"ANALYSIS OF CLAY FILL USING X-RAY TECHNIQUE"

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Abstract

Use of moderately to highly plastic clays to backfill utility trenches is a common procedure and, if performed properly, results in acceptable performance. Placed improperly, however, plastic clays can either settle or heave. This paper presents an analysis of collapse of backfill associated with placement of clay below optimum moisture content as determined by ASTM D 698.

High matrix suction within plastic clay results in the formation of dense clods with very high internal effective shear strength. Dependent upon the compaction effort, these clods may not break down during placement, resulting in an interlocked structure with large voids between the clay clods. Upon wetting, the suction pressure decreases, thus reducing effective stress, allowing the clods to break down and settle. For the case study, the 24 feet of fill settled up to 3 feet.

Included are x-ray photographs of the fill before and after collapse, and of properly placed fill and native soils. Full moisture, suction and relative consistency profiles are provided.

Introduction

In late summer of 1999, Reed Engineering Group was called out to investigate the collapse of a recently constructed utility line. This collapse was occurring within a fill of approximately 24 feet and centered within a conflux of several underground utilities. According to project records, the fill was composed of on-site sandy clays and clayey sands that had been placed under controlled conditions. At the time the investigation was initiated, the main area of the collapse had settled approximately 10 inches and adjoining areas were beginning to show signs of settlement and soil collapse. Several rounds of soil sampling and testing were then conducted, which included soil suction testing and x-ray analysis. When the investigation was completed, the initial area had settled over 3 feet.

This paper presents a brief case history of this investigation. The methodology and analysis used to evaluate the condition of the fill materials and the mode of collapse are presented.

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Case Study

In mid-August 1999, Reed Engineering Group began an investigation to evaluate the cause and potential for future settlement of a new road within a light industrial development. The site was located within the flood plain of the Elm Fork Trinity River over shale and sandstone of the Woodbine Formation. Soil conditions consisted of varying deposits of alluvial soils over residual clays and weathered shale. The alluvial soils varied from sandy clay to clayey sand. The residual soils were predominately sandy clay and clay.

At the beginning of the investigation, a section of paving had been removed at Station 25+00 of the new road. This eight-inch thick concrete section was demolished because of severe cracking and settlement. At the time, this road was not open to general traffic but had been subjected to loads from concrete trucks and landscaping vehicles.

This section of paving was located over a conflux of underground utilities that included sanitary and storm sewer lines (Figure 1). The storm lines were placed 6 to 7 feet below finished grades, while the sanitary line was located 25 to 27 feet below the top of paving. The storm lines consisted of pre-cast, non-gasketed, concrete pipe that extended north from a detention pond just south of the road. The line under the failed area was capped at the edge of the paving to allow for future development. Sanitary improvements consisted of the main line, a manhole and a lateral line.

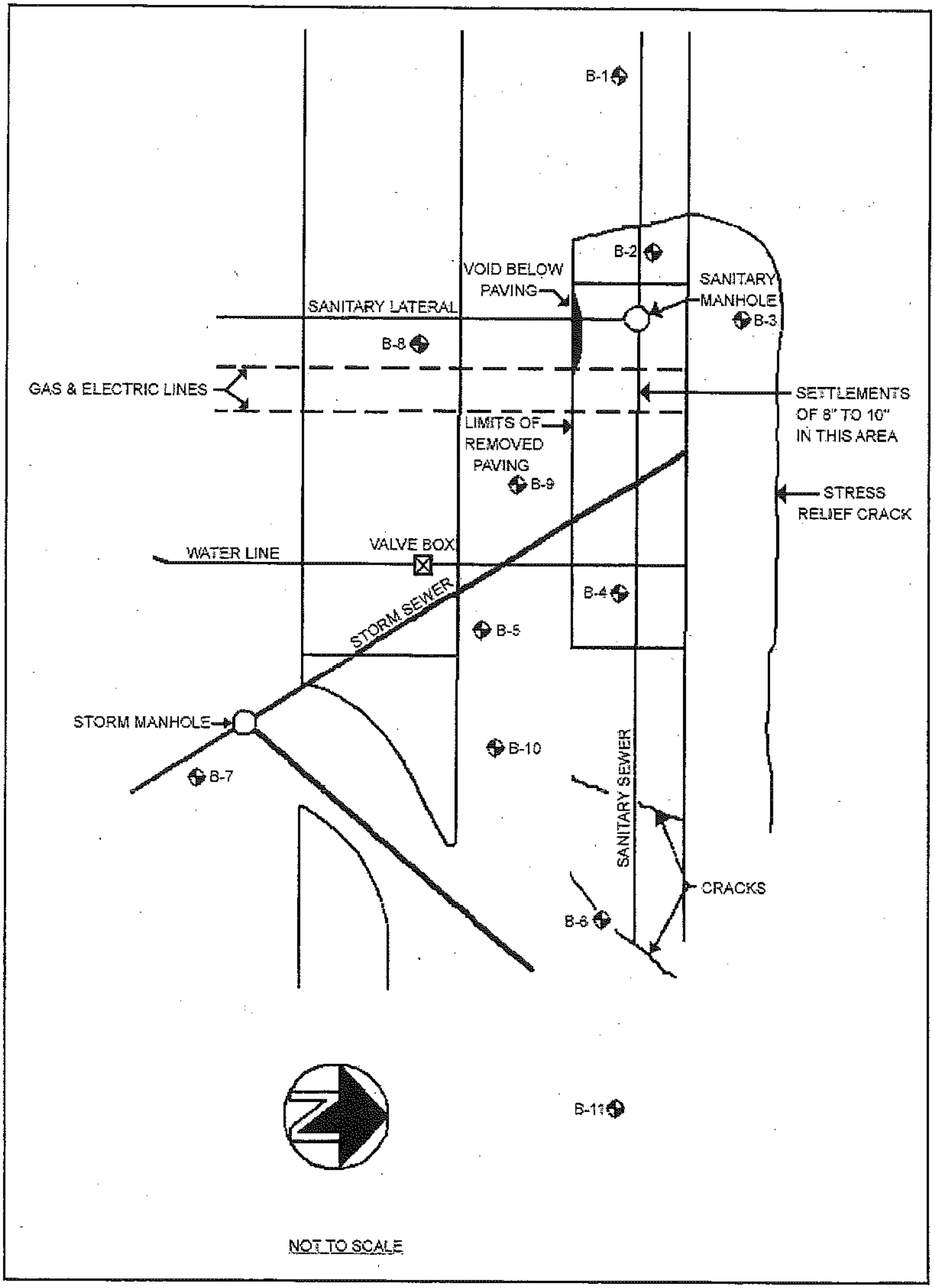


Figure 1: Plan of Borings for first and second rounds of soil sampling in August and October, 1999. Note location of underground utilities and distress.

When the detention pond was operating at normal level, water would back up into the storm pipe and under the roadway. The only section that exhibited severe settlement was that portion over the utility lines within the north, westbound lanes (Station 25+00).

Initially, two small test pits were opened to evaluate the condition of the fill. Water was noted flowing from the sides of the excavations at an approximate depth of 5 feet. Upon completion of one pit, a stress-relief crack developed and the side-wall of the excavation failed within a matter of minutes.

Rough measurements were also made on the water level in the storm line downstream of the failed area. A manhole was removed between the detention pond and the test pits. Water in the manhole basin was estimated at roughly the same elevation as the water seen flowing within the test pits.

A few days later, the area was exposed to rain, which caused further settlement. The distress began to extend west and east of the initial problem area along the sanitary sewer.

A stress relief crack could also be seen developing along the northern edge of the paving. According to construction personnel, this crack mirrored the extent of the initial excavation made to install the underground utilities. Cracks within the concrete paving were also present over the downstream portion of the sanitary sewer, east of the initial area.

Minor amounts of settlement were also noted along the sanitary lateral that extended south of the manhole. It was then decided to investigate the condition of the fill materials.

Three rounds of soil sampling and testing were performed around the initial area and along the sanitary sewer line. The purpose of this testing was to evaluate the quality of the soils and level of compaction. The initial round began in September 1999 and consisted of drilling several borings around and in the failed area. The locations of the borings are presented in Figure 1. Locations were selected based on accessibility, the location of underground utilities and whether the locations had collapsed or were over fill.

Samples of the fill were obtained using 3-inch diameter Shelby tubes. Pocket penetrometer, moisture content, and soil suction analysis were performed on selected samples.

Later, areas adjacent to Station 25+00 began to show signs of collapse. In October 1999, a second round of sampling and testing was conducted just south of the failed area and east along the sanitary sewer line.

A third round of drilling was then conducted at the request of the local municipality. Samples of fill materials were obtained along the main sanitary line, west and east of the failed area. Reed Engineering Group was then informed that a section of paving around a sanitary sewer manhole downstream of the failed area had been replaced because of excess settlement.

Because of time constraints, soil suction tests were not conducted on samples taken during the third round of drilling. Pocket penetrometer, moisture content and dry unit weight determinations were performed.

At the conclusion of the field portion of the investigation, the initial area had settled by over three feet. The collapse extended south of the initial section along the sanitary lateral, and east along the sanitary main. Settlement extended approximately 15 feet upstream of the sanitary manhole. The stress relief crack along the northern edge of the paving continued to develop. The area between the paving and relief crack eventually settled in unison with the road.

The area within the west-bound lanes that had settled was eventually repaired. These repairs consisted of removing the fill within the sanitary sewer trench and then placing these soils back into the excavation. Storm lines that were disturbed during this process were replaced with gasketed pipe. To date, no appreciable amount of movement has been reported.

Laboratory Analysis

As part of the investigation, several samples from the first and second rounds of drilling were submitted for testing. This testing included performing pocket penetrometer, soil moisture and soil suction tests. Samples from the third round of drilling were submitted for soil moisture and dry unit weight determinations. Field density reports were also reviewed to evaluate the level of compaction.

Figure 2 shows the relationship between soil moisture contents between collapsed and non-collapsed areas. For information purposes, in-place moisture measurements from field density reports are also presented. Soil moisture contents in non-collapsed areas are generally lower than from collapsed locations. This relationship was true for all borings drilled west and east of the distress at Station 25+00.

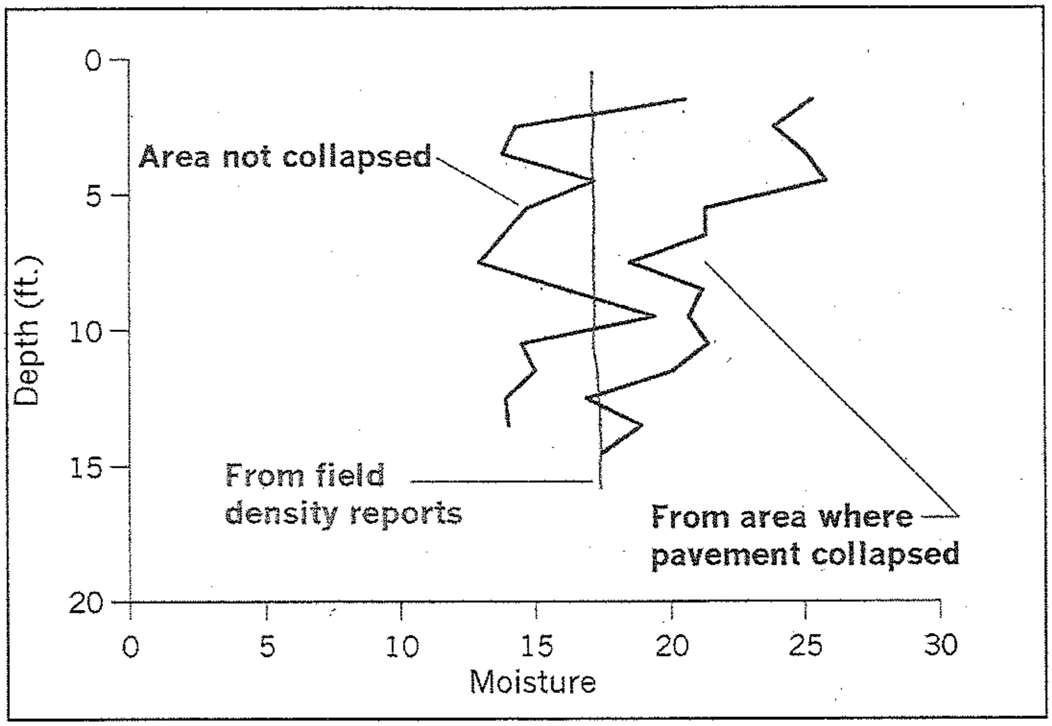


Figure 2: Comparison of soil moisture with depth between collapsed and non-collapsed areas. Results of in-place field density tests are shown for comparison.

Test results indicated fills along the sanitary line that were currently stable had soil moisture contents of 10 to 19 percent with corresponding pocket penetrometer readings of 4.5 tons per square foot (tsf) or higher. Areas that had exhibited collapse or settlement had moisture contents of 19 to 26 percent. Penetrometer values were generally below 2.5 tsf.

Figure 3 presents a comparison among pocket penetrometer readings, soil moisture content, and soil suction values from collapsed and non-collapsed locations. Note the relationship is the same as in Figure 2. Collapsed areas contain lower penetrometer readings that correspond to relatively higher moisture contents, while readings from non-collapsed areas are high. This indicates low soil moisture at these locations.

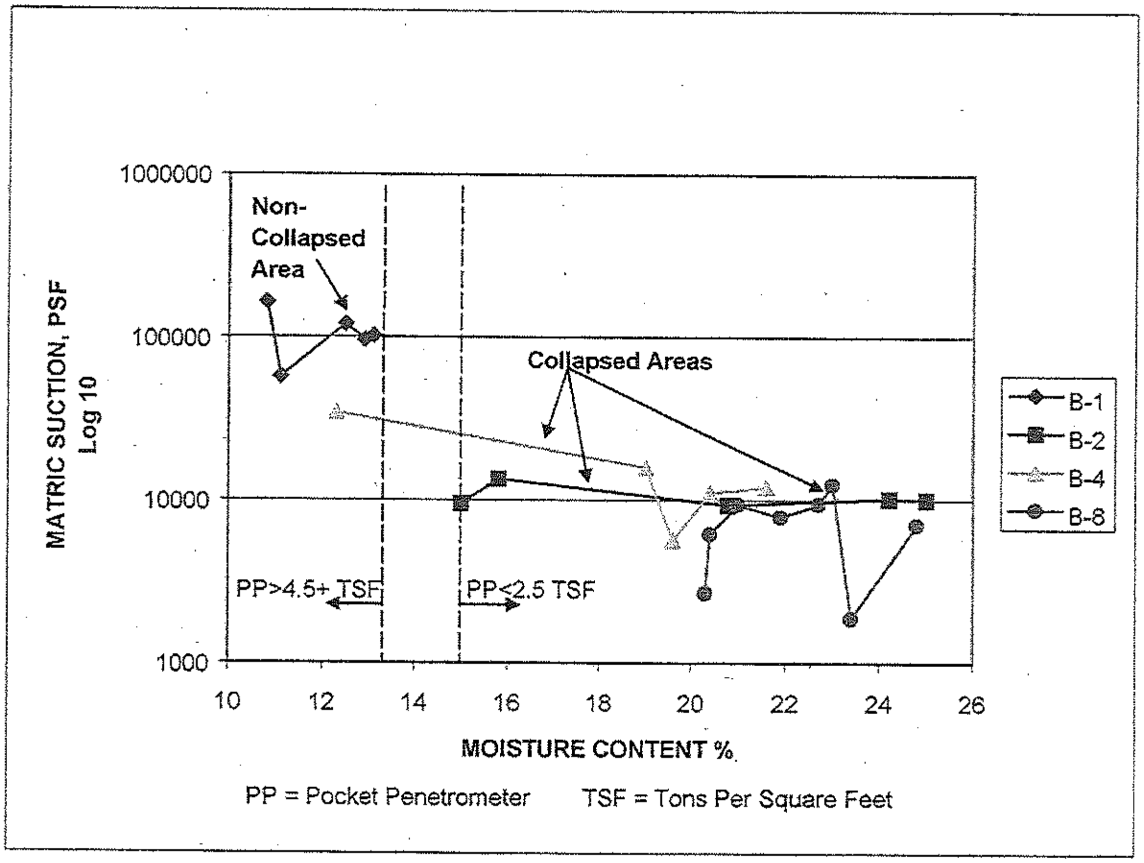


Figure 3: Relationship among matric suction, soil moisture and pocket penetrometer readings for samples taken from utility trench for collapsed and non-collapsed areas.

For dry soils, soil suction values varied considerably while, for fill materials with higher moisture contents, suction values were more uniform.

Role of Matric Suction

When previously undisturbed clay soils are excavated, the soil mass is broken into clods. The lower the moisture content is, the harder the clods become. As moisture increases, the clods become soft. Matric suction plays a direct role in the formation of these clods in disturbed (i.e., excavated) clay soils. Matric suction is defined as the internal stress within clay that is directly related to the soil structure. When previously undisturbed clay soils are excavated, this stress causes the formation of clods with high internal effective shear strength. This internal stress is reduced when the moisture contents of the clods and/or soil mass increases.

Figure 4 shows the relationship among soil moisture, density, and matric soil suction for a highly (CH) plastic clay. As seen, the tendency is for matric suction to decrease with an increase in soil moisture.

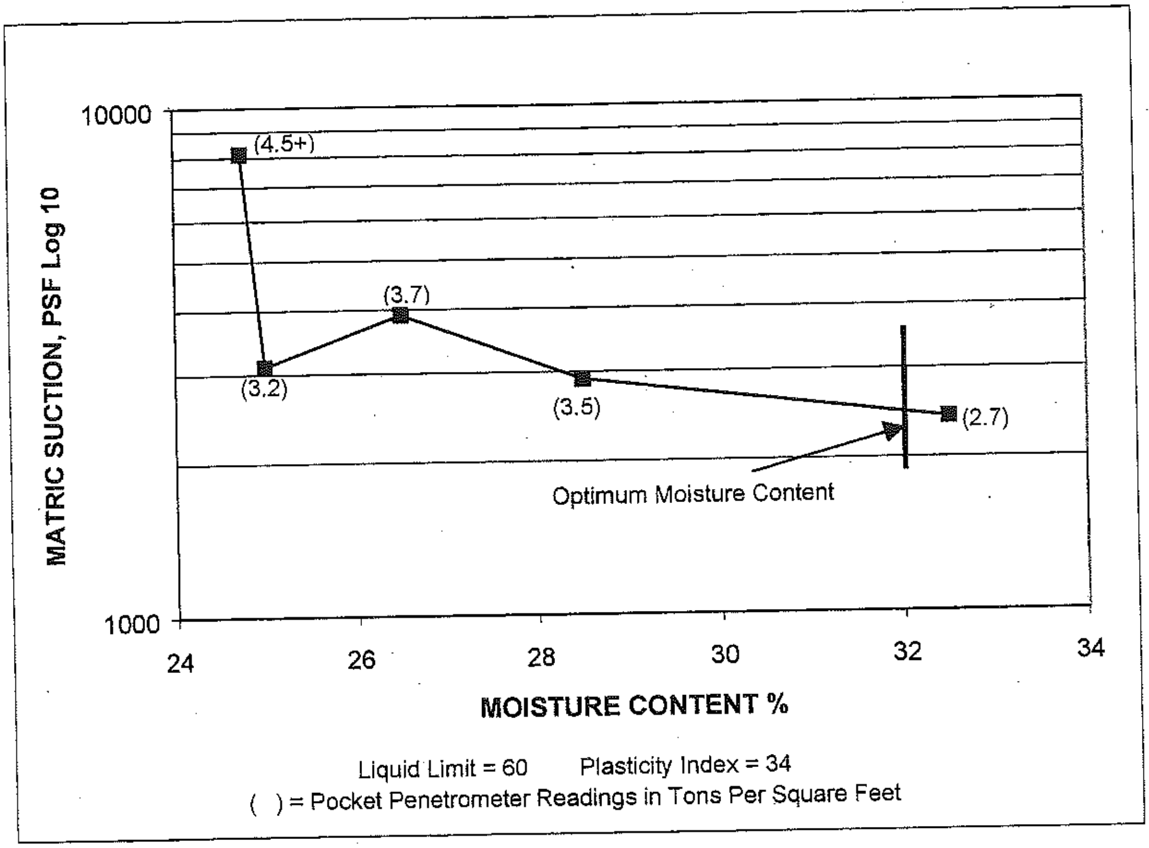


Figure 4: Relationship of matric suction and soil moisture for laboratory samples compacted in accordance with ASTM D-698. Pocket penetrometer readings are shown for comparison.

Research done by Rao and Revanasiddappa[3] shows that clay soils compacted below optimum moisture content, regardless of compactive effort, had higher matric suction values than when compacted at optimum moisture. The higher matric suction values corresponded to a higher potential for collapse when these soils were exposed to water.

This research also found the variation in suction values between samples decreased with increasing moisture content.

The fact that matric suction values are higher at lower moisture contents and the variation in suction values increases supports the idea that clay soils compacted below optimum moisture content have a more irregular soil structure than those compacted at or above optimum moisture.

Considering the results of Rao and Revanasiddappa's research, clay soils compacted below optimum moisture content should contain large amounts of soil clods with the possibility of large void spaces between the particles. Consequently, placing clay fills at

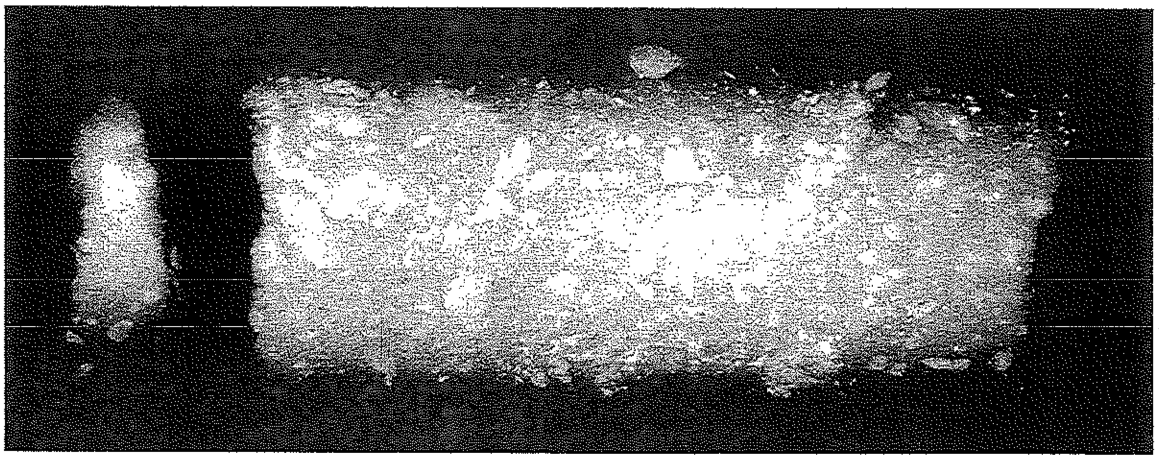
[3] Rao, S.M., and Revanasiddappa, K. "Role of Matric Suction in Collapse of Compacted Clay Soil", Journal of Geotechnical and Geoenvironmental Engineering, ASCE, January 2000, pgs. 85 to 90.

or above optimum would result in relatively fewer clods with less void space. This is caused by a reduction in effective stress, which in turn is caused by a reduction in matric suction. The soil structure of clays placed below optimum would collapse when exposed to moisture as the matric suction decreases and reduces the effective shear stress of the individual clods.

X-ray Analysis

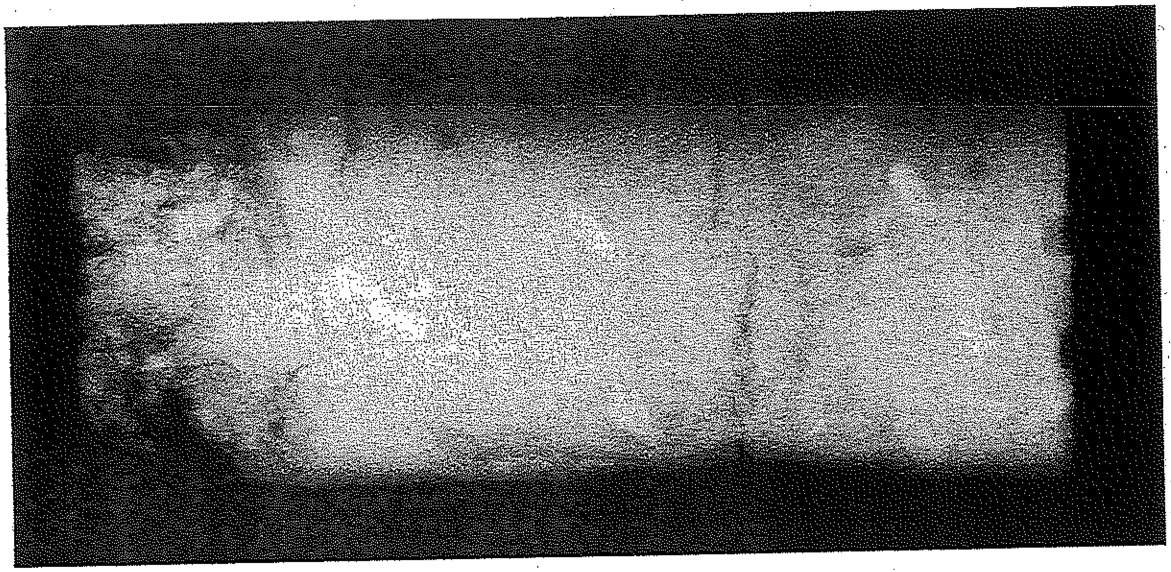
As part of the investigation, samples from collapsed and non-collapsed locations were submitted for x-ray analysis. This analysis was done in general accordance with ASTM D-4452.

Considering the above discussion on the formation of clods in excavated soils, these x-rays indicated the fills used in the utility trenches were compacted below optimum moisture. This is evidenced by the large amounts of soil clods. Photograph 1 shows x-rays of a sample of fill from the utility trench.



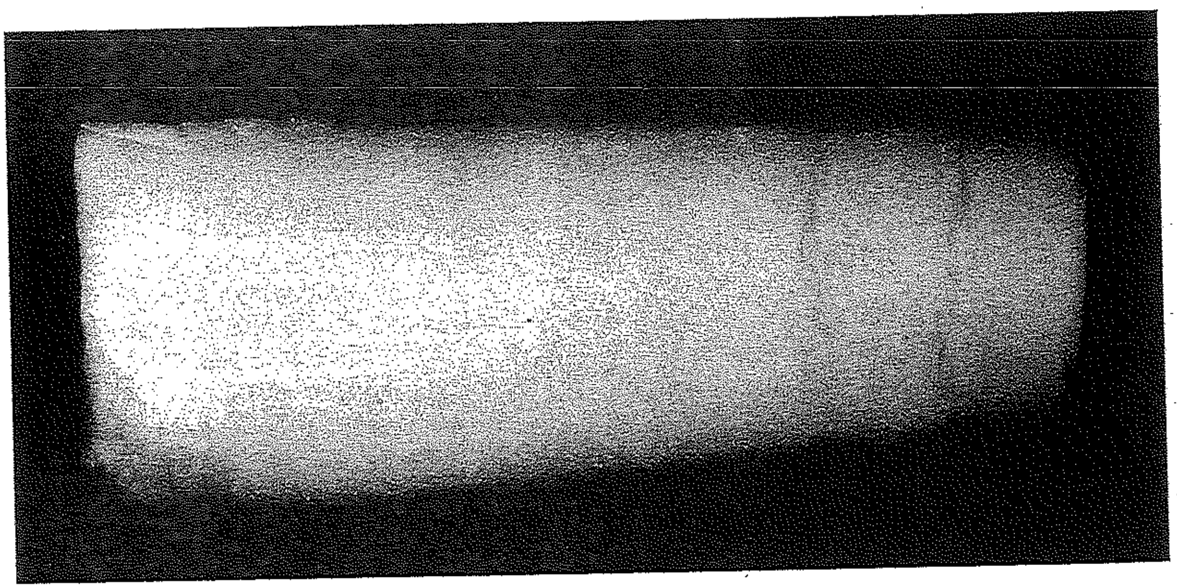
Photograph 1: X-ray of sample from utility trench. Note amount of soil clods within sample.

In all samples, there were a number of clods that resulted in a soil structure with a relatively large void ratio. Additional x-rays were made on samples from a project in the same area that utilized similar soils for fill. These x-rays are presented in Photograph 2.



Photograph 2: X-ray of sandy clay fill placed above optimum moisture content. Note number of soil clods as compared to Photograph 1.

When compared with samples of soil placed above optimum moisture content, relatively few clods are seen. Comparisons between the x-rays of fill samples and undisturbed alluvial clay indicated that clods were absent in the natural soils.



Photograph 3: X-ray of undisturbed alluvial clay. Note lack of soil clods as compared to Photographs 1 and 2.

Conclusion

Based on the results of the investigation, it appears the on-site soils were compacted below optimum moisture. Clods that formed when these soils were excavated were not broken down during the compaction process. This resulted in an interlocked soil structure with relatively large voids between the clods.

The clods formed by this process had high matric suction values and internal effective shear strength. As the subsurface moisture increased, the matric suction decreased, which reduced the internal effective shear strength of the soil clods. As these clods began to disintegrate, the amount of voids between the particles decreased. This resulted in settlement of the overlying pavement and soils.

This conclusion was confirmed by x-ray analysis of selected samples from collapsed and non-collapsed areas. When compared with x-rays of similar materials that had been compacted above optimum moisture content, samples from the utility trench were found to have a large number of clods. Further comparison between x-rays of the fill and undisturbed materials showed that no detectable clods were present in the natural soils.

Based on the research by Rao and Revanasiddappa, the elevated and varied matric suction values measured from the samples are also indicative of clays being compacted dry. This work shows that x-ray analysis and matric soil suction tests can be used to qualify the condition of clay fills.