Fuzzy Soil Expert System for Prediction of Expansive Soils

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***Abstract*— Fuzzy soil expert systems is a fuzzy rule based system using fuzzy IF-THEN rules to qualify the expansion potential considering the index properties of expansive soils and expanding clay minerals. Fine Fraction, Liquid Limit, Shrinkage limit, Plasticity Index and Free Swell Index are used as Linguistic and numeric input variables. The expansion potential is determined from the membership function. An example of fuzzy soil expert system is given.**

Keywords— fuzzy logic, fuzzy conditional inference, fuzzy soil expert system, prediction of expensive soil

I. INTRODUCTION

Expansive soils are classified basing on the term called potential expansion also termed as potential swell or degree of expansion. Criteria were developed by several investigators for classifying the expansive soils to ascertain the expansion potentiality using such factors as clay content, Liquid Limit (W_L), Plasticity Index (I_P), shrinking Limit (W_S) and Free Swell Index (FSI) Ssimple soil properties for identification of expansive soils and to assess the potential degree of expansion of any soil using these simple properties by expressing them as linguistic variables in addition to numerical variables. The relationship between these variables are characterized by conditional fuzzy statements. This facilitates the decision making regarding the potential expansiveness nears heuristic than mechanistic thereby can be adopted for development of expert systems for identification and classification of expansive soils.

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II. FUZZY DESCRIPTION OF EXPANSION POTENTIAL OF A SOIL

The process of estimation of expansion potential of a soil begins with search for presence of expanding clay minerals in the soil indirectly from the soil properties and parameters The liquid limit, plasticity index, shrinkage limit and free swell index of expanding clay minerals significantly differ from those of non-expanding clay minerals.

Taking on this several investigators developed criteria for classification of expansive soils and their potential for expansion making use of two or more of these properties. The expansion potential is qualitatively expressed by terms like Very High, High, marginal, critical etc. For each degree of expansion potential the probable range of liquid limit, plasticity index etc., are suggested based on their experience and perception keeping in view the characteristics of expanding clay minerals. Amongst the several parameters used for identification of expansive soils by different investigators, percentage passing 75µ sieve, liquid limit, plasticity index, shrinkage limit and free swell index tests are easy to determine and are routinely determined in any laboratory.

Hence these properties are used for estimating the probable degree of expansion. Since the natural soil may contain both expanding clay minerals and non-expanding clay minerals along with slit and coarse fraction their property may fall in between those of expanding clay minerals and non-expanding clay minerals leading to some uncertainty and ambiguity in assessing the expansion potential of a soil by comparing its properties with those of clay minerals.

III. FUZZY LOGIC

Fuzzy sets are useful for describing the ambiguity and vagueness in conceptual or mathematical models of empirical phenomena (Gupta & Yamakawa, 1988). A brief introduction to the fuzzy set theory is presented as follows. According to Zadeh (1965),

If x is a collection of objects denoted by x, a fuzzy set A in X is then a set of ordered pairs defined as follows.

$\underline{A} = \{(x, \mu_A(x)) / x \in X\}$

Where $\mu_A(x)$ is the membership function of x in $\underline{A}$ which maps X to an evaluation set [0, 1].

Fuzziness may computed using the function or may be given with commonsense by absevations.

Let A and B be the fuzzy rough sets .

The operations on fuzzy rough sets are given by

$1\text{-}A = 1 - \mu_A(x)$ Negation

$A V B = \max\{\mu_A(x) .\ \ \mu_B(x)\}$ Disjunction

$A \Lambda B = \min\{\mu_A(x) .\ \ \mu_B(x\}$ Conjunction

$A \rightarrow B = \min\{1, 1 - \mu_A(x) + \mu_B(x\}$ Implication

$A_1 \text{ o } A \rightarrow B = \min\{A_1 , A \rightarrow B\}$ Composition

The fuzzy quantifiers "very" and "more" are given by

$\mu_{\text{very B}}(x) = \mu_{\text{very B}}(x)\}^{2}$

$\mu_{\text{more B}}(x) = \mu_{\text{more B}}(x)\}^{0.5}$

Mamdani fuzzy conditional inference is given for the relation between A and B is known.

if x_1 is A_1 and x_2 is A_2 and … and x_n is A_n then y is B

$= \min(A_1, A_2 ,\ldots ,A_n , B)$

The fuzzy conditional inference is given for the relation between A and B is not known.

$=\min(A_1, A_2 ,\ldots ,A_n ,1)$, where B=1 because B is not known.

$=\min(A_1, A_2 ,\ldots ,A_n ,1)$

$\min(A_1, A_2 ,\ldots ,A_n)$

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IV. FUZZY SOIL EXPERT SYSTEM

In this study, fuzzy theory is used to assess the expansion of a soil using five index properties viz., percentage passing 75μ sieve, liquid limit, plasticity index, shrinkage limit and free swell index. The problem of qualitative assessment of degree of expansion potential can be approached using combination of degree of match and the fuzzy rule based system. In a fuzzy rule based system, the knowledge concerning the classification of the object (potential expansion) is represented in the form of rules. Each rule has a set of antecedent propositions comprising of attributes names liquid limit, plasticity index, shrinkage limit and free swell index and linguistic description of attributes like very high, high etc. These linguistic variables are invariably imprecise keeping in view the inadequate information on influence of each attribute on the object (expansion potential) and the integrated effect of all the attributes on the potential expansion.

TABLE1: Typical Rules Framed for F I S

S.No		FF	W_L	I_P	W_S	FSI		EP
1	if	x_{11}	x_{12}	x_{12}	x_{14}	x_{15}	then	y_{11}
2	if	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	then	y_{12}
	…		…	…	…	…	…	---
n	if	x_{n1}	x_{n2}	xn3	x_{n4}	x_n5		y_{n5}

Typical clay minerals and their characteristics are reported in literature are presented in Table 1.

TABLE 2: Clay Mineral Characteristics

Clay	FF	W_L	I_P	W_S	FSI

The system is developed using a fuzzy inference system of fuzzy tool box in Matlab environment. The Schematic diagram of Fuzzy Inference System (FIS) is shown in Fig 1. There are five primary graphical User Interface tools for building, editing and observing fuzzy inference systems in the fuzzy logic toolbox: the Fuzzy Inference System or FIS editor, the Membership Function Editor, the Rule Editor, the Rule Viewer and the Surface Viewer. In the fuzzy Logic Toolbox, there are five parts of the fuzzy inference process:

1. Fuzzification of the input variables
2. Application of the fuzzy operator (AND or OR) in the antecedent
3. Implication from the antecedent to the consequent
4. Consequent may be derived from anticident across the rules
5. Defuzzification.

Fuzzification is the process of making a crisp quantity fuzzy. The input parameters to the system are percentage passing 75μ sieve, liquid limit, plasticity index, shrinkage limit and free swell index. Ambiguity

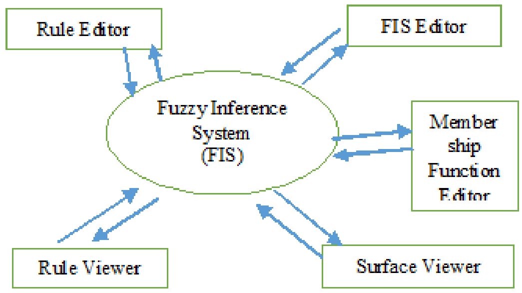
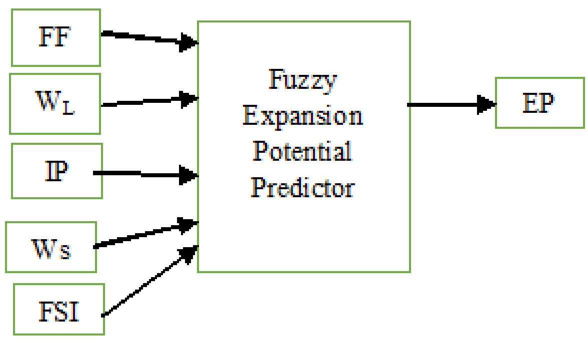


Fig. 1. Fuzzy Inference System

or vagueness exist in all these parameters as their relation to degree of expansion is not crisp. Fuzzy sets for all these parameters are developed and are represented by membership functions as shown in Fig.1. The fuzzy sets or membership functions are constructed taking into account the perception of the experts

The system consists of five fuzzy inputs namely Fine Fraction (FF), Liquid Limit (W_L), Plasticity Index (I_P), shrinkage Limit (W_S) and Free Swell Index (FSI), and one output namely Expansion Potential (EP) as shown in Fig. 2. The probable expansion potential predicted by the proposed Fuzzy rule based system along with the other methods are presented in Table-3. From this table it is clear that the proposed system predicts the expansion potential reasonably well. The main advantage of the proposed method is that it can be used as a subsystem for Expert systems which are used for identification and classification of soils which can be used for rough assessment of engineering properties. One such Expert system by being developed by the authors was described Sudharani etal., (2004).



. Fig 2. Fuzzy Expansion Potential

In the first step the inputs are taken to determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions presented in Fig.1. In the fuzzy logic tool box, the input is always a crisp numerical value limited to the discourse of the input variable (range). Fuzzification of the input is based on the table or a function evaluation. In the second step fuzzy operator (AND or OR) is applied to obtain one number that represents the result of the antecedent for that rule. The input to the fuzzy operator is two or more membership values from fuzzified input variables. The output is a single truth value between 0 and 1. In the third step every rule has weight (between 0 and 1), and is applied to the number given by antecedent and then implication method is implemented. Two methods are supported, these are functions used by AND method: min and prod. The consequent is a fuzzy set represented by membership function. In the fourth step the rules must be combined in some manner to take decision. Three aggregation methods are supported in FIS (Fuzzy Inference System): max (maximum), prior (probabilistic or) and sum (sums each rules output). In the fifth step the aggregate fuzzy set is defuzzufied in order to resolve a single output value from the set. Five built-in methods are used to defuzzify the output set: centroid, bisector, middle of maximum, largest of maximum and the smallest of maximum. Most of the times centroid method of defuzzification is adopted.

. TABLE 3. validation of proposed system

Clay sample	FF (%)	W_L (%)	I_P (%)	W_S (%)	FSI (%)
1.	*86*	76.5	45.5	20.1	126.3
2.	100	59.5	34.4	17	100.3
3.	72	61	38.8	12.2	126.8
4.	73	100	80.5	23.5	200.5
5.	98.5	79.1	74.6	20	192.5
6.	92.5	75	45.3	16.7	115.2
7.	96	72.4	40.2	12.5	105
8.	98	82	48	23.4	133.3
9.	95.5	85	52.4	12.9	107.5
10.	92	78.2	47.8	14.2	122

The membership functions for the input variables and the output variables are shown in figure 3.

$\mu_{FF}(x)= (x-70)/ (100-70)$

$\mu_{WL}(x)= (x-50)/ (150-50)$

$\mu_{Ip}(x)= (x-30)/ (120-30)$

$\mu_{Ws}(x)= (x-10)/ (30-10)$

$\mu_{FSI}(x)= (x-100)/ (210-100)$

TABLE 3. Fuzzifiction

S.No.	$\mu_{FF}(x)$	$\mu_{WL}(x)$	$\mu_{FIp}(x)$	$\mu_{Ws}(x)$	$\mu_{FFSI}(x)$
1.	0.32	0.265	0.172	0.505	0.239
2.	0.6	0.095	0.048	0.35	0.002
3.	0.04	0.11	0.097	0.11	0.243
4.	0.06	0.5	0.561	0.675	0.913
5.	0.57	0.291	0.495	0.5	0.840
6.	0.45	0.25	0.17	0.335	0.138
7.	0.52	0.224	0.113	0.125	0.045
8.	0.56	0.32	0.2	0.67	0.302
9.	0.51	0.35	0.248	0.145	0.068
10.	0.44	0.282	0.197	0.21	0.2

Fuzzy conditional inference (FCI) and Defuzzification is given by

TABLE 5.. Defuzzificcation

S.No.	FCI	ESP= (f*(b-a)+a)
1.	0.172	45
2.	0.002	100
3.	0.04	72
4.	0.06	72
5.	0.291	79
6.	0.138	115
7.	0.045	105
8.	0.2	48
9.	0.0681	107
10.	0.197	47

V. FUZZY SOIL EXPERT SYSTEM IMPLEMENTATION

LAB IDENTIFICATION

Fuzziness may be computed with the fuzzification (x-a)/(b-a)

FF range=70-100;range Wl=50-150; range Ip=30-120;range Ws=10-30;range FSI=100-130;EP=10-100

"

if FF and Wl and Ip and Ws and FSI then Expansion Potential

ESP maybe computed with the defuzzification ESP=(f(b-a)+a)*

Enter a value of FF in field:
90

Enter a value of WI in field:
110

Enter a value of Ip in field:
80

Enter a value of Ws in field:
25

Enter a value of FSI in field:
120

Expansion Potential fuzzy value: 0.55
Expansion Potential fuzzy value: 60

VI. CONCLUSIONS

A rule based Fuzzy Expert System has been developed for estimation of potential degree of expansion of a soil basing on simple index properties of the soil. Methods of Fuzzy knowledge representation and fuzzy reasoning were employed to convert uncertain system inputs to Fuzzy linguistic information. The results from 10 different soils reported in literature indicate that the proposed system is effective in predicting potential degree of expansion. The proposed system can be effectively used as a subsystem for expert system dealing with prediction of engineering properties of soils using Index propertie.

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