TECHNICAL REPORT STANDARD PAGE

1. Report No. LADOTD/322	2. Government Accession No.
3. Recipient's Catalog No.	
4. Title and Subtitle: Digital Image Analysis Techniques for Fiber and Soil Mixtures	5. Report Date: May 1999
	6. Performing Organization Code
7. Author(s): Ronaldo Luna	8. Performing Organization Report No.
9. Performing Organization Name and Address: Department of Civil & Env. Engr. Tulane University New Orleans, LA 70118	10. Work Unit No.
	11. Contract or Grant No. 98-2TIRE
12. Sponsoring Agency Name and Address: Louisiana Transportation Research Center 4101 Gourier Baton Rouge, LA 70808	13. Type of Report and Period Covered: Final Report Aug. 97 - May 1999
	14. Sponsoring Agency Code
15. Supplementary Notes	

16. Abstract

ABSTRACT

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17. Key Words	18. Distribution Statement

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 57	22. Price

Form DOT F 1700.7 (8-69)

DIGITAL IMAGE ANALYSIS TECHNIQUES FOR FIBER AND SOIL MIXTURES

by

Ronaldo Luna, Ph.D., P.E.

Department of Civil and Environmental Engineering
Tulane University
New Orleans, LA 70118

LTRC PROJECT No. 98-2TIRE
STATE PROJECT No. 736-99-0572

conducted for

Louisiana Department of Transportation and Development
Louisiana Transportation Research Center

May 1999

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The objective of image processing is to visually enhance, quantify, and/or statistically evaluate some aspect of an image not readily apparent in its original form. Processed digital image data can be analyzed in numerous ways. In order to summarize the gathered data into helpful information, classification techniques must be employed. Most analysis techniques use image-classifying algorithms that involve aspects of mathematical morphology. Digital image analysis is a powerful method for gathering information using a computer-based system. The analysis will be geared towards the applications of digital imaging in Geotechnical Engineering and soil enhancement. The use of admixtures, such as synthetic fibers, in soils is intended to increase the mechanical properties of the soil. These synthetic produce net-like configurations when used in correct quantity, which in turn provides a means for reinforcement of the soil matrix and therefore an increase in strength. Characteristics such as void ratio, spatial variability, orientation, roughness, and the ability to identify the synthetic fiber in the sample are all essential in forming parameters to the use of the admixture.

ACKNOWLEDGEMENTS

The work described in this report was made possible with the support of the Louisiana Transportation Research Center (LTRC). Additional support was provided by the Department of Civil and Environmental Engineering and the School of Engineering at Tulane University. This support is gratefully acknowledged. The contribution of numerous investigators that worked directly in this project is highly recognized. These individuals are: Jasmine Hopkins, Patrick Ibert, Yong Wu, Jessica Tyler, Marcus Howard, Dr. Lee Zimmerman, and Dr. Joe Omojola. Investigators at LTRC also made this project possible by a strong collaboration and sharing of data and resources, in particular Mark Morvant, Dr. Khalid Farrag, and Kevin Gasspard. During the course of the research study, discussions were made with individuals in the research community which helped forming and focusing these ideas, in particular: Dr. David Frost, Dr. Chung-Yi Kuo, and Jimmy Hill.

IMPLEMENTATION STATEMENT

The results of this research can be used in the goal of automating the process of analyzing the soil/fiber mixtures via image processing. Soil/fiber mixtures are used by LA DOTD in the stabilization of road sub-grades, bases, and embankment slopes. What this study sets to achieve is the derivation of a systematic and automatic process of image processing that can be used to identify the soil/fiber mixtures. By identifying the mixtures, further steps can be taken to identify various soil properties.

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INTRODUCTION

In general accordance with the Transportation Innovation and Research Exploration program (TIRE), this project was set to explore new techniques of digital image analysis to study the nature and character of materials being used or considered for use by the LA DOTD. As originally proposed, this project was to consider two different materials that were deemed pertinent to the Louisiana Transportation Research Center (LTRC). These two materials were (1) asphalt concrete and aggregate structure and (2) the use of synthetic fibers in pavement bases and slope stabilization. However, after discussions with the program manager and other researchers at LTRC, it was decided that synthetic fibers would be the only material studied in this project.

LTRC has two in-house projects related to the use of fibrillated polypropylene fibers or geo-fibers in conjunction with Louisiana soils. The first project is related to the effect of fibers in a soil-cement mixture. The second project is related to the effect of these same fibers in natural Louisiana soils (silts and clays) for stabilization of roadway embankments where both field and laboratory tests were performed by LTRC. The common goal of these projects is to evaluate the added value of the fibers when used in conjunction with Louisiana soils and soil-cement.

In addition to the body of this report supplementary material related to the topics discussed are included in the four appendices located in this volume.

OBJECTIVE

- Establish a working relationship with the LTRC and LA DOTD in image analysis techniques for material characterization.
- Identify image processing routines to characterize the complex structure of soil/fiber mixtures.
- Prepare a report that includes the research findings and recommend future work in this area for LTRC.

SCOPE OF WORK

- Integrate an image analysis system to capture, synthesize, manipulate, and analyze images from a specimen prepared in the laboratory or field.
- Select and develop analytical routines that can quantify the character structure and fabric (if any) of soil/fiber mixture.

METHODOLOGY

Image Processing Background

Image processing and analysis is a combination of the visual enhancement of an image and the numerical evaluation of some aspect of the acquired image that would not be apparent in its analog form. The processing of a digital image refers to the actual refinement procedure. The analysis of a digital image is the translation of the improved image's features into useful data *[1]*. The necessity for this technology is due primarily to the difference between human vision and "computer vision." This contrast is most pronounced when comparing the type of information obtained from images and the methods used. Human vision is fundamentally qualitative and comparative, but not quantitative. Humans judge the relative size and shape of objects by mentally manipulating them to the same orientation and overlapping them to perform a comparison. Humans are particularly poor at assessing the color or brightness of features within images without direct comparison by positioning them adjacently *[1]*. Progressive variations in brightness are typically dismissed as being representative of fluctuations in illumination, for which the human visual system compensates automatically. In a gray scale image where the image is an array of intensities in a two-dimensional (2-D) space, the variation of intensity can provide a sense of texture, trend, edges, and anomalies on a surface. In a controlled environment, the variation of intensity is not merely changes in illumination, but an index of physical characteristics of a material.

Digital image analysis is a powerful method for gathering information. Relying on the convenience of computers, image processing and analysis methods have been used extensively in other disciplines for some time. However, their potential has only begun to be recognized in civil engineering in the past few years. The advancement of technology and decline in cost of computers have provided numerous opportunities for significant advances in geotechnical and materials engineering. Researchers have applied digital image analysis in geotechnical engineering to study: cohesionless soil fabric, membrane penetration, mineral phase percentages in granular rocks, pavement cracking particular shape, and morphological analysis of geotextiles *[2],[3],[4],[5],[6],[7],[8]*. This field of study continues to grow in its form of applications as equipment becomes cheaper and better. For further information on civil engineering application of imaging technology, please refer to the compilation published by ASCE in 1998 *[9]*.

Computer based digital image analysis may involve aspects of mathematical morphology, stereology, and image processing. After thirty years of development, mathematical morphology has become one of the major tools in 2-D image processing. Mathematical morphology is the use of systematic numerical algorithms that extract qualitative and quantitative information from digital spatial data. Mathematical morphology also discards excess information in a controlled way. The removal of irrelevant detail makes images easier for analysis *[2]*. Stereological methods are precise tools for obtaining quantitative information about 3-D microscopic structures, based mainly on observations made on sections of a specimen. It has been demonstrated that without stereology, material science cannot evolve into a truly quantitative science *[10]*. The information extracted using these methods may lead to a better understanding of an observed structure and related phenomena.

Digital Image Analysis

After acquisition and storage, the digital image can be subjected to a number of processes that require handling of the image matrix. A digital image is a two-dimensional (2-D) matrix (or array) where its elements are called pixels (picture elements) (figure 1). The pixel values are a light intensity function f(x,y) where x and y are spatial coordinates and the function "f" is a measure of brightness (or gray level) or color of the image at that point. In a gray scale image the value of 0 denotes black (or lowest intensity) and the value of 255 denotes white (or highest intensity). A pixel usually denotes a dot on a computer display or monitor depending on the screen resolution.

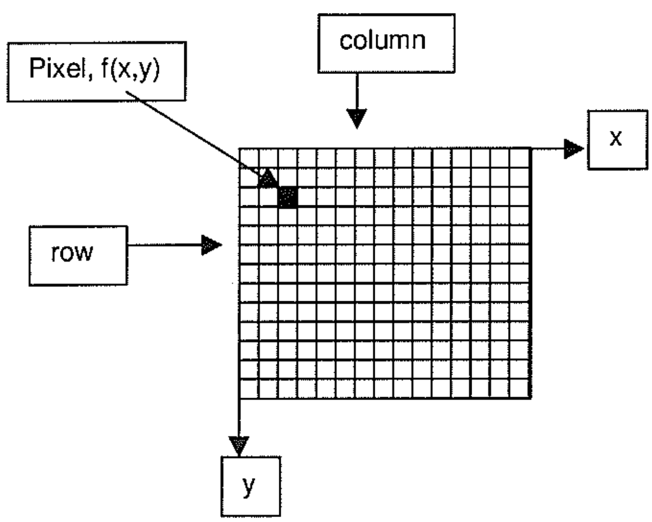


Figure 1

Matrix representation of an image

Image processing is a manipulation of matrices in the form of algorithms. Most processing functions can be implemented in a software application. The only reason to have specialized image-processing hardware is the need for speed in some applications. However, with high-speed desktop computers and storage devices becoming so accessible and affordable, specialized hardware is often not necessary. Today's image processing systems are a blend of off-the-shelf computers and specialized image processing accessories with overall operation being orchestrated by software running on the host computer. Therefore the selection of a software package that controls all aspects of the analysis became crucial in this study. An evaluation of the available applications was performed and is included in appendix A. The software used for most of the measurements was Inspector 2.1® by Matrox, Inc. It was readily compatible with the frame grabber purchased, it was inexpensive, and it allowed for fast operation upon installation. The only drawback related to this software was its limited ability to customize routines and to generate macro operations. The software identified for future testing would be Aphelion v. 2.31®, which is truly for development purposes but is also much more expensive.

Equipment and System Integration

Acquisition, processing, and analysis of images required the integration of a system that consisted of a series of components purchased from different sources and assembled at Tulane University. Figure 3 shows a schematic of the different components and how it was connected for the purpose of this study.

Image acquisition. To acquire an image, both an optical device and a charged couple device (CCD) camera are required at the forefront of the system. These devices together define the scale and field of view (FOV) of the image and translate it into a window frame. The output of the camera is a video signal that is sent to the computer monitor for display in a window frame. Once the lighting and preparation of the surface are ready, the image is captured via a "frame grabber." A high-quality, low-cost PCI color and monochrome Meteor® frame grabber manufactured by Matrox, Inc. was used. The resolution of the image is a product of both the CCD camera and the frame grabber. Image acquisition is a time consuming task since the image quality depends on the ability to control the varying parameters such as lighting, material surface, field of view, magnification, contrast by dyeing, etc.

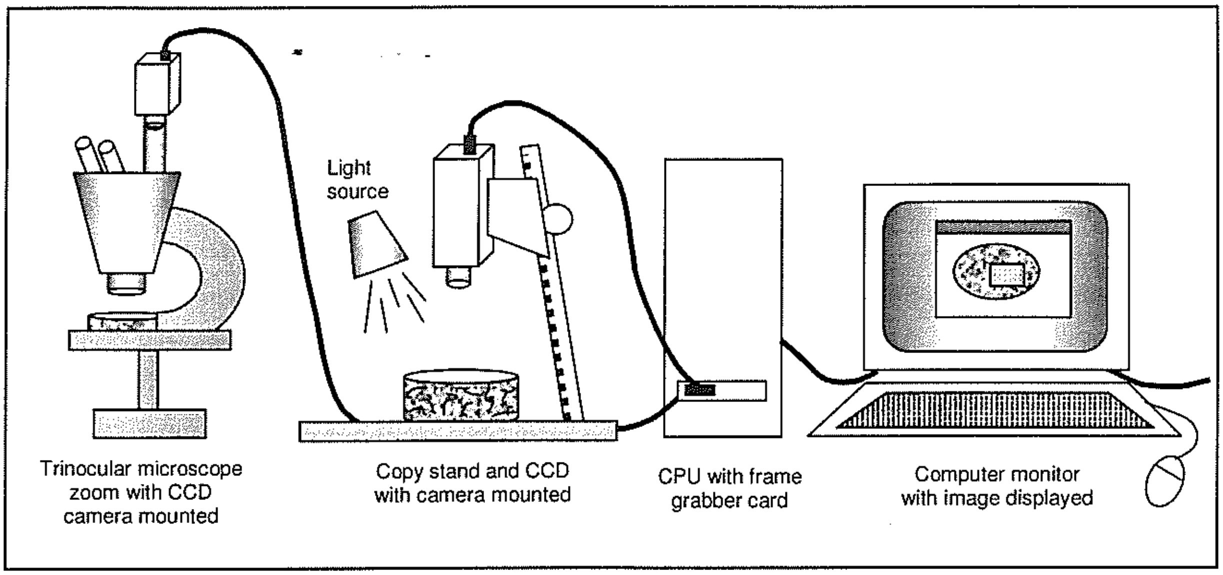


Figure 2
Schematic of digital image analyzer system

The system as it was integrated can accommodate for a color CCD camera (either 1-chip or 3-chip). The use of a 1-chip color camera was evaluated in comparison with a B/W CCD camera for the purposes of this project. Based on this evaluation, the B/W CCD camera was considered the most appropriate tool for the materials under consideration and the morphological measurements of interest. The comparison notes are included in appendix B of this report.

Calibration and preliminary testing. A series of experimental steps were taken for system calibration and testing of the software. Before any soil/fiber mixtures were used with the newly assembled equipment, separate tests were run with known quantities and measurable dimensions to ensure that the system was recording data accurately. Separated fibers were glued on a blank piece of paper to obtain the desired magnification, focal length, and FOV area. The goal of image acquisition was to capture enough fibers in a condition after mixture, so a representative area of the sample had to be captured at a low magnification. As magnification is increased, the FOV area is reduced and it is difficult to capture the spatial distribution of the fibers. A collection of optical lenses was borrowed from the NASA Stennis Space Center to evaluate their focal length. It was found that the NASA lenses were of a much longer focal length. Lenses with a better focal length equivalent to a "close-up zoom lens" are more suitable for this type of image acquisition. Due to budget constraints, these lenses were not purchased. A zoom microscope with 50X magnification was used for the close-up measurements, but the FOV area was too small to characterize sample properties of grouped and isolated fibers.

Lighting was controlled with polarized filters to achieve maximum image quality. Ordinary light consists of electric and magnetic waves at right angles to one another emanating in all possible planes relative to the source. Polarization at this point is considered random and has no preferred direction. If a piece of polarizing material is now inserted, the planes in which the electromagnetic waves travel can be controlled such that only a single plane of resolution exists. This is clearly shown when two polarized filters are used in conjunction with one another. If the transmission axes (polarized planes) are parallel, the light will be transmitted; if they are perpendicular, no light will pass. By varying the angle between the transmission axes it is possible to control the intensity of the transmitted light. From the polarizing kit purchased, numerous filters were tested (filter included: linear, one-forth wave retarder, one-half wave retarder, blue blocking, etc.). It was found that the wave retarders and linear polarizers were the most efficient in cutting down the glare radiating from the sample surface. Different color light bulbs were also tested but they did not provide much improvement to the image quality and the ability to acquire such images.

Characteristics of the Soil/Fiber Mixtures

There was nothing found in the literature regarding image processing of soil/fiber mixtures. However, a review on the usage of soil/fiber mixtures in highway construction was recently reported by J.G. Zonberg *[11]*. Several models have also been proposed to explain the behavior of randomly distributed fibers within a soil mass *[12], [13], [14]*. The common findings included:

- Randomly distributed fibers provide strength isotropy in a soil composite, in contrast to the potential planes of weakness that can develop parallel to continuous planar reinforcements;
- Fiber inclusion significantly increases the "equivalent" shear strength within a reinforced soil mass for both cohesionless and cohesive soil;
- The "equivalent" strength increase is a function of fiber content, fiber length (or aspect ratio), fiber stiffness, and soil-fiber interface friction; and
- The "equivalent" strength increase is higher for well-graded and angular sands.

Zonberg also contains a bibliographical list references on fiber reinforced research in geotechnical applications and a copy of this list is included in appendix D of this report.

Material Properties

Soil. This research project was of an exploratory nature related to digital image analysis techniques of soil/fiber mixtures. Materials under consideration at LTRC were used. Both field samples were obtained from Dr. Khalid Farrag, LTRC Research Associate, in conjunction with the field program of slope stabilization at a segment of the state route LA-15 located in Concordia Parish. A section of the LA-15 embankment was rebuilt utilizing the fibrillated polypropylene fibers in general accordance with the specifications included in appendix C. The field samples were obtained using thin walled "undisturbed" tube sampling in the field by gently pushing the tube into the face of the slope. From these field samples, the geotechnical index properties and classification tests were performed and the results are summarized in table 1.

Table 1
Index Properties for Louisiana Soil

Soil Sample	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Clay Portion (%)	USCS Designation
LA 15 clay	78.4	36.6	41.8	44	CH
N.O. clay	45.4	20.2	25.2	32	CL

The grain size distribution curve shown in figure 2 compares the LA-15 soil gradation with the New Orleans clay soil. Since field sampling was not part of the scope of work in this study and New Orleans clay was easily available at the laboratory site and the gradation relatively similar, this material was used for the preparation of the specimens mixed with fibers.

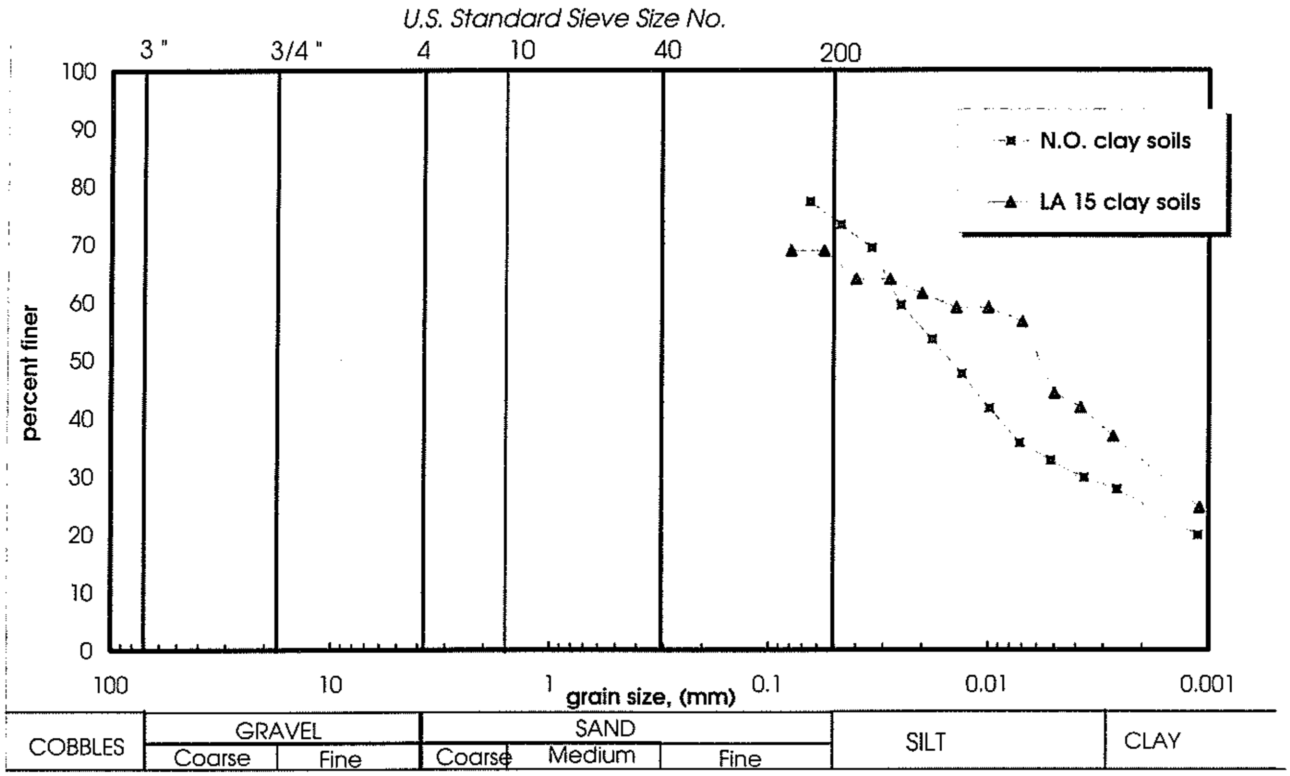


Figure 3

Grain size distribution for N.O. clay and LA-15 clay soil

Fibers (or geo-fibers). Synthetic Industries and LTRC provided two types of geo-fibers (2,600-denier and 360-denier) for evaluation with the digital image analyzer system. The 360-denier fiber is of a blonde semi-transparent color and about two inches long and the 2,600-denier fiber is of a black solid color and about one-inch long. The 360-denier fibers presented a problem when attempts were made in image acquisition. It is required to dye the 360-denier fibers with a color that will provide enough contrast for segmentation and identification at the pixel level. It was decided then to test only the 2,600-denier fibers since the manufactured color provided a good contrast with the Louisiana soil used. The properties for the fiber used in this study are provided in table 2. The "as manufactured" condition of the reinforcing product comes in bundles or groupings of fibers parallel to each other and connected to each other by small filaments. Separation of these fibers can be achieved by slightly pulling the fibers together and by mixing with other soil material.

Table 2

Properties of Geo-fibers 2610B or 2600-denier (source: Synthetic Industries)

Property	Test Method	Requirement
Polypropylene	ASTM D 4101 Group 1/Class 1/Grade 3	99% minimum
Moisture Absorption	----	Nil
Fiber Length	Measured	1 inch, minimum
Color	----	Black
Specific Gravity	ASTM D 792	0.91 gm/cm^3
Carbon Black Content	ASTM D 1603	0.6% minimum
Tensile Strength	ASTM D 2256	40,000 psi, minimum
Tensile Elongation	ASYUM 2256	15%, maximum
Young's Modulus	ASTM D 2101	600,000 psi, minimum

Specimen Preparation

Compaction curve for New Orleans clay soil. For the purpose of determining the degree of compaction and water content of the mixtures used for the specimen preparation, a compaction curve was developed for the native soil as shown in figure 4. The maximum dry density was estimated at 16.4 kN/m^3 at optimum water content of 16.2 percent.

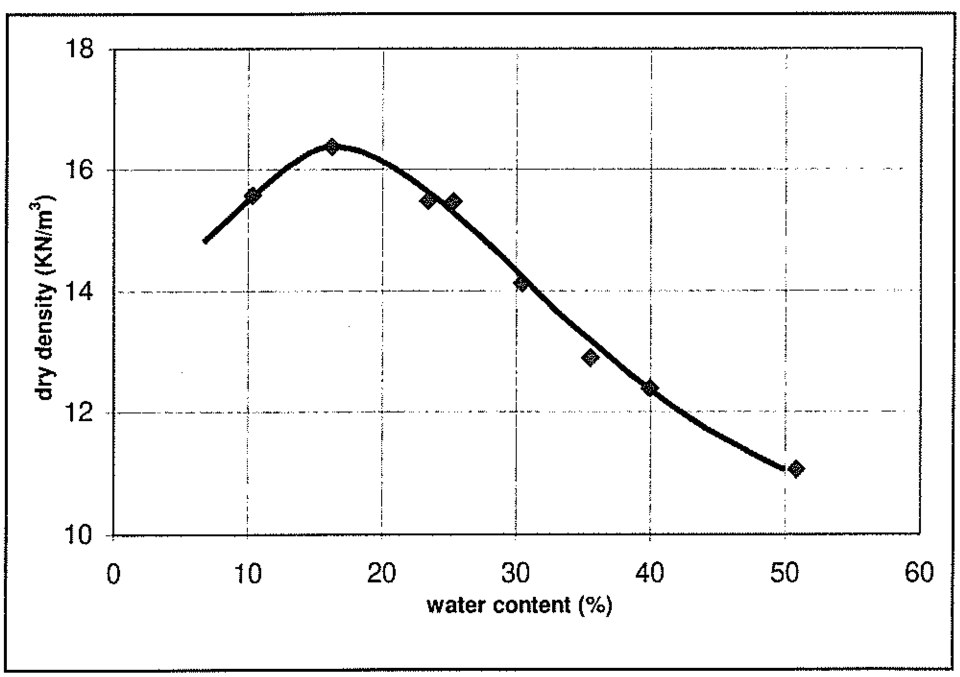


Figure 4

Compaction curve for N.O. Soil (using ASTM D 698)

Mixing Procedure. The following procedure was adapted from Fugro-McClelland *[8]*. This mixing procedure was used with soil retrieved by means of a hand auger from the Tulane University grounds in New Orleans, LA. The material properties for this soil and the fibers used are included in the "Fibers (or geo-fibers)" section of this report.

1. Dry the soil to bring water content below calculated optimum moisture content (OMC), then determine the water content. The soil retrieved in its in-situ state was above its OMC, thus, it was necessary to dry the soil first.

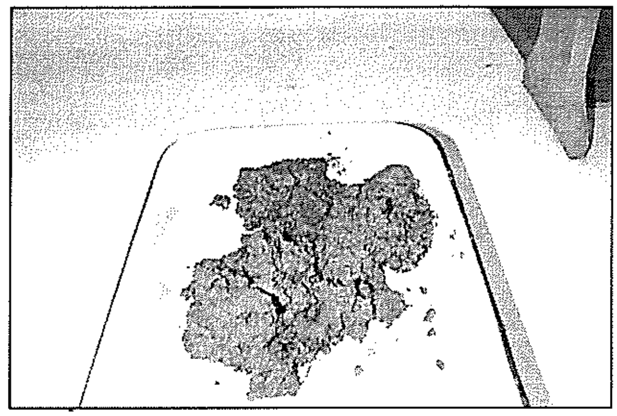


Figure 5
In-situ soil to be dried

2. Next grind the dry soil and then run the sample through a No. 4 sieve. Then determine the weight of the dry soil.

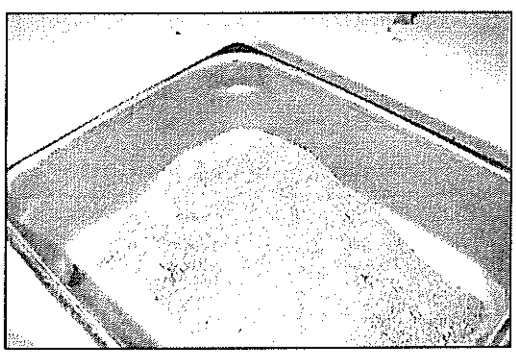


Figure 6
Soil ground after drying

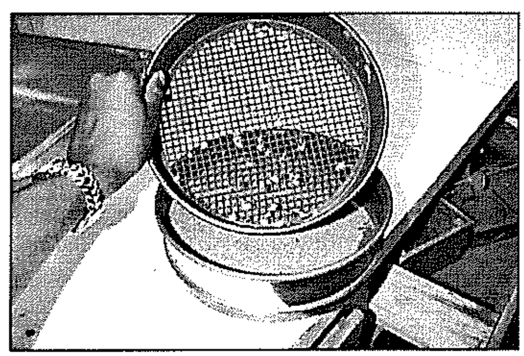


Figure 7
Sieved soil sample

3. Calculate the weight of fibers to be added to the soil sample, and bring dry soil sample to desired percentage of OMC.

4. Place soil in moisture room for 24 hours wrapped in plastic. Then measure out water to be added to bring sample to OMC or dry of OMC.

5. Next place soil and fibers in the bowl in alternating rows: five rows of soil and four rows of fibers.

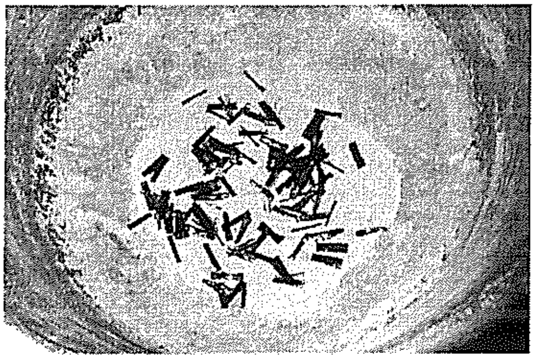


Figure 8
First layer if soil and fibers

Figure 9
Second layer of soil

6. Place bowl in mixer using a solid flat paddle (best results were achieved with this paddle; we avoided wire type paddle as suggested by K. Gasspard from LTRC) and add water slowly while mixing -- this should take not longer than two minutes.

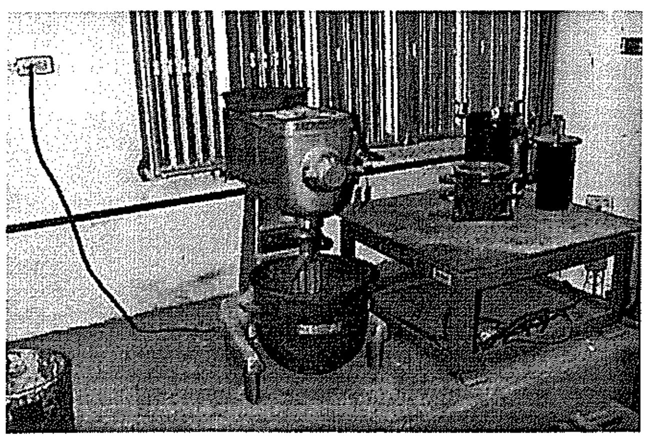


Figure 10
Mixing equipment

7. Perform standard proctor compaction following ASTM D 698. Then use extruder to remove the specimen. Place the sample in the moisture room in saran wrap and foil.

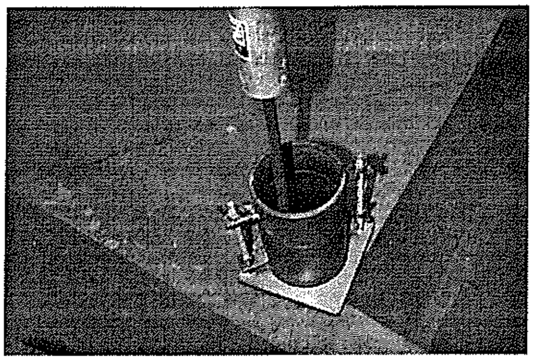


Figure 11
Standard proctor compaction

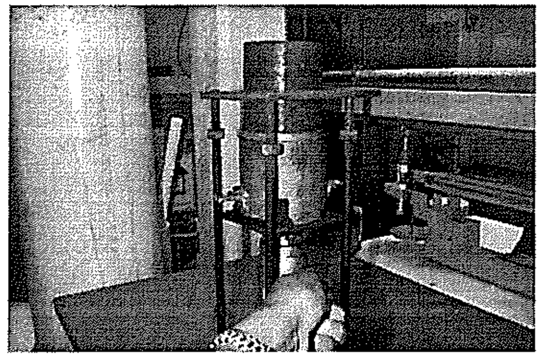


Figure 12
Extruding the sample from mold

8. Retrieve sample of soil and fibers to determine water content of the soil/fiber sample.

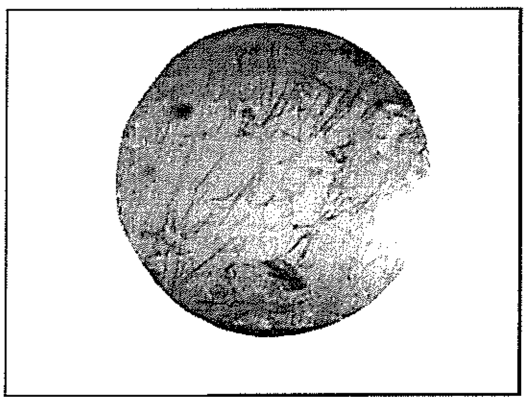


Figure 13
Top view of extrude sample

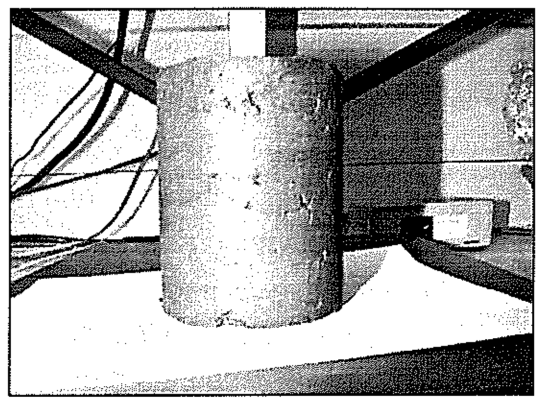


Figure 14
Side view of extrude sample

The above procedure was repeated a few times until the best specimen was produced. Some areas of concerns were identified but not overcome. The sample results in a fissure, and damage occurs during extrusion. A significant number of fibers stick to the mixer bowl and palette. Separation of the fibrillated fibers was not achieved throughout the sample. For future sample preparation, Synthetic Industries has offered to assist in the soil/fiber mixing and specimen preparation.

Summary of prepared specimens. Three types of specimen were prepared based on the compaction curve for the New Orleans clay soil. The amount of fiber was also varied according to guidelines and ongoing testing at LTRC. Table 3 summarizes the soil/fiber specimen characteristics. Two specimens were created for each type to have a backup specimen during surface preparation.

Table 3
Summary of specimen compaction characteristics

	Target Condition		Actual Condition	
Specimen Type	w.c. from optimum	Fiber content (%) by weight	w.c. (%)	dry density (kN/m^3)
#1	dry of opt.	0.2	14.2	15.1
#2	wet of opt.	0.1	17.6	16.1
#3	at OMC	0.2	16.1	16.2

Surface preparation. To capture an image from the specimen, a cross section needs to be cut and prepared. This surface preparation is key for the effectiveness of image acquisition. Anomalies on the surface can be misleading when spatial measurements are carried out. The typical approach to prepare a surface for image acquisition of granular soil is by impregnating the porous structure with a low viscosity resin that upon hardening can be cut and polished. By introducing the resin into soil, the structure of suspended particles is also preserved. Due to the low hydraulic conductivity of the clay soil (in the order of 10^{-5} to 10^{-6} cm/sec), the possibility of impregnating the sample with a resin was not pursued. Numerous methods were attempted to prepare a surface such as drying, freezing, wire cutting, high-speed sawing, etc. The most effective method was fast freezing and then cut wet. Drying the specimen in an oven proved to be very ineffective as the specimen crumbles around the fiber fissures. Cutting the sample as compacted at the water content near OMC caused the fibers to pull out from their compacted location. Fast freezing was accomplished by submerging a small cut sample into a Dewar flask with liquid nitrogen. This way the sample freezes in less than one minute and the sample can be cut. In order to decrease the amount of fibers being pulled out and the crumbling of the sample, we opted to freeze the samples in liquid nitrogen for a longer period of time. The next hurdle was finding the right tool to cut the sample. To cut the sample within a few minutes of freezing, hand held devices will not suffice. At Tulane Mechanical Service shop a mechanical jig saw was available to make a smooth cut. The cut also eroded the blade completely. The blade also streaked the surface severely and no fibers can be detected by the naked eye. Figure 15 shows a freshly frozen and cut sample by a mechanical saw. No fibers can be detected on the surface due to a film of condensed water that forms after pulling specimen from Dewar flask. They seem to be either matted in to the soil or pulled out by the cutting process.

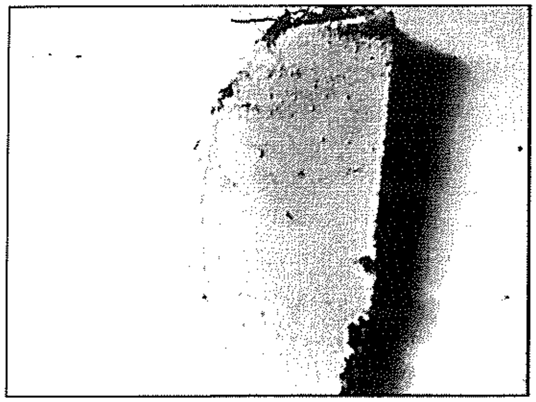


Figure 15
Freshly cut specimen (type #1) after fast freezing

The next frozen sample was larger and was left to sit for 18 hours in a freezer before attempting to cut the sample. In this instance a hand held drill with a rotating disc attachment (for masonry) was used to cut the sample. The disc caused a lot of unevenness in the surface, but minimal amounts of fibers were pulled out. The best surface was obtained when the sample cracked at one point and a surface fell open.

Figure 16 shows a lot of unevenness on the surface of this sample but the fibers are clearly visible. The circumference of the sample had to be trimmed to fit in the Dewar flask, hence the fibers sticking out from the sides. Both specimens had the same fiber content of 0.2 percent of a type #1.

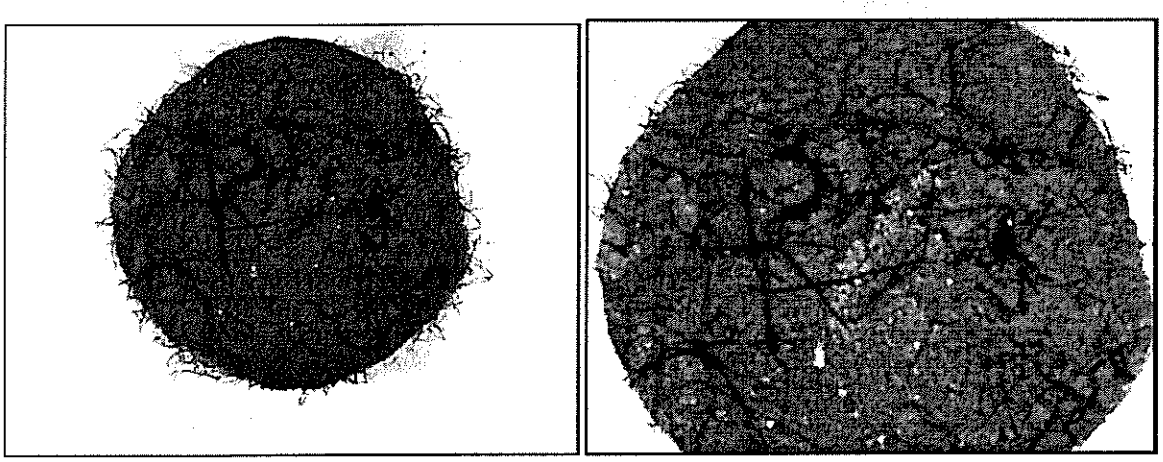


Figure 16
Uneven surface of specimen (type #1) upon slow freezing and crack

Surface preparation will continue to be an area of investigation and was identified as very challenging. The following area of concern were noted:

- Mechanical saws are necessary for a good cut, but the right blade must be identified.
- Hand held machinery caused a lot of damage and disturbance.
- Delaying surface cuts after freezing makes sample more workable but surface evenness is lost. A better surface is produced by using liquid nitrogen then freezing the saran and foil wrapped specimen for an extended period of time.

Image acquisition of soil/fiber mixtures. To capture the best possible image of the soil and fiber specimen, the following equipment was utilized: image analyzer with the low-light monochrome CCD camera, white background under the specimen, and polarization kit for the light source as seen assembled in figure 17.

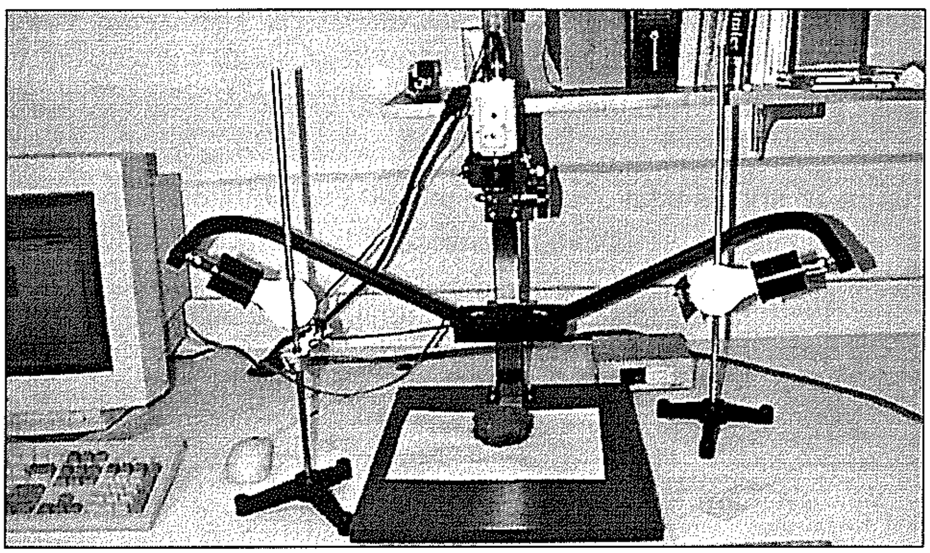
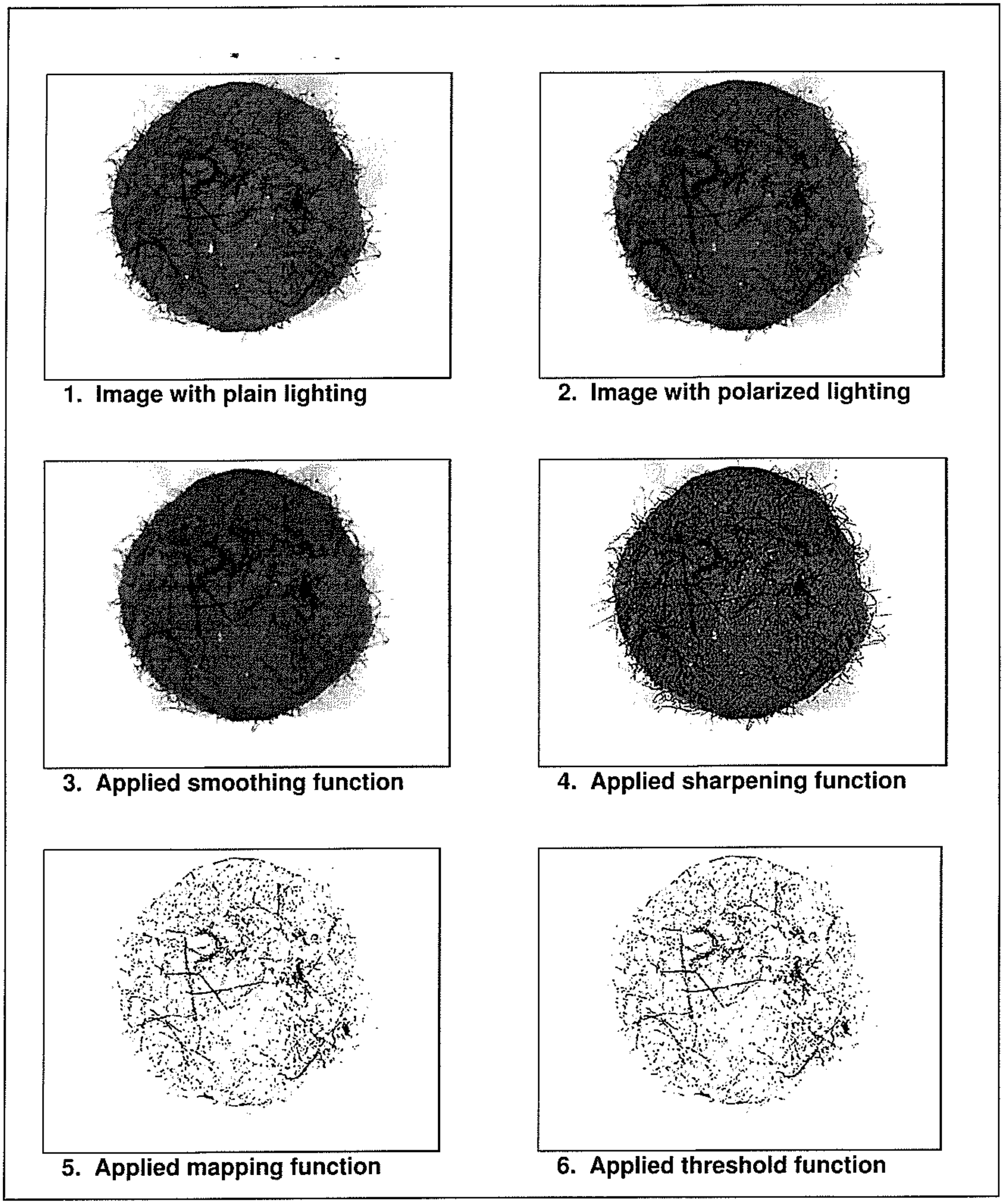


Figure 17
Setup of CCD camera on copy stand with polarized light source

After the image was captured, a series of routines were used to enhance the desired features of the image before feature identification. Routines available in most image software packages were used to manipulate the pixel array of the images such as smoothing, sharpening, edge enhancement, contrast, mapping, inversion, threshold, and others. These routines were applied in a particular sequence as seen in figure 18. To capture an image that encompasses the entire sample (3.25 inches in diameter), the CCD camera was 12.5 inches from the specimen with the lens focused manually. The specimen used in all the following routines and data analysis is type #1 mixture. The sample was placed in the Dewar flask filled with liquid nitrogen for 15 minutes. The sample was then cut with a rotating disc attached to a hand held drill. The two-inch square linear polarized filters were used to reduce shadows and glares in the captured images. The objective after capturing the image is to identify the fibers in a gray scale or binary image. A binary image is one that has only two intensities 1 and 0. For example, the soil may have a "1" or white and the fiber may have a "0" or black. However, to get to this process, it is necessary to smooth, sharpen, map, and threshold the original image.



1. Image with plain lighting
2. Image with polarized lighting
3. Applied smoothing function
4. Applied sharpening function
5. Applied mapping function
6. Applied threshold function

Figure 18

Sequence of image enhancing routines to optimize fiber identification

DISCUSSION OF RESULTS

From Pixel to Real World Measurements

Most of the data produced in an image processing software is offered in the pixel units. Hence, it is necessary to map the data to real world coordinates. The "measurement" function in Inspector® executes this task. Two markers were placed to get an average value of the pixel conversions.

Figure 19
Two line markers to measure features

Table 4
Summary of pixel data obtained from Inspector® software

Marker	x_1	y_1	x_2	y_2	Count	Angle
Line A	281	254	234	192	78 pixels	127°
Line B	349	148	338	211	64 pixels	260°

The values in table 4 were verified by taking actual measurements on the sample with a set of precision calipers and the following values were averaged.

Real world measurement:	maps	
Line A – 10/16" = 78 pixels	$\Longrightarrow$	1 mm = 4.9 pixels
Line B – 8.5/16" = 64 pixels	$\Longrightarrow$	1 mm = 4.7 pixels

Blob Set Analysis

This data acquisition function attempts to identify objects in a segmented image. In this case the objects of interest are the fibers in the foreground. Blob set analysis tries to locate all objects with the assigned intensity of the fibers, and the relevant data are recorded for the user. The quantifiable properties were count number, area, and location. To find an actual fiber is a task in itself, let alone to gather characteristics about the fiber. Blob set analysis takes the threshold and segmented image and places outlines and identification number by each detail that was considered not part of the background, i.e. the fibers. A table is then produced which lists each blob (or fiber) and its characteristics (see table 5).

The outline of each blob (fiber) and its respective identification number is shown in figure 20. Each blob is followed with a corresponding outline that indicates which blobs were actual fibers. Total number of fibers identified by the software was 40. Out of the 40 blob sets identified, 27 were fibers. The highlighted items in table 5 indicate a crack or unevenness in the image surface that has been falsely identified by the program as a fiber. There are more features on the image that are not labeled because the software recognizes the intensity of pixel that may correspond to identifying a fiber. Often three fibers were actually one long fiber. This function is very sensitive to the mapping and threshold routines. Using these routines in different capacities, blob sets can be generated up to 120 or as few as 12.

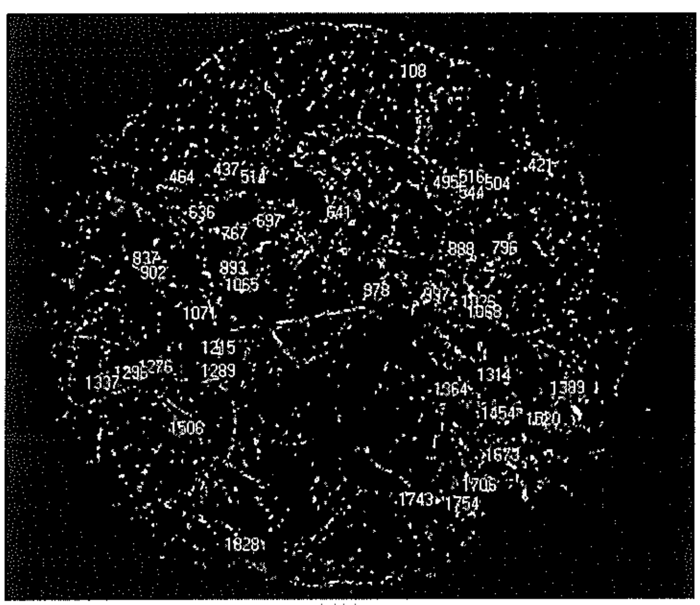


Figure 20
Blob set analysis image identifying fibers by labeling

Table 5

Blob set analysis output table

Label #	Area (pixels)	X	Y
108	29	380	64
421	41	469	138
437	45	264	132
464	22	227	131
495	26	409	141
504	23	441	143
514	117	287	157
516	33	421	138
544	27	424	151
636	72	231	184
641	64	326	169
697	87	277	176
767	44	257	179
796	21	442	185
837	23	192	194
888	235	431	219
893	76	253	200
902	20	203	202
978	22	356	212
997	22	398	218
1026	35	425	235
1065	56	277	226
1068	26	431	235
1071	29	246	229
1215	32	245	261
1276	24	197	267
1289	28	246	271
1296	20	182	269
1314	25	435	273
1337	24	162	281
1364	20	408	287
1389	79	493	292
1454	26	449	302
1506	24	226	313
1520	25	470	311
1673	69	441	343
1706	20	425	352
1743	34	399	364
1754	20	414	363

Object Orientation

To find the orientation of any object identified in an image, it is necessary to define a region of interest (ROI). In this case the objects of interest were individual fibers. The ROI must be drawn for each individual fiber, labeled and numbered to correspond with a table containing the object's orientation. Since the process requires the user to identify the fiber, it is not necessary to use this function with mapped or segmented images. A smoothened and sharpened image will suffice to execute this routine. All that is needed is the ability to find the fibers with the naked eye, define the ROI around the fiber, and run the image orientation function. Four fibers were defined on this image and the computer generated results on the four fibers' orientation. The four fibers chosen were then measured by hand to ensure accuracy. The results are shown in table 6.

Table 6
Computer generated vs. hand measurement object orientation results in degrees

ROI	Computer Measurement	Hand Measurement (using protractor)	% Error
#1	150	145	3.45
#2	118	122	3.28
#3	125	148	15.54
#4	92	96	4.17

Defining the ROI is the key to accuracy in this routine. The fibers tend to bend in various ways. Thus, it is essential to isolate one section of the fiber to get a factual reading on orientation. Also, if a lot of fibers are close together the ROI has difficulty in assessing one particular fiber, making the generated data considerably skewed. However, when a single fiber is identified, the results are close to flawless. Most likely the error is human error as a result of checking the angles by hand.

Intensity line profiles

This function plots intensity vs. position. Through segmentation, the fibers are assigned intensities "255" (white) and the soil's intensity of "0" (black). It is possible to negate the image by switching the intensity values (e.g., "255" corresponds to soil and "0" to fibers). A script was developed to produce a 360-degree representation of an image in ten-degree intervals. The peaks in the profile indicate the presence of a fiber. However, this is only as accurate as the ability to threshold and to segment the image effectively. Hence, some areas of a sample can be identified with clusters of fibers, while another area may not have any fibers at all. For example, if a line intensity profile shows a lot of peaks in a region it means many fibers are present at that spatial location; on the other hand, few peaks in the profile means there is a lack of fibers. If all line intensity profiles are similar or well distributed, then one can infer that a well-mixed specimen was produced. This function provides a means to quantify the specimen's mixing thoroughness based on the 360-degree line profiles. An example of this process is shown for the image shown in figure 21, where three profiles are identified (at 0°, 250°, and 320°), and in figure 22 the actual profiles are shown.

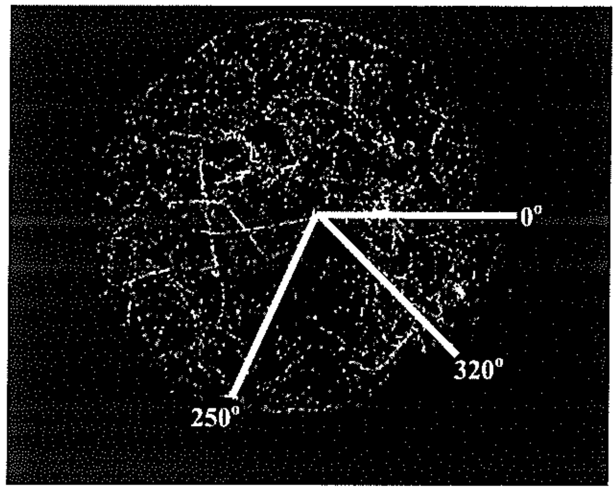


Figure 21
Negative of segmented image with line profiles shown

The script shown in table 7 was developed based on the coordinate system that down is positive and right is positive. In essence, the top left corner of the image is the origin of a Cartesian space. To calculate the coordinated every ten degrees the trigonometric identities were used ($x = r\cos\theta$ and $y = r\sin\theta$).

Figure 23 shows the three profiles for the lines superimposed on the image shown in figure 22. At 0°, the sample has a portion that contains no fibers. Another section indicates six fibers, followed by one fiber and almost immediately another fiber. The 250°-line profile indicates mostly soil with one possible fiber close to the edge of the sample. The 320°-line profile suggests a cluster of fibers close to the edge of the sample, approximately seven fibers.

Table 7

Script for 360° coverage at a 10° line profile increments

```
//Key: 11810                                      Accessed by Crl+F7
//Description: 360-degree Line Profile
Def syn()
{
I_SYNLP=ImgLoad("C:\synopsis\synlp.tif");             Calling the file
ImgSetCurrent(I_SYNLP, R_Def, ALL_BANDS);
ImgSetCurrent(I_SYNLP, R_Def, ALL_BANDS);
      Start
G_GRAPH5=GraphNewProfLineEx(315, 229, 527, 229, 1);       (0°)
G_GRAPH6=GraphNewProfLineEx(315, 229, 524, 192, 1);
G_GRAPH7=GraphNewProfLineEx(315, 229, 514, 156, 1);
G_GRAPH8=GraphNewProfLineEx(315, 229, 499, 123, 1);
G_GRAPH9=GraphNewProfLineEx(315, 229, 477, 93, 1);
G_GRAPH10=GraphNewProfLineEx(315, 229, 451, 67, 1);
G_GRAPH11=GraphNewProfLineEx(315, 229, 421, 45, 1);
G_GRAPH12=GraphNewProfLineEx(315, 229, 388, 30, 1);
G_GRAPH13=GraphNewProfLineEx(315, 229, 352, 20, 1);
G_GRAPH14=GraphNewProfLineEx(315, 229, 315, 17, 1);
G_GRAPH15=GraphNewProfLineEx(315, 229, 278, 20, 1);
G_GRAPH16=GraphNewProfLineEx(315, 229, 242, 30, 1);
G_GRAPH17=GraphNewProfLineEx(315, 229, 209, 45, 1);
G_GRAPH18=GraphNewProfLineEx(315, 229, 179, 67, 1);
G_GRAPH19=GraphNewProfLineEx(315, 229, 153, 93, 1);
G_GRAPH20=GraphNewProfLineEx(315, 229, 131, 123, 1);
G_GRAPH21=GraphNewProfLineEx(315, 229, 116, 156, 1);
G_GRAPH22=GraphNewProfLineEx(315, 229, 106, 192, 1);
G_GRAPH23=GraphNewProfLineEx(315, 229, 103, 229, 1);
G_GRAPH24=GraphNewProfLineEx(315, 229, 106, 266, 1);
G_GRAPH25=GraphNewProfLineEx(315, 229, 116, 302, 1);
G_GRAPH26=GraphNewProfLineEx(315, 229, 131, 335, 1);
G_GRAPH27=GraphNewProfLineEx(315, 229, 153, 365, 1);
G_GRAPH28=GraphNewProfLineEx(315, 229, 179, 391, 1);
G_GRAPH29=GraphNewProfLineEx(315, 229, 209, 413, 1);
G_GRAPH30=GraphNewProfLineEx(315, 229, 242, 428, 1);      (250°)
G_GRAPH31=GraphNewProfLineEx(315, 229, 278, 438, 1);
G_GRAPH32=GraphNewProfLineEx(315, 229, 315, 441, 1);
G_GRAPH33=GraphNewProfLineEx(315, 229, 352, 438, 1);
G_GRAPH34=GraphNewProfLineEx(315, 229, 388, 428, 1);
G_GRAPH35=GraphNewProfLineEx(315, 229, 421, 413, 1);
G_GRAPH36=GraphNewProfLineEx(315, 229, 451, 391, 1);
G_GRAPH37=GraphNewProfLineEx(315, 229, 477, 365, 1);      (320°)
G_GRAPH38=GraphNewProfLineEx(315, 229, 499, 335, 1);
G_GRAPH39=GraphNewProfLineEx(315, 229, 514, 302, 1);
G_GRAPH40=GraphNewProfLineEx(315, 229, 524, 266, 1);
G_GRAPH41=GraphNewProfLineEx(315, 229, 527, 229, 1);
                                                          End
}
```

Origin in the Middle of sample

End-point of line

Creates a new line and graph each time

Inspection of the 36 graphs for each ten-degree increment involved counting the peaks of each graph, where each peak would indicate the presence of a fiber being intercepted by the line. It was taken into consideration that some graphs would be recording the same fiber, in which case the peak positions were very similar. Hence, they were only counted once. A total of 83 fibers were counted; only 62 were identified on the image and sample visually. The discrepancy in these numbers can be attributed to the cracks and unevenness in the specimen surface, which could be mistaken for fibers. The 320°-line profile was also checked and looked up the coordinates that had peaks. Eight peaks were counted and seven fibers were located close to the peak coordinates. This finding results in the conclusion that line profile would be a better approach in detecting fibers.

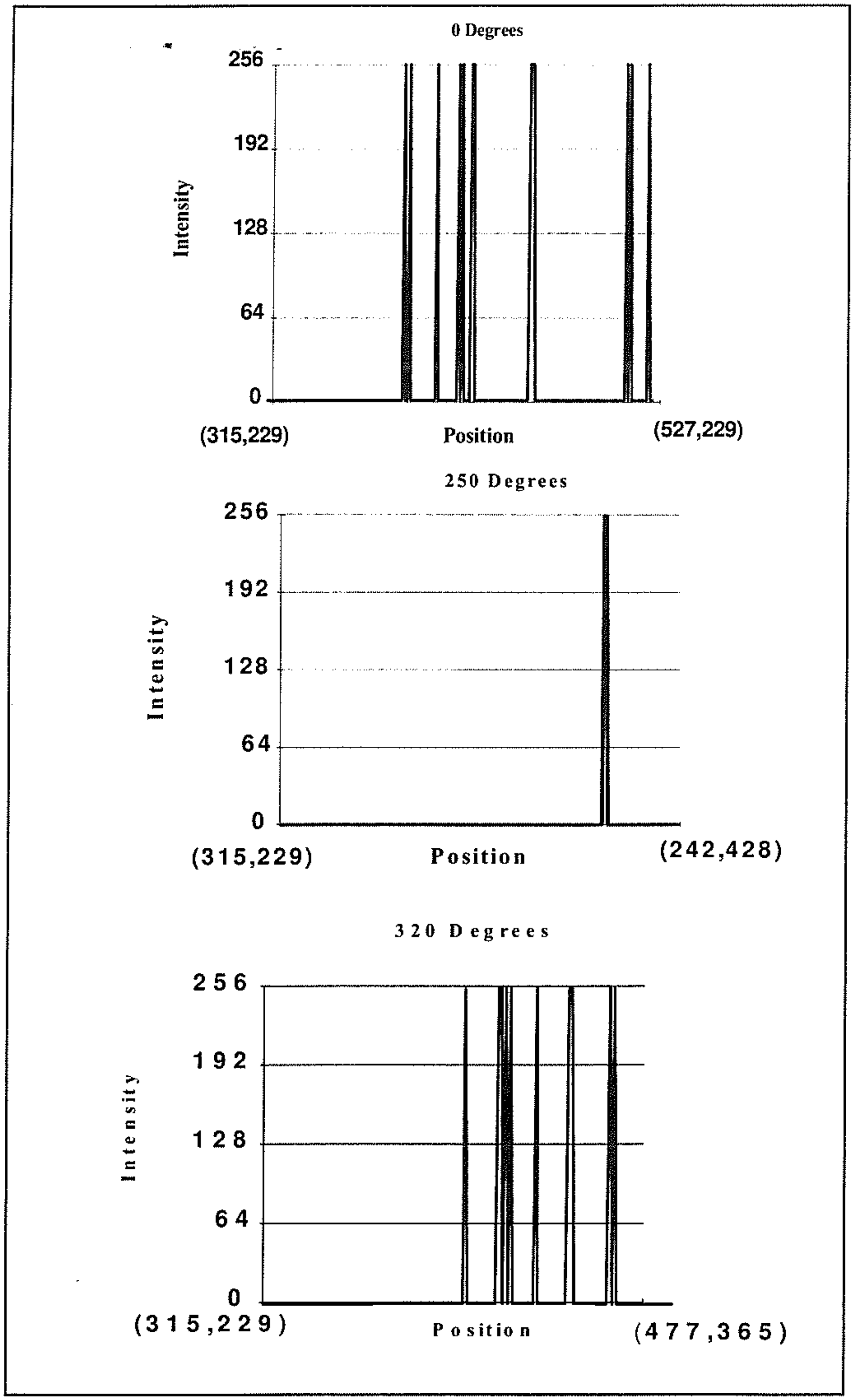


Figure 22
Corresponding intensity line profiles for 0, 250 and 320 degrees

CONCLUSIONS

This project used innovative technologies of digital image analysis for the characterization of a material currently being considered for broad use at the LA DOTD. The material under consideration is a mixture of fiber and soil for use in the stabilization of road sub-grades, bases, and embankment slopes. Field test pads and laboratory work are currently underway at LTRC. It is not apparent that the material has been released for broad use at the state level. One of the reasons for not using this material is the unique mixing requirement for proper distribution of the fibers. The techniques with digital image analysis provide a quantitative means to measure some properties that can characterize the mixture. These properties can be correlated with the performance and strength test results. However, this was considered outside of the scope of the project.

Image acquisition was best achieved with polarized light using linear and half- and quarter-wave retarders. The FOV was generally the size of the sample or a bit larger to achieve the focal length of the lenses available for this project. A close-up lens with a much smaller focal lengths will allow more flexibility with the focus and FOV of interest, which is at about five times the length of the average fiber shown in the surface. The sequence of image enhancement routines before segmenting the image was applied in the following order: polarizing light, smoothing, sharpening, mapping, and thresholding.

The count and area computation of features was accomplished with the "blob set analysis," segmenting routine available in the Inspector® software. The quality of surface preparation of the specimen is crucial to obtain good results using this function. To obtain the orientation of the individual fibers, ROI was required around each fiber. It is anticipated that another macro script can be developed for each blob set to then quantify the orientation angle for each fiber. These routines could be used in conjunction with a statistical software package to eliminate the presence of outlines and calculate distributions of the exposed fiber length and area.

Intensity line profiles routines and macros proved to be an effective method to identify and to quantify clusters of fibers and the degree of spatial distribution of the fibers on the examined surfaces. A macro script was developed to generate the intensity line plots. Several surfaces can be tested separately and then compiled to run statistical analysis and to summarize trend.

The ease and low-cost of the integrated system makes these technologies more available to the research engineers. The material being tested here was not found cited in previous literature. This lack of information posed a significant challenge on achieving successful results. However, this system is a valuable tool for more traditional measurements such as fracture identification, aggregate characterization and pore size distribution of granular materials.

RECOMMENDATIONS

A significant amount of effort was invested towards the surface preparation of a specimen before image acquisition. The material is heterogeneous and its prone to fissures and slip planes if the fibers in the mix do not open or separate from their initial condition. From the surface preparation methods experimented in this study, the cryogenic freezing technique with liquid nitrogen, long freezing time, and then cutting with a power tool was considered the most effective. More experimentation with different types of cutting devices may be required to develop a better technique besides hand blade and cutting disc.

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GLOSSARY

1-Bit Color The least number of colors per pixel for a graphics file. Each pixel is either black or white.

4-Bit Color/16 Colors Each pixel has 4 colors assigned to it, which produces 16 colors.

8-Bit Color/256 Colors Each pixel has 8 colors assigned to it, which produces 256 colors.

24-Bit Color/16.7 Million Colors Each pixel has 24 colors assigned to it, which produces 16.7 million colors. This is the best setting for displaying photographic images

Algorithm Steps in a computer program used to solve a particular problem.

Aspect Ratio The ratio of vertical to horizontal dimensions of an image. For example, the aspect ratio for a TV is 3:2 and for an HDTV it is 16:9.

Binary The system used by computer to store data, represented by two digits, 0 or 1.

Bit A binary digit, which has the value of 0 or 1 (off or on)

Bitmap Graphics A bitmap image is made up of dots or pixels. This type of image is a raster image, which means the image consists of rows of pixels

Byte A byte contains 8 bits. This is the common unit used to represent a character, number, or symbol.

Capture Acquiring an image by a scanner or digital camera.

CCD (Charged Couple Device) A device that converts light into analog. The two main types of CCDs are linear arrays used in flatbed scanners and area arrays used in camcorders and digital cameras.

Cropping The process of trimming away unwanted portions of an image.

Digital Electronic technology that generates, stores, and processes data in terms of two states: positive and non-positive. Positive is represented by the number 1 and non-positive by the number 0. Each of these states is referred to as a bit.

Digital Camera A digital camera records and stores photographic images in digital format that can be transferred to a computer or directly to a printer.

Dot Pitch The distance between the dots on a computer monitor. The closer the dots, the sharper the image.

DPI (Dots per Inch) The measurement of the resolution of a printer or monitor based on the dot density

GIF (Graphics Interchange Format) A graphics file format developed by CompuServe to allow exchange of image files across multiple platforms. It is a standard format on the Internet.

Gray Scale An image containing shades of gray as well as black and white.

GUI (Graphical User Interface) A graphical user interface (such as Windows and Windrows programs) rather than a textual interface (such as DOS) to a computer.

Hue A term used to describe the entire range of colors of the spectrum.

Image Resolution The number of pixels per unit length of the image. For example : pixels per inch.

Inspector A hardware-independent 32-bit Windows based application software designed to let you work interactively with images for capture, storage, and processing

Lossy Compression A compression that eliminates unneeded data, causing a slight degradation of image quality. JPEG compression is lossy.

Morphing A special effect to produce a smooth transformation from one object or shape to another.

MPEG (**M**oving Pictures **E**xpert **G**roup) Sets standards for digital video and digital audio compression.

Noise Unwanted electrical or electromagnetic energy that can degrade the quality of signals and data

Optical Scanner A device that changes images from either reflective or transparency medium to digital data.

Palette A range of available colors

Pixel (Picture Element) The smallest element on a computer display or computer image

PPI (Pixels per Inch) Number of pixels per inch in an image. Often used interchangeably with DPI.

Raster Image An image that is made up of individual pixels arranged in a rectangular array.

Resolution The number of pixels per unit length of the image. For example: pixels per inch.

Sharpening A tool used in an image-editing program to sharpen (or bring into focus) the details of the image.

TIFF (Tagged Image File Format) The standard file format for high-resolution bitmapped graphics. TIFF files are cross-platform compatible.

True Color Color that has 24-bits (16.7 million colors)

TWAIN A program that lets you load an image from a scanner or digital camera directly into an application.

Vector Graphics As opposed to a bitmap graphic that is made up of individual pixels, a vector graphic consists of mathematical statements that place lines and shapes in a two-dimensional or three- dimensional space.

APPENDIX A – SOFTWARE EVALUATION

Inspector 2.1 by Matrox, allows for the extraction of precise data from images by providing access to a set of functions for image processing, blob analysis, measurement, and pattern matching. Among these functions are those geared toward image enhancement and processing, image analysis, and selection and processing of non-rectangular regions or interest. Regions of interest and objects of interest, both rectangular and non-rectangular, can be selected and processed by Inspector. Inspector also has an interactive "magic wand" which selects all the pixels that are similar (within a specified range) to a pixel value. Image enhancement and processing features include filters for sharpening, smoothing, edge enhancement, and noise removal. Other available filters include average, horizontal edge, Laplacian, median, Prewitt, relief, Sobel, vertical edge, and user defined filters. Shapes and boundaries of objects can be defined using morphology. For image analysis, objects can be counted and labeled, and features such as area, perimeter, and diameter can be measured. Mapping operations include histogram equalization, thresholding, contrast stretch, window leveling, and brightness and contrast adjustment. The types of morphological operations available through Inspector include binary and grayscale, close, open, erode, dilate, distance, thin, thick, hit or miss, and user-defined. Pattern matching can be used in finding image orientation, by defining and fine-tuning a model by importing mask or manually generating one. Various search parameters of pattern matching and search results can also be customized. All of Inspector's imaging operations are performed with sub-pixel accuracy, providing necessary precision in its data-oriented functions.

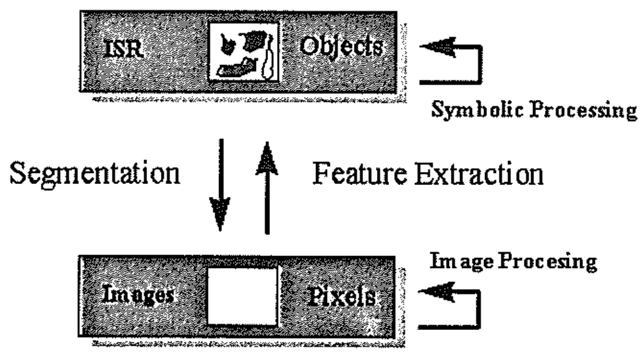
Image Processing Toolbox 2.1 is a complete suite of digital image processing and analysis tools for MATLAB 5. Its main features are image analysis, image enhancement, pixel values and statistics, region of interest processing, linear filtering, linear 2-D filter design, and binary image operations. The new features added to Toolbox 2.1 include interactive pixel-value display, object measurement, and the ability to fill holes in binary images. The pixel values and statistics feature is useful in extracting grayscale statistics and other information about pixel values in images. One such function of this feature is demonstrated by the "improfile" function, used to compute pixel-value cross-sections along line segments. The image analysis features, such as the "edge" function, are used to extract info about the structure of the image in question. The previously mentioned "edge" function locates edges in an intensity image. The image enhancement aspect of Toolbox 2.1 is useful in making certain features easier to see or to reduce noise. This includes 2-D median, order-statistic, and adaptive noise-removal filters. Image Processing Toolbox's linear filtering capabilities enable the application of arbitrary, as well as predefined, filters to images. This feature includes 2-D and N-Dimensional convolution, 2-D filtering, and user-created filters. Region-based processing allows for image processing and analysis operations on arbitrary regions of images. ROI's can be filtered and "holes" within these arbitrary regions can be filled. Binary image operations are also available for image enhancement and the extraction of desired features. Morphological operations such as erosion and dilation can be performed on binary images, and the area and perimeter of objects within these binary images can be determined. Image Processing Toolbox shares a similar focus on data extraction and image analysis with Matrox Inspector, but necessitates additional purchases.

Aphelion v.2.3 is an image processing and image understanding software. Aphelion imaging toolkits are available for the end-user and the developer. The toolkits are available as a set of ActiveX controls callable from any software environment supporting the COM technology, or as a set of dynamic-link libraries (DLLs) easily callable from Visual C++. In addition to be a developing environment it provides general purpose and state of the art modules for: filtering, segmentation, edge detection, grouping, morphology, analysis, geometry, classification and image transforms.

At the low-level, data is derived from digitized images. Digitized data consists of two-dimensional arrays whose elements are called pixels. Processing at this level consists of traditional signal or image processing. This processing takes the form of transformation functions, such as contrast enhancement to better recognize the difference in densities between the various components within an image. Inputs to these processes consist of arrays of pixels, and the outputs of these processes are also pixel arrays.

Various algorithms can be applied to low-level data to extract images that have some meaning in a vision application. These abstractions usually represent an area of more than one pixel and contain descriptive information about the pixel data in the group. Software acting on image data at this low-level can convert intensity information into symbolic descriptors that represent the boundaries of the components in the image.

Symbolic representations of image components are Objects and can be stored in an intermediate level database, called the Intermediate Symbolic (ISR). Objects of the same type, usually derived from same algorithm, are stored in lists called Object sets. Once an object has been defined, attributes (also called features) can be calculated for each Object. For example, average density can be calculated for each Object. These values of density can be then used to identify components or to assess relational or contextual information, such as nearness, subpart, etc.



LView Pro 2.0 is a package designed for image viewing and editing, and is primarily a manipulator of graphics. For the viewing of images, LView is capable of loading files quickly into multiple windows and allows for easy zooming in and out. There is a relatively wide variety of image editing, filtering, and retouching tools available through this software package, although lacking in some features found in other similar image processing programs. The types of filtering operations available include edge enhancement, find edges, trace contour, blur, soften, sharpen, emboss, despeckle, median, erode, dilate, noise, and user-defined filters. A color replacing brush enables the alteration of foreground or background colors, thus giving rise to greater contrast between the object in question and the less significant background. Localized retouch operations such as lighten, darken, soften, sharpen, blur, emboss, and smudge are available through a retouch brush. Multiple windows for a single image or a catalog of images can be opened concurrently. An image can be viewed in its original state in one window, while editing an altered portion of it in another window. Using LView's ability to create image catalogs enables the viewer to manage large numbers of files, and store thumbnails (miniature versions of the original images). A functional zoom operation is available, with scaling from 1:16 to 16:1, and all editing operations are available in all zoom levels. Easy labeling of images is possible by adding text directly to the image, if desired. There is also extensive on-line help for LView

Pro, making it useful for both beginners and highly advanced users. While LView Pro 2.0 offers a relatively wide range of features, it also falls short in terms of some of the features for the extraction of data from acquired images. Apparently, LView would be most beneficial when used to preprocess and enhance images before analyzing them with the other software packages with a greater focus on image analysis and data extraction, such as the previously described Matrox Inspector and Matlab's Image Processing Toolbox.

APPENDIX B – EVALUATION OF COLOR CCD CAMERA

1 chip camera
- less resolution
- cannot put out 3 channels (RGB)

3 chip camera
- need RGB compatibility

6 / 15 / 98

Color camera with microscope and blank sample soil a (LA – 15)

- Decent image through the microscope and screen
- Grabbed image decreases in quality, red hues and undertones come in the image *mscblank.tif*

6 / 16 -17 / 98

Color camera without microscope

- Got accurate representation of image then after grabbing screen image, the results were discolored
- Proceeded with processing routines and segmented as best as possible
- Able to discern fibers from soil....color does help the visual aspect of image
- Ran blob analysis...identifies fibers but soil is so brittle the routine also identifies cracks
  clrcam.tif , origclrcam.tif , cc.txt , blobclrcam.bst

Monochrome camera without microscope

- Hard to identify fibers from the shadows of an uneven surface and cracks in the soil
- Blob analysis made more mistakes in classification entire edges as a blob/fiber
  bwcam.tif , blobbwcam.bst , bw.txt

Color camera with microscope

- Good image of fibers and soil clearly projected
- Importance of a flat image surface is emphasized
  clrmsc.tif

Monochrome camera with microscope

- Same comments as with the color camera
- Microscope picks up any evenness in the surface of the specimen
- Shadows create a problem
  bwmsc.tif

APPENDIX C

SPECIFICATIONS AND SPECIAL PROVISION FOR EMBANKMENT REPAIR USING FIBRILLATED POLYPROPYLENE FIBERS

STATE PROJECT NO.	PARISH	SHE. 10.
177-04-0030	CONCORDIA	1

STATE OF LOUISISANA
DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

PLANS OF PROPOSED

STATE HIGHWAY

S.P.NO. 177-04-0030
SHAW - SLOCUM
LA 15
CONCORDIA PARISH

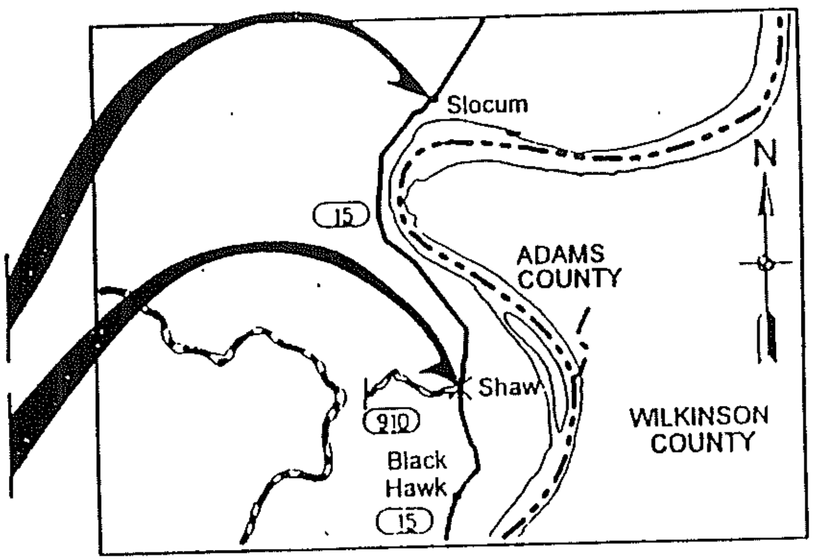
STANDARD PLANS TO BE USED ON THIS PROJECT

STANDARD PLAN	REV. DATE
BM-01	02-19-86
CB-01	06-25-82
CB-03	06-25-82
DW-04	09-16-82
EC-01	01-14-94
HS-01	03-17-87
MB-01	01-14-92
PM-02	12-07-81

TOTAL SHEETS = 28

C.S. LOG MILE 7.718
STA. 417+50 END
S.P. NO. 177-04-0030

C. S. LOG MILE 0.000
STA. 10+00 BEGIN
S.P. NO. 177-04-0030



STATE OF LOUISIANA
RONALD J. BERTHOT
REG. No. 24027
REGISTERED
PROFESSIONAL ENGINEER
IN
CIVIL ENGINEERING

Ronald J. Berthot 12/13/95

RECOMMENDED BY:

DISTRICT ADMINISTRATOR

12/13/95
DATE

APPROVED:

R. E. Dillard
CHIEF ENGINEER

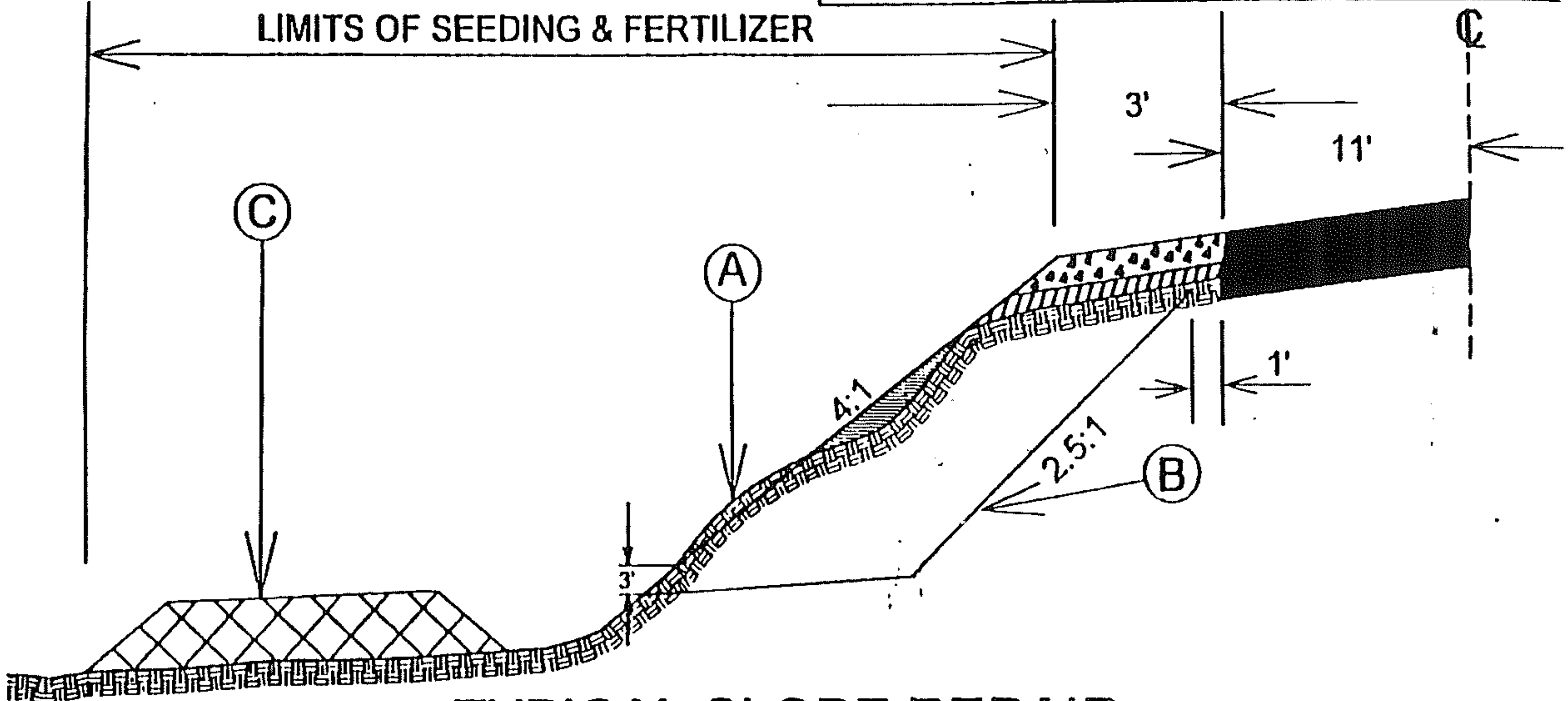
6-19-96
DATE

1996 ADT = 800 2004 ADT = 1000 D = 55% K = 10% T = 24%

7-2-96	Sheets 1 & 15	7-3-96	N.K.T.	7-8-96	R.E.D.
DATE	REVISION	DATE	RECOMMENDED	DATE	APPROVED

The 1992 Louisiana DOTD Standard Specifications for Roads and Bridges, as Amended by the Project Specifications, shall Govern on this project.

177-04-0030	CONCORDIA	5



TYPICAL SLOPE REPAIR

(A) EXISTING SLOPE

(B) THEORETICAL CUT SLOPE TO BE EXCAVATED ON A 2.5:1 SLOPE.

(C) IN AREAS REQUIRING TREATMENT, EXCAVATED MATERIAL TO BE TREATED AT FOOT OF ROADWAY BERM BEFORE PLACEMENT ON SLOPE.

NOTE: ANY ADDITIONAL BORROW REQUIRED TO SUPPLEMENT EXCAVATED MATERIAL SHALL BE BLENDED WITH EXCAVATED MATERIAL PRIOR TO TREATMENT WITH LIME OR FIBERS IN THOSE AREAS REQUIRING TREATMENT. IN THOSE AREAS NOT REQUIRING TREATMENT, MATERIAL SHALL ALSO BE BLENDED WITH THE EXCAVATED MATERIALS PRIOR TO PLACEMENT ON THE SLOPE. BORROW TO BE PAID FOR UNDER ITEM NO 203(08) BORROW (VEHICULAR MEASURMENT).

NOTE: SEE CONSTRUCTION NOTES FOR DETAILS AND LIMITS.

2	10-30-96	CHANGED NOTES AND FINISHED LINES
	DATE	REVISION

(4) Titanium Dioxide: The titanium dioxide shall meet ASTM D476, Type II, Rutile grade – 93% minimum titanium content.

(5) Yellow Pigment: The yellow pigment for the yellow thermoplastic material shall be 4% minimum.

(6) Specific Gravity: The specific gravity of the thermoplastic pavement marking material shall not exceed 2.35.

(7) Flowability: After heating the thermoplastic material for four hours ±5 minutes at 425° ± 3°F (218° ± 2°C) and testing flowability, the white thermoplastic shall have a maximum percent residue of 22 percent and the yellow thermoplastic shall have a maximum residue of 24 percent.

(8) Reflectivity: The initial reflectance for the in-place marking shall have the minimum reflectance value of 450 mcd/lux/m^2 for white and 350 mcd/lux/m^2 for yellow when measured with a geometry of 1.5° observation angle and 86.5° entrance angle.

(9) Wet Reflectivity: The minimum in-place marking when wet shall have the minimum reflectance value of 200 mcd/lux/m^2 for white and 175 mcd/lux/m^2 for yellow when measured with a geometry of 1.5° observation angle and 86.5° entrance angle. The stripe shall be wet utilizing a pump type garden sprayer for 30 seconds. After 5 seconds, place the reflectometer on the stripe and measure the retro reflectance..

(10) Retained Reflectivity: The thermoplastic pavement marking material shall retain the minimum reflectance value of 130 mcd/lux/m^2 for at least four years after placement. Failure to meet this requirement shall require the contractor to replace the portion of the material shown to be below these minimums. The contractor shall supply a written warranty indicating the terms of this requirement.

(11) Inverted Profile: The thermoplastic pavement marking material shall be applied to have a individual profiles having a minimum height of 0.140 inches with the recessed inverted profiles having a thickness of 0.025 to 0.050 inches. The profiles shall be well defined and not excessively run back together.

ITEM S-001 THRU S-006 SLOPE REPAIR: These items consist of excavating and repairing the embankment slope failures in accordance with the Standard Specifications except as modified herein by fiber reinforcement for some items and in conformance with the lines, grades, dimensions and notes shown on the plans or established by the engineer.

MATERIALS:

(a) Polypropylene Fiber Reinforcement: Material specifications shall be in accordance with Item S-007, Polypropylene Fiber Reinforcement.

(b) Lime: Material specifications shall be in accordance with Section 304, Type E of the Standard Specifications.

CONSTRUCTION METHODS:

(a) Excavation and Slope Preparation: Stripping of sod or removal of vegetation in the slope repair areas prior to excavation work shall be as shown in the plans, and/or as directed by the engineer. Minimum excavation requirement and limits shall be as shown in the plans. The subgrade surface shall be level, free from deleterious materials, loose, or otherwise unstable soils. When removing the existing embankment to the theoretical cut slope, the backslope shall be benched into competent soil as directed. Steps shall have a depth and height of 2.0 feet minimum and 4.0 feet maximum. The slope repair shall be excavated within the slope structure along the theoretical cut slope to a depth of three (3) feet below where the slip or failure plane exits as determined by the engineer. All soil affected by the slide failure shall be removed and stockpiled at a location approved by the engineer for subsequent treatment in accordance with the slope embankment repair method specified in the plans.

(b) Slope Embankment Repair Methods: Each slope embankment repair site shall be constructed in accordance with the repair method indicated in the plans and as specified herein.

(1) Fiber Reinforced Repair Method:

(i) Test Area/Fiber Manufacturer Representative: A test area to determine the mixing lift thickness and the construction procedures shall be made near the toe of the slope to be repaired or as directed by the engineer. The test area can be made in advance or during preparation of the first slope repair. The test area shall be approximately 25 ft. square. One test area will be required for each moisture condition specified in the plans under construction control. The test area shall be prepared and mixed in accordance with these specifications and using the same construction equipment and methods as will be used for the actual slope repair. The contractor shall provide a qualified and experienced representative from the fiber manufacturer, for a minimum of three days, to assist the contractor and DOTD inspectors during construction of the test area. The representative shall also be available on an as needed basis, as requested by the engineer, during repair of the remaining fiber reinforced slopes.

(ii) Fiber Dosage Rate: The fiber dosage rate shall be 0.2 % fibers by the soil's dry weight (5.4 lbs. Fibers/cu.ft. for a material dry weight of 100 lbs./cu.ft.). The volume of the excavated embankment material shall be estimated as precisely as possible. The bags of fiber shall be laid out over the excavated soil in a grid pattern with the amount of fibers calculated based on the soil volume.

(iii) Mixing: The soil mixture content of the excavated soil shall be as required by the construction control method required in the plans and this specification prior to mixing with the discrete, fibrillated polypropylene fibers. The excavated soil shall be spread over the working area in a uniform loose lift thickness. The loose lift thickness will be determined from the results of the test area. This lift thickness should allow the effective mixing of the fibers and the soil. The bags of fibers shall be manually opened and spread uniformly over the excavated soil to be worked. The fibers shall be spread with the use of lawn rakes in order to achieve a uniform spread. The mixing of the fibers and excavated soil shall be achieved by the use of a commercial size, rotary pulverizer mixer. The number of passes required by the mixer shall be determined from the results of the test area. A minimum of three complete passes of the mixer shall be required for each lift of soil being mixed with fibers. An effective fiber-soil mixture shall be attained when fibers achieve triaxial and three-dimensional dispersion without the fibers balling or clumping. Fibrillated fibers should open up or filamentize when properly mixed to create a filament strand and a net reinforcing configuration that interlocks with the soil. The appearance of properly opened and filamentized fibers shall resemble a high density, synthetic root system that penetrates into the soil mass. The properly mixed fiber reinforced soil should manually demonstrate improved shear strength and cohesion properties as specified by the Materials Laboratory and/or by the discretion of the engineer.

(iv) Embankment Placement: The surface of the slope excavation shall be scarified or disked to a depth not less than 4 inches and cut in steps (keyed) prior to placement of fiber-reinforced soil. The fiber-reinforced soil shall then be placed and compacted in layers parallel to the roadbed. Each lift shall be uniform as to material, fiber content, density, and moisture content before beginning compaction. The soil that has been loosened through scarifying, etc. shall be recompacted simultaneously with the fiber-reinforced soil placed at that elevation. The fiber-reinforced soil slope repairs shall be constructed to the lines and grades shown in the plans or as directed by the Engineer.

(2) Lime Repair Method: Lime shall be mixed with a commercial size rotary pulverizer mixer (stabilizer) and the lime stabilized embankment repair shall be in accordance with plan detail and the following requirements. Embankment materials for lime stabilization shall consist of material excavated from this project or usable soils, furnished by the contractor, conforming to Subsection 203.06. Additional usable soils will be furnished and paid for under Item 203(08), Borrow (Vehicular Measurement).

Site excavation requirements and limits shall be as shown in the plans. The quantity of lime has been computed based on 10% by volume. Actual percentage of lime shall be determined by the District Lab Engineer. A unit weight of 35 pounds per cubic foot will be used to compute the required application rate of hydrated lime or quicklime regardless of the actual unit weight of the lime used.

Soils shall be pulverized prior to mixing with lime and shall meet the following gradation, exclusive of aggregate material, when tested in accordance with DOTD TR 431.

U.S. Sieve	Percent Passing (by weight)
¾"	95
No.4	50

Lime treated materials shall be compacted and finished in accordance with the normal embankment construction procedures of Section 203. Prior to compaction the material shall be within –2.0 percent and +4.0 percent of optimum moisture when tested in accordance with DOTD TR 403). No vibratory compactors will be allowed. Material shall be placed in maximum lifts of 12 inches uncompacted thickness. Material shall be placed and compacted within 48 hours after the addition of lime.

Sampling will be in accordance with Section 203 of the Materials Sampling Manual.

(3) Control Sections: Embankment materials shall be processed as specified in plan and/or in the Standard Specifications as applicable.

(c) Construction Control: Each slope embankment repair site shall be constructed in accordance with the construction control methods indicated in the plans and Section 203 of the Standard Specifications except as stated in paragraphs (ii) and (iii).

(1) Standard Specification Section: Placement of the embankment materials within the slide area shall be in accordance with Section 203 of the Standard Specifications.

(2) Optimum Moisture, Minor Compaction Section: The moisture content of the embankment section shall be in accordance with Section 203 of the Standard Specifications. The embankment materials shall be placed in uniform layers not to exceed 12 inches of uncompacted thickness. The layers shall be placed in horizontal lifts and compacted with tracked equipment for a minimum of six passes.

(3) High Moisture, Minor Compaction Section: The contractor shall dry the embankment material by disking until the moisture content is reduced to within +* percent of optimum. The material shall be processed to the desired moisture content prior to mixing fibers into the soil, if applicable. The embankment materials shall be placed in uniform layers not to exceed 12 inches of uncompacted thickness. The layers shall be placed in horizontal lifts and compacted with tracked equipment for a minimum of six passes.

(d) Finishing and Grading: After the slope area has been repaired and compacted as specified it shall be brought to the required lines and grades in accordance with the typical sections as shown in the plans. If sodding or seeding for erosion control is specified, it shall meet the requirements of Sections 714, 715, 716 and 717 of the Standard Specifications.

(e) Instrumentation: Inclinometer tubing will be installed by the Louisiana Transportation Research Center (LTRC) at each repair site. The drilling for the installation of the inclinometer tubing will be performed by the DOTD forces. The instrumentation will be installed after final grading of the slopes. After installation, the contractor shall use extreme caution not to damage the inclinometer tubing. The contractor shall replace any instrumentation that is damaged due to contractor error.

MEASUREMENT: All slope repair areas will be measured as follows.

Slope repairs will be measured by the cubic yard in its final position as the volume of soil embankment computed in-place between the excavated ground surfaces constructed during slope preparation and the final lines, grades, and slopes of the accepted embankment slope repair. The average end-area method shall be used to compute the volume. The contractor shall schedule his operations in such a manner as to facilitate the measurement of the various pay items.

CONSTRUCTION NOTES FOR SLOPE REPAIRS

S-004 SLOPE REPAIR (HIGH MOISTURE, MINOR COMPACTION)(CONTROL SECTION) CU. YD.

S-005 SLOPE REPAIR (HIGH MOISTURE, MINOR COMPACTION)(FIBER REINFORCED) CU. YD.

S-006 SLOPE REPAIR (STANDARD SPECIFICATION)(LIME TREATMENT) CU. YD.

STANDARD SPECIFICATION: COMPACTIVE EFFORT, LIFT THICKNESS, MOISTURE CONTENT ETC. AS PER THE STANDARD SPECIFICATIONS.
OPTIMUM MOISTURE: AS PER TR 415.
CONTROL SECTION: ADDITION AND BLENDING OF BORROW MATERIAL AS NEEDED AND PLACING ON SLOPE.
MINOR COMPACTION: MATERIAL TO BE PLACED IN LIFTS AND COMPACTED WITH TRACKED EQUIPMENT TO SIMULATE REPAIR BY MAINTENANCE FORCES AS DIRECTED BY THE PROJECT ENGINEER.
HIGH MOISTURE: MINOR DRYING AND MANIPULATION AS DIRECTED BY THE PROJECT ENGINEER.

LIME USED IN LIME TREATMENT SHALL BE PAID FOR UNDER ITEM NO. 304(01) LIME (TON).
COST OF FIBERS TO BE INCLUDED IN SLOPE REPAIR ITEMS AT NO DIRECT PAY.

ADDITIONAL BORROW TO BE PAID FOR UNDER ITEM NO. 203(08) BORROW (VEHICULAR MEASURMENT. BLENDING, PLACEMENT AND COMPACTION TO BE PAID FOR UNDER THE APPLICABLE SLOPE REPAIR ITEM.

CONSTRUCTION NOTES FOR SLOPE REPAIRS

FIBERS SHALL ACHIEVE TRIAXIAL AND THREE DIMENSIONAL DISPERSION WITHOUT THE FIBERS BALLING OR CLUMPING. FIBRILLATED FIBERS SHOULD OPEN UP OR FILAMENTIZE WITH PROPER MIXING TO CREATE FILAMENT STRAND AND NET REINFORCING CONFIGURATIONS THAT CAN INTERLOCK WITH THE SOIL AND PROVIDE BINDING ABILITY. THE APPEARANCE OF PROPERLY OPENED AND FILAMENTIZED FIBERS SHALL RESEMBLE A HIGH DENSITY, SYNTHETIC ROOT SYSTEM THAT PENETRATES INTO THE SOIL MASS. THE PROPERLY MIXED FIBER REINFORCED SOIL SHOULD MANUALLY DEMONSTRATE IMPROVED SHEAR STRENGTH AND COHESION PROPERTIES MUCH ON THE ORDER OF A HIGH DENSITY, SYNTHETIC ROOT SYSTEM.

5) PLACEMENT: STANDARD SPECIFICATIONS APPLY EXCEPT WHERE NOTED OTHERWISE.

6) MEASUREMENT AND PAYMENT

SLOPE REPAIR WILL BE MEASURED BY THE CUBIC YARD IN ITS FINAL POSITION AS THE VOLUME OF EMBANKMENT COMPUTED IN-PLACE BETWEEN THE GROUND SURFACES CONSTRUCTED DURING THE SLOPE PREPARATION EXCAVATED WORK AND THE LINES, GRADES AND SLOPES OF THE ACCEPTED FINAL MECHANICALLY PLACED EMBANKMENT, BY THE AVERAGE END AREA METHOD. THE CONTRACTOR SHALL SCHEDULE HIS OPERATIONS IN SUCH A MANNER AS TO FACILITATE THE MEASUREMENT OF THE VARIOUS PAY ITEMS.

PAY ITEMS:

S-001 SLOPE REPAIR (STANDARD SPECIFICATION)(FIBER REINFORCED) CU. YD.

S-002 SLOPE REPAIR (STANDARD SPECIFICATION)(CONTROL SECTION) CU. YD.

S-003 SLOPE REPAIR (OPTIMUM MOISTURE, MINOR COMPACTION)(FIBER REINFORCED) CU. YD.

CONSTRUCTION NOTES FOR SLOPE REPAIRS

1) DE-GRASS SLOPE AND A SUFFICIENT AREA AT THE FOOT OF THE SLOPE TO PROVIDE A WORKING TABLE FOR MIXING OF THE EXCAVATED MATERIALS AND SUPPLEMENTAL BORROW.
2) EXCAVATE EMBANKMENT ON A 2.5:1 SLOPE TO NATURAL GROUND. PLACE EXCAVATED MATERIAL ON DE-GRASSED WORKING TABLE AREA ALL AT NO DIRECT PAY.
3) BLEND REQUIRED BORROW WITH EXCAVATED MATERIAL.
4) <u>TREATMENT</u>

a) <u>CONTROL SECTION:</u> MANIPULATE MATERIAL TO REQUIRED MOISTURE CONTENT.

b) <u>LIME TREATMENT:</u> SPREAD AND MIX REQUIRED LIME INTO MATERIAL. PROCESS AND AIR DRY OR WATER AS NECESSARY TO ACHIEVE DESIRED MOISTURE CONTENT.

c) <u>FIBER REINFORCED:</u> <u>FIBER DOSAGE RATE.</u> THE BAGS SHALL BE LAID OUT OVER THE EXCAVATED SOIL TO BE REINFORCED IN A GRID METHOD WITH THE AMOUNT OF FIBER CALCULATED TO THE SOILS VOLUME. VOLUME ESTIMATES MUST BE MADE AS PRECISELY AS POSSIBLE. FIBERS SHALL BE ADDED TO THE SOIL AT A RATE OF 0.2% FIBERS BY THE SOILS DRY WEIGHT. (5.4 LBS. FIBERS/CU. YD. FOR MATERIAL OF 100 LBS./CU. FT.)

<u>MIXING:</u> AFTER THE BAGS ARE MANUALLY OPENED AND SPREAD, THE SOIL WILL BE BLENDED WITH THE FIBERS IN A MEASURED LIFT THAT CAN BE EFFECTIVELY WORKED TO ENSURE PROPER MIXING. THE SOILS VOLUME WILL BE CALCULATED FROM THE PHYSICAL DIMENSIONS OF THE FIELD LIFT OR LAYER TO BE WORKED. THE FIBERS SHALL BE SPREAD UNIFORMLY AND EVENLY OVER THE EXCAVATED MATERIAL TO BE WORKED, AND PREFERABLY SPREAD WITH THE USE OF LAWN RAKES IN ORDER TO ACHIEVE A UNIFORM SPREAD. ACTUAL MIXING OF THE FIBERS SHALL BE ACHIEVED BY THE USE OF A COMMERCIAL SIZE, ROTARY PULVERIZER MIXER. A MINIMUM OF THREE COMPLETE PASSES OF THE MIXER SHALL BE REQUIRED FOR THE FIBER MIXING OF EACH LIFT OR LAYER. MIXING REQUIRES ADEQUATE ROTATIONAL SHEAR MOTION BY MEANS OF A ROTARY PULVERIZER MIXER TO UNIFORMLY BLEND AND DISTRIBUTE THE FIBERS THROUGHOUT THE SOIL MASS TO BE FIBER REINFORCED.

APPENDIX D

BIBLIOGRAPHIC LIST OF FIBER REINFORCED SOIL (from Zonberg, 1998)

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