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Earth reinforcement application for hazardous waste containment

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ABSTRACT: This paper describes the design and construction of geogrid-reinforced steepened slopes that provide perimeter containment to a hazardous waste landfill. The geogrid-reinforced slopes (GRS) were constructed as part of a 28,000 sq. m. (7-acre) landfill closure completed in the southeastern part of Michigan, USA in 1995. The GRS, which is up to 14 m (45 ft) high and 460 m (1,500 ft) long, with typical side slopes of 1 horizontal to 1 vertical (1H:1V) was used to stabilize a natural slope in a complex geologic setting around the landfill. In addition to providing stability to the side slopes of the landfill, the GRS provides stability to the 2 m (6.5 ft) thick cover constructed over the landfill. This paper presents a general discussion of the design and construction procedure of the GRS for the landfill. To the best of the authors' knowledge, this is the largest geogrid-reinforced slope constructed to date in the State of Michigan.

1 PROJECT DESCRIPTION

The project site is a 134,000 sq. m. (33-acre) abandoned sand and gravel borrow pit. The southern 28,000 sq. m. (7 acres) of the site were used for waste disposal after mining activities ceased. Previous field investigations identified the landfill as the source of chemical contaminants which were detected in groundwater downgradient of the site (north of the landfill). The proposed remedial action for the site consisted of two primary components; 1) capping/closure of the landfill, and 2) pump and treat with subsequent reinfiltration of the treated water through a seepage basin.

Surface topography of the site before cover construction consisted of rough terrain with some steep slopes created from mining activities. Maximum topograph relief on the site was in the order of 24 to 27 m (80 to 90 ft). Slopes as steep as 40 degrees from horizontal were present along the north and south sides of the landfill. Such steep slopes required specific design to provide adequate stability to the proposed clay cover for the landfill.

2 SUBSURFACE CONDITIONS

Five geotechnical borings and eight trenches were conducted along the northern and southern limits of the landfill to provide subsurface information for geotechnical design.

The soils logged in the borings and trenches consist predominantly of fine to coarse poorly-graded to well-graded sand with trace gravel to depths of at least 11 m (35 ft) below the toe elevation of the landfill. In one boring, a very stiff to hard silty clay layer was encountered at a depth range of 1 to 3.5 m below the toe elevation of the landfill. The water table was present at a depth of 12 m (40 ft) below ground surface.

The angle of inclination of the existing natural sandy slopes was measured at several locations within the site with a Brunton compass. The angle of inclination of the existing slopes represents the angle of repose of the natural soil, which in turn represents the angle of frictional resistance for the granular soil slopes. Angles of slope inclination were recorded as high as 39° and 40° from horizontal at locations on the north and

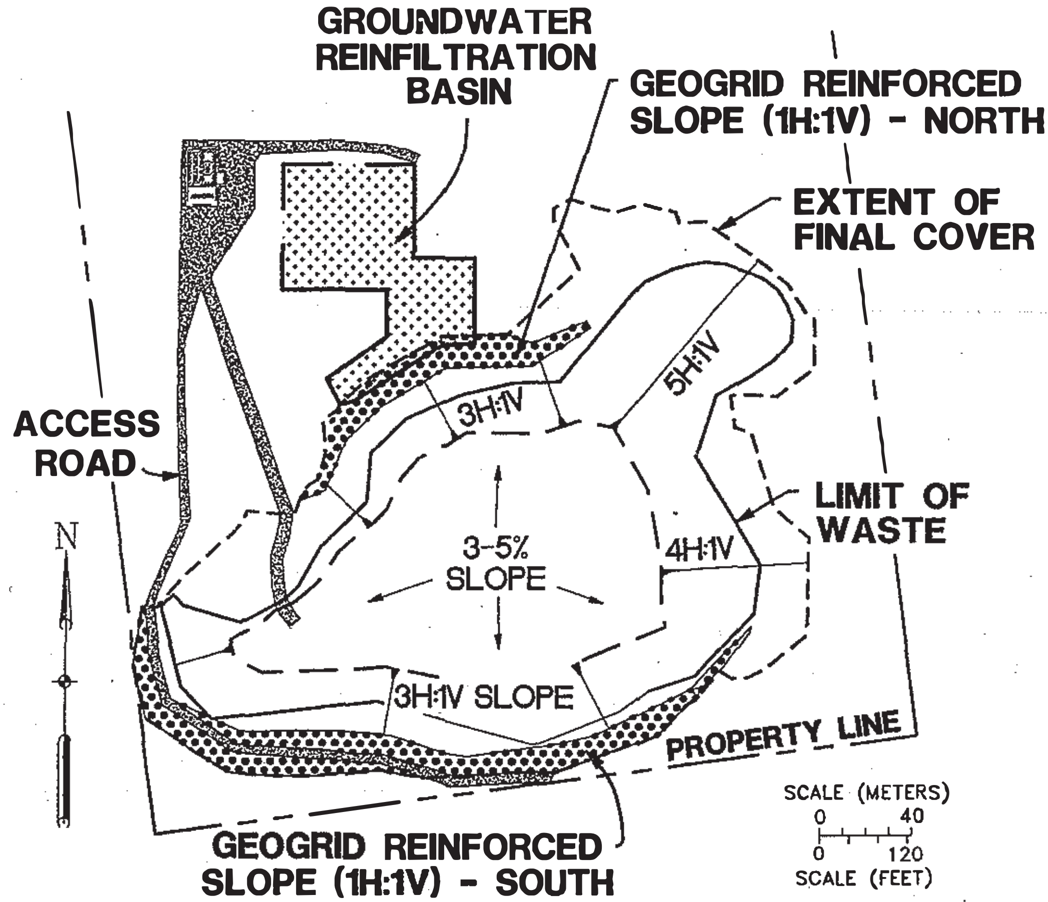

Figure 1- Final Site Topographic Map

south slopes of the landfill. These high friction angles may be attributed to the slight cementation observed for the natural sand. Cone Penetration Tests (CPT) confirmed the in-situ shear strength of the sand.

3 LANDFILL COVER SLOPE ALTERNATIVES

Because of the natural steep slopes and large slope heights, a large volume of fill material would be required if the landfill was designed using conventional side slopes in the order of 3H:1V.

In addition, constructing 3H:1V side slopes would have required encroaching on the property south of the site. In the case of the north slope, a 3H:1V side slope would have covered the area immediately north of the landfill where space was required for construction of reinfiltration basins as part of groundwater and soil remediation (see Figure 1).

Several alternatives were considered to avoid substantial regrading of the side slopes and to permit the construction of the landfill cover within the site boundary and outside the reinfiltration basin area. In addition, these alternatives were selected to minimize waste disturbance within the landfill. These alternatives consisted of: 1) A conventional 3H:1V slope; 2) A combination of conventional 3H:1V slope and a short geogrid-reinforced or gabion wall at the toe of the slope; 3) A full height geogrid-reinforced slope to provide steeper slopes than could be achieved with ordinary compacted fill.

Cost comparisons between these alternatives indicated that the cost per unit length of perimeter slope did not differ appreciably. Considering space limitations dictated by the site conditions, the full height geogrid-reinforced slope was considered more desirable since it required the minimum area for slope construction beyond the landfill limits, and thus did not impinge on the adjacent property or reinfiltration basin area.

4 GEOGRID-REINFORCED SLOPE DESIGN

4.1 Methodology

The principles and procedures discussed in Christopher, et al. (1990), Koerner (1990), and Leshchinsky (1993) were used in the design of the geogrid-reinforced slopes. Potential modes of failure that were evaluated include: internal stability (failure surface completely in reinforced zone), compound stability (failure surface partially in reinforced zone and partially outside), global or deep-seated stability (failure surface outside reinforced zone), sliding stability (reinforced zone slides on bottom layer of reinforcement), and pullout of the geosynthetic. The computer program "STBREF" (Humphrey and Holtz, 1986, and Reyna at al., 1992) was used for slope stability analyses with tensile reinforcement. The computer program "STABL5M" (1988) was used for the sliding stability analyses.

4.2 Typical Sections

Typical sections along the perimeter of the landfill ranged from 9 to 14 m (30 to 45 ft) in height with 1H:1V reinforced slopes. At the crest of the reinforced slope the slope typically broke off at a 3H:1V grade for another 9 m (30 ft) in vertical height (on the south slope, it broke to 2H:1V and then 3H:1V). There were three typical sections: south, southwest, and north. The south typical section is shown on Figure 2.

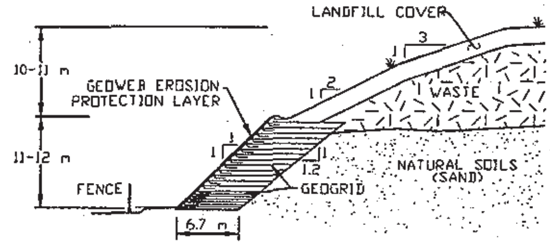

Figure 2- Typical South Slope Cross Section

4.3 Shear Strength Parameters

A friction angle of 38 degrees with no cohesion was used for the naturally occurring, slightly cemented sands. A friction angle of 32 degrees with no cohesion was used for the waste in the landfill (Singh and Murphy, 1990). Friction angles of 35 and 40 degrees were used for granular fill and select fill, respectively, in the geogrid-reinforced zone.

4.4 Stability

Slope stability analyses were performed on the typical sections around the perimeter of the landfill. The Federal Highway Administration (Christopher, et al., 1990) recommends minimum factors of safety for reinforced slopes of 1.3 for internal stability, 1.3 for compound stability, 1.3 for global stability and 1.5 for sliding stability and pullout. These factors of safety were met in the design of the GRS. Generally the factors of safety were near 1.5 for all of the modes of failure. The reinforcement force gained from the geogrid was applied horizontally at the base of the slice where the circle intersected the geogrid. A pseudo-static stability analysis was checked for all of the sections and found to have a satisfactory factor of safety in the event of an earthquake. The GRS were designed such that excavation of the existing slopes and waste within the landfill would be minimized.

4.5 Geogrid Specification

The geogrid was designed for partial factors of safety for creep, installation damage, and durability. Also, the geogrids were specified such that strains would not exceed 5 percent for the design section.

The design of the south slope, as shown in Figure 2, resulted in a 6.7 m (22 ft) wide base width with the bottom 2 m (6 ft) of the slope having geogrid with ultimate tensile strengths of 109 kN/m (7,400 lb/ft) vertically spaced at 0.3 m (1 ft) and above that the same strength geogrid spaced at 0.6 m (2 ft) (see Figure 2). This uniaxial geogrid was also specified to achieve a tensile strength of 30 kN/m (2,000 lb/ft) at or before 5 percent strain in order to limit deformations. The geogrid was to be wrapped over (re-embedded) a distance of 1.5 m (5 ft) from the face of the slope.

An oriented HDPE (high-density polyethylene) geogrid was specified due to the uncertainty of the

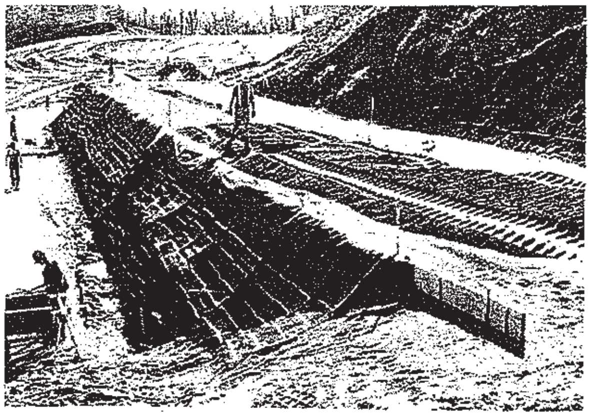

Figure 3- Temporary Form Placement to Maintain Shape of the Wall Facing

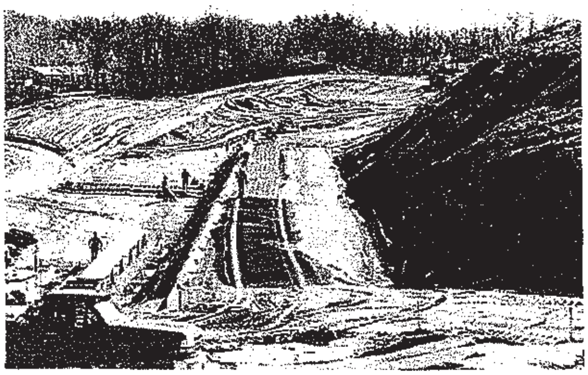

Figure 4- Geogrid and Fill Placement

composition, of the waste in the landfill. To provide permanent erosion control of the face and prevent sloughing upon saturation, a 100 mm (4 inch) high geoweb was specified to be placed on the 1H:1V slopes and filled with topsoil and hydroseeded. Surface-water runoff was diverted around the crest of the slope to further minimize erosion.

5 CONSTRUCTION

The construction of the north GRS was initiated first in May 1995 to allow an early start of the construction of a groundwater infiltration system in the northern area of the site. The south GRS was initiated several weeks later. The subgrade for both sections were prepared by compaction of the native granular soils and placement and compaction of select fill (friction angle of 40 degrees) to provide a stable, level base course.

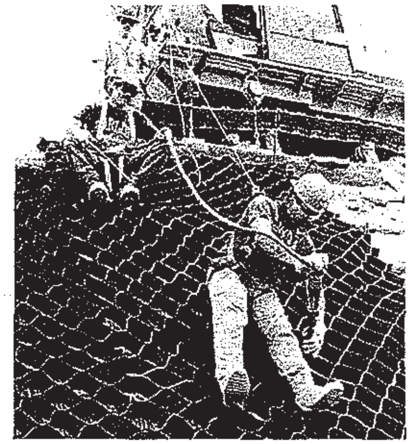

Figure 5- Placement Procedure of the Erosion Control Blanket (Geoweb)

The uniaxial geogrid was precut at the manufacturer's factory. The geogrid sections were typically placed at 0.6 m (2 ft) vertical spacing and the shape of the facing was maintained by wooden forms (Figure 3 and 4). Erosion of the granular backfill soils was expected to occur after installation, and prior to the placement of the topsoil-filled geoweb, because the aperture size of the uniaxial geogrid exceeded 90% of the backfill particle size. Therefore, a lightweight geotextile was placed inside the geogrid facing to retain the sand-sized particles behind the geogrid.

The select fill material selected for the base course and the lower 2 m (6 ft) of the height of the GRS in the south section, was a crushed rock with a required minimum friction angle of 40 degrees. The granular fill for the remainder of the GRS required a minimum friction angle of 35 degrees; a natural (non-processed) sand was expected to be provided. However, the Contractor elected to use a processed granular material.

The geoweb was installed top to bottom of the slope and staked into place (Figure 5). Topsoil was spread using a smooth-edged bucket of an excavator as shown on Figure 6. There was adequate clay content in the topsoil that enabled the topsoil to withstand rainfall and erosion prior to establishment of the grass vegetative cover. A successful test of the hydroseeding procedure was conducted on the lower portions of the north slope in July. The remaining slopes were hydroseeded in September. Because the

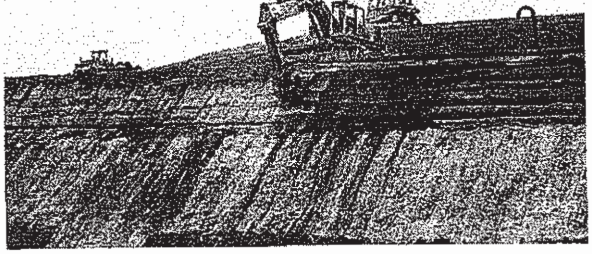

Figure 6- Spreading Top Soil Using Smooth-Edged Bucket of an Excavator

Figure 7- Aerial View of the Completed North Slope

hydroseeding occurred late in the growing season, the remaining slopes had less established grass prior to the dormant winter season. An aerial view of the completed north slope is shown on Figure 7.

There were the following difficulties constructing the GRS:

- First, the Contractor had considerable difficulty providing an acceptable natural sand backfill ("granular fill") for the upper levels of the wall. The Contractor only tested one on-site and one off-site borrow source; neither source met the friction angle requirement. Because the Contractor delayed testing additional borrow sources, he elected to place a select fill used for the lower levels of the GRS.

- Second, the facing had to be stable throughout construction. The use of forms and lightweight geotextile on the facing overcame this difficulty.

- Third, the steepness of the slopes made it difficult for workers to walk on the facing to place the geoweb. Therefore, the workers were placed on tether ropes and safety harnesses and held on the slopes by workers holding the tethers at the top of the slopes (Figure 5).

- Lastly, placement of the topsoil inside the geoweb was difficult because of the 9 to 14 m (30 to 45 ft) height of the slopes. Long-armed excavators were located either at the bottom or top of the slopes to place the topsoil.

6 CONCLUSION

The use of geogrid reinforced slopes (GRS) was demonstrated to be an effective solution to retain the slopes of a hazardous waste landfill cover where there was limited space available to construct conventional slopes.

A comparison of the cost of the GRS compared to estimated costs of conventional slopes indicated they were comparable. However, the GRS allowed construction of the south slope entirely on site, thereby precluding purchasing the neighbor's property that would have been necessary to construct conventional slopes; purchasing of the neighbor's property could have delayed the project and increased costs. Further, the use of a GRS on the north slope avoided interference with other remediation systems.

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