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Hugo Reservoir Embankment Depression Study

By

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ABSTRACT

The cause of unusual depressions in the embankment slopes is examined of the causeway crossing over Lake Hugo in Southeastern Oklahoma. The design of the embankment slope consisted of a rip rap armor underlain by a filter fabric and 1.22m thick sand. The failure patterns observed from the lake were oblong depressions in the riprap varying in distance from the lake pool elevation up to and near the highway shoulder. The average depression dimensions (length, width, and depth) were 7.5, 2.1, and 1.5 m respectively clay plate. The embankment interior was constructed from an unclassified borrow source consisting of predominantly silty clay but lensed with layers of clayey silt, clayey sand, and silty sand. Twelve borings originally were made to evaluate the engineering properties of the clay plate and underlying embankment material. Extensive laboratory testing in supplementary investigations, documented through the crumb, double hydrometer, pinhole, soil chemistry, and x-ray diffraction tests, confirm that the A-6 clay plate material used was highly dispersive. The original design had specified an A-7 material for the clay plating, but a value engineering proposal was accepted using the A-6 soil. The repair of the depressions consisted of cutting off water infiltration into the clay plate along the shoulder and filling in the depressions. Results were not totally successful. Additional testing and monitoring of the road performance continued into the mid-nineties.

INTRODUCTION

The purpose of this report was to investigate the cause of 126 recorded depressions in the embankment slopes of a highway embankment causeway crossing Lake Hugo on state highway 93 in Choctaw County, Oklahoma. The causeway embankment was constructed in 1971-72, with the lake level in the Hugo reservoir filling up by the end of 1974. The earthwork was constructed under plans and special provisions of Project No. SAP 12(14). The extent of the depressions covered both right and left embankment slopes between stations 425+00 and 560+00; however, the preponderance of the depressions, 78.1 percent, were located on the lakeside embankment slope. Details of the slope design are presented in Figure 1. In 1979 fishermen began informing the Division 2 engineers in Antlers, Oklahoma of the depressions observed near the lake pool elevation extending up the slope to near the shoulder. Subsequently in September 1980, a geotechnical

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investigation was conducted and preliminary findings reported. The primary dispersion test used in the 1980 investigation was the double hydrometer test, and results were generally indicative of dispersive soils. Four samples were also sent during this time to the USDA, Soil Conservation Service, and Technical Service Center in Ft. Worth, Texas. Their analysis indicated that all four samples were dispersive based on the pinhole and double hydrometer tests. Two samples were selected at random to be analyzed by x-ray diffraction by Dr. Lester Reed, at Oklahoma State University School of Agronomy (personal communication). The results were inconclusive with regard to identifying the presence of montmorillonite. Additional tests for dispersion were completed in a review of the project in 1993 to further explain the mechanisms involved. Monitoring of the roadway performance was done periodically from 1980 until the end of 1995. This paper presents the overall findings of these investigations.

The clay plate material was specified on the original plans to be an A-7 soil. The contractor submitted a value engineering proposal to change the soil classification from an A-7 to an A-6, since there was no significant difference in the compacted soil permeability between an A-6 and A-7 soil. The A-6 material was argued to be more economical being readily available along the state highway 93 corridor. The contractor was successful in his argument, and the clay plate was changed to an A-6 material and constructed.

FIELD INVESTIGATION

A detailed survey was first made of the 126 depressions by a field party in which the location of the depression in reference to the centerline of survey, length, width, and depth were recorded. Riprap was removed from slope in order to measure the depressions in the clay plate. The failure patterns observed from the lake as well as by physical measurement had the appearance of oblong depressions. The mean depression length, width, and depth measured were 7.5, 2.1, and 1.5 m respectively. Figure 2 presents a two dimensional view of the typical depression shape. It was observed that once the riprap and filter fabric had been removed, several depressions showed erosion tunnels and rills running up the slope. The clay plate material was observed to highly fissured. An unusual feature found in the clay plate construction was an approximately 0.5 m thick sand with gravel layer found in both cross sections slightly above the lake pool elevation, see Figure 3. No explanation was ever given by the Division 2 construction engineer.

A total of twelve borings were made in two cross-sections, stations 500+00 and 512+00 during the 1980 investigation. Borings 7 and 8 were continuous Standard Penetration Test borings at 0.304 m interval spacing according to ASTM D1586 standard, and the remaining ten were continuously sampled hand auger borings according to ASTM D1452 standard. The results of these borings indicated that the embankment was constructed from unclassified borrow sources within distances of 150 m from the toe of the embankment. The embankment consisted of mostly of silty clay lensed with clayey sands or silty sands. Borings at both cross-sections confirmed the presence of a 0.5m layer of coarse material near the lake pool elevation. In a 1993 supplemental investigation, the hand auger borings 1 through 4 at station 500+30 were duplicated, see Figure 3. These borings were sampled at 100-mm intervals to a depth of 1.22 m.

The distinguishing characteristics of the A-6 clay plate material were the gray and strong brown mottled color and the fissured structure with iron concretions. A comparison of the clay plate description with bottomland soils mapped along the causeway corridor identifies it as coming from the Guyton soil series (Choctaw County Soil Survey, 1979, recorrelated). The soil taxonomy of the Guyton series indicates that it has predominantly argillic B-horizons but there is the potential for natric B-horizon inclusions. These alluvial clays are known for high perched watertables and occur in a hot, humid climate.

LABORATORY TESTS

Visual observation of the depressions and associated erosion and the potential of natric B horizon borrow being used from the surrounding Guyton soil series landscape suggest that the A-6 clay plate material was a dispersive clay. A testing regiment was set up in 1993 to provide additional data to reinforce the original conclusions of the 1980 report and explain mechanisms in more detail. The laboratory testing was divided into three phases: a) index property and compaction tests, b) mechanical soil dispersion tests, and c) chemical analysis tests, see Tables 1, 2, and 3 respectively. Appropriate test procedures are indicated in the respective tables (ASTM 04.08).

Two samples were selected at random to be analyzed for x-ray diffraction by Dr. Lester Reed at Oklahoma State University, School of Agronomy (Personal Communication) during the 1980 investigation. These samples were at the depths as sample numbers 3892 and 3910 from the 1993 investigation and were so labeled. The results of x-ray diffraction test ran on sample 3892 saturated with sodium showed that there was little indication of montmorillonite but the predominate clay mineral found was illite. When the sample was saturated with sodium, it went into permanent suspension. The results of x-ray diffraction on sample number 3910 after saturation with sodium indicates that the principle clay mineral is an interlayered vermiculite-montmorillonite-chlorite.

ANALYSIS

The sources of water that promote the formation of the depressions are presented graphically in Figure 4. It appears that the significant source of water was the sand and gravel layer discovered near the midpoint of the clay plate slope, providing an avenue for lake water to enter into the embankment. Other sources of water are rainfall on the slope and parallel internal seepage. The latter two sources of water would be dependent upon cracks and fissures in the clay plate soil, which were documented in the field investigation.

The depression shapes and associated tunnels and rills observed are consistent with dispersed soil features in our experience in Division 2. Case histories of tunnel formation and associated erosion on the lakeside slopes of earth dams near the lake waterline similar to this problem are reported by (Cole et al.1977) and by (Phillips, 1977).

It was determined in the 1993 sampling of borings 1 through 4 that one sample was classified as an A-4 soil, nine samples were an A-7 soil, and twenty-three samples as an A-6 soil, see Table 1 for summary statistics. The percentage of samples that met the revised specification was 69.7.

From the quantitative analysis in Table 2, the pinhole test data indicates that predominantly the samples tested were dispersive with 87.5 percent having a D2 classification and 12.5 percent having a probable dispersion classification of ND4. Based on the hydrometer test results from Table 2, 30.3 percent of the samples are probably dispersive with 66.7 percent where other tests are needed to establish whether the sample is significantly dispersive. And the crumb test results show that 53.1 percent of the samples are dispersive. The samples indicating a 3 or 4 reaction rating in the crumb test were positively dispersive in the pinhole test thus pointing to its value as a good positive indicator. The criterion used for these quantitative tests was (Soil Mechanics Note No. 13 1991).

In the chemical analysis test results from Table 3, a sample of the pore water is extracted from saturated slurry and analyzed for cations. A total of 55.2 percent of the samples was found to have more than 60 percent of their total salts being sodium, which indicates dispersive soils. A review of the relationship between dispersive soil classes and total dissolved pore water salts (Sherard et al., 1976) can be seen in Figure 5. Results indicate only 17.2 percent of the samples can be classified into Zone A for dispersive soils with the vast majority, 72.4 percent ranked in the nondispersive Zone B and the remainder in transition Zone C. The estimate for this result is at very low total salt concentrations, higher percentages of sodium may occur in samples and the samples still not have dispersive field behavior. Because so few salts occur in these soils, the influence on the soil behavior is minimal. Also from Table 3, the SAR and ESP provide a good indication of the stability of clay soil structure to breakdown and particle dispersion. A SAR between 4 and 12 (Carter et al., 2000) provides a good indication of soil dispersion and results show that 67.9 percent of the samples tested are potentially dispersive. Soils with an ESP greater than 2 percent may be susceptible to spontaneous dispersion (Mitchell, 1993). Results from Table 3 indicate that 84.4 percent of the samples are dispersive.

The results of the x-ray diffraction on the two samples tested are inclusive with regard to identifying the presence of montmorillonite clay mineral. However, both samples went into permanent suspension upon saturation with sodium.

CONCLUSION

It can generally be concluded from the battery of tests performed that the depressions are the result of dispersive soil behavior. Also there is the likelihood that an unexplained construction deviation from the plans in the form of a sand and gravel layer near mid height of the clay plate layer facilitated the formation of some of the depressions.

Results of the dispersion tests from Table 2 shows that the pinhole tests, a direct and performance test as opposed to double hydrometer and crumb tests, indirect and index tests, is far superior in identifying soil dispersive behavior. Similarly, in the chemical tests, SAR and ESP show indication of dispersive clay potential.

An explanation of the randomness of occurrences of the depressions can be found in the study of soil genesis of sodic (dispersive) soil development of the Guyton soil series. The soil taxonomy for the Guyton series points to the presence of a natric B-horizon inclusions found in the borrow source found along the causeway corridor. Classical soil science theory views natric (also known as solonetz) soils as one stage in evolution of the sodic (dispersive) soil (Carter et al., 2000). The natric soil has a relatively high amount of exchangeable sodium and a low amount of soluble salt references Figure 5. If there is a slow rate of lowering of the watertable, the ground water will add more sodium salts by capillary rise through the soil horizons, followed by evaporation during the hot season. During the rainy season, the soluble salts are leached. The amount of exchangeable sodium gradually increases. This soil natric soil genesis will have occurred as random inclusions.

ACKNOWLEDGEMENTS

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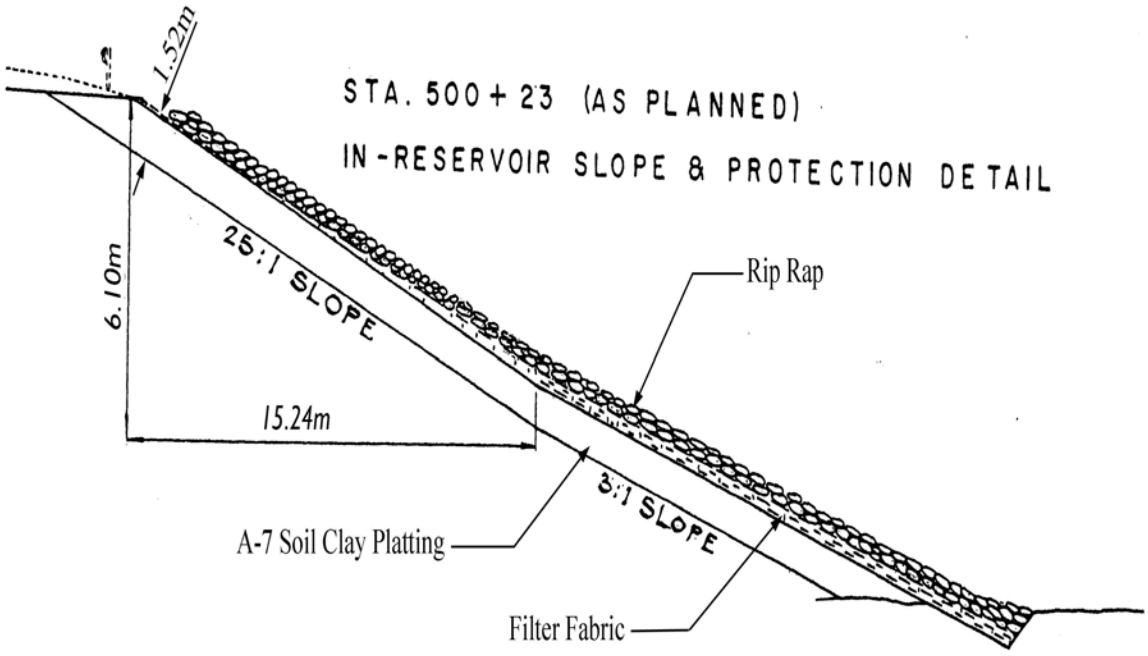


Figure 1 - Slope Design Detail

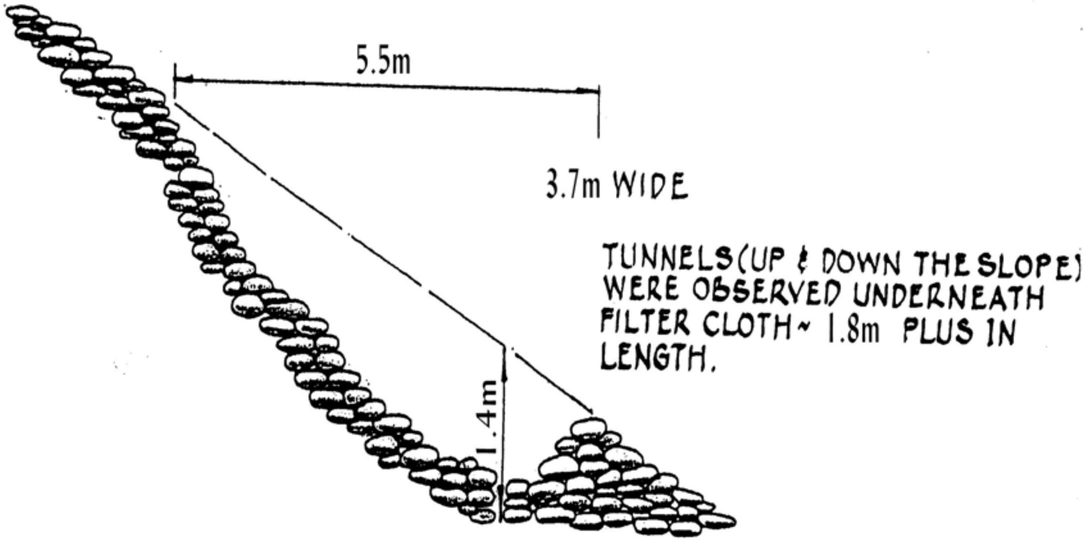


Figure 2 - Two Dimensional View of Typical Depressions

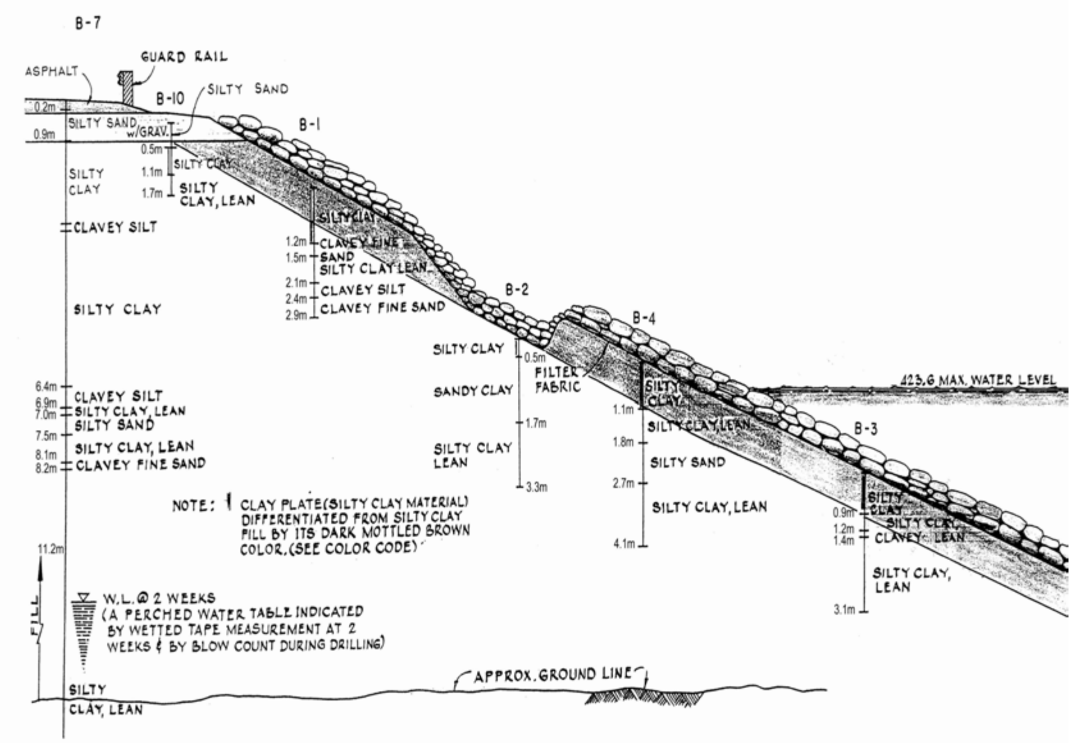
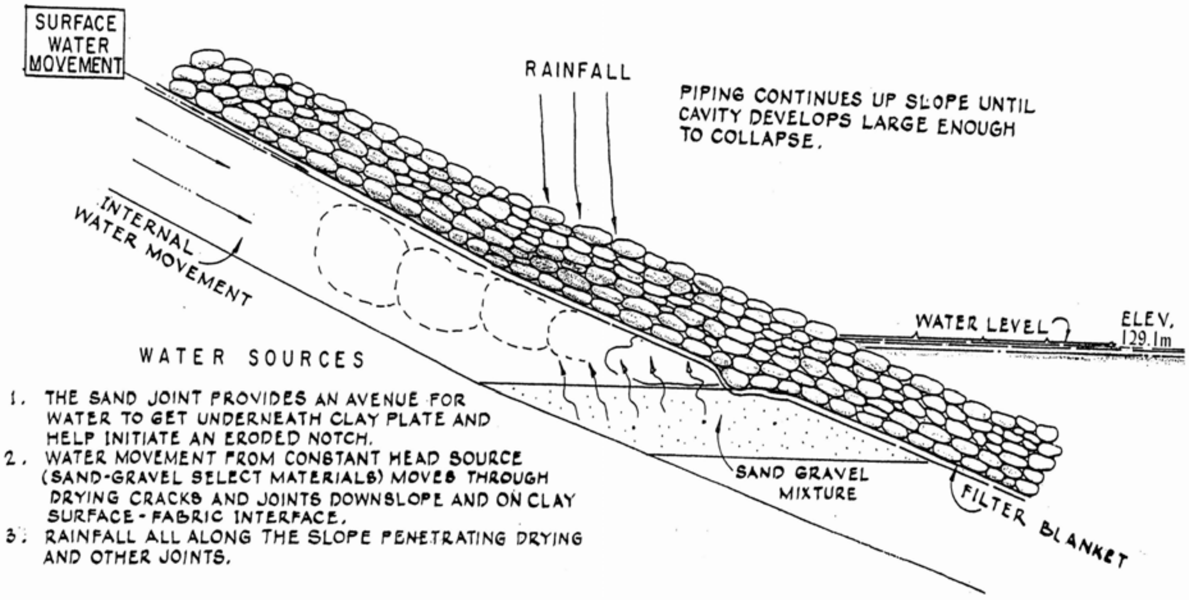


Figure 3 - Hand Auger Boring Location



WATER SOURCES

1. THE SAND JOINT PROVIDES AN AVENUE FOR WATER TO GET UNDERNEATH CLAY PLATE AND HELP INITIATE AN ERODED NOTCH.
2. WATER MOVEMENT FROM CONSTANT HEAD SOURCE (SAND-GRAVEL SELECT MATERIALS) MOVES THROUGH DRYING CRACKS AND JOINTS DOWNSLOPE AND ON CLAY SURFACE-FABRIC INTERFACE.
3. RAINFALL ALL ALONG THE SLOPE PENETRATING DRYING AND OTHER JOINTS.

Figure 4 - Sources of Water

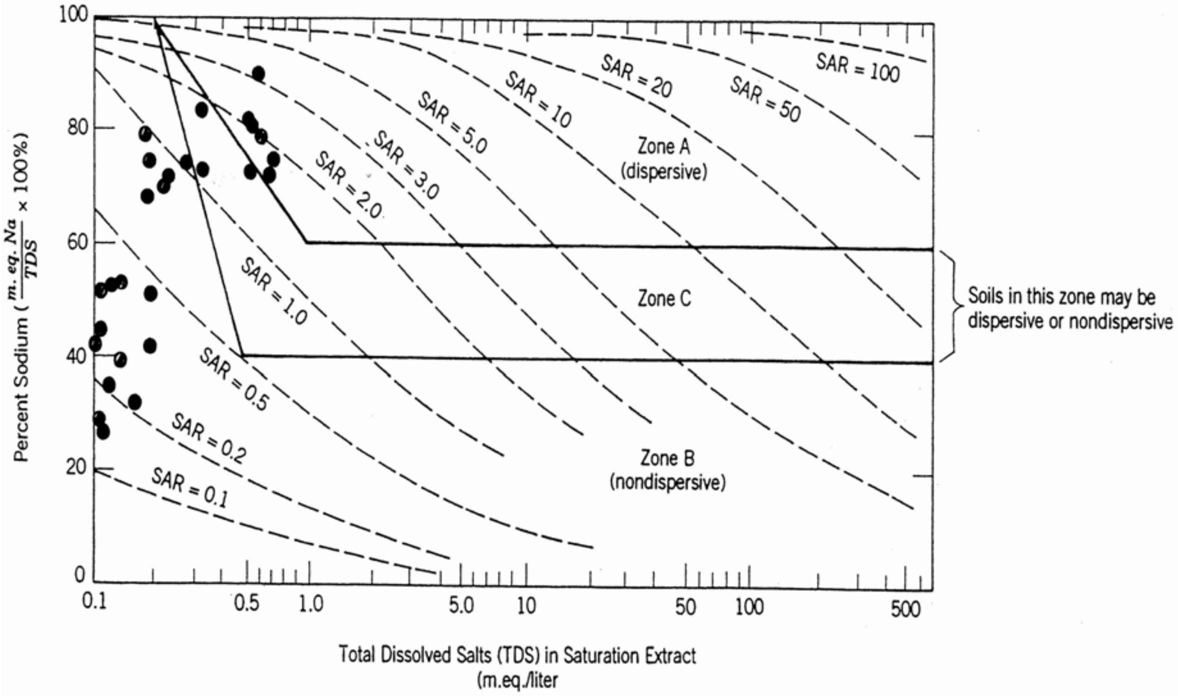


Figure 5 - Relationship Between Dispersive Soil Classes and Total Dissolved Salts