ABSTRACT

This paper investigates the development of digital image analysis approach for estimation of physical properties of soil in lieu of conventional laboratory approach. The traditional laboratory approach attracts some drawbacks such as lot of manual involvement, time consuming, chances of creeping of human errors, uncertain prediction and always invasive in nature. Hence to reduce above said drawbacks, this research work is undertaken to develop a correlation between soil image feature namely Fractal Dimension (FD) and physical properties of soil material namely water content (w), specific gravity (G), coefficient of curvature (Cc), uniformity coefficient (Cu), liquid limit (w\textsubscript{L}), plastic limit (w\textsubscript{P}), shrinkage limit (w\textsubscript{S}) and filed density. The present research deals collecting soil samples for trail pits at designated site as per IS code procedure. The digital image database is prepared for the collected soil sample in the laboratory and physical properties (Y) are determined. Digital image analysis is adopted to estimate the image feature namely fractal dimension (X). Correlation is developed between Y and X by fitting appropriate polynomial equations using regression models. The final results of this research will contribute to make soil physical properties estimation automatic up to a certain degree of level, which will assist to a geotechnical engineers, in soil classification. The results of present work emphasizes that there is a great potential in the use of fractal dimension for estimating physical soil properties for practical application, with minimum human error.

1. INTRODUCTION

The physical properties such as water content (w), specific gravity (G), coefficient of curvature (Cc), uniformity coefficient (Cu), liquid limit (w\textsubscript{L}), plastic limit (w\textsubscript{P}), shrinkage limit (w\textsubscript{S}) and filed density of soil materials are estimated by conducting laboratory tests [6]. These properties are essential for the classification of soils. Laboratory approach is one of the traditional techniques followed so far, which attracts some drawbacks such as lot of manual involvement, time consuming, chances of creeping of human errors and uncertain prediction. Hence to reduce above drawbacks, this research work is undertaken to develop a correlation between soil image feature and physical properties of soil materials through Digital Image Processing.

Image processing is becoming a tremendous tool for analyzing image data in all areas of engineering science. The scope of this research paper is to extend the utility of image processing technique in civil engineering field. There are already innumerable application of Digital Image Processing techniques to deal with the study of slurry system (Zelelew 2008), automated aggregate shape characterization (Das 1954), pavement crack sealing performance (Kim and Soleymani 2006) and detection of lane and pavement boundaries (Ma, 2000).

The present research deals with capturing digital image for known soil sample and conducting laboratory test for same soil sample. Digital Image Processing is adopted to extract the image feature i.e. fractal dimension and laboratory test is adopted to estimate the physical properties of same sample. The correlation between image feature(X) and physical soil features (Y) are developed using suitable regression models in this research work.

2. METHODOLOGY

Figure 1 depicts flow chart of methodology adopted in this research work.
Authors collected the soil samples from test pit 1, 2, 3 at the designated site has depicted in Figure 2. Authors also collected the digital images of same soil sample, for the corresponding test pits 1, 2, 3 and maintain proper labeling system to identify uniquely images and soil samples. Laboratory experiments are conducted to estimate physical properties of soil sample as explained in section 2.2 and image analysis is performed to estimate fractal dimension as explained in section 2.5. Finally developing a correlation between image features and physical features by using linear regression model is explained in section 3.

**Description of Site Plan and Location**

The site which is used to collect the soil sample and images as shown in Figure 2. This site has dimensions of 40ft×30ft, located at right side of the Hassan to Belur main road at distance of 1km from Malnad College of Engineering, Hassan, Karnataka, India.

**Experimental Procedures**


**Preparation of Laboratory Image Database**

The soil samples collected at pits 1, 2, 3 at the designated site as depicted in Figure 2 are spread on three different trays and images are captured using Sony Cyber-shot S2100 digital camera. For each soil sample ten images are captured to extract the image feature. Figure 3 shows a typical case of preparation of laboratory image database.

**Box Counting Method**

The box counting method is one of the widely adopted algorithms for estimating the fractal dimension of a binary image (Castrejon Pita 2002). Box counting principle can be easily understood from the following example.

Box counting principle involves with counting the number of one’s covered by a specified box size in a binary image as depicted in Figure 5 until completion of full image size and recorded as N(S). The reciprocal of box size is also recorded as 1/S. This procedure is repeated for all the binary images obtained by varying threshold values from 0.2 to 0.6 of an average digital soil image of same pit. The Fractal Dimension of digital soil (Eq. 1) is estimated as slope of line obtained by logarithmic of N(S) and (1/S) as depicted in Figure 5.

From Figure 5, Box size (S) = 3, Number of one’s in that box (N(S)) = 5.

$$\text{FD} = \frac{\log(N(S))}{\log(1/3)} = -1.46$$  \hspace{1cm} (1)

**Fractal Dimension (FD)**

Fractal dimension (FD) is defined as a mathematical descriptor of image feature which characterizes the physical properties of soil images. Fractal dimension of image feature presents the evolution of earth material, soil, in terms of roughness through fractal theory. The fractal, introduced in 1975 by Mandelbrot (Buczko 2005) provides a framework for the analysis of natural phenomena in various scientific domains. The fractal is an irregular geometric object with an infinite nesting of structure of different sizes. Fractals can be used to make models of any natural object, such as soil, islands, rivers, mountains, trees, clouds. The most important properties of fractals are self-similarity, chaos and non-integer fractal dimension. Some of the important methods to estimate the fractal dimension are area perimeter method, line divider method, skyscrapers method and box counting method (Bojoviæ 2008; Castrejon Pita et al. 2002 & Ghosh 2008).

**Box Counting Principle**

From Figure 5, Box size (S) = 3, Number of one’s in that box (N(S)) = 5.

$$\text{FD} = \frac{\log(N(S))}{\log(1/3)} = -1.46$$  \hspace{1cm} (1)
3. RESULTS AND DISCUSSION

Experimental Results

Tables 1, 2, 3 depict physical soil properties obtained as per IS code provisions in geotechnical laboratory, Civil Engineering Dept., Malnad College of Engineering, Hassan, Karnataka, India.

Table 1: Experimental Results of Soil Sample of Pit 1

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th>Trail Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (w) in %</td>
<td>Pit 1</td>
<td>8.54</td>
<td>9.42</td>
<td>8.79</td>
<td>8.93</td>
<td>9.80</td>
</tr>
<tr>
<td>Specific gravity (G)</td>
<td></td>
<td>2.62</td>
<td>2.58</td>
<td>2.70</td>
<td>2.72</td>
<td>2.65</td>
</tr>
<tr>
<td>Sieve analysis (a) Coefficient of curvature (Cc)</td>
<td></td>
<td>0.64</td>
<td>0.58</td>
<td>0.69</td>
<td>0.60</td>
<td>0.62</td>
</tr>
<tr>
<td>(b) Uniformity coefficient (Cu)</td>
<td></td>
<td>7.34</td>
<td>7.21</td>
<td>6.90</td>
<td>7.10</td>
<td>7.17</td>
</tr>
<tr>
<td>Liquid limit (wL) in %</td>
<td></td>
<td>34.2</td>
<td>33.3</td>
<td>34.50</td>
<td>34.70</td>
<td>33.90</td>
</tr>
<tr>
<td>Plastic limit (wP) in %</td>
<td></td>
<td>23.47</td>
<td>23.32</td>
<td>23.37</td>
<td>23.79</td>
<td>23.63</td>
</tr>
<tr>
<td>Shrinkage limit (wS) in %</td>
<td></td>
<td>18.53</td>
<td>18.57</td>
<td>18.70</td>
<td>18.89</td>
<td>18.43</td>
</tr>
<tr>
<td>Field density (ρd) in gm/cm³</td>
<td></td>
<td>1.52</td>
<td>1.60</td>
<td>1.63</td>
<td>1.50</td>
<td>1.68</td>
</tr>
</tbody>
</table>

Table 2: Experimental Results of Soil Sample of Pit 2

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th>Trail Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (w) in %</td>
<td>Pit 2</td>
<td>9.56</td>
<td>9.98</td>
<td>9.95</td>
<td>10.01</td>
<td>10.53</td>
</tr>
<tr>
<td>Specific gravity (G)</td>
<td></td>
<td>2.63</td>
<td>2.57</td>
<td>2.67</td>
<td>2.70</td>
<td>2.60</td>
</tr>
<tr>
<td>Sieve analysis (a) Coefficient of curvature (Cc)</td>
<td></td>
<td>0.53</td>
<td>0.59</td>
<td>0.61</td>
<td>0.51</td>
<td>0.57</td>
</tr>
<tr>
<td>(b) Uniformity coefficient (Cu)</td>
<td></td>
<td>8.06</td>
<td>8.24</td>
<td>7.83</td>
<td>8.12</td>
<td>7.94</td>
</tr>
<tr>
<td>Liquid limit (wL) in %</td>
<td></td>
<td>34.40</td>
<td>33.70</td>
<td>34.67</td>
<td>34.83</td>
<td>34.52</td>
</tr>
<tr>
<td>Plastic limit (wP) in %</td>
<td></td>
<td>23.51</td>
<td>23.34</td>
<td>23.37</td>
<td>23.82</td>
<td>23.89</td>
</tr>
<tr>
<td>Shrinkage limit (wS) in %</td>
<td></td>
<td>18.46</td>
<td>19.58</td>
<td>17.66</td>
<td>18.78</td>
<td>18.21</td>
</tr>
<tr>
<td>Field density (ρd) in gm/cm³</td>
<td></td>
<td>1.69</td>
<td>1.63</td>
<td>1.72</td>
<td>1.59</td>
<td>1.66</td>
</tr>
</tbody>
</table>

Table 3: Experimental Results of Soil Sample of Pit 3

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Trail number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (w) in %</td>
<td>Pit 3</td>
<td>11.84</td>
<td>13.06</td>
<td>11.18</td>
<td>10.18</td>
<td>11.52</td>
</tr>
<tr>
<td>Specific gravity (G)</td>
<td></td>
<td>2.74</td>
<td>2.63</td>
<td>2.61</td>
<td>2.70</td>
<td>2.65</td>
</tr>
<tr>
<td>Sieve analysis (a) Coefficient of curvature (Cc)</td>
<td></td>
<td>0.55</td>
<td>0.62</td>
<td>0.52</td>
<td>0.58</td>
<td>0.65</td>
</tr>
<tr>
<td>(b) Uniformity coefficient (Cu)</td>
<td></td>
<td>6.80</td>
<td>6.23</td>
<td>6.98</td>
<td>6.75</td>
<td>6.71</td>
</tr>
<tr>
<td>Liquid limit (wL) in %</td>
<td></td>
<td>35.20</td>
<td>35.21</td>
<td>35.23</td>
<td>35.54</td>
<td>35.42</td>
</tr>
<tr>
<td>Plastic limit (wP) in %</td>
<td></td>
<td>27.27</td>
<td>27.54</td>
<td>27.07</td>
<td>26.93</td>
<td>27.73</td>
</tr>
<tr>
<td>Shrinkage limit (wS) in %</td>
<td></td>
<td>22.76</td>
<td>22.57</td>
<td>20.74</td>
<td>21.76</td>
<td>22.87</td>
</tr>
<tr>
<td>Field density (ρd) in gm/cm³</td>
<td></td>
<td>1.60</td>
<td>1.58</td>
<td>1.63</td>
<td>1.69</td>
<td>1.55</td>
</tr>
</tbody>
</table>

Results of Image Analysis

Table 4 summarizes fractal dimension (FD) estimated for different threshold for box size ‘4’. The threshold value varies from 0.2 to 0.6 to get binary image. The fractal dimension values are obtained for average digital soil image.

Table 4: Results of Laboratory Image Analysis of Soil Samples of Pits 1, 2 and 3

<table>
<thead>
<tr>
<th>Threshold (d)</th>
<th>Fractal Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pit 1</td>
</tr>
<tr>
<td>0.2</td>
<td>1.74</td>
</tr>
<tr>
<td>0.3</td>
<td>1.69</td>
</tr>
<tr>
<td>0.4</td>
<td>1.48</td>
</tr>
<tr>
<td>0.5</td>
<td>1.46</td>
</tr>
<tr>
<td>0.6</td>
<td>1.55</td>
</tr>
</tbody>
</table>

Correlation of Laboratory Image Fractal Dimension with Soil Features

The correlation curves by regression models, obtained for values tabulated in Tables 1, 2, 3 and Table 4 are depicted in Figures 6 and 7.

Fig. 6: Correlation of Fractal Dimension of Image with Water Content, Liquid Limit, Plastic Limit and Shrinkage Limit
Fig. 7: Correlation of Fractal Dimension of Image with Specific Gravity, Coefficient of Curvature (Cc), Uniformity Coefficient (Cu) and Field Density

Validation of Results

The validation of digital image analysis is cross checked by conducting laboratory test and image analysis of soil sample from the site other than used in correlation equations developed. The query site is located in Chickmagalure from Hassan at distance of 65 k.m on the road of Hassan to Chickmagalure. From image analysis, fractal dimension of a query image is found to be FD(X) = 1.6168 by box counting method as explained in section 2.5.1. All the physical soil properties(Y) are determined in the laboratory as explained in section 2.2. Table 1, 2, 3 summarizes physical soil properties obtained using correlation equations, by substituting fractal dimension(X) value. The percentage of error between conventional and present new method varies from 1.26% to 8.92% with respect to different soil properties as depicted in Table 5.

Table 5: Physical properties from laboratory test and from image analysis for query soil sample.

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>From laboratory test</th>
<th>From image analysis</th>
<th>Absolute percentage of error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content(w) in %</td>
<td>10.83</td>
<td>10.20</td>
<td>5.81</td>
</tr>
<tr>
<td>Specific gravity(G)</td>
<td>2.45</td>
<td>2.56</td>
<td>4.48</td>
</tr>
<tr>
<td>Sieve analysis (a)Coefficient of curvature(Cc)</td>
<td>1.12</td>
<td>1.22</td>
<td>8.92</td>
</tr>
<tr>
<td>(b)Coefficient of uniformity(Cu)</td>
<td>7.13</td>
<td>7.22</td>
<td>1.26</td>
</tr>
<tr>
<td>Liquid limit(WL) in %</td>
<td>33</td>
<td>33.89</td>
<td>2.69</td>
</tr>
<tr>
<td>Plastic limit(WP) in %</td>
<td>22.76</td>
<td>23.83</td>
<td>4.70</td>
</tr>
<tr>
<td>Shrinkage limit(Ws) in %</td>
<td>18.69</td>
<td>19.71</td>
<td>5.45</td>
</tr>
<tr>
<td>Field density(ρ) in gm/cm³</td>
<td>1.52</td>
<td>1.63</td>
<td>7.23</td>
</tr>
</tbody>
</table>

4. CONCLUSION

The laboratory experimental results are obtained in order to develop relations between fractal dimension and index properties are tabulated in Table 1, 2, 3. Figures 6 and 7 depicts that correlation between fractal dimension and physical soil properties of soil sample using appropriate curve fitting technique which give rise to polynomial equations. Table 4 reveals that fractal dimension value which varies from 1.32 to 1.92 (maximum 2) for laboratory images for different threshold values of binary images. Table 5 shows that percentage of error between conventional laboratory and image analysis approach varies from 1.26% to 8.92% for query soil sample image for determination of physical properties of soil sample based on correlated equations developed in this research work. The results of present work emphasizes that there is a great potential in the use of fractal dimension for estimating physical soil properties for practical application, with minimum human effort.

REFERENCES


