LESSONS LEARNED FROM AN IMPOUNDMENT SLOPE FAILURE INVOLVING GEOSYNTHETICS

by K.E. Nay, T.D. Stark, and W.D. Evans

ABSTRACT: This paper describes a recent slope failure involving a reinforced geosynthetic clay liner in a sedimentation pond at a waste containment facility. Some of the lessons learned from this case history include: (i) the ability of geosynthetic clay liners to hydrate during on-site storage, (ii) the importance of site specific interface testing and slope stability analyses, (iii) the fluid level in a liquid impoundment may be lowered resulting in shear stresses that lead to a slope failure, (iv) rainfall induced seepage forces in a protective soil layer can lead to slope instability, and (v) several factors can coalesce to result in slope instability.

KEYWORDS: Geosynthetic clay liners, Interface Shear Strength, Waste containment, Strength, Stability, Shearbox test, Failure, Landfill, Sedimentation pond

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1 INTRODUCTION

A slope failure is used to illustrate the importance of (i) properly storing geosynthetic clay liners (GCLs) to reduce the amount of hydration prior to deployment, (ii) the buttressing force applied by the fluid in a liquid impoundment, (iii) conducting appropriate testing and stability analyses, and (iv) seepage forces in the stability of veneer cover slopes. The slope failure occurred in the State of Ohio, USA and provides valuable lessons for the use of geosynthetics in liquid impoundments.

2 FAILURE OF GEOSYNTHETIC CLAY LINER SYSTEM

2.1 Summary of the Case

The municipal solid waste landfill occupies about 5.7 ha (14 acres) in Ohio, USA. The landfill underwent final closure construction in the summer of 1994. The landfill previously accepted an average of 135 tonnes (150 tons) of residential solid waste per day.

The slope failure occurred in October 1997 and involves sliding along the side slope of a sedimentation pond. The pond design utilized a single layer of GCL installed on the side slope as a low permeability layer to reduce seepage from the pond. The rectangular sedimentation pond was excavated into the grey shale/limestone bedrock with a length of 60 m and a width of 25 m. The side slopes were to be constructed at an inclination of 1V:3H. However, the side slopes were actually constructed at an inclination of approximately 1V:2H. This resulted in slope lengths of 10 to 12 m. The initial pond design was a bedrock slope backfilled with an approximately 0.3 m thick layer of compacted crushed grey shale as a soil cushion layer prior to placement of a single layer of GCL (see Figure 1). A 0.3 m thick protective soil layer was placed on top of the GCL. The elevations at the top and bottom of the sedimentation pond are +247.1 m and +242.8 m, respectively. All construction for the sedimentation pond and the landfill closure was completed by 31 December 1994.

The GCL used at this site was reinforced with the granular bentonite being held between a polypropylene slit-film woven geotextile (with a mass per unit area of 109 g/m^2) and a polypropylene needle-punched nonwoven geotextile (with a mass per unit area of 204 g/m^2). The reinforcement is provided by polypropylene fibers from the nonwoven geotextile being needle-punched through the bentonite and the woven geotextile. The bentonite typically used in this GCL is Wyoming bentonite with a liquid limit and plasticity index of 600 to 650 and 560 to 610, respectively (Gleason et al. 1997).

2.2 Design Change

While constructing the final composite cover system for the landfill, which is adjacent to the sedimentation pond, a number of GCL rolls were deemed unsuitable prior to installation. The final landfill cover consisted of a VLDPE geomembrane underlain by a GCL on a 1V:4H slope. The GCLs became unsuitable due to hydration during on-site storage. The manufacturer wrapped each GCL roll in plastic; however, some of the plastic wrapping had unraveled. In addition, the rolls were not covered by a large plastic sheet or stored in a building or shelter. The rolls were stacked directly on 0.3 m by 0.3 m timbers after unloading from a truck. The thick cardboard cores in the middle of the rolls on the bottom of the stack broke or collapsed due to the weight of the overlying GCLs. The cores are used by manufacturers to facilitate rolling up of the GCL after manufacturing and to facilitate installation. The collapse of the cores allowed the GCLs to slump down between the timbers and contact the ground surface in a number of locations. The rolls were stored in an area of surface runoff and water ran underneath the rolls. As a result, it is anticipated that the bentonite hydrated from precipitation, runoff, and/or humidity, which made the majority of the GCLS, especially the bottom rolls, unsuitable for installation. In addition, the collapse of the roll cores made installation of the GCLs with a typical “spreader bar” difficult.

Instead of disposing of the 243 rolls of damaged GCL, the owner/operator decided to install an additional layer of GCL on the side slope of the sedimentation pond. This resulted in two layers of GCL being installed on the side slopes that were constructed at 1V:2H instead of 1V:3H. The two layers of

GCL were placed on top of each other with the woven geotextiles facing up. The seams of the upper layer of GCL were offset from the seams of the bottom layer by one-half the width of the panel. The best possible material was used from the 243 rolls of hydrated GCL but this material was still at least partially hydrated.

2.3 Failure

Figure 2 shows a photograph of the failure from across the sedimentation pond. The upper GCL and cover soil are displaced down the slope about 1 to 1.5 m. The failure occurred just below the top of the slope at approximately elevation 247.0 m and about a meter (elevation 245 m) above the maximum water level of elevation 246.1 m (Figure 1). The failure occurred near the center of the north side of the sedimentation pond. The upper GCL, i.e. both geotextiles, was torn over a length of 20 to 25 m. The sedimentation pond had been filled to various levels for approximately three years. The change in vegetation on the side slope in Figure 2 indicates that the long-term pond level before the pond was emptied was about elevation 245.0 m.

During the week prior to the failure, 25 to 50 mm of rainfall occurred at the site. It is anticipated that this rainfall induced seepage forces in the protective soil cover contributing to a reduction in the stability of the slope. Field observations show that an important parameter in the stability of veneer cover slopes is the depth of water, and thus seepage forces, in the cover soil (Giroud et al. 1995 and Koerner and Soong 1998).

The pond had been emptied (see Figure 2) for approximately one month prior to the failure. This was the first time that the pond had been emptied since being constructed. The reduction in fluid level removed some of the buttressing force on the slope and also may have contributed to the failure.

Figure 3 presents a close up of the failure and the torn upper layer of GCL. A cross-section of the slope after failure is shown in Figure 4. After the failure, bentonite was found extruded through the woven geotextile of the GCL and in between the two layers of GCL. This probably created a weak interface between the two GCLs and a potential failure surface.

2.4 Causes of Failure

The failure occurred when the pond was empty, but after it had been filled to various levels for a period of three years. It is anticipated that during the roughly three years of service the pond level reached the maximum elevation of 246.1 m. Therefore, the GCL was probably near full hydration to elevation 246.1 m at the time of failure. Since the failure occurred after the GCLs became completely hydrated, it probably did not make any difference whether the GCLs were hydrated or not when they were installed. However, it should be noted for future projects that there was a slope stability risk for the protective soil cover that was placed on top of the partially hydrated to hydrated GCLs prior to pond filling and the creation of a fluid buttress. This risk was due to bentointe being extruded out of the bottom GCL and creating a potential failure surface during placement of the protective cover soil.

In summary, if instability had occurred before pond filling it could have been caused by hydration of the bentonite during storage. However, since instability occurred after the pond had been filled, instability can be linked to the complete hydration of the bentonite, bentonite extrusion into the GCL/GCL interface, reduction of the buttressing force, and rainfall induced seepage forces in the cover soil.

This case history illustrates how several factors can coalesce to result in a slope failure. The four main factors are: (i) constructing a 1V:2H slope instead of a 1V:3H slope, (ii) installing two adjacent layers of a GCL and thus a potential weak surface, (iii) rainfall inducing seepage forces in the protective soil cover material, and (iv) reducing the fluid level in the pond, which reduced the buttressing force on the slope. It is recommended that sedimentation ponds be designed for an emptied condition because these ponds usually have to be cleaned out periodically. It is important that interface testing be conducted under hydrated conditions to reflect the saturated state prior to emptying of the pond.

Of course, two layers of GCL probably would not have been installed if the bentonite had not become at least partially saturated during on-site storage. Therefore, one of the lessons from this case history is the importance of GCL storage prior to installation to limit the amount of hydration and increase the acceptability of GCLs. As noted previously, the GCLs were wrapped in plastic by the manufacturer and stored on 0.3 m by 0.3 m timbers. However, some of the wrapping was damaged. It is recommended that a large plastic sheet be placed over the individually wrapped GCL rolls and weighted down to reduce infiltration especially for the rolls that have damaged plastic wrapping. It may also be beneficial to stack the GCL rolls on timbers that are closer together so the rolls do not collapse and/or reduce the height of the GCL stack. Another alternative is stack the GCL rolls on wooden pallets, or other suitable material, to provide continuous support to the rolls, reduce bentonite migration, and maintain a distance from the ground surface and potential moisture and surface runoff.

2.5 Previous Experience

Hydrated bentonite exhibits an extremely low shear strength, which has caused many slope stability problems. This suggests that the stability of landfill liner and cover slopes constructed with a GCL might be susceptible to static, e.g., Stark et al. (1998), and seismic slope instability. There are two possible failure modes for reinforced GCLs: (i) sliding at the interface between the top or bottom of the GCL and the adjacent material (termed interface failure) and (ii) sliding through the bentonite or midplane of the GCL (termed internal failure).

Interface shear strength of the GCL can be affected by extrusion of hydrated bentonite through a woven geotextile into the adjacent geomembrane interface (Byrne 1994 and Gilbert et al. 1996). Bentonite can also migrate into the interface from a bentonite impregnated geotextile. This can result in a slope stability problem along the geomembrane/woven geotextile interface. This problem was observed at the GCL slope stability research project in Cincinnati, Ohio (Koerner et al. 1996; Scranton 1996; Bonaparte et al. 1999) and a landfill liner system near Hong Kong (Cowland 1996). This previous experience is similar to the situation described in this case history and may have been used to conclude that sliding could develop between the two adjacent layers of GCL on a 1V:2H slope. It appears that bentonite extruded out of the bottom GCL into the GCL/GCL interface creating a weak surface.

2.6 Remedial Measures

The slope failure in the sedimentation pond was remediated by removing all of the GCL and reducing the slope to 1V:3H. Compacted crushed grey shale was placed on the 1V:3H slope instead of a GCL. The sedimentation pond is performing satisfactorily.

2.7 Lessons Learned

This paper presents a recent case history of slope instability in a sedimentation pond at a waste containment facility. The following lessons can be learned from this case history:

1. If geosynthetics do not perform satisfactorily, natural materials will replace them.

2. State-of-practice limit equilibrium stability analyses and interface test results could have been used to predict this failure. As a result, it is recommended that state-of-practice testing and analyses and a suitable factor of safety be used when geosynthetics are involved.

3. Storage of GCL rolls at a project site is important to limit the amount of hydration. It is recommended that the manufacturer wrap the GCL rolls in plastic and a large plastic cover be placed over all of the rolls after unloading. It is recommended that the rolls be placed on closely spaced timbers, wooden

pallets, or other suitable material, to provide adequate support to the roll cores, reduce bentonite migration, and maintain a distance from the ground surface and potential surface runoff. Of course, storage of the GCL rolls in a building or shelter may be more effective in reducing the amount of hydration.

4. Bentonite extrusion may occur through a woven geotextile and cause instability at a GCL/GCL interface, which is similar to other experiences with a GCL/geomembrane interface. Solutions to this interface problem include flipping the bottom GCL over so the woven geotextile is facing the subgrade instead of the overlying GCL or using a reinforced GCL with two nonwoven geotextiles.

5. Sedimentation ponds and other impoundments should be designed for an unbuttressed condition that will develop when the pond is emptied. This unbuttressed condition will occur after complete hydration of the geosynthetics and may prove to be the critical design condition.

6. This case history and others show that an important parameter in the stability of veneer cover slopes is rainfall induced seepage forces in the protective cover layer.

7. Several factors may coalesce to result in slope instability and thus stability analyses should consider this possibility. For example, this case history suggests that a weak interface between two hydrated GCLs, an unbuttressed slope, rainfall, and an oversteepened slope can occur at the same time.

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REFERENCES

Byrne, R.J., 1994, "Design Issues with Strain-Softening Interfaces in Landfill Liners", *Proc. Waste Tech '94 Conference,* National Solid Waste Management Association, San Francisco, California, January, 26 p.

Bonaparte et al., 1999 [JPG TO ADD REFERENCE WHICH IS IN THIS BOOK]

Cowland, J. W., 1997, "What is the Acceptable Shear Strength of a Geosynthetic Clay Liner?", *Proceedings of Symposium on Testing and Acceptance Criteria for Geosynthetic Clay Liners*, American Society for Testing and Materials, STP 1308, American Society for Testing and Materials, West Conshohocken, Pennsylvania, USA, pp. 229-239.

Gilbert, R.B., Fernandez, F., and Horsfield, D.W., 1996, "Shear Strength of Reinforced Geosynthetic Clay Liner", *Journal of Geotechnical Engineering*, ASCE, Vol. 122, No. 4, pp. 259-266.

Giroud, J.P., Bachus, R.C., and Bonaparte, R., 1995, "Influence of Water Flow on the Stability of Geosynthetic-Soil Layered Systems on Slopes", *Geosynthetics International*, Vol. 2, No. 6, pp. 1115-1148.

Gleason, M.H., Daniel, D.E., and Eykholt, G.R., 1997, "Calcium and Sodium Bentonite for Hydraulic Containment Applications", *Journal of Geotechnical Engineering*, ASCE, Vol. 123, No. 5, pp. 438-445.

Koerner, R. M. and Soong, T.Y., "Analysis and Design of Veneer Cover Soils", *Proc. of 6th International Conference on* Geosynthetics, sponsored by the Intl. Geosynthetics Society, March, 1998, Vol. 1, pp. 1-26.

Koerner, R. M., Daniel, D. E., and Bonaparte, R., 1996, "Current Status of the Cincinnati GCL Test Plots", *Proceedings of the 10th GRI Conference on Field Performance of Geosynthetics and Geosynthetic Related Systems*, Drexel University, Philadelphia, PA, pp. 147-175.

Scranton, H.B., 1996, "Field Performance of Sloping Test Plots Containing Geosynthetic Clay Liners", thesis presented to the University of Texas at Austin in partial fulfillment of the requirements for the Degree of Master of Science, 207 p.

Stark, T.D., D. Arellano, W.D. Evans, V. Wilson, and J. Gonda, 1998, "Unreinforced Geosynthetic Clay Liner Case History", *Geosynthetics International*, Industrial Fabrics Association International (IFAI), Vol. 5, No. 5, December, pp. 521-544.

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Figure Captions:

Figure 1. Cross section through north slope of sedimentation pond prior to failure

Figure 2. View of sedimentation pond and slope failure

Figure 3. Close up of slope failure and torn upper GCL layer

Figure 4. Cross section through north slope after failure

Figure 1. View of sedimentation pond and slope failure

Figure 2. Different view of sedimentation pond and slope failure

Figure 3. View of GCL stockpile

Figure 5. Close up of GCL stockpile

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