International Conference on Case Histories in Geotechnical Engineering

(1993) - Third International Conference on Case Histories in Geotechnical Engineering

03 Jun 1993, 2:00 pm - 4:00 pm

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Recommended Citation

Knitter, Clifford C.; Haskell, K. G.; and Peterson, M. L., "Use of Low Plasticity for Soil Liners and Covers" (1993). *International Conference on Case Histories in Geotechnical Engineering*. 5.
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Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 12.02

Use of Low Plasticity Silt for Soil Liners and Covers

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-SYNOPSIS: Loess, which consists predominantly of low plasticity to non-plastic silt ($PI \leq 10$) with varying amounts of sand and clay-sized (- 5 microns) material, covers much of north-central Oregon and eastern Washington. Several landfills operate in this area. Because of the lack of clayey soils and clayey bedrock in the region, loess was proposed for use as the low permeability soil barrier layer. Laboratory testing and large-scale field tests of test fills using SDRI's have shown that the remolded permeability of the loess is related to grain-size, soil gradation, and the percent saturation of the placed soil. We had an approximately 1:1 correlation between the permeability results of laboratory remolded samples, undisturbed Shelby tube samples of test fills, and field SDRI tests. Data from six different sites have consistently shown that in order to achieve a permeability of less than $1x10^{-6}$ cm/s, the loess must contain greater than 70 percent minus U.S. No. 200 sieve and have at least 15 percent minus 5 microns material. In addition, the loess must be placed at a minimum of 2 percent over standard Proctor optimum moisture content and be compacted to a dry density which corresponds to a minimum of 85 percent saturation at the measured moisture content.

INTRODUCTION

Several municipal solid waste (MSW) landfills and one hazardous waste (HW) landfill are located in eastern Washington and north-central Oregon. Much of this area is underlain by basaltic bedrock, tuff, tuffaceous siltstone, sandstone, and claystone or volcaniclastic sandstone and conglomerate. These materials in general, are not suitable for use as relatively low permeability soil barrier layers. Permit requirements for these facilities require a single composite (soil and flexible membrane liner) liner for the MSW landfills and a double composite liner for the HW landfill. Single composite covers are required for the MSW and HW facilities. The maximum permeability requirement for the soil liner/cover is $1x10^{-6}$ cm/s or $1x10^{-7}$ cm/s, depending upon the site.

The bedrock over much of this area is overlain by Quaternary loess, which ranges in thickness from zero to approximately 100 feet (Figure 1). The loess consists of silt with varying amounts of sand and clay-sized material. Due to the lack of other appropriate natural materials for use in the soil liners and covers, the loess was evaluated for use as a low permeability barrier material.

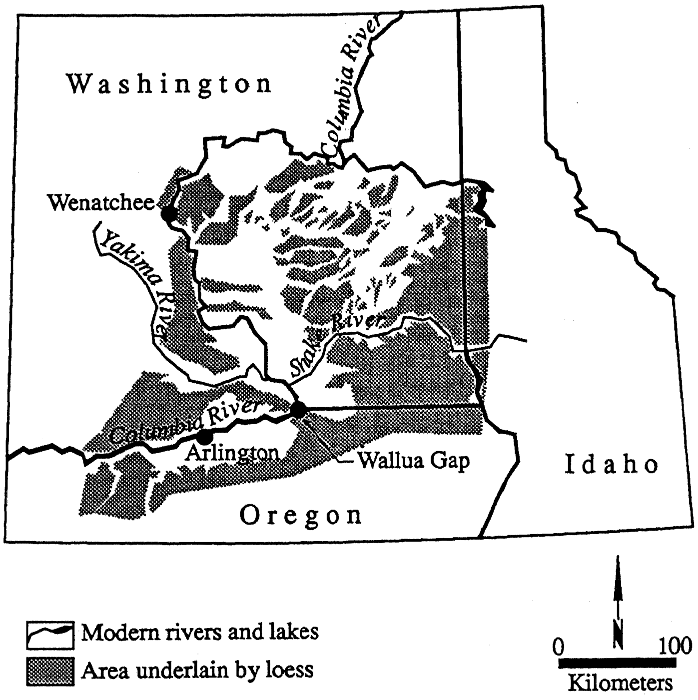


Figure 1. Extent of Quaternary Loess in Washington and Northern Oregon

GEOLOGIC SETTING

Loess blankets much of eastern Washington and north-central Oregon. The source area of the loess appears to have been the eastern flank of the Cascade Mountain Range and foothills, with the Miocene Ringold Formation and the Touchet beds being the primary contributors (Higgins and others, 1989; Foley, 1982). The grain-size of the loess decreases from a sandy silt to a clayey silt from the eastern Cascade Foothills and western Columbia Basin east to approximately the Washington-Idaho border (Higgins and others, 1989). In addition, there appears to be a similar, but less pronounced decrease in grain-size westward down the Columbia River gorge, from approximately Wallua Gap to west of the Arlington, Oregon area (Figure 1). An increase in grain-size with depth below four to eight feet, was also observed in the eastern Columbia River gorge area. Typical ranges of grain-size distribution are shown in Figure 2.

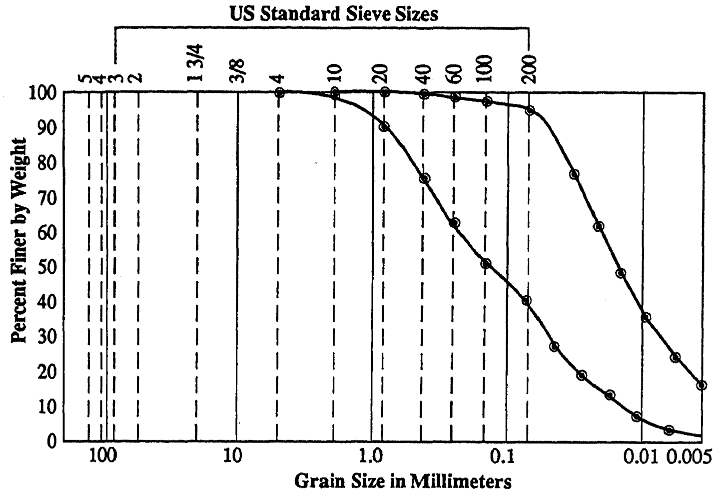


Figure 2. Grain Size Distribution

The loess is thickest in the areas that were not scoured by the Pleistocene Lake Missoula floods. In the Palouse area of southeastern Washington, the loess exceeds 100 feet in thickness. In the vicinity of the Columbia River, the loess tends to be less than 20 feet thick, and in several places is interbedded with alluvium deposited by the Lake Missoula floods. Several tephra and calcic soil horizons are exposed in large road-cuts near Washtucna, Washington (Foley, 1982). These marker units have been dated and paleomagnetic stratigraphy has been performed on samples collected from near the base of the section. The chronologic and paleomagnetic data suggest that the loess is at least 730,000 years old, and that deposition occurred irregularly, throughout the Pleistocene (Foley, 1982). Near Wenatchee, Washington, Mazama tephra (6,800 to 7,000 years Before Present) was found buried by two to four feet of loess, suggesting continued loess deposition, at least in this area, into the early Holocene.

On a local, site scale, the grain-size and soil plasticity of the loess can vary significantly over relatively short vertical and horizontal distances. Layering and lensing of silty and sandy horizons are common. In outcrop, the loess is compact to dense in relative consistency below the upper bioturbated zone, which is typically two to three feet thick. The loess is generally massive in appearance and displays little to no internal structure, with the exception of some root holes that are typically less than one-sixteenth of an inch in diameter. The root holes have been observed throughout loess exposures even at depths up to twenty feet. The clayey loess also typically appears blocky in outcrop and in test pits, with numerous vertical and horizontal cracks. In the drier, western Columbia Basin and eastern Columbia River gorge (average annual precipitation less than 12 inches), calcic soil layers (caliche) occur at widely varying depths. In eastern Washington, near the Idaho border, where the average rainfall is greater (annual precipitation 20 to 25 inches), calcic layers are uncommon or lacking (Higgins and others 1989). Natural moisture contents for the loess range from about 2 to 8 percent water.

INDEX PROPERTIES OF THE LOESS

The index properties of the loess are relatively consistent throughout the area and can be correlated to grain-size distribution. In general, the loess that contained less than approximately 13 to 15 percent minus 5 microns material was non-plastic. This same material also tended to contain more sand. Loess that contained 15 to 22 percent minus 5 microns had plasticity indices (PI's) that ranged from 4 to 12 percent. Loess that contained over 25 percent minus 5 microns (this type of material was not prevalent in the study areas) tended to have PI's from 15 to 25 percent. Standard Proctor (ASTM D 698) maximum dry densities ranged from approximately 92 pounds per cubic foot (pcf) to 110 pcf, and optimum moisture contents ranged from 17 percent to 27 percent; with the typical range being 100 to 108 pcf at 17 to 21 percent water content.

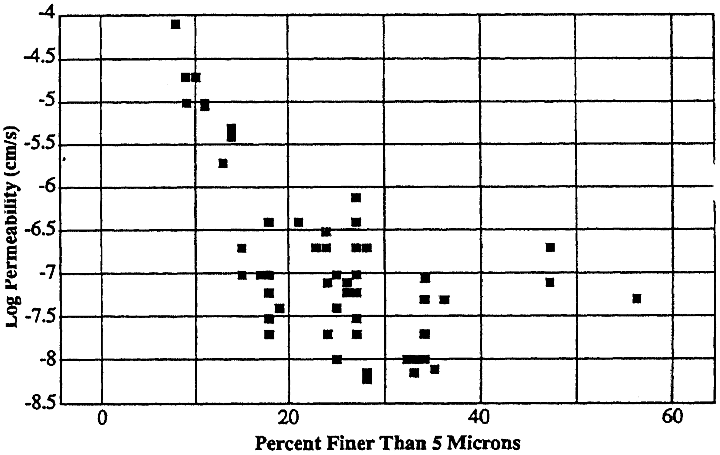
Shrinkage tests were also performed on samples of the loess. The apparatus used consisted of a tray made from cutting an approximately 3/8-inch diameter, 12-inches long tube lengthwise. Compacted, moisture conditioned samples of the loess were placed in the tray and allowed to dry from over optimum water contents to approximately 2 to 5 percent water content, the typically observed natural moisture content of the loess. As the sample dried, desiccation cracks formed. The amount of shrinkage was determined by measuring the change in length of the sample in the tray from the initial moisture content to its final moisture content. For the silty samples (13 to 15 percent minus 5 microns), the shrinkage averaged approximately one percent. For the samples that contained 18 to 22 percent minus 5 microns material, an average shrinkage of approximately two percent was observed.

PERMEABILITY CHARACTERISTICS

Laboratory Testing

To determine the remolded permeability characteristics of the loess, samples were remolded in a three-inch diameter cylindrical mold in the laboratory, at varying moisture contents and dry densities. Relatively undisturbed samples were also collected from test fills using steel Shelby tubes. Permeability testing of the laboratory remolded and Shelby tube samples were performed using flexible membrane permeameters per ASTM D 5084.

The remolded permeability characteristics of the loess appeared to be grain-size dependant. As can be seen in Figure 3, samples with less than 15 percent minus 5 microns material tended to have permeabilities greater than $1x10^{-6}$ cm/s and samples with greater than 15 percent minus 5 microns material had permeabilities less than $1x10^{-6}$ cm/s.



igure 3. Percent Finer Than 5 Microns vs. Permeability

n addition to the grain-size distribution f the loess, the placement criteria used ad a significant influence on the remolded ermeability. We initially attempted to etermine the placement criteria for the oess using the method proposed by Daniel nd Benson (1990). This method determines he permeability of samples at various ater contents and dry densities compacted er the modified Proctor (ASTM D 1557), tandard Proctor (ASTM D 698), and reduced roctor (standard Proctor method with only 5 blows per lift instead of the normal 25) ethods. We observed that the laboratory amples could meet the permeability equirements by compacting to at least 80 o 85 percent saturation at water contents lightly over modified Proctor optimum ater content. The samples compacted at hese water contents; however, had a dry, laky appearance, tended to layer, and did ot knead well into the underlying lift. herefore, we were concerned regarding the otential for secondary permeability eatures in the soil liners, which could esult in actual permeabilities for the soil liner greater than that measured in the relatively small samples tested. We observed that at water contents above approximately two percent over standard Proctor optimum water content, the soil tended to form a homogenous fill with no lensing or layering. In addition, at moisture contents approximately 6 to 7 percent over standard Proctor optimum water content, the workability of the soil was greatly reduced.

As can be seen in Figures 4 and 5, there is a weak trend toward lower permeability with increased dry density and increased remolding water content. However, as shown in Figure 6, there is a prominent trend toward a decrease in permeability with an increase in the initial percent saturation of the sample. This differs from the results reported by Elsbury and others (1990) for a highly plastic clay. Samples of the loess containing at least 15 percent minus 5 microns material, compacted to dry densities that corresponded to at least 85 percent saturation at the measured moisture contents, consistently had remolded permeabilities less than $1x10^{-6}$ cm/s.

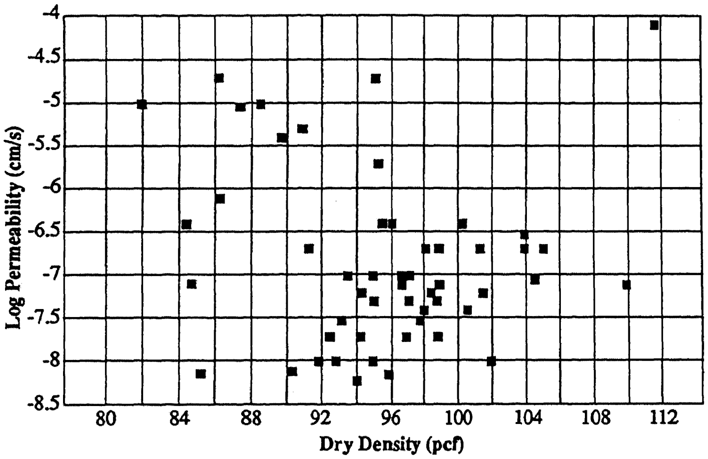


Figure 4. Dry Density vs. Permeability

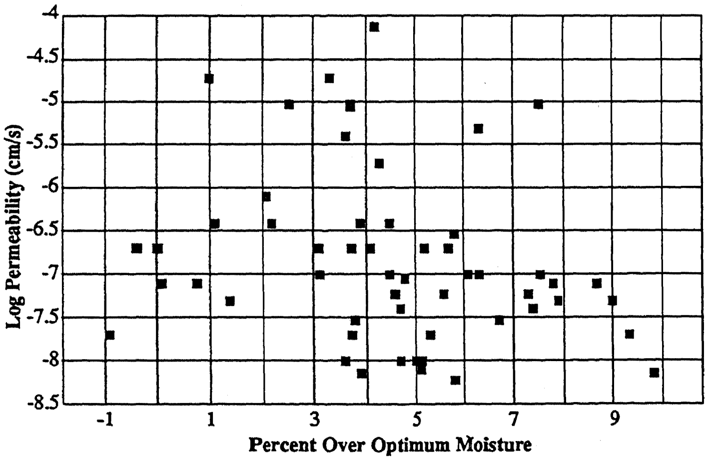


Figure 5. Percent Over Optimum Moisture vs. Permeability

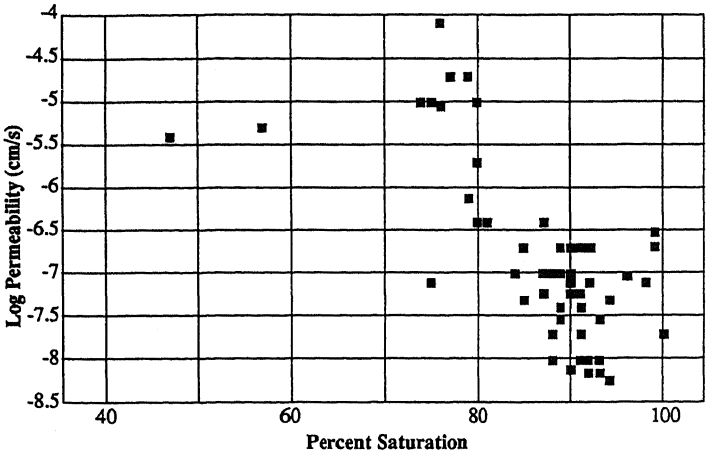


Figure 6. Percent Saturation vs. Permeability

Field Testing

To confirm the laboratory determined permeabilities of the laboratory remolded and Shelby tube samples, large-scale field permeability tests were performed using sealed double-ring infiltrometers (SDRI's) on test fills constructed at various sites. The criteria used to construct the test fills were developed based on the laboratory testing and recommended placement procedures described in the recent literature (e.g., Elsbury and others, 1990; Daniel 1987). The test fill construction criteria were as follows:

- Native loess soils were required to contain ≥ 18 percent minus 5 microns material and ≥ 75 percent passing the U.S No. 200 sieve.
- Water was added to the loess to bring the soil to 2 to 6 percent over optimum moisture content, as determined by ASTM D 698 (standard Proctor method).
- The moisture conditioned soil was compacted using large, penetrating-foot compactors (e.g., Caterpillar 815) to a dry density that corresponded to at least 85 to 90 percent saturation at the measured moisture content. Typically four to six one-way passes of the compactor were required to achieve the required dry densities.

The loess in the test fills were typically placed near the upper limit of the water content range given because, it tended to result in a more homogenous and consistent appearing fill, which lacked features that could have contributed to secondary permeability effects. If the loess was much more than 6 percent over optimum water content, the workability of the soil was greatly compromised. Test pits excavated into the test fills showed that they were uniform in appearance with no layering or lensing apparent when placed near the upper water content range.

The field determined permeabilities were equal and in some cases lower than the average of the laboratory determined permeabilities of Shelby tubes samples collected from the same test fills. This is consistent with laboratory and field-scale permeability measurements reported by Benson and others (1992), for material placed using a percent saturation specification as opposed to material placed using a percent compaction specification. In all cases, it was not possible to track the movement of the wetting front in the SDRI tests using tensiometers because, they never showed any soil suction. We interpret the observed lack of soil suction to the high degree of soil saturation and the predominantly granular nature of the placed soils.

At one site, because the available loess contained less than 15 percent minus 5 micron material, it was necessary to admix the loess with bentonite to meet the permeability specifications. In general, we observed that the bentonite sources resulted in no significant difference in the permeability of the samples, as long as powdered sodium bentonite was used. In addition, the general grain-size distribution specification given above was found to serve as guide for determining the amount of bentonite to add. We observed that it was necessary to add enough bentonite to bring the samples to containing approximately 18 percent minus 5 micron material. By adding bentonite to reach this amount of minus 5 micron material (typically approximately 5 percent powdered bentonite), we found that the laboratory and large-scale field permeabilities were generally less than $1\text{x}10^{-7}$ cm/s. Using less than 5 percent bentonite usually resulted in little to no decrease in the remolded permeability of the loess.

CASE HISTORY IN LANDFILL LINER CONSTRUCTION

The results of the laboratory and field testing results and our recommended material placement specifications were submitted to the governing regulatory agencies and received overall acceptance. At the time of writing, three large (30 to 35 acres each) MSW cells have been constructed using loess which meets the material and placement specifications given above. This equals over 300,000 cubic yards of placed soil liner. Permeability testing was performed as part of the construction quality assurance (CQA) testing for these cells. Out of a total of approximately 75 tests using Shelby tube samples, only one did not meet the maximum permeability requirement. The one failing sample was due to material that was placed with a water content less than two percent over standard Proctor optimum water content. The dry area was identified, additional water was added, and the area was recompacted. A subsequent test showed that the permeability was less than the required maximum.

This overall success in the performance of the loess as soil liner can be attributed the use of well characterized material and good CQA. The loess borrow areas, moisture conditioning tables, placement, and compaction were closely monitored during construction to ensure that a uniform, homogenous fill was being constructed. Due to material inhomogeneity in the borrow area, the loess mining was closely monitored and the contractor was directed as to what material could be used as liner material and what material was to be left in the ground or spoiled. In addition, the moisture conditioning tables were monitored to ensure that the loess was conditioned to a uniform moisture content. The placement and compaction of the soil liner material was monitored and tested per the project CQA Plan.

CONCLUSIONS

Based on laboratory and large-scale field testing and observations of soil from several different sites in eastern Washington and northern Oregon, it is possible to use predominantly silty soils for low permeability barrier layers. These soils, however, must meet relatively well defined material and placement specifications in order to meet the required performance criteria. In addition, good CQA practices must be employed to consistently achieve the desired performance criteria.

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