Fuzzy Modeling of Performance of Composite Soil Reinforced with Rice Straw

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Abstract: Rice straw is widely cultivated and harvested once or twice annually in almost all rural areas in north of Iran and could be used in producing composite soil blocks with better characteristics. This paper reports on an experimental investigation into the physical and mechanical performance of a composite soil reinforced with rice straw and the model the behavior of composite soil. The main objective of the work is to analyze the characteristics of a sample of soil that available in the Markazi province region of Iran and to investigate the possibility of enhancing soil properties by reinforcement with rice straw at different levels. Based on the experiments on the soil, the following features are obtained: Soil type: cl, $W_{op}=15\%$, $g_{max}=1.83$, P.L. = 22\%, L.L. = 33\%, PI=11\% Stress–strain relation is highly nonlinear and sensitive to various factors such as fiber contents, confining pressures and sample curing periods. This paper uses the fuzzy modeling for finding the nonlinear relations. Simulation results are very promising.

Key words: Clay, rice straw, fuzzy modeling, reinforcement.

INTRODUCTION

Mechanical behavior of soil under static and dynamic loading plays an essential role in performance of infrastructures such as durability of pavement, road beds, stability of slopes and bridge foundations, etc. To improve engineering properties of soil, soil reinforced with other materials is more and more widely applied in geotechnical engineering (Michalowski, R.L., A. Zhao, 1995; Li, J., D.W. Ding, 2002; Rasdoslaw, L., J.C. Michalowski, 2003; Rasdoslaw, L., J.C. Michalowski, 2002). Moreover, a growing interest has been focused on stabilizing earth construction, as it is widely used in desert and rural areas because of its abundance and cheap labor. However, although a lot of ancient constructions and recent prototypes have been built, they tend to have a short lifetime span as earth construction suffers usually from lack of strength and shrinkage cracking due to the drying process and lack of resistance to water. To overcome this problem, two ways have been explored. The first is achieved by means of stabilization of the earth either by using chemical binders such as cement and lime or by means of mechanical compaction while the second consists of adding natural fibers to the earth. Natural fibers have been used for a long time in many developing countries in cement composites and earth blocks because of their availability and low cost (Ghavami, K., 1999; Savastano, H., 2000; Bouhicha, M., 2005).

Rice straw is widely cultivated and harvested once or twice annually in almost all rural areas in north of Iran and could be used in producing composite soil blocks with better characteristics, but no published data is available on its performance as reinforcement to soil or earth blocks. This paper reports on an experimental investigation into the physical and mechanical performance of a composite soil reinforced with rice straw and the model the behavior of composite soil. The main objective of the work is to analyze the characteristics of a sample of soil that available in the Markazi province region and to investigate the possibility of enhancing soil properties by reinforcement with rice straw at different levels.

It has been proved that when soil is physically reinforced with short fiber and chemically stabilized with lime powder, strength of soil can be considerably improved (Li, J., L.J. Zhang, 2003; Bahar, R., 2002).

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However, to quantitatively evaluate the enhancement of mechanical behavior of the composite soil still remains challenging since the stress–strain relation is highly nonlinear and sensitive to various factors such as lime and fiber contents, confining pressures and sample curing periods. This paper uses the fuzzy modeling for finding the nonlinear relations.

In section 2 the terra added straw and experiments are described. In section 3 the procedure of the proposed fuzzy modeling is described. Section 4 presents the simulation results. Section 5 includes conclusions.

MATERIALS AND METHODS

2.1. Terra Added Straw Experiments:
The main objective of the work is to analyze the characteristics of a sample of soil that available in the Markazi province region of Iran and to investigate the possibility of enhancing soil properties by reinforcement with rice straw at different levels.

Based on the experiments on the soil, the following features are obtained:

Soil type: cl, $W_{op}=15\%$, $g_{dmax}=1.83$, P.L.= 22\%, L.L.=33\%, PI=11\%

The samples of soil with different percentage of rice straw (0%-2%-4%-6%-8%-10%) were prepared, based on optimal moisture rates, $w_{op}$, the maximum special weight $g_{dmax}$, consolidation samples with a density up to 95\% (minimum), are remolded in the consolidation frames. For each of these soil samples, the consolidation test was done by applying various loadings (.5, 1, 2, 4, 8, 16) and a curve was drawn by which $(D-\sqrt{t})$, $(U-\sqrt{t})$, CV and the coefficient of consolidation were obtained by using the Tailor’s method. In addition, based on the porosity data, the proportionate with every loading was calculated and primary porosity; moisture and saturation of the six samples were obtained.

After sampling from five different kind of soils and conducting preliminary experiments on them, the appropriate sample has been collected from the aforementioned samples. The hydrometery experiments and determination of Etterberg threshold as well as optimal percentage of humidity and maximum unit weight have been determined in Soil Mechanics Laboratory of the Ministry of Road and Transportation (SMLMRT) of Arak, Iran. The results were documented (See Fig.1 and Fig. 2). Soil samples with different percentage of straw (0%, 2%, 4%, 6%, 8%, 10%) were prepared (See Fig 3 and Fig. 4).

![Fig. 1: Experiments for determining](image1)

![Fig. 2: Hydrometrical experimentation](image2)

Using the compression test, the optimal percentage of humidity, $W_{op}$, maximum dry unit weight and $g_{dmax}$ have been determined for each sample. Table 1 gives the experimental results.

<table>
<thead>
<tr>
<th>%Straw</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_{op}$</td>
<td>11.5</td>
<td>11.8</td>
<td>12.1</td>
<td>12.4</td>
<td>13.1</td>
<td>13.5</td>
</tr>
<tr>
<td>$g_{dmax}$</td>
<td>1.97</td>
<td>1.925</td>
<td>1.87</td>
<td>1.84</td>
<td>1.705</td>
<td>1.68</td>
</tr>
</tbody>
</table>
After these tests, the consolidated samples for at least 95% has been remolded in the consolidation molds and were prepared for the test. For each of the soil samples the consolidation test for different loadings (0.5, 1, 2, 4, 8, 16 Kg) has been conducted (See Fig. 5 and Fig. 6).

Using diagrams of the Drainage – Time square root \(\sqrt{D-T}\) and the Consolidation – Time root square \(\sqrt{U-T}\) and applying Taylor's method the consolidation coefficient \(C_v\) is determined (table 2). Using the experimental results the porosity corresponding to each loading has been obtained (table 3).

### Table 2: Variations of consolidation coefficient with different percentage of straw with increasing load \(P\)

<table>
<thead>
<tr>
<th>%Straw</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load (kg)</td>
<td>0.378</td>
<td>0.396</td>
<td>0.408</td>
<td>0.417</td>
<td>0.429</td>
<td>0.437</td>
</tr>
<tr>
<td>0.5</td>
<td>0.346</td>
<td>0.366</td>
<td>0.368</td>
<td>0.387</td>
<td>0.391</td>
<td>0.401</td>
</tr>
<tr>
<td>1</td>
<td>0.331</td>
<td>0.354</td>
<td>0.360</td>
<td>0.380</td>
<td>0.382</td>
<td>0.390</td>
</tr>
<tr>
<td>2</td>
<td>0.313</td>
<td>0.336</td>
<td>0.398</td>
<td>0.358</td>
<td>0.370</td>
<td>0.377</td>
</tr>
<tr>
<td>4</td>
<td>0.294</td>
<td>0.318</td>
<td>0.328</td>
<td>0.337</td>
<td>0.345</td>
<td>0.355</td>
</tr>
<tr>
<td>8</td>
<td>0.294</td>
<td>0.305</td>
<td>0.314</td>
<td>0.319</td>
<td>0.323</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.24</td>
<td>0.268</td>
<td>0.277</td>
<td>0.284</td>
<td>0.287</td>
<td>0.290</td>
</tr>
</tbody>
</table>

### Table 3: Variation of porosity \(e\) with different percentage of straw with increasing load \(P\)

<table>
<thead>
<tr>
<th>%Straw</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>9.132</td>
<td>10.12</td>
<td>11.298</td>
<td>12.2</td>
<td>12.83</td>
<td>13.603</td>
</tr>
<tr>
<td>2</td>
<td>10.106</td>
<td>11.723</td>
<td>12.1</td>
<td>12.85</td>
<td>13.03</td>
<td>14.08</td>
</tr>
<tr>
<td>4</td>
<td>10.722</td>
<td>12.01</td>
<td>12.524</td>
<td>12.93</td>
<td>13.01</td>
<td>14.103</td>
</tr>
</tbody>
</table>

In the next section we review a fuzzy modeling method.
2.2. Fuzzy Logic Modeling Method:

An introduction to the fundamental concepts of fuzzy logic has been given by Zadeh (1973). System modeling based on conventional mathematical tools (e.g., differential equations) is not well suited for dealing with ill-defined and uncertain systems. By contrast a fuzzy inference system employing fuzzy if-then rules can model the qualitative aspects of human knowledge and reasoning processes without employing precise quantitative analyses.

This fuzzy modeling or fuzzy identification, first explored systematically by Takagi and Sugenon (1985), has found numerous practical applications in control (Pedrycz, W., 1989; Sugeno, M., 1985), prediction and inference (Kandel, A., 1988; Kandel, A., 1992).

Information used for fuzzy logic modeling will be placed in two groups:

(a) Quantitative information from measurements,
(b) Qualitative information from expert operators.

In neural network analysis only quantitative information will be used, but in fuzzy logic qualitative data can be used as well as quantitative information. Some approaches was proposed for fuzzy modeling (Menhaj, M.B., 1999; Jang, J.R., 1993; Yager, R., D.P. Filev, 1994; Suratgar, A.A., 2009; Suratgar, A.A., 2003; Suratgar, A.A., 2005), here we use a method for constructing rule base based on available quantitative and qualitative data. The model used in this paper has 2 inputs and 1 output. Following we explain the fuzzy modeling method.

2.2.1. Fuzzy Model Design Steps:

In this section the steps of fuzzy modeling is listed. The interested reader may refer to (Menhaj, M.B., 1999). Here we consider a series of data consisting of two inputs and one output as input-output of the desired control \((x_1^{(i)}, x_2^{(i)}, y^{(i)})\), \(\ldots\), \((x_1^{(i)}, x_2^{(i)}, y^{(i)})\), with \(x_1^{(i)}, x_2^{(i)}\) as inputs and \(y^{(i)}\) as output. The method can be easily extended for multi-input multi-output systems. Our objective is to map the inputs to the desired output(s).

The design procedure is summarized below:

Step 1: Select the total number of fuzzy sets for inputs and outputs fuzzification. It is called partition number.

The next step is to construct membership functions. The intervals of variables \(x_1, x_2, y\) are respectively considered as \([x_1^-, x_1^+]\), \([x_2^-, x_2^+]\) and \([y^-, y^+]\) in which the operating data exist more probably.

Step 2: We considered five primary fuzzy partitions with equal length. However in general each partition can have its own particular length.

Step 3: Consider Gaussian membership functions with the centers coincident with fuzzy partitions midpoints, and with spread equal to distance between neighborhood centers.

\[
\mu(x) = \exp \left( -\frac{(x - m)^2}{\sigma} \right)
\]

\(\mu = \)Membership function
\(\sigma = \)Spread of membership functions
\(m = \)Center of membership functions

Different input/output intervals are labeled as follows:

\(S_N, \ldots, S_1, CE, L_1, \ldots, L_N\)

Step 4: Membership degree of each pair of given data \((x_1^{(i)}, x_2^{(i)}, y^{(i)})\) in different partitions are specified and then \(x_1, x_2, y\) are assigned to the partitions with maximum membership degree. At last one rule from the input-output pair will be produced. For example for the given triple \((x_1^{(i)}, x_2^{(i)}, y^{(i)})\), we have:
If maximum membership of \( x_1^{(1)} \) is in \( L_1 \) and If maximum membership of \( x_2^{(1)} \) is in \( S_1 \) and If maximum membership of \( y \) is in CE. Then we conclude following rule:

If \( x_1^{(1)} \) is \( L_1 \) and \( x_2^{(1)} \) is \( S_1 \) then \( y \) is CE.

Step 5: Assign a degree of credit to each rule. Since there are many data pairs and each pair makes a rule, there may be overlapping rules (rules with the same if-part and different then-part). To overcome this problem, a degree of credit is assigned to each rule, which is equal to the product of membership functions of that rule. Among the overlapping rules, those with greater degree of credit are chosen and will be placed in the rule base.

Step 6: Construct a compound rule base. The rule base is constructed based on rules resulted from numeric data and rules stated by expert operator. Each rule expressed by expert operator will be stated in a conditional form, and a degree of credit is assigned to it. Then this rule will be added to the rule base.

Step 7: Evaluate the I/O mapping. For defuzzification, center of area method (COA) is used and we proceed as follows to find a crisp output. First the 'if' parts of the \( i \)th rule will be combined to find the degree of firing of the \( i \)th rule based on inputs \( x_1, x_2 \). We use the product method for combination:

\[
m_{O_i} = m_{T_1}(x_1)m_{T_2}(x_2)
\]

where \( O_i \) and \( T_{ij} \) denote respectively output and input region. Then center of area (COA) is applied:

\[
y = \frac{\sum_{i=1}^{k} m_{O_i} * y}{\sum_{i=1}^{k} m_{O_i}}
\]

In the above, \( y_i \) indicates center of region \( O_i \) and \( k \) is the number of rules.

The fuzzy model can be tuned using artificial neural networks. Member ship function parameters can be adjusted using artificial neural network. For more precision \( ANFIS \) (adaptive-network-based fuzzy inference system) is used for modeling (Jang, J.R., 1993). It is a fuzzy inference system implemented in the framework of adaptive networks. By using a hybrid learning procedure, the proposed ANFIS can construct an input-output mapping based on both human knowledge (in the form of fuzzy if-then rules) and stipulated input-output data pairs. In the simulation, the ANFIS architecture is employed to model nonlinear functions, identify nonlinear components on-line in a control system, and predict a chaotic time series, all yielding remarkable results. In the next section the simulation results are proposed.

RESULTS AND DISCUSSIONS

The proposed approach is simulated with MATLAB 7.3 and the simulation results are very promising. The maximum error between the model output and actual data is 0.000176. The two norm of error between them is 8.0825e-005. The figures 9-16 show the simulation results. The simulation results are very promising.

A fuzzy model for terra added straw behavior has been designed and simulated. The simulation results show good performance of this model for a wide range of behavior. Straw is cheap and abundant and as a by-product of agricultural activities is available to be used in construction industry. Statistics show that under developing countries are the main producers of rice in the world and also based on the same data, 200kg of straw would be produced per one ton that is a considerable amount. Given to the conducted researches, it can be claimed that presence of straw in the soil will approximately cause a 10% increase in porosity and the reinforced coefficient, and by these two increased parameters, the speed of water drainage from the watery layers would be accelerated. Consequently, the time to achieve the ultimate subsiding as a result of consolidation would be reduced.
Fig. 7: The proposed fuzzy model results and the experimental initial porosity of samples

Fig. 8: The proposed fuzzy model results and the experimental percent of saturation of samples

Fig. 9: The proposed fuzzy model results and the experimental percent of humidity of samples
Fig. 10: The proposed fuzzy model results and the experimental coefficient of compression of samples

Fig. 11: The proposed fuzzy model results and the experimental C of samples

Fig. 12: The proposed fuzzy model results and the experimental $\phi$ of samples
Fig. 13: The proposed fuzzy model results and the experimental $e$ of samples.

Fig. 14: The proposed fuzzy model results and the experimental $C_v$ of samples

REFERENCES


