantageous characteristic not only in the case of earthquakes, but also while using such structures as protection against rock-falls, debris flow, rushing stone or snow avalanches etc. as described later herein.

Such soil-geosynthetic structures can be combined with other "classic" stabilization systems e.g. doweling piles, drainage etc.

For reconstruction, rehabilitation and / or stabilization of landslides for the soil-geogrid walls the local soil or even the slid soil mass after a landslide activation can be used after reinstallation and compaction as soil fill. This results in high cost-efficient and environmental friendly solutions. Note, that in such cases special attention has to be paid to the choice of appropriate reinforcement. Usually, the best solution are flexible, high-strength, low-creep geogrids due to their easy installation, high efficiency of interaction with a large range of soils and their open grid structure being in fact totally water-permeable normally to their plane (thus providing free drainage normally to reinforcement).

Today geogrid reinforcement soil walls and dams can be built with any shape, height, slope inclination and geometry and consequently be easily adapted to e.g. mountain terrains. Construction is mostly weather independent and can be performed in complicated terrains. Standard earthwork construction equipment can be used together with conventional building and compaction techniques.

Herein three different projects are shortly described: the reconstruction and stabilization of an activated and slid landslide, the stabilization and widening of a road in the mountains and a rock-impact and stone avalanche protective dam in a steep valley.

2 PROJECT "STEINMADERER WAND" IN THE AUSTRIAN ALPS, 1994

In Spring 1994 a huge landslide occurred on a natural slope of about 25 m height just below a ski-lift station some kilometers above the town of Lech in the Austrian Alps. The slid soil masses blocked the road at the toe of slope. The upper part of the sliding surface reached very quickly the foundation of the lift station on top of slope destroying the earth platform in front of the station and endangering the entire building (Fig. 1).

Figure 1. Steinmaderer Wand, Austria: Lift-station endangered after failure of landslide mass (1994)

The main reason for the slope slide seemed to be oversaturation resulting in overpressure and effective soil strength reduction due to increased water inflow from behind which was localized mainly in the bottom half of slope. A quick stabilizing and slope-reconstruction solution had to be found and executed as soon as possible and to be completed in less than three months until September 1994, the beginning of the ski-season.

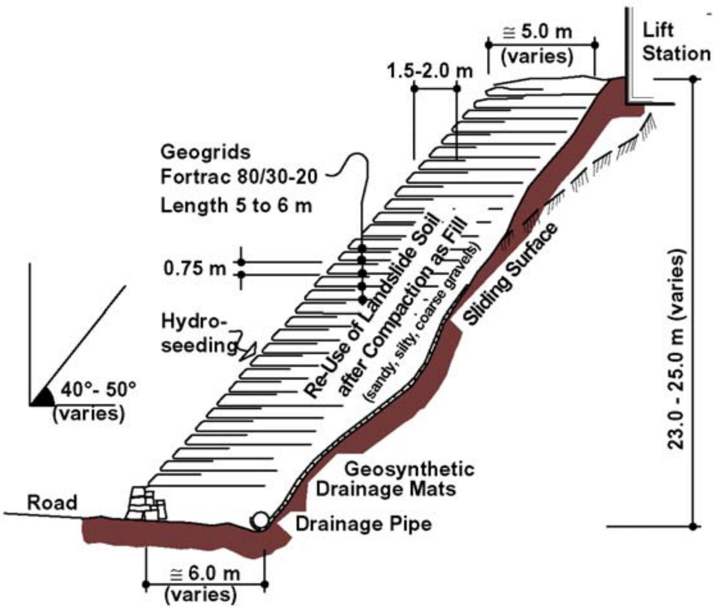

Figure 2. Steinmaderer Wand: typical cross-section of new Fortrac®-geogrid-reinforced slope

The solution had to meet following requirements: quick and easy construction, cost efficiency, minimized transportation of building materials (High Alps, 3000 m over the mean sea level, small access roads), “natural solution”, i.e. environmental (landscape) friendly. A system meeting all these requirements was developed by the Geotechnical Consultant “3P Geotechnik”, Lauterach, Austria and the Engineering Department of HUESKER, Gescher, Germany (3P Geotechnik 1994, HUESKER 1994).

A typical cross-section of the landslide stabilization system is shown in Figure 2. The focal points are:

- re-use of the available slid soil mass (sandy, silty gravels to stones) after re-installation and compaction as fill for the steep reinforced reconstructed slope;

- use of geogrids Fortrac® 80/30-20 as reinforcement for the rebuilt “oversteep” slope providing the internal and overall stability required; these geogrids are flexible, 5m wide, made of low-creep polymer and have a coefficient of interaction in the shear mode against soils of 1.0 and in the pull-out mode of ≥ 0.8; the latter allows shorter reinforcement lengths;

- use of drainage mats in the bottom half of interface “new reinforced slope” – “old sliding failure surface “ to ensure keeping new compacted soil mass dry (the re-used local soil itself is not free-draining); wrapping-back the flexible UV-resistant Fortrac®-geogrids at the facing creating a soft stepped, natural geometry.

Thus, only the light-weight (due to their high specific strength) geogrids and drainage mats had to be transported to the building side, but no gravels, concrete, steel etc. No transportation of “new “ soil and e.g. drainage gravel to the building site was required.

Note, that the drainage mats were installed with some horizontal distance between adjacent rolls to avoid the creation of indiscrete interface between old surface and reinforced soil.

The entire structure was completed in less than two months (Figs. 3, 4) using standard earthwork equipment; 1 m high formwork panels were used for soil compaction in the front zone; the fill was compacted to ≥ 0,97 of Proctor density. Finally, hydroseeding was applied at the facing.

The solution proved to be successful from any point of view over nine years until now (Fig. 5).

Figure 3. Steinmaderer Wand: construction stage of stabilizing reinforced slope (1994)

Figure 4. Steinmaderer Wand: slope reconstruction just after completion (1994)

Figure 5. Steinmaderer Wand: green reinforced slope completely integrated in the landscape (1995 until now)

3 PROJECT "JUGOVSKO HANCHE, BULGARIA, 2000

A short stretch of a road in the Rhodopa Mountains in Bulgaria had to be stabilized and widened due to increasing traffic and indications of slope instability. During construction the traffic had to be kept running at least on the right lane of the road (Fig. 6), thus the existing old stone masonry retaining wall had to remain in place during widening and stabilization works.

Note, that both the terrain and the rock bed become even steeper to the right in Figure 6, which is not shown in the figure itself due to the lack of place, but can be seen e. g. in Figure 8. Additionally to the requirement of keeping the right half of the existing road under traffic, the Road Authority asked for a solution which should be safe, easy to built, cost efficient and landscape friendly.

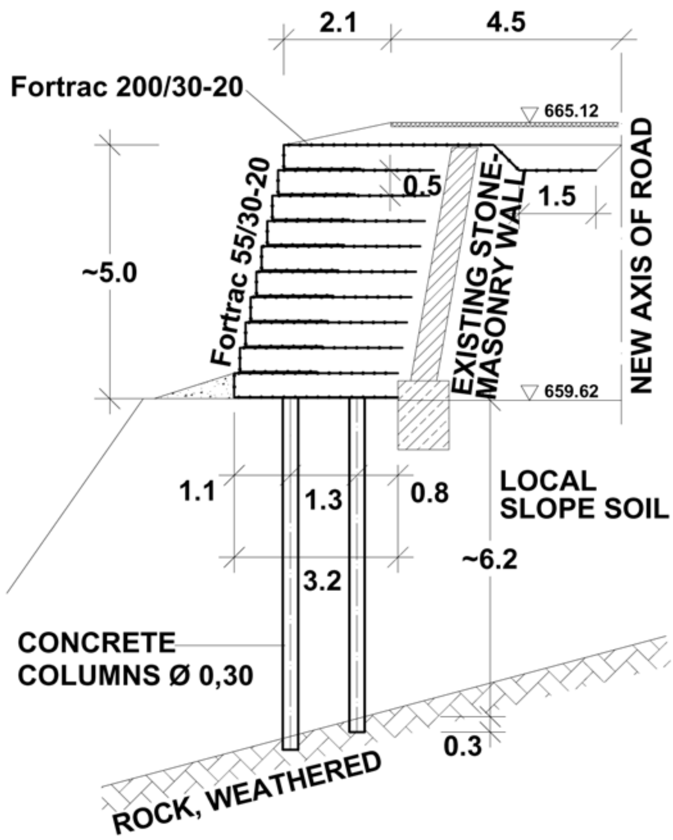

Figure 6. Jugovsko Hanche: typical geotechnical situation and solution with a combined system

Critical sliding surfaces were identified below the road and the old wall through the silt gravelly local slope soil founded on a weathered rock bed (Fig. 6).

Generally, the road and the masonry wall were built in the early 30ies. The stability analyses performed in 2000 were based on actual geotechnical data and resulted especially including the planed widening to the left (Fig. 6) in global factors of safety of 1.0 to 1.1 and even < 1.0 under seismic conditions, which was alarming.

The stability analyses included both circular (Bishop) and polygonal (Janbu) failure surfaces according to DIN 4084.

A combined solution was found to be the optimal one (Fig. 6): a new geogrid-reinforced soil wall was added in front of the old stone masonry using crushed well-graded gravel and geogrids Fortrac® 55/30-20; the reinforced package was founded on dowelling concrete columns. To make construction easier and to save time due to the critical situation (see above) the Fortrac® geogrids were not connected to the old retaining wall: instead of that a single strong Fortrac® 200/30-20 was applied on top and anchored behind the old wall and below the left lane of the road to ensure integrity of new and old structure in both horizontal and vertical direction even in the case of an earthquake (Fig. 6).

Small diameter (0.3 m) concrete dowelling columns in two rows were installed below the Fortrac®-wall to allow the use of light drilling equipment in the narrow space in front of the old wall; their position and spacing were optimized during design.

The combined system presented was cheaper and easier to build than e.g. a second new concrete or RC-wall. A new type of green facing was used in front of the geogrid wall (the so called "Muralex®") to meet the environmental (landscape) requirements. The entire system was successfully built up in less than two months in Autumn 2000 by a local contractor without any problems despite its lack of experience with geogrid reinforcement (Figs. 7, 8), confirming the easiness of construction. An "inner formwork" of well sand-filled bag was applied during compaction in the front area. The technique is easy and efficient in combination with flexible geogrids (Fig. 8).

Figure 7. Jugovsko Hanche: construction of geogrid-reinforced wall, top part of old stone masonry retaining wall to the left

Figure 8. Jugovsko Hanche: completing landslide stabilization and road widening (before installation of the final Muralex® facing)

The new widening and stabilizing system is since three years under traffic without any indications of movement, differential settlements etc. The solution seems to be successful. A more detailed description of the project can be found in Jossifowa & Alexiew (2002).

4 PROJECT "GONDO DEBRIS AND STONE IMPACT WALL", SWITZERLAND, 2002

At the town of Gondo in Switzerland a stone-rock avalanche which was provoked by snow thawing destroyed in Spring 2002 some houses and blocked the main road (Fig. 9).

Figure 9. Gondo: catastrophic stone-rock avalanche

After removal of the slid stone-rock mass a protection system had to be built as soon as possible because the risk of repetition was high. The solution had to be effective in costs, easy to built and to fit in the natural landscape.

A "green-faced" geogrid reinforced wall was found to be the optimal solution. An additional specific advantage of such walls is their very high ductility respectively the high dynamic energy dissipation potential e.g. in cases of falling rock impact, rushing stone avalanche etc. Due to the lack of place that important point cannot be discussed more detailed herein. The design resulted in the typical cross section in Figure 10.

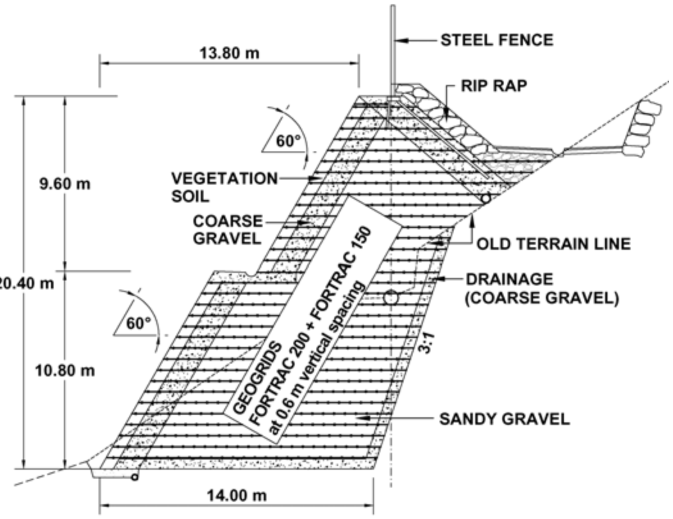

Figure 10. Gondo: typical cross-section of the stone avalanche and rock-fall protective wall

The relatively strong geogrids Fortrac® 200 and Fortrac® 150 were necessary not only due to the big height of 20 m, but also due to the consideration of dynamic loads from stone avalanches or rock impact on the upper site of wall. On Figure 10 the old existing terrain is also shown. To ensure both the external stability of the structure and the so called "compound mode of failure" (a failure surface crosses both the geogrid-reinforced and the non-reinforced zone behind and/or below, Alexiew & da Silva (2003)). The protective wall had to be embedded in the existing slope. An additional reason was to block potential flat instability zones parallel to the old terrain line. A temporary steep excavation was done and temporarily fixed by shotcrete (Fig. 11), then the installation of the geogrids, soil layers and facing started. Attention was paid to an appropriate drainage system (Fig 10). This is always an important issue for geogrid reinforced earth walls and may not be underestimated, because the consequence can be a loss of stability due to pore overpressure or hydraulic driving forces. Construction was completed in less than two months (Figs. 11, 12).

Figure 11. Gondo: start of construction; Fortrac®200-geogrid, fill layers and facing installation

Figure 12. Gondo: wall completed; well harmonizing with the environment

The final result is a well landscape-integrated structure.

5 REFERENCES

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