Geotextiles and Geomembranes 43 (2015) 412–423

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Evaluation of geofibers and nontraditional liquid additives on erodible slopes in Interior Alaska

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ARTICLE INFO

Article history:
Received 18 November 2014
Received in revised form
23 April 2015
Accepted 24 April 2015
Available online 3 June 2015

Keywords:
Soil stabilization
Erosion resistance
Geofibers
Synthetic fluid
Polymer emulsion
Critical shear stress

ABSTRACT

Non-cohesive soils are extensively distributed in Interior Alaska and soil erosion in a newly constructed roadside embankment is of great concern. Geofibers and nontraditional additives have been used for stabilizing non-cohesive soils and controlling soil erosion. However, in cold regions where permafrost exists such as Interior Alaska, any erosion control measures in a newly constructed roadside embankment must also allow a vegetation establishment at the same time, to mitigate potential permafrost degradation caused by surface modifications. Literature review indicates that no previous research has been done to consider both effects. There is a great need to investigate if geofibers and nontraditional additives can be used in Interior Alaska for soil erosion control and permafrost degradation mitigation.

This paper presents the laboratory and field test results on use of geofibers and nontraditional additives (synthetic fluid and polymer emulsion) to control soil erosion in Interior Alaska. Locally available non-cohesive soils were used as a control and compared with the same soils treated with different doses of geofibers and nontraditional additives, including: 1) 4% synthetic fluid and 0.5% geofibers, 2) 2% polymer emulsion + 0.5% geofibers, 3) 2% polymer emulsion, and 4) 0.5% geofibers only. The results on soil critical shear stresses, sediment collections, soil organic matter, and plant available nutrients were analyzed from which some conclusions were made regarding working mechanisms of the geofibers and two nontraditional additives on soil erosion control in Interior Alaska.

1. Introduction

Interior Alaska has large amounts of non-cohesive silty soils which are frequently used in embankment construction. These soils, when present on the surface of newly constructed embankment slope prior to establishment of vegetation, are sensitive to erosion during rainfall or snow thaw events. Erosion of surface material affects the stability of the embankment and causes sediment runoff to streams that potentially generate environmental concerns and destroy fish spawning ground. In addition, road construction in Alaska often extends into permafrost regions, which are often covered by vegetation and organic soil layers. Vegetation and surface soil organic layer insulate and reduce heat transfer due to low bulk density, high porosity when dry, and high heat capacity when wet (O'Donnell et al., 2009), thus preserves the permafrost layer from thawing. Removal of vegetation and the organic layer during road construction can disturb the existing thermal balance and cause thawing of the permafrost layer, which results in shoulder slumping, roadside collapse, and longitudinal cracks in the pavement. Consequently, any soil stabilization methods for embankment side-slope in Interior Alaska must be able to (1) prevent soil erosion immediately after completion of construction and (2) facilitate the quick establishment of vegetation to mitigate the potential permafrost degradation. Once vegetation is established, plant roots can help to hold the soil together which prevents erosion and reduce thermal disturbance for potential permafrost degradation. Preliminary studies on geofibers and nontraditional liquid additives for to stabilizing non-cohesive soils as base course materials show positive impact of these materials (Hazirbaba and Gullu, 2010; Collins, 2011). A direct question

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http://dx.doi.org/10.1016/j.geotexmem.2015.04.015
0266-1144/Published by Elsevier Ltd.

is therefore as follows: when the same treatments are used in the embankment construction, will the side-slope experience significant soil erosion? Will the same treatments be able to facilitate vegetation establishment and mitigate permafrost degradation? At present, there are no published studies regarding whether the same treatments can be used in the embankment side-slope to control soil erosion and mitigate permafrost degradation. There is a great need to investigate if geofibers and nontraditional additives can be used in Interior Alaska for embankment side-slope soil erosion control and permafrost degradation mitigation.

Previous studies on soil erosion control using geofibers and nontraditional liquid additives are summarized as follows. The stabilization methods usually consist of mechanical or chemical methods to reduce erosion. Orts et al. (2001) used biopolymer additives to in a lab-scale furrow test for controlling erosion. The results show that starch xanthate, cellulose xanthate, and acid hydrolyzed cellulose microfibrils can reduce soil erosion significantly. Das et al. (2009) reinforced fly ash specimens with various dosages of fibers to improve resistance against piping in embankments. Test results showed that polyester fibers 50 mm in length and at a 0.05% dosage reduced seepage velocity and improved piping resistance. Estabragh et al. (2014) investigated improvement of piping resistance of silty sand using randomly distributed geofibers. Geofibers were found to reduce seepage velocity and increase piping resistance of soil. Indraratna et al. (2008) examined the erosion resistance of silty sand stabilized with cement and lignosulfonates. The stabilizers evaluated were found to reduce the coefficient of soil erosion and increase the critical shear stress. Lignosulfonates was also found to be a more effective stabilizer than cement for erosion resistance in the silty sand used for the study. Indraratna et al. (2013) developed a theoretical model that predicts the rate of erosion based on the principle of energy conservation. Lignosulfonate was found to increase strain energy per unit volume of treated samples of silty sand. This was used to develop a relationship between strain energy and erosion rate. Liu et al. (2011) sprayed organic polymer soil stabilizer on a clay material at the surface of the test slope and allowed for drying of 48 h and then tested it in a simulated rainfall. The results show that the organic polymer is effective for improving the erosion resistance of slope topsoil. Sariosseiri et al. (2011) used Portland cement and cement kiln dust (CKD) to stabilize silty sand and silt materials. They looked at the effectiveness of using the combination on a slope for erosion control. Soil loss results in both the lab and field show that increasing amounts of CKD lead to a decrease in soil loss. The samples mixed with 10% and 15% CKD, respectively, give the highest reduction in soil loss. Ekwue et al. (2011) used polymer emulsion to treat clay soil in slopes in a laboratory to measure the effectiveness of polymer emulsion for controlling soil erosion. The results show that soils treated with polymer emulsion have less erosion than the untreated soils.

In order to fully understand how the additive work in soil for erosion control, studies have been done to determine the impact of the additives (traditional or nontraditional) on soil physical, chemical and biological parameters. In testing the effectiveness of geofiber or chemical additives on soil strength, parameters that reflect soil physical properties are usually used, such as California bearing ratio, unconfined compression strength or Atterberg limit (Yetimoglu and Salbas, 2003). The critical shear stress of a soil is directly related to the soil ability to resist erosion. There are several examples of methods used to determine the critical shear stress of fine-grained soils. However, no literature was found regarding measurement of the critical shear stress of soils treated with erosion-control additives. For example, Kamphuis and Hall (1983) observed that critical shear stress increased as compressive strength, vane shear strength, plasticity index, clay content, and consolidation pressure increased. The authors also observed that once the critical shear stress for a soil is reached, erosion progresses immediately, and any alteration to the surface of the sample causes increased erosion due to the change in roughness. Wan and Fell (2004) show the two most relevant test methods for slope erosion control purposes are flume tests and rotation cylinder tests. The flume test measures erosion of soils in channels/canals. The rotating cylinder test, which determines the critical shear stress and erosion rate, can be used to study the relationship between erosion characteristics and fundamental soil properties. Mallison (2008) compared an in situ submerged jet testing device with a laboratory flume to estimate erosion characteristics of cohesive soil. The flume, however, did not cause erosion on the surface of the soil, due to lack of sufficient power.

More recently, soil chemical parameters such as soil pH (Miller and Azad, 2000) and cation exchange capacity and clay surface area (Stavridakis, 2006) are added to the test list to help further understand the effectiveness of chemical additives added in soil. Nevertheless, the research on mechanism from which the nontraditional chemical additives function in soil is largely unclear (Tingle et al., 2007). One of the reasons might be lack of field data to support the product specification (Katz et al., 2001, Kota et al., 1996). From perspectives of commercial interest, it is understandable that companies in such business are reluctant to disclose the chemical structure and composition of the nontraditional additives. Another reason can be attributed to less knowledge accumulated in understanding mechanisms of those additives to stabilize soil. Due to lack of understanding, engineers are reluctant to use them (Katz et al., 2001). Tingle et al. (2007) used a variety of instruments to characterize the commercially available nontraditional additives, they concluded that enhancement of inter-particle contact in soil may be the way of these nontraditional additives strengthen soil. In a more recent publication, Tingle et al. (2007) conclude that the nontraditional additives alter the nonexpendable clay lattice.

The goal of this work was to (1) determine if geofibers and nontraditional liquid additives can be used to effectively protect embankment side-slopes constructed using non-cohesive silty soils in Interior Alaska from soil erosion and to facilitate grass establishment and (2) to identify the mechanisms of stabilization in polymer emulsion and synthetic fluid. A multifaceted research was conducted with three main aspects: (1) determination of the critical shear stress for treated and untreated soils, (2) construction of a lab-scale model slopes to simulate resistance of soil erosion immediately after treated with the additives, and (3) construction of a full scale field embankment to determine grass growth, soil erosion at rain event and soil chemical property changes from soil treated with the additives.

2. Experimental methods

2.1. Materials

Fig. 1 shows the grain-size distribution curve for the soils used in the study. The soils were collected at a construction site in Fairbanks, Alaska. According to the Unified Soil Classification System, the soil is silty sand which contains 47% of Fairbanks silts with plastic and liquid limits of 18.2 and 19.7, respectively. The soils are non-cohesive and the predominant soil type found throughout Interior Alaska. The maximum dry density and optimum moisture content were determined using modified proctor compaction, which were 1.84 g/cm^3 and 12%, respectively (Fig. 2). Specific gravity of the soils is 2.70.

The geofibers used in this study were 70 mm long fibrillated geofibers. There are many variations of geofibers available however fibrillated was decided on due to successful use in Collins (2011).