Reinforced Dredge Materials for Landfill Construction Using Geogrids

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ABSTRACT: A disposal site for spoil materials dredged from the river channels was selected as a sanitary landfill site. The foundation soil at this site consists of dredge spoil materials with very low shear strength. Because of the weak soil condition, foundation settlement and stability of soil and waste slopes are of greater concern in the design and construction of the landfill. Tensile reinforcement with geogrids placed within the sand blanket is used to reduce shear stress and strain, and plastic deformation in the foundation. It is one of the highest landfills constructed on dredge spoil material. The stability of dikes and landfill slopes with different landfill configurations, and the settlement with strength gains of subsoil resulting from the consolidation of dredge material are examined in the analysis. This paper presents the results of the investigation performed for the design and construction for the landfill over the dredge material disposal area.

1 INTRODUCTION

Scarcity of suitable sites for landfill and the public sentiment of "not in my backyard" have made a disposal site for dredged material the best possible siting for a landfill in Wilmington, Delaware in the United States. In addition, the low permeability characteristic of the dredge spoil makes it very suitable for the base of the landfill. Unfortunately, the dredge spoil materials are unstable saturated materials with very low shear strength. The conventional construction options for this landfill would require (a) excavation and replacement of dredge material, (b) stabilization with injected additives, and (c) increased soil consolidation process via preloading or other means. These methods are neither economically feasible nor cost effective. The imminent closure of the existing landfill has made the construction of this new landfill an urgent need. The placement of structural high strength geogrids as reinforcing elements over the site was the only feasible and cost effective solution. Moreover, geogrids were required to function as structural layers to allow access to the site, preventing bearing capacity failure and withstanding the pressure of construction equipment and placement material. In this project, the design objective was: (a) to develop an environmentally safe landfill with the maximum possible capacity and (b) to be able to construct and operate the landfill in a short time frame.

2 SITE AND SOIL CONDITIONS

The project site for the landfill is located on Edgemoor dredge disposal area of Cherry Island, Wilmington, Delaware. This site has been used by the U.S. Army Corps of Engineers (COE) to dispose spoil materials resulting from the Delaware and Christina rivers dredging operation. Construction of dikes along the site limits is necessary to avoid inundation as dredge spoil disposal continues to the south of the site. The new landfill will cover an area of 33 ha and will have a gross volume of 5 million cubic meters. Geologically, it is seated in the Coastal Plain of the northeastern United States. The sediments of the Coastal Plain consist of interbedded unconsolidated layers of gravels, sands, silts and clays. A generalized cross-section of the site geology is shown in Figure 1. The lower unconsolidated layer overlying the weathered rock is the Potomac Formation, which consists of multicolored silts and clays and interbeds of sand and some gravel. This formation has a thickness of varying from about 2 m in the northwest corner to about 44 m in the southeast corner. Overlying the Potomac Formation is the Columbia Formation, which varies from 3.5 m thick along the western edge to 20 m thick along the eastern edge. This formation generally consists of multicolored sands and gravels, with interbeds of silty sand, silty clay, and clayey silt. Recent deposits and thick layers of dredged spoil are found overlying the unconsolidated

Columbia Formation. These materials consist of silty clays, clayey silt with some organic content, and layers of peat and clay. Their low permeability causes the soil to be slow-draining and weak in resisting shearing stress. The thickness of the dredge spoil deposit varies from 18 m at the eastern limit to 21 m at the western limit.

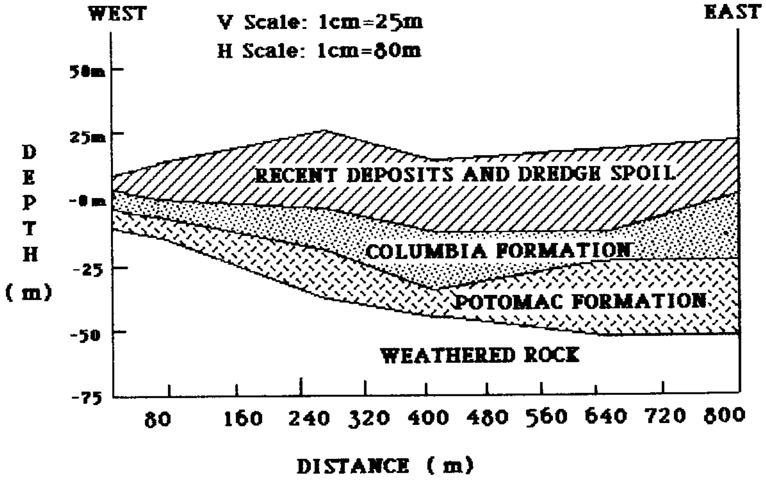


Figure 1 A generalized geologic cross-section at the site

Field and laboratory tests are conducted on soil samples to determine the soil parameters required for analyses. Results of the laboratory tests indicate that most of the subsoil can be classified as MH to ML and occasionally OH, according to the Unified Soil Classification system. Plastic limits of the soil range from 26 to 51 percent whereas liquid limits vary from 38 to 89 percent. The values of moist unit weight of the samples tested vary from 14 to 17.5 kN/m^3. The unconfined compressive strength was found to be in the range of 12.5 to 31.5 kN/m^2. Laboratory permeability tests performed on the remolded samples yield the coefficient of permeability in the order of magnitude of 10^{-7} to 10^{-8} cm/s. Compression indices varied from 0.54 to 0.84 whereas the coefficients of consolidation ranged from 1.6×10^{-4} to 3.9×10^{-4} cm^2/s.

Based on the results of subsurface exploration and laboratory testings, dredge spoil materials can be subdivided into 5 layers, layers 1 through 5 as shown in Figure 2. Consolidation of dredge spoil material upon the landfilling would result in the strength gain in the dredge layers. Strength gain in dredge layers was calculated based on the equation $\Delta c_u = \Delta\sigma_v \tan\phi$ (Bowles, 1984), where Δc_u is the change in undrained shear strength of the soil and $\Delta\sigma_v$ is the change in effective overburden pressure. The final strength of the soil is obtained by adding the predicted strength gain to the initial strength of the soil layers. The final properties of dredge layers are shown in Table 1

Table 1 The final strength properties of dredge layers

Layer	Soil Type	ϕ^0	C (KN/Sq.m)	γ (KN/Cu.m)
1	Dredge Spoil	0	33.0	16.8
2	Dredge Spoil	0	23.7	16.8
3	Dredge Spoil	0	24.2	16.2
4	Dredge Spoil	0	36.0	17.3
5	Dredge Spoil	0	22.5	15.7
6	Sand	32	0	19.0
7	Solid Waste	10	10.0	7.0
8	Sand & Gravel	38	0	20.5

3 DESIGN ANALYSIS

Because of the poor foundation conditions, two design factors are of concern: stability and settlement analyses of the landfill site. Stability of the perimeter dikes and overall stability of the site must be evaluated with landfilling sequence and maximum thickness for any excessive deformation or collapse. Meanwhile, the compressible dredge spoil material underlying the geomembrane liner may result in differential settlement upon the placement of landfill material. The associated stretching or straining of the geomembrane liner may cause the failure of the liner system.

3.1 STABILITY ANALYSES

The stability analyses were performed in order to determine both the stability of the existing dikes as well as the stability of overall site as landfilling progresses. Stability analyses were performed for different landfill thicknesses and configurations to determine the allowable landfill configuration. Figure 2 shows the final landfill configuration with 3 horizontal to 1 vertical side slopes and a landfill height of 24.5 m with the 30.5 m setback at the top 12 m. These stability analyses were divided into four cases in which the combination of landfill height, landfill strength, and geogrid reinforcements were varied. Case 1 considers stronger landfill strength parameters of unit weight (γ)=7 kN/m^3, cohesion (c)=36 kN/m^2, and frictional angle (ϕ)=0°, and no geogrid reinforcements. Case 2 is similar to Case 1 except using the weaker landfill strength parameters of γ=7 kN/m^3, c=10 kN/m^2, and ϕ=10°, and no geogrid reinforcement. Case 3 is similar to Case 1 but with an equivalent geogrid tensile strength of 292 kN/m. Finally, Case 4 is similar to Case 2 but with an equivalent geogrid tensile strength of 292 kN/m. The above landfill scenarios were analyzed with respect to slope stability by using computer programs, "STABL5M" and "STABL6". Undrained stability analysis was performed using the Simplified Bishop method. The results from the slope stability analyses are presented in Table 2.

Table 2 Results of slope stability analyses

Case 1

Landfill Height	Factor-of-Safety
0 m	1.19
6 m	1.30
12 m	1.14
18.5 m (30.5 m offset)	1.17
24.5 m (30.5 m offset)	1.14
24.5 m (after 1 year)	1.24

Case 2

Landfill Height	Factor-of-Safety
0 m	1.19
6 m	0.94
12 m	0.89
18.5 m (30.5 m offset)	0.97
24.5 m (30.5 m offset)	1.02
24.5 m (after 1 year)	1.13

Case 3

Landfill Height	Factor-of-Safety
0 m	1.19
6 m	1.30
12 m	1.25
18.5 m (30.5 m offset)	1.27
24.5 m (30.5 m offset)	1.19
24.5 m (after 1 year)	1.28

Case 4

Landfill Height	Factor-of-Safety
0 m	1.19
6 m	1.13
12 m	1.06
18.5 m (30.5 m offset)	1.15
24.5 m (30.5 m offset)	1.08
24.5 m (after 1 year)	1.18

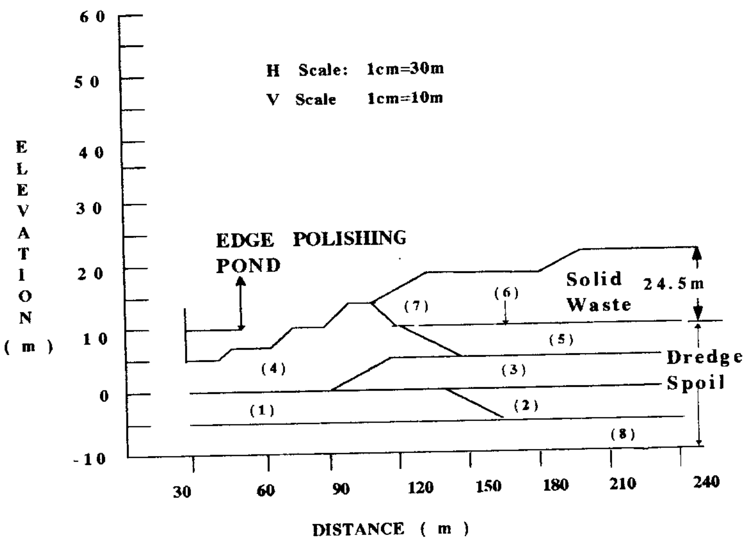


Figure 2 Final landfill configuration at fill height of 24.5 m

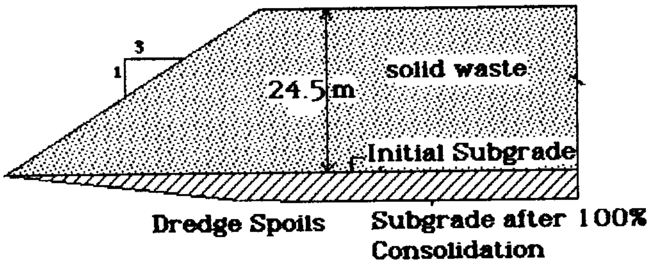
For the landfill material, strength parameters of c=36 kN/m^2 and ϕ=0°, and c=10 kN/m^2, and ϕ=10°, are utilized as the upper and lower bounds in these analyses, are obtained from the range of values cited in the literature (Singh and Murphy, 1990). From Table 2, it can be seen that the factors of safety (FS) determined in the cases of no reinforcement ranged from 1.14 to 1.30 for stronger landfill strength parameters and from 0.89 to 1.19 for weaker landfill strength parameters. Typically, the minimum factor of safety (FS) for slope stability should be 1.3 or greater to account for variation in material properties and uncertainty in subsurface conditions. However, it is prohibitively expensive to achieve the normal minimum FS of 1.3 in the early life of the landfill due to the very weak nature of the dredge spoil at the site. The landfill stability design is based on achieving a minimum FS of 1.2 in conjunction with extensive monitoring instrumentation. This value may be considered acceptable because the stability failure which could result in this case would probably be slow in nature with ample warning signs. Also, the field monitoring program implemented not only monitored any distress signal as the landfill was constructed but also measured soil parameters to verify the design. Appropriate steps could be taken to alleviate the potential instability problem and prevent a widespread failure.

The benefit of geogrid reinforcement can be evaluated by comparing the results in Cases 1 and 3 , and Cases 2 and 4. The average increase in the factors of safety to due to the addition of 292 kN/m of geogrid reinforcement considering all cases was 0.12. This means that the addition of geogrid reinforcement does not cause a significant increase in the stability of slopes the analyzed. The results presented also show that the effect of geogrid reinforcement is less pronounced as the landfill height and soil properties are increased.

In order to study the effect of time on the landfill stability, the factors of safety were determined for the 24.5 m of landfill material just after final placement and after the refuse material was in place for a year. In the case of 24.5 m of refuse in place for a year, the geogrid tensile strength was reduced from 292 kN/m to 131 kN/m to account for time-dependent phenomena such as creep. However, the factor of safety is increased even though the geogrid tensile strength is reduced. This indicates that the consolidation of the dredge materials will provide the increase in strength and stability in the long term.

3.2 SETTLEMENT ANALYSES

Settlement calculations caused by landfilling were performed assuming landfill configuration of 24.5 m high and with 1 vertical to 3 horizontal slope as shown in Figure 3. The configuration was assumed without the setback because that setback will eventually be filled with refuse. Considering dredge spoil deposits as under consolidated strata, settlements were calculated using the conventional consolidation theory. Total settlements were estimated to be 3.8 m at the center portion of landfill and decrease to approximately 0 m at the edge. Figure 3 shows the settlement profile of the landfill. Ninety percent of this settlement is expected to occur over a period of 70 years. Differential settlement, which is more detrimental to liners was expected across the site due to the varying thickness of the dredge spoil strata. However, calculation showed that this magnitude is not expected to exceed 0.60 m from one point to another because the thickness of this compressible layer varies by approximately 3.3 m across the site.



(Scale: V: 1cm=2.5m, H: 1cm=5m)

Figure 3 Settlement profile of the landfill

4. SELECTION OF REINFORCEMENT

The type of reinforcement was selected based on the stress-strain characteristic, the creep characteristic, and chemical compatibility of the candidate materials. These considerations, along with the damage to geogrids during construction and durability of the material, were used to determine the wide-width tensile strength. The stress strain characteristics of the geogrid reinforcement were chosen to match as closely as possible the stress-strain characteristics of soil and waste materials. The creep characteristics of the candidate materials were compared based on the 10,000-hour long-term creep test data supplied by the geosynthetic manufacturers. The materials were also evaluated for their chemical compatibility with the leachate from a typical municipal solid waste landfill. Biological degradation of the materials was examined from the test data supplied from the manufacturer. Polyethylene was chosen as the preferred material because it is chemically compatible with the waste and exhibits high chemical and biological resistance. To obtain high tensile strength, high-strength high-density polyethylene with high modulus was selected. The other requirements of the geogrids are given in Table 3.

Table 3 Minimum requirement properties of geogrids

Design tensile strength (long-term, 20 yr.)	292 kN/m
Design tensile strength (short-term, 5 yr.)	218 kN/m
Tensile strength @ 5% strain	1315 kN/m
Tensile Modulus	2335 kN/m
Junction strength	145 kN/m
Coefficient of direct sliding	0.80

5 SUMMARY AND CONCLUSIONS

This case history demonstrates the use of geogrid reinforcement in construction of landfills over soft dredge spoil materials. Overall, the factor of safety can be increased by placing geogrid reinforcement within the slope configuration such that they intersect the critical failure surface. However, the increase in factors of safety is not very significant for the slopes analyzed because the critical failure surfaces for the case of no geogrid reinforcement becomes non-critical when they are analyzed with geogrid reinforcement. In general, as the landfill height and soil strength properties are increased, the effects of geogrid reinforcement become less pronounced.

6 REFERENCES

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