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Long-term experience with a geogrid-reinforced landslide stabilization

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ABSTRACT: In summer 1994 a landslide occurred just below a ski-lift station in the Austrian Alps. It blocked the road at the toe of slope and endangered the stability of the lift station. A quick solution for the slope stabilization and reconstruction had to be developed and executed. The solution had to meet a wide range of requirements, some of them controversial. Finally, a geogrid-reinforced full-height slope was designed and constructed reusing the local soils and reconstructing approximately the former natural slope shape. The system was successfully built in less than two months and is still stable after twenty years of service. This is most probably the first geogrid landslide stabilization at least in Europe. Problems, boundary conditions, philosophy and design from 1994 are described together with the unknown factors and specific solutions, and the construction technology and experience as well. The current state is described and commented.

1 INTRODUCTION

The region of Lech is one of the most famous ski regions in the Austrian Alps (Figure 1). A huge net of ski trails and lifts is available. They have to be integrated in an optimal way into the natural landscape.

In summer 1994 a landslide occurred in a natural slope just below the lower ski-lift station at the so called Steinmähder Wand (Figure 1).

2 OVERVIEW AND SOME FACTS

In Lech snow fall usually starts in October and ends in April. The landslide occurred (surprisingly) in July 1994. There were some days at that time with up to 30 mm rain per day, but such values are believed not to be critical. Average precipitation over the year is in the range of 30 to 40 mm/day without a significant scattering. The most probable trigger was may be a "global" over-wetting due to massive "delayed" snow melting on the slopes above the lift station (Figure 1).

The slid soil mass blocked an unpaved but important alpine road at the toe of slope. The upper part of the sliding surface reached the foundation of the lift station on top of slope destroying the earth platform in front of the station and endangering the entire building (Figure 2) despite the micro-piles below the front part of foundation. The width of landslide amounted to about 50 m, the height varied from 23 to 25 m.

Twenty years ago spontaneous quick landslides occurred relatively rare. As known, in the meantime the problem of "surprising" landslides and avalanches has increased worldwide, Alexiew (2005), Alexiew & Bruhier (2013). Thus, the case described herein is even of greater importance.

Approximately in the same position a former smaller lift station had existed for 14 years; the new one was built in 1993, i.e. one year before the landslide occurred.

3 GEOTECHNICAL CIRCUMSTANCES

Long-term experience with the "older" smaller station did not indicate possible instabilities or

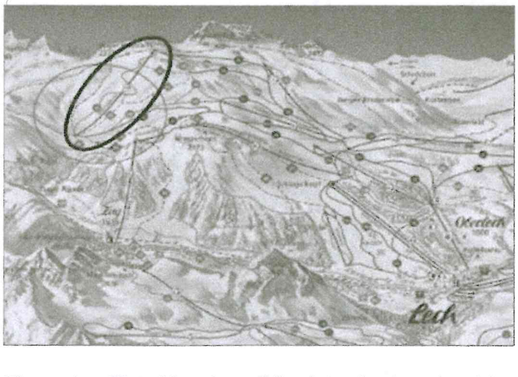

Figure 1. The ski region of Lech in the Austrian Alps (the Steinmähder Wand is marked).

geotechnical problems. However, because of some scattering in the geotechnical and hydrological data from the reports in 1993 (for the new station), intuitive slope stability doubts and the more or less permanent risk of oversaturation, in 1993 a proper drainage around the new station was recommended and—on the safe side—the installation of micro-piles below the foundation near the slope.

After landslide neither a specific soil layer as possibly pre-defined sliding plane (e.g. clay), nor concentrated wells (despite some extremely wet areas) could be visually identified. The failure surface was three-dimensional, non-planar and quite irregular (Figure 2).

The typical data of the local slope soil were:

talus material, sandy gravelly silt, coefficient of uniformity ca. CU = 50, gravel 22%, sand 27%, fines 51% (silt 42%, clay 9%), unit weight ≈ 18 kN/m^3, Proctor density $\approx \rho d = 2.07$ g/cm^3, $w_{opt} = 11.3\%$. The soil fraction < 2 mm (fines and sand) possesses an angle of internal friction φ'peak = φ'post-peak = 36.5° (say no indication of "progressive" shear failure tendency) and a cohesion $c' \approx 0$ to 5 kPa (a bit surprisingly modest). The coefficient of permeability had not been tested, but based on granulometry, soil classification and local experience it was obvious, that the soil is not "free draining".

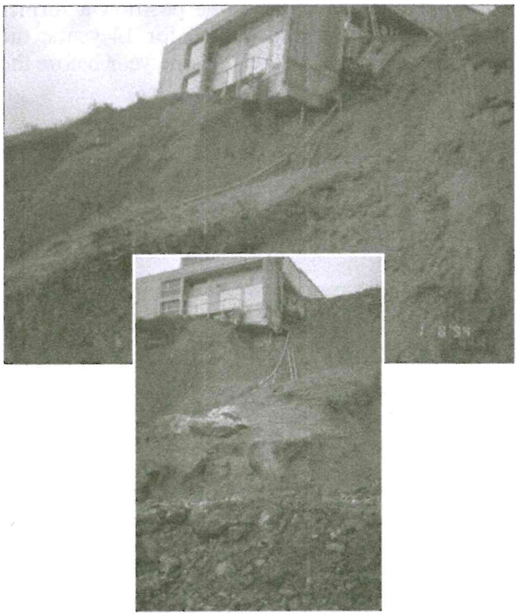

Figure 2. Part of landslide with endangered lift station (Photos from 01 Aug 1994).

4 WHAT HAD TO BE DONE AND HOW?

The slope had to be "repaired" as quickly as possible due to both the endangered lift station and the blocked road. The frame conditions for an "ideal solution" from the point of view of the owner "Skilifte Lech" were:

- guarantee in the long term the stability and serviceability of the lift station (i.e. a permanent solution was required),
- reconstruct the platform in front of the station,
- protect the entire slope against similar problems in future,
- reconstruct to the greatest possible extent the natural shape of terrain as prior to failure,
- reuse the local soil (slid masses) so far as possible,
- minimize the transport (import) of any construction materials in terms of weight and volume,
- put the lift station in operation latest end of September (beginning of the ski season), say the time to find an optimal solution, to design it and to build was about two months,
- use a simple and adaptive technology avoiding a special contractor's qualification and skills,
- "green" solution (vegetated surface) to fit the green natural surroundings,
- keep the total costs as low as possible (!).

These requirements were complex, to some extent controversial and not easy to meet.

5 LEVEL OF KNOWLEDGE AND DIFFICULTIES IN 1994

The solution finding process was in the same time very intensive and quick due to the stringent time limitations mentioned above. A geosynthetic reinforced soil block stabilizing the slope and regenerating the landscape was identified as generally the best solution. All the thoughts and discussions from this time cannot be explained herein due to brevity.

Note, that at that time the experience with high geosynthetic reinforced slopes—being today a routine—was quite modest, and no geosynthetic-based system or solution for landslide stabilization was known (even to our best knowledge today it had never been built at least in Europe before 1994).

Some additional difficulties were faced:

- scattering of soil parameters was not known, and there was no time for additional sufficient soil testing. There was also no time for analysis of the failure and its reason(s). Thus some hypotheses and assumptions had to be made by engineering judgement and on the safe side.

- the hydrological situation was not clear enough. Consequently, an extensive drainage had to be provided.
- there were no standardized or codified calculation and design procedures for such systems, not to mention corresponding software.
- difficult access to the site: unpaved narrow mountain roads.
- there was no experienced contractor for such a work.

6 SUGGESTED SOLUTION

A typical simplified cross-section is depicted in Figure 3.

The solution as depicted is may be the third or fourth (and final) version. Some previous drafts became step by step modified.

Some short comments:

It was decided to reuse totally the local soil (slid mass) as fill (compare Chapters 4 and 5). The authors were optimistic due to its good compactibility (wide gradation) and its sufficient shear resistance (Chapter 3) despite the relatively low permeability expected. In 1994 such a decision seemed risky: state-of-the-art was the exclusive use of high-quality non-cohesive completely free-draining fills.

However, due to the modest permeability intensive drainage had to be foreseen.

Geosynthetic drainage mats were preferred to a gravel layer in the interface to the sliding surface: they are easier to transport and install. The mats were connected to a drainage pipe (Figure 3). They had to be installed upslope vertically in a "zebra" pattern: 1 m mat, 1 m spacing, i.e. after each mat there was 1 m of direct contact of the compacted fill to the local soil. The reason was that usually the interface "mat to soil" has a lower shear resistance (bond) then the internal shear resistance of the contacting soils itself; due to the extremely tight schedule there was no time for testing. Thus, it was believed that the risk of creating an artificial surface prone to sliding in the case of continuous full-area drainage mat installation is too high.

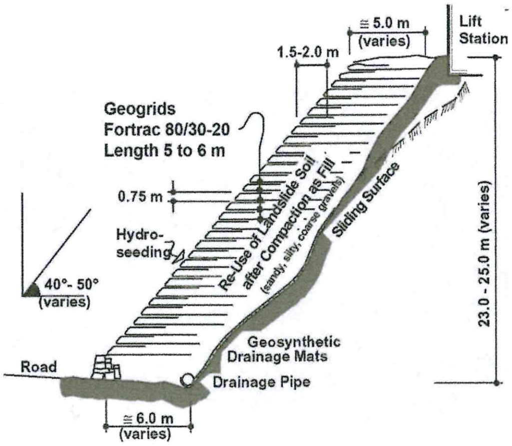

Figure 3. Typical cross-section of the landslide stabilization solution (Note: geometry is generally varying).

As geosynthetic reinforcement providing the required stability high-tenacity low-creep flexible polyester geogrids from the Fortrac® family were chosen being easy to transport and install due to their low weight and flexibility.

Due to logistic reasons, the extremely tight time schedule and the not precisely known total final amount of reinforcement it was decided to use a unified single type of geogrid for the entire system, although a differentiation could result in a more cost-efficient solution. The geogrids were 5 m wide and exhibited based on previous tests for other projects a very high coefficient of interaction (bond) to a wide range of soils. There lengths varied typically from 6 m to 5 m. They had to be installed in the so called "wrap-back" manner using removable formwork without e.g. supporting steel meshes in front, thus creating a "soft" nature-alike reconstituted slope surface to be vegetated by hydro-seeding.

The owner decided that no additional anti-erosion geotextile should be installed at the inner side of the geogrids at the facing (front) as it was suggested by the authors.

For stability analysis a design software under MS DOS was used based on a simplified version of a polygonal block-sliding method in combination with some additional checks using Bishop's method. In 1994 there was no complete specialized software available in the market dealing specifically with geosynthetic reinforcement. Finally, some decisions had to be made by engineering judgment.

For the choice of the unified geogrid (see above) two options seemed possible: a lighter geogrid with an Ultimate Tensile Strength (UTS) of 55 kN/m at 0.5 m vertical spacing and a stronger one with an UTS of 80 kN/m at 0.75 m. The latter option was chosen (Figure 3) to make installation, fill compaction and construction quicker, although at that time no experience with such a big vertical spacing was available.

Due to brevity no further details can be explained herein.

A fill compaction of at least $D_{pr} = 98\%$ was prescribed.

The design and technology concept avoided any export or import of soils, steel, concrete etc.: only the light-weight, low-volume geosynthetic rolls had to be transported.

7 EXECUTION AND EXPERIENCE

Construction started mid of August 1994 and was completed just in time end of September. A removable formwork was used for the front. Some construction stages are shown in Figures 4 and 5.

Figure 4 shows at a glance all components of the system and the compaction procedure. Note the use of heavy compaction for the 0.75 m thick fill layers and the installation of drainage mats with a space in between (Chapter 6). One can see (Figure 5) that due to the lack of experience (the contractor had never built such a system) and the extreme time pressure the geometry at the front of the first geogrid-soil layers was not really precise. However, because this was not critical for stability and due to the anyway intended nature-alike final shape, this was tolerated.

Quality of compaction was controlled at several points at every fill layer.

All the time the structure geometry had to be adapted to reconstruct so far as possible the shape of the previous natural slope (Chapter 4) keeping always the design basics as per Figure 3. This procedure was quite unique: strictly speaking complete precise execution drawings had never existed; instead, engineering judgement and ad hoc decisions were applied. It was a demonstration of the flexibility and adaption capability of such systems.

Figure 4. Construction: first layers, fill compaction by heavy equipment, formwork, geogrids, drainage mats.

Figure 5. Construction: partial view of the geogrid-reinforced slope. Note the “bellies” at front of the first layers.

Figures 6 & 7 show the geogrid-reinforced stabilization just after completion and one year later.

It should be noted that considering all the problematic factors and circumstances such a short construction time was a real achievement.

It is recognizable how the adapted soft, to some extent irregular 3D-geometry fits successfully the natural alpine landscape.

In summer 1995, after almost a year after construction and after a winter-spring cycle there were no indications of stability or serviceability problems of any type. (Note that a year ago at that time the landslide failure occurred). The hydroseeding seemed to be quite successful although not perfect.

Then for a very long time the authors had no contact to the project. However, in such cases the motto applies: no news, good news...

8 AUGUST 2014: TWENTY YEARS LATER

In August 2014 the authors had the opportunity to visit the structure again together with the project leader of the owner in 1994 being still active.

In Figures 8, 9 and 10 the present situation is depicted.

By the way: it is interesting to compare Figures 6 and 7 from 1994 with Figure 8 from 2014.

During the site inspection no indications of any relevant deformation of the geogrid-reinforced landslide stabilization system from 1994 were

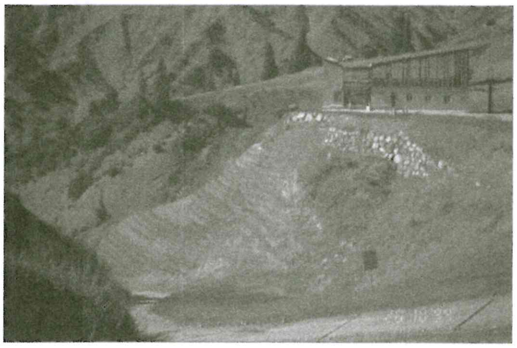

Figure 6. Geogrid reinforced landslide stabilization after completion end of September 1994 (Photo from 20 Oct 1994).

found: neither vertical, nor horizontal. Although no precise measurements had been done over the twenty years passed, the systematic inspections of the owner over this period had attested no problems from the point of view of stability or serviceability of the reinforced slope or of the platform and station foundation on top.

The facing was to more than 90% vegetated, although only marginal maintenance had been done. In the meantime the typical local vegetation dominated the picture. The only spots with meager vegetation were the almost vertical parts of some "belly" layers (Figure 10). Some erosion of fines was visible (Figure 10) due to the missing anti-erosion geotextile behind the geogrids (decision of the owner in 1994, see Chapter 6). However, this had no further negative consequences. Note, that the completely uncovered geogrids at this spot are still intact despite twenty summer-winter cycles and UV impact.

Figure 7. The system in summer 1995, almost a year after completion and after a winter-spring cycle.

Figure 8. August 2014: left up: overview, reinforced slope is marked; right down: persons as a scale for the structure.

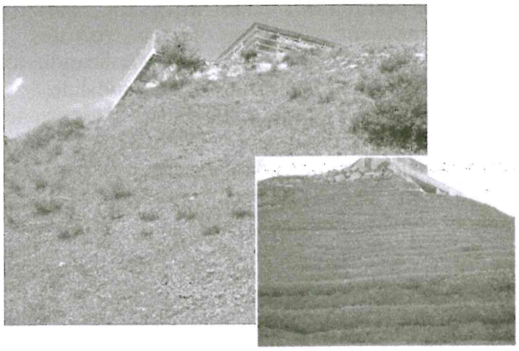

Figure 9. August 2014: view upslope.

Figure 10. August 2014: left: zoom of a vertical layer of the geogrid facing with a "belly"; right: same section in September 1994.

The inspection of the runout of the drainage system (Figure 3) showed a small but steady flow of clear water indicating its effective operation as well.

In summary: after twenty years in operation the system is completely in a good condition without any additional measures or corrections in that period.

9 FINAL REMARKS

It seems that the geogrid-reinforced landslide stabilization structure designed and built in less than two months in 1994 proves to be generally a successful, efficient and durable solution despite the unfavorable climatic, hydrological and geotechnical conditions and a number of specific disadvantageous circumstances in 1994 resulting in ad hoc solutions based to some extent on engineering judgment. Even the design procedures and tools were in 1994 quite modest.

The solution included a number of aspects being non-common in 1994 (Chapters 5 and 6).

In our opinion this demonstrates the flexibility, adaptiveness and robustness of such structures.

It is may be the first geogrid application for rehabilitation and stabilization of a landslide.

In our understanding the positive experience gained should encourage the intensive application of such solutions nowadays especially in consideration of the globally increasing landslide problems due to climate change.

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