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"Research Note"

APPLICATION OF FUZZY SET THEORY IN EVALUATION OF SOIL COLLAPSE POTENTIAL*

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Abstract– Collapsible soils have considerable strength and stiffness in their dry natural state but settle dramatically when they become wet. This paper documents a low-cost, qualitative evaluation scheme using fuzzy set analysis to determine regional collapsibility based on subjective knowledge of the geological and geotechnical conditions and their uncertainty. The geological and geotechnical factors and their category were defined based on relevant literature. Each factor and category was then weighted or rated using linguistic terms developed from expert assessment. The linguistic data or information obtained from the assessments was represented and processed using fuzzy sets. To assess the criteria, 87 collapse potential tests were performed on undisturbed soil samples gathered from 27 different locations throughout Iran. It is shown that the geotechnical criteria predict soil collapsibility much better than the geological criteria.

Keywords– Collapse, geological criteria, geotechnical criteria, fuzzy set theory

1. INTRODUCTION

Collapsible soils are generally characterized by the sudden and substantial decrease in volume that occurs when subjected to inundation under constant stress [1-2]. Collapsible soils are found throughout the world, particularly in semi-arid and arid environments [3]. Geological environments where collapsible soils can be found are colluviums, mudflows, alluvial fans, residual soil and Aeolians [4]. The identification of collapsible soil involves laboratory and/or field response-to-wetting testing [1-3]. Owens and Rollins [4] also used geological criteria to prepare a collapsible soil hazard map. However, there are no standard or unique geological criteria by which one can distinguish collapse susceptibility on a regional scale.

There is abundant literature on the determination of soil collapse potential; however, it is rare to find references that directly address all factors contributing to it. The present paper categorizes geological and geotechnical factors contributing to soil collapsibility on a regional scale. For each factor, subcategories were defined based on literature. Each factor and category was then weighted or rated using linguistic terms developed from expert assessment. The linguistic data or information obtained from the assessments was represented and processed using fuzzy sets. To evaluate the criteria, 87 collapse potential tests were performed on undisturbed soil samples gathered from 27 different locations throughout Iran. It is shown that the geotechnical criteria predict soil collapsibility much better than geological criteria.

2. GEOLOGICAL FACTORS FOR COLLAPSE SUSCEPTIBILITY EVALUATION

The geological factors affecting the collapsibility of a natural soil were initially identified and examined in a comprehensive review of the relevant literature [2-5]. These factors have global applications and are based on the collapse hazard and significant aspects of previous observations worldwide. The factors and

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their weights are shown in Table 1a. These conditions are qualitative and give only a relative measure of collapse susceptibility.

To determine the factors and their weights, an expert opinion survey was used as outlined by Mohammadi [6]. All categories were weighted qualitatively as: A (extremely important), B (very important), C (important) and D (moderately important), (Table 1a). All subcategories were rated as: Se (Sever), Ms (Moderately sever), M (Moderate) and S (Slight), (Table 1b).

Table 1a. Geological factors for evaluation of soil collapse potential and their weights

Geological factors	Weight
Age of deposit	B
Type of deposit	A
Total dissolved solids	C

Table 1b. Geological criteria for rating soil collapse potential

Geological criterion	Linguistic rating Se	Ms	M	S
Age of deposit	<500 years	Late Holocene	Holocene	Pleistocene & Pre-Pleistocene
Type of deposit	Aeolian	alluvial	residual	other
Total dissolved solids (tds) (%dry weight of soil)	tds>15	5<tds≤15	1<tds≤5	tds≤1

3. GEOTECHNICAL FACTORS FOR COLLAPSE SUSCEPTIBILITY EVALUATION

The geotechnical factors affecting the collapsibility of a natural soil were identified and examined in a comprehensive review of the relevant literature [1-9]. The factors were defined so that they could be ascertained by visual inspection of a geotechnical or geological expert. Tables 2a, 2b and 2c show the categories and their weights or rates for the geotechnical factors. All categories were weighted qualitatively as: A (extremely important), B (very important) and C (important). All subcategories were rated as: Se (Sever), Ms (Moderately sever), M (Moderate) and S (Slight).

Table 2a.Geotechnical factors for evaluation of soil collapse potential and their weights

Geotechnical characteristic	Type of material	Fine-grained	A
		Coarse-grained	C
	Degree of saturation		A

Table 2b. Geotechnical criteria: weight of geotechnical factors

Geotechnical factor	A	B
Fine- grained material	Porosity	Liquid limit plus dry density
Coarse- grained material	Porosity	Clay content

Table 2c. Rating of geotechnical factors

Geotechnical factor		Linguistic rating Se	Ms	M	S
Fine grained material	porosity (n)	n≥0.35	0.2≤ n<0.35	0.1≤n<0.2	n<0.1
	liquid limit plus dry density	Region I	Region II	Region III	
Coarse grained material	porosity (n)	n≥0.50	0.4≤n<0.50	0.3≤n<0.4	n<0.3
	% clay content (cc)	10≤cc<30	5≤cc<10	cc<5	30≤cc
Degree of saturation (s_r)		$s_r<0.1$	$0.1\le s_r<0.5$	$0.5\le s_r<0.7$	$s_r\ge 0.7$

4. APPLICATION OF FUZZY SET THEORY

The procedure used herein to quantify the factors uncertainty is based on the fuzzy set theory, the most effective tool for processing qualitative information and inexact data [10-11]. Fuzzy sets are usually characterized by their membership functions. The triangle membership functions for the fuzzy sets used in this study are shown in Fig. 1 [12].

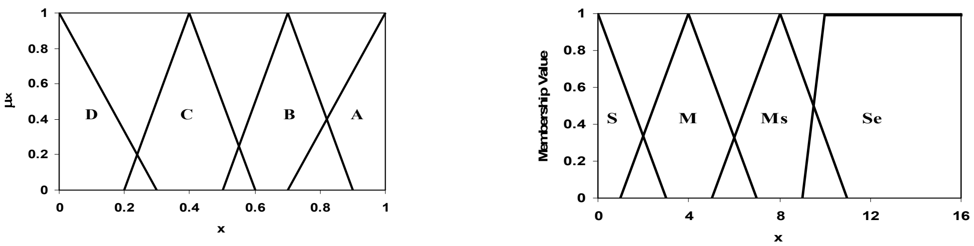

Fig. 1. Graphical representation of the input fuzzy sets for the weights and the rates (μ_x =Membership value)

The next step in the evaluation is to calculate the overall susceptibility using a mathematical rating model. The main thrust of the proposed methodology for determining collapse potential of a soil or site was a decision-tree analysis. On each level or branch of the decision tree, the information expressed in terms of the selected evaluation criteria, their weights and rates of soil collapse potential were processed using fuzzy weighted average. The resulting fuzzy set represents the overall collapse potential of the soil ($\widehat{C}_p$).

To evaluate the proposed method based on either geological or geotechnical criteria, 87 undisturbed soil samples were gathered from 27 locations throughout Iran [12]. The undisturbed soil samples were obtained using a three-part ring with the soil specimen retained in the middle ring used for laboratory testing. One-dimensional response-to-wetting tests were then carried out on each sample to obtain its collapse index (I_e) according to ASTM D 5333 specifications [13].

To evaluate the proposed models based on geological and geotechnical criteria, the fuzzy set for collapse potential ($\widehat{C}_p$) was computed for the 27 sites. Centroid defuzzification of $\widehat{C}_p$, (C_p) is compared with I_e at each location (Fig. 2). For example, a cell of the study area (Kerman city) has been rated for its collapse potential based on the geological and geotechnical criteria (Table 3). The analysis, using a prepared computer program based on the presented method, resulted in a C_p of 9.7 and 10.2 for geological and geotechnical criteria respectively. An average test result in this location is: I_e=10.25. The figures clearly indicate that geotechnical factors predict collapse potential better than geological factors, since the geotechnical criteria provide more detailed data regarding soil collapse potential (standard deviation of errors for geological and geotechnical models is 5.3 and 3.63 respectively). However, it appears that evaluation using geotechnical factors requires much more effort and experience.

Table 3. Rating of collapse potential- sample analysis

Geological criteria		Geotechnical criteria		
Factor/criterion	rating	Factor/criterion		rating
Age of deposit	Ms	Fine grained material	porosity (n)	Se
Type of deposit	Ms		liquid limit plus dry density	Ms
Total dissolved solids	M	Degree of saturation (s_r)		Ms

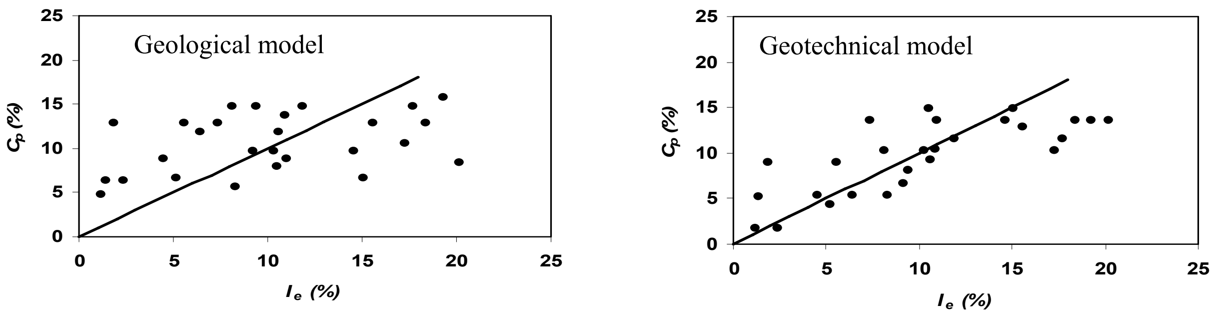

Fig. 2. Evaluation of the geological and geotechnical model

5. RESULTS AND CONCLUSIONS

One method of identifying and classifying collapsible soils considering uncertainties was presented. The method, based on geological or geotechnical criteria, uses a decision tree with linguistic terms and enables the engineer to investigate the effect of parameter uncertainty on computed soil collapsibility in a systematic way.

The geological and geotechnical factors which affect soil collapsibility were established based on a literature review and expert opinion. A set of evaluation criteria was established for each factor using appropriate weights and ratings.

Fuzzy set theory was used to model uncertainty for the proposed model. All the linguistic terms were interpreted by fuzzy membership functions, then, on the basis of the arithmetic mean, a deterministic model was used as an evaluation criterion to rate soil collapse potential.

To evaluate the model, laboratory collapse potential tests were carried out on 87 undisturbed soil samples gathered from 27 locations throughout Iran. It was shown that the model based on geotechnical factors predicts soil collapsibility much better than the geological-based model. One may even use a combination of geological and geotechnical factors to evaluate collapse susceptibility.

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