Assessment of field stabilization methods to prevent recurring surficial failures
L'évaluation de méthodes de stabilisation de champ pour empêcher d'échec superficiels reproduisant

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ABSTRACT
Surficial failures are shallow slope failures with an average depth of failure ranging from 0.30 m to 1.20 m and frequently occur on several earthfill dams. One of the principal causes of such shallow failures is attributed to desiccation cracking in soils. Infiltration of rain water causes saturation and loss of strength of surficial soil. Hence, shrinkage crack control will be a key factor in controlling the surficial slope failures. Field test sections were constructed at Joe Pool Dam site with various combinations of admixtures including lime, polypropylene fibers and compost. The dam site was heavily instrumented. The test sections were monitored for more than one year and the results indicated that the treatment of top soil with admixtures was effective in preventing desiccation cracking.

RÉSUMÉ
Les échecs superficiels sont les échecs de pente peu profonds avec une profondeur moyenne d'étendre d'échec de 0.30 m à 1.20 m et arrivent fréquemment sur plusieurs barrages d'earthfill. Une des causes principales de tels échecs peu profonds sont attribuées à craquer de dessiccation dans les sols. L'infiltration d'eau de pluie cause la saturation et la perte de force de sol superficiel. Donc, le contrôle de fissure de recul sera un facteur clé dans contrôler les échecs de pente superficiels. Les sections de test de champ ont été construites au site de Barrage de Réserve de Joe avec les diverses combinaisons de mélanges y compris la lime, les fibres de polypropylène et composte. Le site de barrage était lourdement instrumenté. Les sections de test ont été contrôlées pour plus qu'un an et les résultats ont indiqué que le traitement de premier sol avec les mélanges était efficace dans empêcher de craquer de dessiccation.

Keywords : Surficial failure, earthfill dams, desiccation, wetting and drying cycles, polypropylene fibers

1 INTRODUCTION

Surficial failures are shallow slope failures with an average depth of failure ranging from 0.30 m to 1.20 m and in many cases the failure surface is parallel to slope face (Day, 1996). One of the predominant causes of these failures has been observed to be desiccation cracking followed by rainfall events (Dronamraju, 2008). A schematic showing the surficial failure is shown in Figure 1.

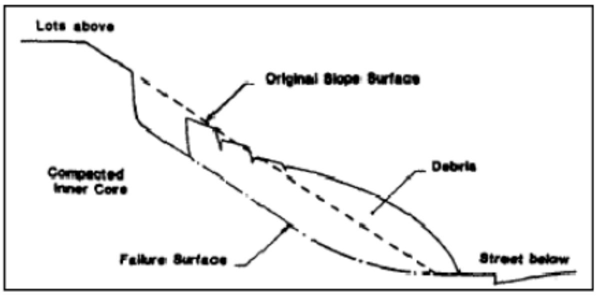

Figure 1. A Sectional view of a surficial failure (Day, 1996).

During summer or periods of drought, desiccation cracks are induced by evaporation of water and shrinkage of soil (Omidi et al. 1996). These shrinkage cracks get filled up during infiltration and the resulting hydrostatic pressure acts as a destabilizing force to cause a surficial slope failure (McCarthy, 2002). Rainwater infiltration in to the top layer of soil slope also reduces matric suction and increases pore water pressure resulting in decrease of shear strength in the top layer of slope (Rahardjo et al. 1994). The effective cohesion approaches zero and the increase in pore pressure reduces the contribution of friction angle. All or a combination of these factors are resulting in surficial failures (Day, 1996; Dronamraju et al. 2008).

Several rolled earthfill dams of the United States Army Corps of Engineers (USACE) experienced numerous surficial failures with repair costs above hundred thousands of dollars (McCleskey, 2005). A typical surficial failure occurred at the Joe Pool Dam, USA is shown in Figure 2.

Figure 2. A typical surficial failure at Joe Pool Dam.

The surficial failures may not lead to catastrophic conditions if identified and repaired quickly (Dronamraju et al. 2008). Traditionally, these surficial failures were repaired by removing the soil within the failure block and replacing with the same soil, borrow soil or lime-modified soil which met with varied success.

A research investigation was undertaken at the University of Texas at Arlington with the main objective of mitigating surficial failures by preventing desiccation cracking. McCleskey (2005) conducted research with the help of chemical

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admixtures and reported that addition of lime, compost and polypropylene fibers improved the desirable properties of soil which helped mitigate desiccation cracking. Addition of lime was found to reduce the plasticity index and volumetric shrinkage tendencies of soil. Addition of polypropylene fibers to lime mixed soil was found to improve tensile strength of soil. Addition of compost to soil was found to help the soil absorb higher moisture content.

Based on these findings, field trials were conducted at Joe Pool Dam site of USACE. The results of the field trials are explained in this paper and the best performing admixture is recommended based on the analysis of field data collected over a period of one year.

2. CONSTRUCTION OF TEST SECTIONS AT JOE POOL DAM

Joe Pool Dam is located 24 km southwest of Dallas in the state of Texas in USA. The climate of North Central Texas is humid subtropical with hot summers. There is a wide range of temperature variation in either extreme. Precipitation varies from 500 mm to 1000 mm. As such, the site was selected for the research involving alternate drying and wetting cycles.

The dam was constructed between 1979 and 1986 and impoundment started in January 1986. The length of dam is about 7.4 km and maximum height of dam is 33 m. The dam has a downstream side slope of 2.8H:1V (20°). The soil of the dam is classified as CH soil and it has an average Plasticity Index of 37. The activity of the soil is around 3.2. The dam experienced its first surficial failure in 1988. Later on, a number of surficial failures occurred at the dam site.

Five test sections 18 m long and 7.5 m wide (planar dimensions) and 0.45 m thick were constructed on the downstream side slope of the dam. The test sections consisted of four treated sections and a control section for relative comparision to judge the performance of admixtures under similar conditions. The four test sections were soil mixed with 20% compost, 4% lime with 0.30% polypropylene fibers, 8% lime with 0.15% polypropylene fibers and 8% lime.

The construction began during September 2007 and completed in three weeks. The slope was mowed and all the vegetation cover was removed. The top soil was initially excavated followed by excavation of the slope soil of the dam. The soil excavated was transported to a level ground called level pad. The soil was spread uniformly on the level pad and pulverized with the help of pulverizers. The soil was divided into five zones. The soil in the zone 1 was earmarked for control section. Zones 2 through 5 are shown in Figure 3 where the soil was mixed with admixtures. Soil in the zone 2 was mixed with 20% compost consisting of wood fibers and yard trimmings. Soil in zone 3 was mixed with 4% lime and soil in zones 4 and 5 was mixed with 8% lime. After mixing the soil with lime with the help of rotary mixer, 0.30% and 0.15% of polypropylene fibers were added to the soil in zones 3 and 4 respectively. The fibers were mixed thoroughly with the soil.

After completing the mixing of admixtures with the soil, the treated soil was transportated back to the slope and placed in layers of 23 cm thick and compacted with the help of a sheepsfoot roller. Proper Quality Control and Quality Assurance measures were taken during construction. The soil layers were compacted on wet side of optimum moisture content with a targeted dry density of over 95% of maximum dry density. The desired compacted density and moisture content were achieved by monitoring with nuclear gage. Soil mixed with admixtures was tested for all basic properties in the laboratory and confirmed that the construction was carried out to the desired standards and as per specifications.

After compacting the 23 cm thick top soil above the 45 cm thick treated soil, the test sections were heavily instrumented as

Figure 3. Construction of test sections (view from crest of dam) (Inset: Spreading of lime slurry).

shown in Figure 4. Two TDT (Time Domain Transmission) type moisture probes were installed at a depth of 25 cm and 50 cm from the surface for each test section to monitor the moisture fluctuations continuously. One temperature probe was installed at a depth of 25 cm from the surface for each test section to monitor the soil temperature continuously. Two vertical inclinometers were installed to a depth of 4 m at each test section to monitor the lateral displacement of test section. In addition, 125 survey pegs were installed at the site to monitor the vertical movement of surface by regularly conducting elevation survey with the help of total station.

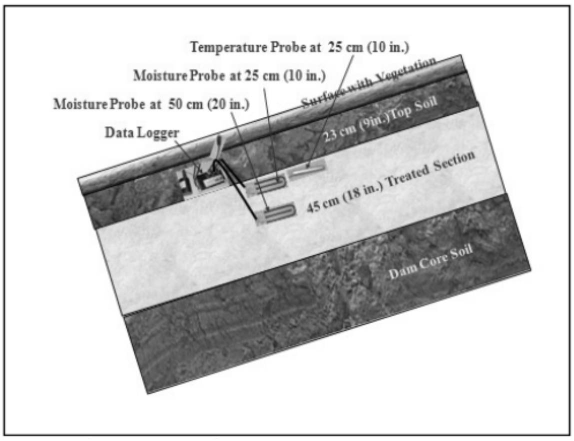

Figure 4. Location of moisture probes and temperature probe.

The instruments were monitored continuously with elevation survey and inclinometer survey conducted periodically.

3. ANALYSIS OF FIELD SENSOR'S DATA

The volumetric moisture content recorded by the top and bottom probes for each section was downloaded from the data loggers to a laptop at regular intervals. The data was analyzed typically to see the response of treated sections to various weather conditions and compared with the performance of the control section. During the period of observation there was a total annual rainfall of 89 cm against the average annual rainfall of 94 cm for Dallas, Texas. The average ambient temperature varied from 10° C to 27° C. The average annual volumetric moisture content of each treated section for top probe located at a depth of 25 cm from the surface is shown in Figure 5.

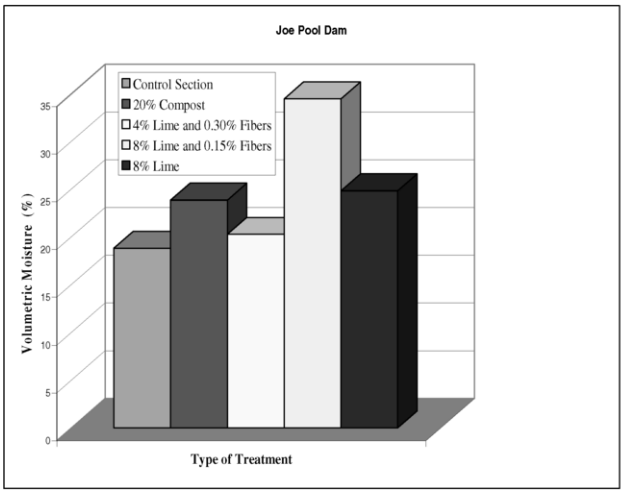

Figure 5. Average annual moisture content of top probe.

It can be seen that the treated sections hold higher moisture content than the control section. Compost and polypropylene fibers are hydrophilic in nature and hence absorbed higher moisture content than the control section. Of all the sections, 8% lime with 0.15% fiber section is found to be holding higher moisture content than the other sections.

It is apparent that the presence of higher moisture content in the top layer of soil is beneficial to prevent desiccation cracking.

Prominent cracks were noticed along the construction joint at the top of test sections as shown in Figure 6.

Figure 6. Desiccation cracks along construction joint.

A number of desiccation cracks were noticed on the surface in the control section and fewer cracks were noticed on the compost section. However, the cracks appeared along the construction joint were wider in compost section. Digital image analysis showed that the percentage of desiccation cracking in control and compost section excluding the crack at construction joint was 0.20% and 0.03% respectively. There were no signs of any distress in the other three sections which were treated with lime and polypropylene fibers. No other kind of failure of any test section was noticed during the period of monitoring.

Analysis of temperature probe data revealed that there is no significance difference in the soil temperatures recored among the test sections. The average minimum and maximum temperatures of test sections were 15° C and 26° C respectively.

4. ANALYSIS OF INCLINOMETER DATA

Two vertical inclinometers were installed for each test section and the notation used is indicated in Figure 7.

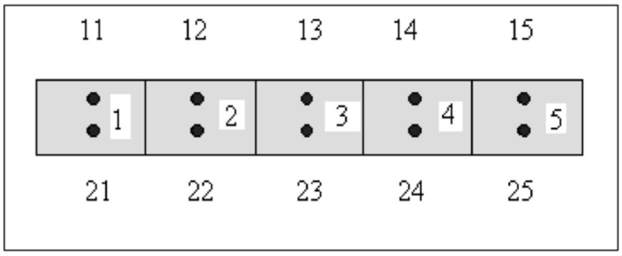

Figure 7. Notation used for inclinometers

Sections 1 to 5 are in the same order as shown in Figure 5. The vertical profile of the inclinometer casing was regularly recorded with the help of inclinometer probe at every 30 cm interval. The profile recorded for control section is shown in Figure 8 for the inclinometer installaed at the bottom of test section. The cumulative displacement shown is with respect to the initial observations of 10/10/2007. The profile indicates that there is a lateral movement of the control section. The profile of other treated sections also showed lateral movement in the direction of slope as indicated in Table 1.

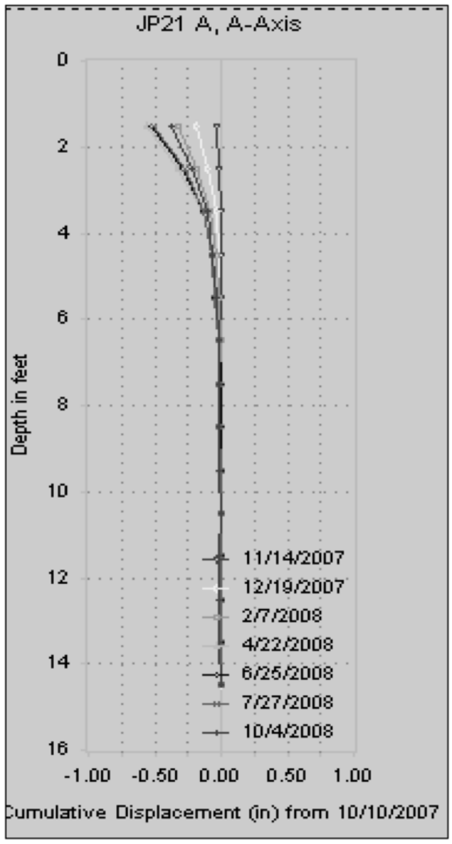

Figure 8. Inclinometer profile for control section.

It can be seen from Table 1 that the maximum lateral displacement was recorded in the inclinometers installed in the second row near the bottom of test section. The displacement was highest in the control section followed by compost section and 4% lime with 0.30% fibers. The displacement was the least in 8% lime with 0.15% fibers section followed by 8% lime section.

Table 1. Lateral movement of inclinometer casings.

Section	Inclinometer number	Maximum lateral displacement (mm)
Control	11	6.1
Section	21	14.7
20% Compost	12	5.3
Section	22	14.7
4% Lime with	13	8.9
0.30% fibers	23	13.2
8% Lime with	14	5.1
0.15% fibers	24	8.6
8% Lime	15	5.6
Section	25	6.6

5. RESULTS OF ELEVATION SURVEY

Elevation survey was conducted regularly to montor the vertical displacement of the surface soil. Elevation pegs were marked in a grid pattern both on the test sections and on the surface outside the test sections. The results of the elevation survey are presented in Table 2.

Table 2. Vertical movement as per surface elevation survey.

Section	Maximum average Variation (mm)	Minumum average variation (mm)	Total Average variation (mm)
Control	93.5	-60.3	153.8
20% Compost	40.1	-21.9	62.0
4% Lime with 0.30% fibers	69.9	16.1	53.8
8% Lime with 0.15% fibers	52.8	20.3	32.5
8% Lime	72.9	40.6	38.6
Outside	56.1	-18.4	74.4

In Table 2, positive movement is as a result of swell and negative movement is as a result of shrinkage of soil. It could be seen from Table 2 that the maximum variation of swell or shrinkage movements occured in the control section. The variation was the least in 8% lime with 0.15% fiber treated section. The maximum shrinkage was noticed during the driest month of June 2008. The desiccation cracks as explained in Section 3 were also noticed during the same period. The moisture recorded was the least during that month which also resulted in wilting of vegetation.

The swell and shrinkage results were also correlated with the laboratory test results of field soil specimens. The laboratory results showed that the swelling and shrinkage was highest in control and compost section and were the least in lime and fiber treated soil samples.

7. CONCLUSIONS

Lime, polypropelene fibers and compost were proved to be effective admixtures to mitigate desiccation cracking of soil based on laboratory tests conducted at the University of Texas at Arlington. Field test sections were constructed at Joe Pool Dam site of the United States Army Corps of Engineers to study the effectiveness of these stabilizers in the field conditions. The test sections constructed consisted of the control section, the 20% compost section, the 4% lime with 0.30% fibers section, the 8% lime with 0.15% fibers section and the 8% lime section. The test sections were heavily instrumented with moisture probes, temperature probes, inclinometers and elevation grids.

The results of the moisture probes, inclinometer survey, and elevation survey were analyzed. The results indicated that the soil treated with 8% lime with 0.15% fibers performed to the highest degree of satisfaction to mitigate desiccation cracking, reduce swell and shrinkage tendencies.

The initial swell movements of soil in the lime treated section was attributed to the swelling tendencies of the top soil. The compost and fibers, which are known to be hydrophilic absorbed higher moisture contents. However, the strength did not siginificantly improve with addition of compost. Similarly, addition of 4% lime with 0.30% fibers did not improve the properties of CH soil significantly underlining the fact that the lime quantity is insufficient for CH clay.

Performance of field test sections over a one year period suggest that best overall performance was achieved with an admixture of 8% lime with 0.15% fibers, followed by 8% lime to treat CH soils. The admixture may be used at select locations prone for desiccation cracking, to repair exising failues, and to treat the crest and slope portion prone to tensiion cracks. The results may be used not only to prevent surficial failuers of earthfill dams, but also to solve similar problems in case of highway embankments, levees, cut slopes and landfill slopes.

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